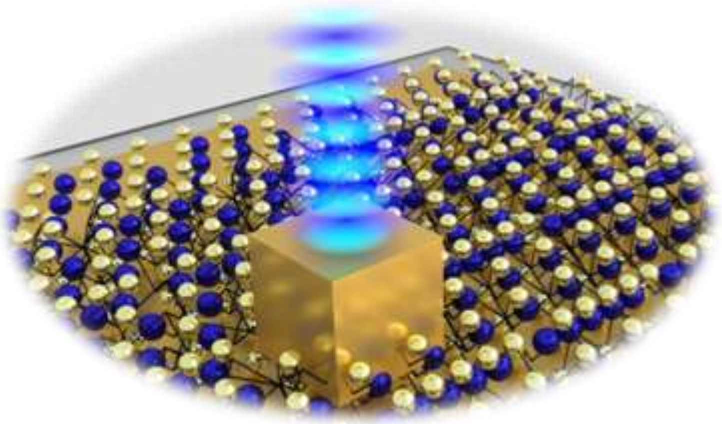
MINISTRY OF PRESCHOOL AND SCHOOL EDUCATION OF THE REPUBLIC OF UZBEKISTAN

REPUBLIC OF UZBEKISTAN
MINISTRY OF HIGHER EDUCATION, SCIENCE AND INNOVATIONS

URGANCH STATE PEDAGOGICAL INSTITUTE
FACULTY OF EXACT AND NATURAL SCIENCES

INTERNATIONAL SCIENTIFIC-PRACTICAL CONFERENCE ON THE TOPIC

“RECENT ADVANCES IN PHOTONICS AND QUANTUM OPTICS: NEW OPTOELECTRONIC TECHNOLOGIES, QUANTUM COMMUNICATIONS, AND QUANTUM COMPUTERS”



Urgench, 2025, September 29-30

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BOOK OF ABSTRACTS

Urgench 2025

At the International Scientific and Practical Conference, international and domestic scientists thoroughly discussed the urgent issues on the topic **“Recent Advances in Photonics and Quantum Optics: Novel Optoelectronic Technologies, Quantum Communications and Quantum Computers”**.

This collection includes the results of scientific research conducted by international and domestic scholars in the field of photonics and quantum optics. The following areas are covered: modern mathematical modeling methods and algorithms, physical and quantum foundations of light–matter interaction, novel optoelectronic devices and their applications, quantum communications and information security, quantum computing systems, laser technologies applied to photonic materials, environmentally sustainable “green” optical technologies, as well as modern methods of training engineering personnel in quantum technologies.

The authors are personally responsible for the accuracy and content of the information, facts and figures presented in the abstracts included in this collection.

На международной научно-практической конференции зарубежные и отечественные учёные подробно обсудили актуальные вопросы по теме **«Последние достижения в области фотоники и квантовой оптики: новые оптоэлектронные технологии, квантовые коммуникации и квантовые компьютеры»**.

В данный сборник вошли результаты научных исследований зарубежных и отечественных учёных в области фотоники и квантовой оптики. В нём освещены следующие направления: современные методы математического моделирования и алгоритмы, физические и квантовые основы взаимодействия света и вещества, новые оптоэлектронные устройства и их практические применения, квантовые коммуникации и информационная безопасность, системы квантовых вычислений, применение лазерных технологий к фотонным материалам, экологически устойчивые «зелёные» оптические технологии, а также современные методы подготовки инженерных кадров в области квантовых технологий.

Авторы несут персональную ответственность за точность и содержание информации, фактов и цифр, представленных в тезисах, включённых в настоящий сборник.

Xalqaro ilmiy-amaliy konferensiyada xalqaro va respublikamiz olimlari tomonidan **“Fotonika va kvant optikasi bo‘yicha so‘nggi yutuqlar: yangi optoelektronik texnologiyalar, kvant kommunikatsiyalar va kvant kompyuterlari”** mavzusidagi dolzarb muammolar atroflicha muhokama etildi.

Ushbu to‘plamda xalqaro va respublikamiz olimlarining fotonika va kvant optikasi sohasida olib borgan ilmiy tadqiqotlari natijalari jamlangan. Unda quyidagi yo‘nalishlardagi izlanishlar yoritilgan: zamonaviy matematik modellashtirish usullari va algoritmlari, yorug‘lik-materiya o‘zaro ta’sirining fizik va kvant asoslari, yangi optoelektron qurilmalar va ularning amaliy qo‘llanmalari, kvant kommunikatsiyalari va axborot xavfsizligi, kvant hisoblash tizimlari, lazer texnologiyalarining fotonik materiallarga tatbiqi, ekologik barqaror “yashil” optik texnologiyalar, shuningdek, kvant texnologiyalari bo‘yicha muhandis kadrlarni tayyorlashning zamonaviy metodlari.

Ushbu to‘plamga kiritilgan tezislarda keltirilgan ma’lumotlar, faktlar va raqamlarning haqqoniyligi hamda mazmuniga mualliflarning shaxsan o‘zlari mas’uldirlar.

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ANALYSIS OF THERMAL CONDITIONS AND MICROSTRUCTURE DEVELOPMENT IN LASER MELTING OF A REFRACTORY ALLOY

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Laser Powder Bed Fusion (L-PBF) is a prominent additive manufacturing (AM) technique capable of producing complex geometries. The final microstructure and mechanical properties of the printed component are highly sensitive to the dynamic thermal conditions, such as thermal gradient (G), cooling rate (dT/dt), and solidification velocity (R), which are dictated by the laser processing parameters [1, 2]. For refractory alloys like niobium-based C103, which have extremely high melting points, directly measuring these parameters is crucial for understanding and controlling solidification behavior [3, 4]. This study aims to experimentally resolve these thermal parameters during the laser melting of C103 using high-speed infrared thermography and to correlate them with the resulting grain morphology.

Single-track laser melting experiments were performed on polished C103 substrates under varying laser powers (130 W, 170 W) and scan speeds (200, 400, 600 mm/s). The process was monitored in situ using a high-speed infrared (IR) camera operating at 15,136 frames per second [5]. A key methodological innovation was applied for temperature conversion. Instead of relying on pre-calibrated emissivity values, the melt pool width was measured ex situ using Scanning Electron Microscopy (SEM). The liquidus temperature of C103 (≈2411 °C) was then assigned to this identified boundary in the IR images. Temperature maps were derived by integrating Planck's law over the specific detection range of the IR camera (3–5.5 μm), rather than applying the full-spectrum Stefan-Boltzmann law, leading to greater accuracy [6]. This method determined an effective emissivity of 0.083 for the alloy under the given experimental conditions. The melt pool shape and its movement were found to be relatively stable, with its trailing edge velocity matching the laser scan speed, indicating a near-steady-state condition. Point analysis along the laser path revealed extremely rapid thermal cycles, with heating and cooling occurring within approximately 1 ms. Spatial analysis along the melt pool boundary showed that the thermal gradient (G) is highest at the pool edges and decreases towards the center.

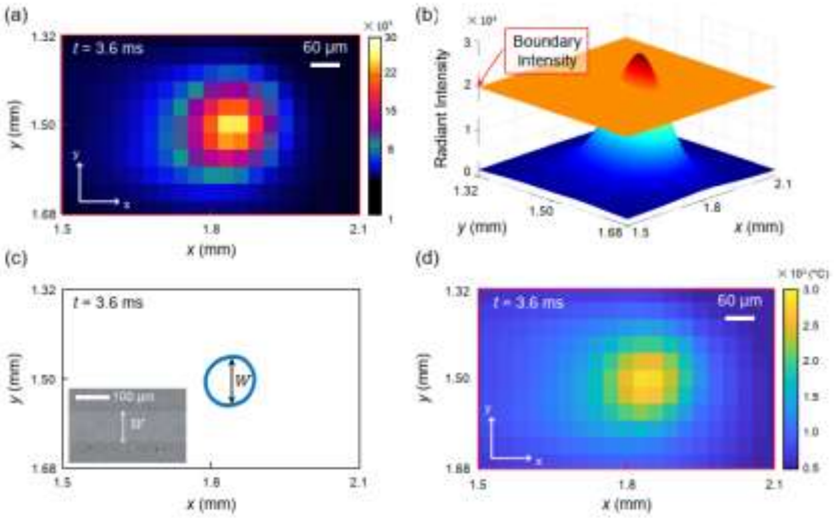

Figure 1: Conversion of IR intensity to temperature. (a) *Raw IR image (NUC values) of the C103 melt pool (170 W, 600 mm/s).* ***(b)*** *3D replot of the intensity map, smoothed to reduce noise. A horizontal plane is used to identify the melt pool boundary.* ***(c)*** *Extracted melt pool shape (width* ***W****) matching ex situ SEM measurements (inset).* ***(d)*** *Final temperature map derived from the calibrated IR data.*

Conversely, the solidification velocity (R) increases from the edges towards the center. Microstructural analysis of the melt pools revealed a distinct transition: epitaxial (columnar) grain growth was observed at the pool boundaries, where G is high and R is low. In wider melt pools (>90 μm), nucleated equiaxed grains were found towards the center, where G decreases and R increases. This observation is consistent with the Columnar-to-Equiaxed Transition (CET) phenomenon. The cooling rate (dT/dt) was found to be predominantly controlled by the laser scan speed, with higher speeds resulting in faster cooling, while laser power had a more significant effect on melt pool size than on cooling rate.

This work presents a robust methodology for directly measuring critical thermal parameters during the L-PBF process of a refractory alloy, bypassing the challenges of high-temperature emissivity calibration. By experimentally linking local thermal conditions (G and R) to microstructural evolution, the study provides a valuable framework for predicting and controlling solidification morphology in additive manufacturing. This enhanced understanding is a significant step towards mitigating process variability and improving the reproducibility of AM for high-performance materials.

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THERMAL CONDITIONS AND HOT CRACKING IN LASER-BASED ADDITIVE MANUFACTURING: EXPERIMENTAL AND NUMERICAL INVESTIGATIONS

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Laser powder bed fusion (PBF-LB) is an important additive manufacturing technique that enables the fabrication of components with complex geometries. However, the resulting microstructure and material properties strongly depend on rapidly varying thermal conditions dictated by laser parameters [1,2]. For high-strength aluminum alloys (e.g., AA2024) and refractory alloys with high melting temperatures (e.g., Nb-based C103), it is particularly crucial to accurately quantify parameters such as the temperature gradient (G), cooling rate (dT/dt), and solidification rate (**R**) near the melt pool. Understanding how these parameters influence microstructure evolution and hot cracking behavior is essential [3,4].
Single-track laser melting was performed on C103 samples under varying laser powers (130, 170 W) and scanning speeds (200, 400, 600 mm/s). The process was monitored with a high-speed infrared (IR) camera at 15,136 fps.

Instead of relying on emissivity assumptions, the melt pool boundary was calibrated to the alloy's liquidus temperature (2411 °C), determined via ex-situ SEM measurements. Planck's law was integrated over the camera's spectral range (3–5.5 μm) to convert IR signals into accurate temperature maps. From the thermal fields, G, dT/dt, and R were calculated and linked to microstructural features such as grain morphology. Aluminum alloy AA2024 [6]: Single-track laser melting was performed on AA2024 disks with varying pulse distances (PD: 15, 30, 45, 60 μm).

The experiments were complemented by multiphysics CFD simulations. The RDG (Rappaz–Drezet–Gremaud) criterion was applied to evaluate hot cracking susceptibility by computing the maximum pressure drop (ΔPmax) at dendrite roots. Subsequently, 3D PBF-LB samples were analyzed for crack formation.

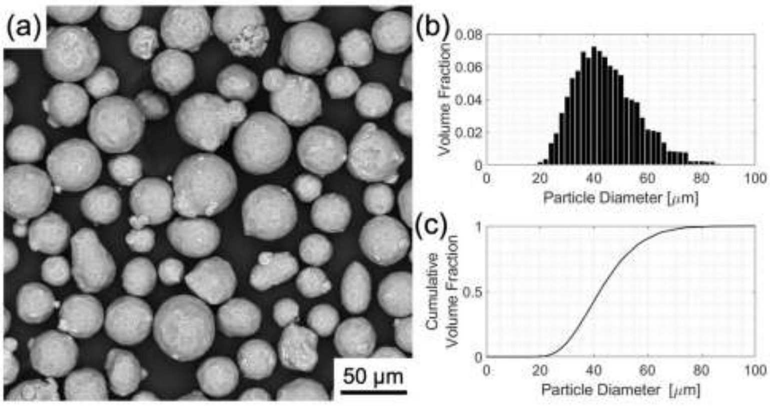

Fig. 1 a SEM-BSE image showing the morphology of the AA2024 powder. b Particle size distribution and c cumulative particle size distribution

The scanning speed primarily controlled the cooling rate (dT/dt) higher speeds resulted in faster cooling. The temperature gradient (**G**) decreased, while the solidification rate (R) increased toward the pool center [5]. Pulse distance strongly influenced hot cracking. Small PD values (15, 30 μm) produced crack-free tracks, while larger PD values (45, 60 μm) led to cracking. CFD results indicated that larger PD expanded vulnerable regions during solidification, with ΔPmax exceeding the RDG critical threshold [6]. Columnar epitaxial growth dominated at the melt pool boundary (high G, low R), whereas near the center, reduced G and increased R promoted nucleation of equiaxed grains, resulting in a Columnar-to-Equiaxed Transition (CET) [5]. Cracks were mainly observed along high-angle grain boundaries (HAGBs). In 3D PBF-LB parts, crack susceptibility was higher than in single tracks due to multiple overlapping tracks and grain boundary networks [6]. Both studies focused on single-track experiments, enabling rapid parameter scanning and analysis. The C103 study relied on direct high-speed IR thermography, while the AA2024 study combined experiments with CFD simulations and employed the RDG model for quantitative assessment of hot cracking. Both investigations highlight the importance of understanding thermal conditions to control microstructure and defects in PBF-LB. The C103 study demonstrated direct measurement of solidification parameters (G, R) and their connection to CET, while the AA2024 study revealed the physical mechanism of hot cracking (ΔPmax along HAGBs) and the influence of pulse distance. Together, these approaches provide strategies for optimizing laser parameters and enhancing the processability of challenging alloys in additive manufacturing.

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ВКЛАД МАГНИТНОГО КРУГОВОГО ДИХРОИЗМА В ГРАНАТАХ ТЕРБИЯ В ЭФФЕКТ ФАРАДЕЯ

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Аннотация: В данной работе проанализирована взаимосвязь между эффектом Фарадея (ЭФ) и магнитным круговым дихроизмом (МКД) в тербий-железном гранате (TbIG). С использованием программы на Python, основанной на формулах Крамерса–Кронига, рассчитан вклад МКД в ЭФ в различных спектральных областях. Полученные результаты хорошо согласуются с литературными данными и указывают на возможность поиска новых магнитооптических эффектов в многослойных наноструктурах.

Ключевые слова: ферритовые гранаты, эффект Фарадея, магнитный круговой дихроизм, формула Крамерса–Кронига, TbIG, магнитооптические явления, спектральный анализ.

Магнитооптические явления в ферритовых гранатах в течение длительного времени являются предметом исследований и нашли своё отражение в обзорных статьях и монографиях [1–3]. В качестве одного из важных результатов проведённых исследований следует отметить, что величина эффекта Фарадея (ЭФ) в ферритовых гранатах существенно зависит от ионов, входящих в состав граната, включая диамагнетики, а также в определённой степени от объёма элементарной ячейки, внешнего магнитного поля и других факторов. Характер значительного влияния различных факторов на интенсивность и положения электронных переходов и, соответственно, на ЭФ остаётся неясным, и дальнейшие исследования в этом направлении представляются актуальными.

В настоящей работе рассматривается задача анализа взаимосвязи между ЭФ в области прозрачности (вдали от интенсивного поглощения) и диапазонами индивидуального магнитного кругового дихроизма (МКД) в широком спектральном интервале до 42500 см$^{-1}$ (5,27 эВ).

Для вычисления относительного вклада МКД в угол поворота Фарадея на различных длинах волн нами была разработана программа на языке Python [4], основанная на формуле Крамерса–Кронига (1). Для приведения величины МКД к формуле она умножается на коэффициент 180/π.

$$\alpha_f(\nu) = -\frac{2}{\pi}\int_0^{\infty} \nu^2\ \theta(\nu')[(\nu^2 - (\nu')^2)\nu']^{-1} d\nu' \qquad (1)$$

С помощью данной программы были выполнены расчёты для тербий-железного граната (TbIG).

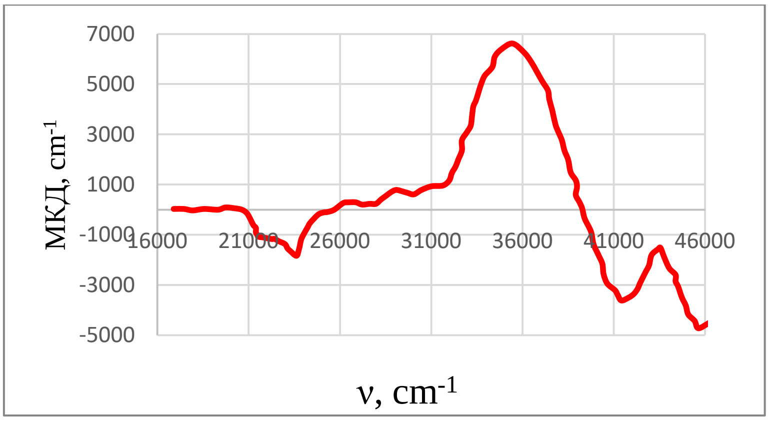

Рис. 1. Частотная зависимость МКД для TbIG.

На основе данных, полученных из графика частотной зависимости МКД для TbIG (рис. 1), с помощью разработанной программы рассчитываются графики интегральных функций под кривой для трёх длин волн TbIG, а также относительный вклад МКД в эффект Фарадея.

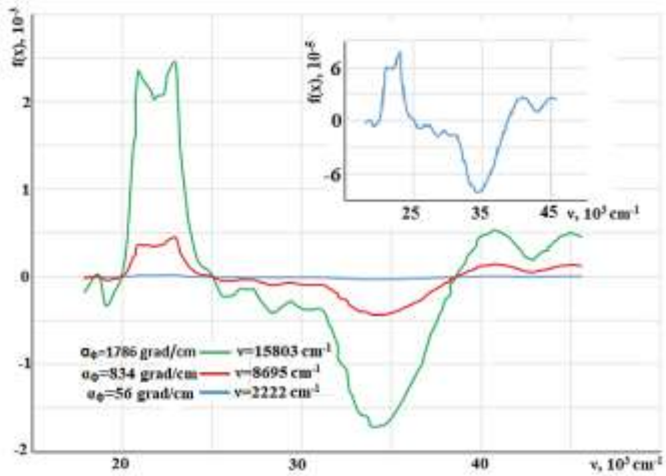

Рис. 2. Интегральные функции под кривой для трёх длин волн TbIG.

Таблица 1. Относительный вклад МКД в эффект Фарадея в TbIG.

ν, cm^{-1}	18000-25000	22700-33000	33000-45000	Результаты расчётов	Данные из литературы
2222	-62	152	-34	56	-
8695	-1109	2480	-537	834	-
15803	-6031	9793	-1976	1786	1830
Рост вклада МКД в эффект Фарадея (ЭФ) в различных спектральных областях, в процентном выражении	97	64	58		

Согласно данным таблицы, полученные результаты хорошо согласуются с ранее опубликованными сведениями в научной литературе. В настоящее время внимание исследователей сосредоточено на изучении многослойных и поликристаллических наноматериалов, так как именно в подобных структурах прогнозируется проявление новых оптических и магнитооптических эффектов. Такие эффекты обладают высоким потенциалом для применения в спинтронике и вероятностных системах искусственного интеллекта.

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NANOFOTONIKA HAMDA METAMATERIALLAR OLISH ISTIQBOLLARI

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Fotonika - bu yorug'lik (fotonlar) bilan bog'liq texnologiyalar va ilm-fan sohasidir. Fotonika yorug'likni yaratish, ishlov berish, o'zgartirish, uzatish va o'lchash bilan bog'liq barcha jarayonlarni o'z ichiga oladi. Fotonika asosan quyidagi sohalarda qo'llaniladi. Optik aloqa tizimlari: Optik tolalar yordamida ma'lumotlarni uzatish texnologiyalari. Lazer texnologiyalar lazerlar turli sohalarda, jumladan, tibbiyot, sanoat, ilmiy tadqiqotlarda qo'llaniladi. Kvant fotonika: Fotonlarning kvant xususiyatlaridan foydalangan yangi texnologiyalarni, masalan, kvant kompyuterlar va kvant kommunikatsiyalarni rivojlantirish. Fotonik sensorlar: Yorug‘likni o'lchovchi va detektorlash vositalari, ular atrof-muhitni monitoring qilish, xavfsizlik va sanoatda ishlatiladi. Fotonika - bu yorug‘lik va uning modifikatsiyasiga asoslangan texnologiyalarni o‘rganadigan fan sohasidir. Fotonika sohasining asosiy obekti fotonlar (yorug‘lik zarrachalari) bo‘lib, ular elektromagnit to‘lqinlar sifatida xususiyatlarga ega. Fotonika - yorug'likni yaratish, boshqarish, o‘tkazish va qayta ishlash bo‘yicha ilmiy va texnologik jarayonlarni o‘z ichiga oladi. Fotonika zamonaviy texnologiyalar, masalan, optik aloqa, lazerlar, optik sensorlar, mikroskopiya va fotovoltaik qurilmalar kabi sohalarda muhim rol o‘ynaydi. Optik mikroskopiya va fotonik tasvirlash texnologiyalari mikro va nano miqyosda materiallarni o‘rganishda yordam beradi. Fotonika yordamida bir nechta qatlamli yoki uch o‘lchovli tasvirlar yaratish mumkin, bu ilmiy tadqiqotlarda va tibbiyotda muhim ahamiyatga ega [1].

Aslida, barcha optik uskunalar barchasi kvant fizikasi darajasida ishlaydi deb bemalol aytish mumkin. Chunki, ular yorug‘lik fotonlari bilan o‘zaro ta’sirlashish asosida ishlaydi. Ko‘zgu, linza kabi obyektlar ham kvant elektrodinamikasi doirasida tushuntiriladi. Lekin, so‘nggi vaqtlarda kvant nazariyasini bevosita optika fanining o‘ziga tadbiq etish amaliyoti jadal rivojlanmoqda, fan va texnikaning mazkur sohasini OAVda «fotonika» deb yuritilmoqda. Ushbu sohaga oid eng ajoyib ishlanmalardan biri oddiy linzalardan butunlay farq qiluvchi, ya’ni, fotonlarning o‘zini umuman boshqacha tutishiga asoslanib ishlovchi – kvant linzalaridir. Misol uchun metamateriallarni keltirish mumkin bo‘ladi. Metamateriallar – murakkab struktura tuzilishiga ega bo‘lgan, panjaralardan, yoki, mayda-mayda tirqishlar qatoriga ega metall plastinalaridan tashkil topgan materiallar bo‘lib, ularga kelib tushgan yorug‘lik, juda ajabtovur ravishda, g‘ayrioddiy yo‘nalishlarda sinishga uchraydi. Masalan, unga kelib tushgan yorug‘lik manfiy sindirish ko‘rsatkichi tufayli, umuman akslanmasligi, ya’ni, qaytmasligi mumkin. Material strukturasining o‘zi esa, oddiy linzalardan ham ko‘ra yanada maydaroq obyektlarga ham fokuslanish imkonini beradi. Shu sababli, bunday materiallar asosida tayyorlangan linzalarni «superlinzalar» deyiladi. Kvant optikasiga tegishli yana bir struktura bu – foton panjarasi bo‘lib, uning fotonlarga ta’siri, xuddi yarimo‘tkazgichlarning elektronlarga ta’siri singari bo‘ladi. Kelajakda foton panjaralaridan optik kompyuterlar ishlab chiqarishda foydalanilishi mumkin [2,3].

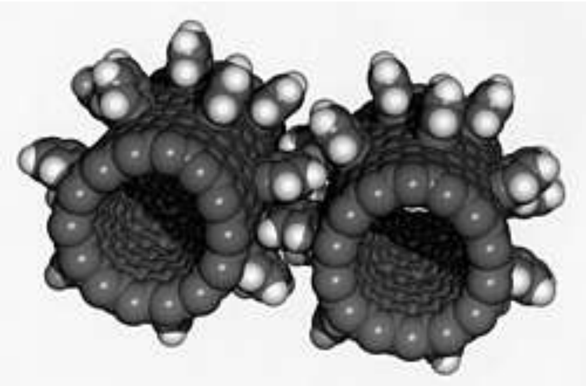
Ushbu yo‘nalishdagi yangi sohalar “Nanofotonika” va “Metamateriallar” sohalari hisoblanadi.

Nanofotonika yorug‘likni nano o‘lchamda boshqarish va o‘rganishni o‘z ichiga oladi. Bu texnologiyalar yuqori samarali qurilmalar va tizimlar yaratish uchun ishlatiladi.

Nanofotonika - bu yorug‘lik (fotonlar) va nanometr o‘lchamdagi ob’ektlar o‘rtasidagi o‘zaro ta’sirni o‘rganuvchi, yorug‘likni kichik masshtablarda boshqarish va undan foydalanish bilan shug‘ullanuvchi fotonikaning bir sohasi. U yorug‘likning to‘lqinsimon xususiyatlaridan foydalanib, nanostrukturalar yaratish hamda nanometr o‘lchamdagi lazerlar kabi ilovalarni ishlab chiqishga qaratilgan [4].

Nanofotonikaning asosiy jihatlari:

- **O‘lcham:** "Nano" (nanometr) - bu bir milliarddan bir ulushni bildiradi, ya’ni juda kichik, nanometr o‘lchamdagi masalalarni qamrab oladi.



1-rasm. Molekulyar o‘lchamdagi nanotrubalar.

Fotonlar: "Foton" esa yorug‘likning elementar zarralari bo‘lib, bu soha yorug‘likning zarralari bilan o‘zaro ta’sirini o‘rganadi.

Nazorat: Nanofotonika yorug‘likni kichik o‘lchovlarda g‘ayrioddiy tarzda boshqarish imkoniyatlarini yaratadi, bu oddiy optika usullaridan farq qiladi.

Metamateriallar - bu materiallar oddiy materiallar o‘rniga yangi fizik xususiyatlarga ega bo‘lib, ular yorug‘likni har xil yo‘llar bilan boshqarishga yordam beradi. Lazerlar keng qo‘llaniladi. Masalan *tibbiyotda*: lazerli jarrohlik, ko‘zni davolash (masalan, lazerli ko‘z operatsiyalari), tish davolash. *Sanoatda*: materiallarni qayta ishlash, o‘yma, kesish, payvandlash va boshqalar. *Qurilmalarda*: lazerli printerlar, optik disklar (DVD, Blu-ray) va laserli skanerlar. Ilmiy tadqiqotlar: lazerlar, masalan, spektroskopiyada yoki materiallarning xususiyatlarini o'rganishda ishlatiladi.

Fotovoltaik (Quyosh Energiya) texnologiyalari Fotonika quyosh energiyasini elektr energiyasiga aylantiruvchi fotovoltaik panellarni ishlab chiqish uchun ishlatiladi. Fotovoltaik texnologiyalar quyosh nurlarini yutib, ularni elektr energiyasiga aylantiradi. Quyosh batareyalari (fotovoltaik panellar) to'g'ridan-to'g'ri quyosh nuridan foydalangan holda, uylar, sanoat qurilmalari va boshqa ob'ektlar uchun toza energiya manbaiga aylanadi. Nanofotonika yorug'lik va materiallar o'rtasidagi o'zaro ta'sirni nano o'lchamda o'rganadi [5].

Bu soha, ayniqsa, yangi texnologiyalar va qurilmalar yaratishda yordam beradi, chunki yorug'likni manipulyatsiya qilishda nano o'lchamdagi strukturalar yuqori samaradorlikka erishishni ta'minlaydi. Nanolentalar va nanostrukturalar yordamida yangi materiallar va optik qurilmalar ishlab chiqiladi, ular an'anaviy optik materiallardan farq qiladi va ko'proq miniatyuralashgan tizimlar yaratishga imkon beradi.

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ZAMONAVIY OPTOELEKTRONIK TEXNOLOGIYALARNING ASOSIY YO'NALISHLARI

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Hozirgi kunda zamonaviy optoelektronik texnologiyalarning asosiy yo'nalishlari, ularning fizik asoslari, amaliy qo'llanilish sohalari hamda ularni yanada takomillashtirish bo'yicha ko'plab ilmiy-texnik izlanishlar olib borilmoqda.

Optoelektronika texnologiyasi - bu fotonik texnologiya va elektron texnologiyalarning kombinatsiyasi natijasida hosil bo'lgan yangi texnologiya. Bu optik aloqa, optoelektron displey, yarimo'tkazgichli yoritish, optik saqlash, lazerlar va boshqa qo'llash sohalarini o'z ichiga olgan materiyadagi yorug'lik va elektronlarning gigant o'zaro ta'sirini va uning energiya konversiyasini o'rganish bilan bog'liq texnologiya axborot va aloqaning asosiy texnologiyalari hisoblanadi.

Optoelektronika - bu yorug'lik (optik) va elektr signallarining o'zaro ta'siri bilan bog'liq bo'lgan fan sohasi bo'lib, zamonaviy texnologik taraqqiyotda muhim o'rin egallaydi. U elektronika, fotonika, materialshunoslik va kvant fizikasining kesishgan nuqtasida joylashgan. Hozirgi kunda optoelektron qurilmalar aloqa, axborot texnologiyalari, tibbiyot, harbiy sanoat va ekologik monitoring sohalarida keng qo'llanilmoqda [1].

Vaqt o'tishi bilan sanoat va texnologiyalar taraqqiyoti shiddat bilan davom etar ekan, jarayonlarni avtomatlashtirish, boshqaruvni aniqlik bilan amalga oshirish va energiyani tejash masalalari dolzarb bo'lib bormoqda. Ana shunday muhim texnologik vositalardan biri bu - optoelektron datchiklardir. Ushbu datchiklar yorug'lik nurlarini yuborish va qabul qilish asosida harakat, masofa, obyekt mavjudligi, holat yoki yoritilish darajasini aniqlash imkonini beradi. Ular mexanik bo'g'inlarsiz ishlashi, yuqori tezlik va sezuvchanlik bilan ajralib turadi. Optoelektron datchiklarning ishlash prinsipi nur yuboruvchi (LED yoki lazer), nur qabul qiluvchi (fotodiod, fototranzistor) va signalni qayta ishlovchi modullardan tashkil topgan. Bu elementlar o'zaro muvofiqlashtirilgan holda harakat, obyekt mavjudligi yoki yorug'lik intensivligidagi o'zgarishlarni aniqlab, elektr signaliga aylantiradi. Bunday tizim kontaktga kirmasdan ishlagani bois og'ir sanoat sharoitlarida ham ishonchli natija beradi [2].

1-rasm. Optik datchik.

Optoelektronik qurilmalar, odatda, quyidagi asosiy komponentlarni o'z ichiga oladi:

- Yorug'lik manbalari (emisiv qurilmalar)
- Yorug'lik detektorlari
- Modulyatorlar.
- To'lqin yo'llari va tolalar.

Ushbu qurilmalar ko'pincha yarimo'tkazgich materiallar asosida ishlab chiqiladi. Galliy arsenid (GaAs), indiy fosfid (InP), silikon (Si) va yangi paydo bo'layotgan materiallar - grafen va kvant nuqtalar ayniqsa dolzarb hisoblanadi [3, 4].

Zamonaviy optoelektronik texnologiyalar yo'nalishlari quyidagilar hisoblanadi:

***1. Lazer texnologiyalari* -** Zamonaviy lazerlar yuqori quvvat, aniqlik va tor spektrli nurlanish xususiyatlariga ega. Ular telekommunikatsiya, tibbiyot (masalan, lazer operatsiyalar), sanoat (kesish, payvandlash) va harbiy texnologiyalarda keng qo'llanilmoqda. Lazerlarning to'lqin uzunligini moslashtirish orqali ular turli muhitlar uchun optimallashtiriladi.

2. Fotodetektorlar - Hozirgi fotodetektorlar yuqori sezuvchanlik, past shovqin va tezkor javob berish xususiyatlariga ega. Ayniqsa, infraqizil diapazon uchun ishlab chiqilgan detektorlar issiqlik tasvirlash (termoviziya) va xavfsizlik tizimlarida qo'llaniladi.

3. Organik optoelektronika - OLED texnologiyasi (organik LED) displeylar va yoritish texnologiyalarida inqilob yasadi. OLED lar yuqori yorqinlik, past energiya sarfi va egiluvchanlikka ega.

4. Kvant texnologiyalar asosidagi optoelektronika - Kvant nuqtalar, kvant g'ovaklar, kvant tolalari orqali yuqori samaradorlikka erishilmoqda. Bu texnologiyalar kvant kompyuterlar va yuqori aniqlikli optik datchiklar yaratish uchun muhim ahamiyatga ega [5].

Optoelektronikani takomillashtirishning zamonaviy yo'nalishlari quyidagilar xisoblanadi:

1. Yangi materiallar izlanishi.

Metamateriallar, 2D-materiallar (grafen, MoS_2) asosida ishlovchi optoelektron qurilmalar tobora ko'proq e'tiborni tortmoqda. Bu materiallar orqali o'zgaruvchan optik xususiyatlarga ega, kichik hajmli va energiyani tejovchi qurilmalar yaratilmoqda.

2. Integratsiyalashgan optoelektronika.

Optik integratsiyalashgan sxemalar orqali ma'lumotlarni yuqori tezlikda uzatish va qayta ishlash mumkin. Bunday sxemalar sun'iy intellekt tizimlari, neyroprotsessorlar uchun juda muhim.

3. Nanotexnologiyalar bilan uyg‘unlik.

Nanofotonik elementlar va kvant optika asosida qurilgan tizimlar kelajakda oddiy elektron qurilmalarning o‘rnini bosishi mumkin. Bu esa ulkan tezlik va miniaturizatsiyani ta’minlaydi.

Optoelektronika texnologiyalarining jadal rivojlanishi zamonaviy fan va texnikaning eng muhim yo‘nalishlaridan biri bo‘lib, kelajakda turmush tarzimizni butunlay o‘zgartirish salohiyatiga ega. Ularni takomillashtirish uchun yangi materiallar, fizikaviy yondashuvlar hamda texnologik jarayonlar izchil o‘rganilishi lozim. Shu yo‘nalishda olib borilayotgan ilmiy tadqiqotlar yuksak energiya samaradorligi, ekologik xavfsizlik va yuqori aniqlikdagi qurilmalarning yaratilishiga xizmat qilmoqda.

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OPTICAL PROPERTIES OF SEMICONDUCTOR FERROELECTRIC STRUCTURES

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Semiconductor-ferroelectric structures, in our case structures (ZnO-$LiNbO_3$), attract much attention from researchers due to the possibility of creating radiophotonics and functional microelectronics devices based on them: ultraviolet nanolasers, sensors, solar cells and nanogenerators. The creation of ultraviolet (UV) surface acoustic wave sensors based on zinc oxide nanostructures as sensitive elements is a very urgent task; they are promising for use in cost-effective wireless and battery-free devices.

To study the optical properties of the resulting semiconductor-ferroelectric structures in the UV and visible spectral ranges, absorption spectra were studied. The study of absorption spectra (fig. 1) was carried out in the wavelength range from 300 to 1100 nm. Absorption spectra were taken from both samples – from the ZnO side (1.4) and from the substrate side (2.3).

The spectra show that the ZnO layer is transparent and the spectrum of the ZnO-$LiNbO_3$:Fe structure is higher (fig. 1, curve 4). We can say that this is the influence of Fe ions present in the structure. The resulting absorption spectrum in the decreasing linear part of the graph was approximated by a straight line until it intersected with the abscissa axis. The point where this line intersects the x-axis is the wavelength corresponding to the absorption edge of the crystal. The band gap was determined by the formula:

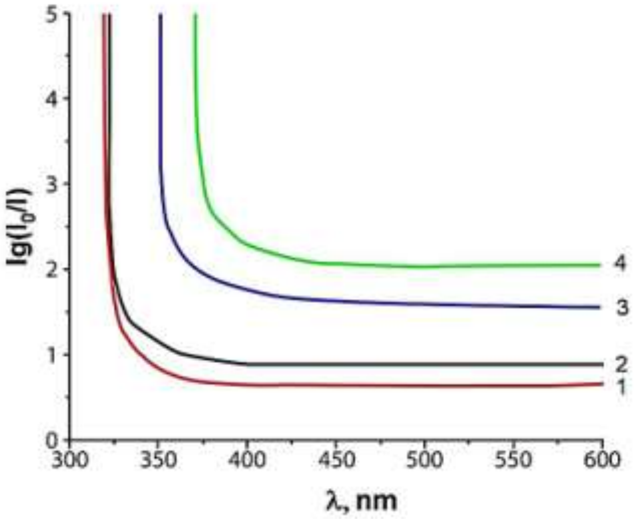

Fig. 1. Absorption spectra: $ZnO\text{-}LiNbO_3$ (1.2), $ZnO\text{-}LiNbO_3{:}Fe$ (3.4)

$$E = \frac{hc}{\lambda} \tag{1}$$

where, λ – is the wavelength corresponding to the absorption edge, h – is Planck's constant, c – is the speed of light in vacuum.

The shift in the absorption boundary and the increase in optical absorption of $ZnO\text{-}LiNbO_3$ and $ZnO\text{-}LiNbO_3{:}Fe$ are determined from the Beer-Burger-Lambert law for the intensity of light passing through the medium:

$$I = I_0 e^{-\alpha d} \tag{2}$$

where, I-is the intensity of light passing through a medium of thickness d, I_0-is the intensity of light incident on the medium, α-is the absorption coefficient.

Below, Tables 1 and 2 present changes in the absorption coefficients of the structure of $ZnO\text{-}LiNbO_3$ and $ZnO\text{-}LiNbO_3{:}Fe$ for the ultraviolet and visible parts of the spectra.

Measurements were carried out for four wavelengths in the range 350÷380 nm in the ultraviolet part of the spectrum and 550 nm in the visible part of the spectrum. As can be seen from the tables, the absorption coefficient for both parts of the spectrum increases significantly in all samples.

To determine the relationship between the refractive index and band gaps, we used the empirical formulas below.

The first empirical formula was presented by a group of Indian scientists Ravindra et al [1]. Scientists have proposed various relationships between bandgap and high-frequency refractive index and presented the linear form of n as a function of E_g:

$$n = \alpha + \beta E_g \tag{3}$$

where, α = 4,048 and β = -0,62 eV^{-1}.

Herve and Vandamme [2], taking into account the simplicity of the physics of refraction and scattering of light, proposed an empirical relationship:

$$n = \sqrt{1 + (\frac{A}{E_g + B})^2} \tag{4}$$

where, A = 13,6 eV and B = 3,4 eV.

Having considered the band structure and quantum dielectric formulation of Penn [3] and Van Vechten [4], Ghosh et al. [5] approached the problem differently. They, taking A as the contribution of valence electrons, B as a constant addition to the smallest band gap E_g, obtained an expression for the high-frequency refractive index:

$$n^2 - 1 = \frac{A}{(E_g + B)^2} \tag{5}$$

where, $A=25E_g + 212$, $B=0.21E_g + 4.25$ and $(E_g + B)$ refer to the corresponding band gap of the material.

The corresponding calculated values of E_g, n and α for ZnO-$LiNbO_3$ and ZnO-$LiNbO_3$:Fe are given in Tables 1 and 2.

Table 1. Results of determined – E_g, refractive indices n_i and absorption coefficients α_1 (visible region) and α_2 (UV region) of $ZnO\text{-}LiNbO_3$ structures

$ZnO\text{-}LiNbO_3$	E_g (eV)	n (6)	n (7)	n (8)	α_1 (mm^{-1})	α_2 (mm^{-1})
[1]$ZnO\text{-}LiNbO_3$	3,86	1,6547	2,1234	2.2083	1,9099	2,0585
[2]$ZnO\text{-}LiNbO_3$	3,85	1,661	2,1257	2.2100	2,1943	2,3497

Table 2. Results of determined – E_g, refractive indices n_i and absorption coefficients α_1 (visible region) and α_2 (UV region) of $ZnO\text{-}LiNbO_3{:}Fe$ structures

$ZnO\text{-}LiNbO_3{:}Fe$	E_g (eV)	n (6)	n (7)	n (8)	α_1 (mm^{-1})	α_2 (mm^{-1})
[3]ZnO- $LiNbO_3{:}Fe$	3,52	1,8656	2,2051	2.2678	2,9737	3,7405
[4]ZnO- $LiNbO_3{:}Fe$	3,34	1,9772	2,2520	2.3018	3,5137	4,2344

It is clear from the tables that the refractive indices calculated using the given empirical formulas are very close to the experimental results of other authors, with the closest ones being calculations using formula (5). They also showed a greater decrease in band gaps and a greater increase in the optical properties of samples grown on iron-doped lithium niobate than on undoped lithium niobate.

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Effect of γ-irradiation on a lithium crystal

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The study of radiation effects in lithium niobate ($LiNbO_3$) began almost from the moment the specific properties of photorefractive crystals were discovered. The radiation effects responsible for the mechanisms of their manifestation are discussed in two separate areas: radiation responses inherent in bulk materials, and responses arising from the effects of component geometry. Effects in $LiNbO_3$-based technologies such as thin-film integrated optical devices and volumetric acousto-optic modulators illustrate the widely differing radiation-induced responses that can occur in current component technologies. The radiation sensitivity of the $LiNbO_3$ was determined as in a clean state. Depending on the application, the $LiNbO_3$ may act as a sensitive radiation sensor or material sufficiently resistant to radiation [1].

The purpose of this work is to study the influence of radiation effects (γ-irradiation) on the optical properties (ordinary n_o and extraordinary n_e refractive indices, optical absorption edges, and Raman scattering) of lithium niobate single crystals.

Color centers in $LiNbO_3$ crystals induced by irradiation with γ-radiation and electrons or heat treatment in various atmospheres have been studied previously [2, 3]. However, at present there is no consensus on the nature and mechanisms of formation of color centers. The presence of different models of color centers is assumed: F-type centers and the transition of niobium ions to a lower valence state; hole centers O^- are localized near defects in cation sublattices; bipolarons, as well as charge exchange of doping ions or complex associates consisting of an oxygen vacancy and an impurity. Saturation of dose dependences in $LiNbO_3$ under γ-irradiation indicates the predominance of radiation mechanisms for recharging growth defects.

Based on the model of the x-ray refractive effect, a slight decrease in refractive indices after irradiation can be associated with the relaxation of internal fields formed during irradiation. When $LiNbO_3$ single crystals are γ-irradiated, a photochromic effect is observed, which disappears when the crystals are annealed [4]. The change in the refractive index of the sample with respect to the ordinary and extraordinary laser beam is shown in Fig. 1, it can be seen that the refractive indices increase nonlinearly with increasing radiation dose.

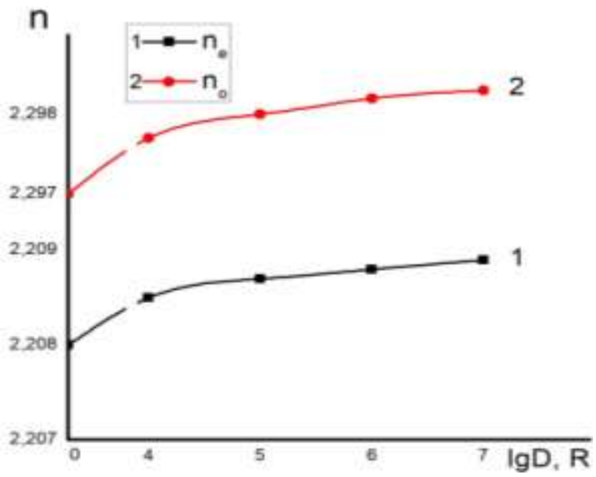
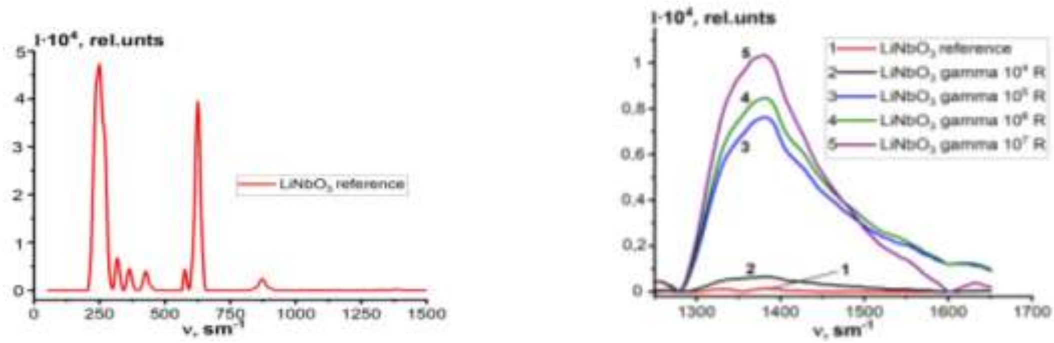


Fig. 1. Dependences of n_e and n_o on the dose of γ-radiation for $LiNbO_3$ crystals

It has been established that irradiation leads to an increase in the refractive indices of $LiNbO_3$ single crystals. The values of n_o and n_e increase with increasing dose of γ-irradiation and reach saturation at a dose of 10^7 R.

In the literature on the influence of γ-radiation there is a lot of data on changes in the optical absorption edge, refractive indices, and sensitivity of photorefractive crystals, but little has been studied on Raman scattering from these crystals. Raman spectra of single-crystal samples of unirradiated and irradiated $LiNbO_3$ crystals are presented in Fig. 2a and 2b. It can be assumed that the displacements of Li cations affect only frequencies in the range of 270–400 cm^{-1}, as evidenced by peaks in the low-frequency part of the spectrum. The range 550–670 cm^{-1} is assigned to the Nb–O stretching modes, which mainly include shifts of oxygen atoms; O–Nb–O bending modes appear at 432 cm^{-1} and below, thus it is clear that the bending modes are strongly coupled to both the Li–O stretching modes and the O–Li–O bending modes. The highest intensity at 245 cm^{-1} is mainly due to the deformation of the Nb-O framework. When taking Raman scattering spectra from γ-irradiated crystals, in the low-frequency part of the spectrum the peak locations at frequencies of 250 cm^{-1} and 600 cm^{-1} did not change, and in the high-frequency part of the spectrum at a frequency of 1375 cm^{-1} peaks appear in Fig. 2b.



a b

Fig. 2. Raman spectra of lithium niobate: a) Unirradiated, b) Irradiated

From the spectra it is clear that in the range of 1300 ÷ 1600 cm^{-1} with γ-irradiation at a frequency of 1375 cm^{-1} peaks appear, the height of which increases according to the increase in the dose of γ-irradiation (the low-frequency part of the spectrum, due to its identity with the spectrum of Fig. 2a, in Fig. 2b. not shown). We believe that the appearance of these peaks is caused by radiation defects, centers of changes in Raman frequencies that arise under the influence of γ-radiation, and this causes changes in the optical properties of lithium niobate crystals.

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LAZER NURLANISHI TA'SIRIDA MIS FOLGA YUZASIDA SHAKLLANGAN PLAZMA SOHASIDAGI ELEKTRONLARNING TEMPERATURASINI ANIQLASH

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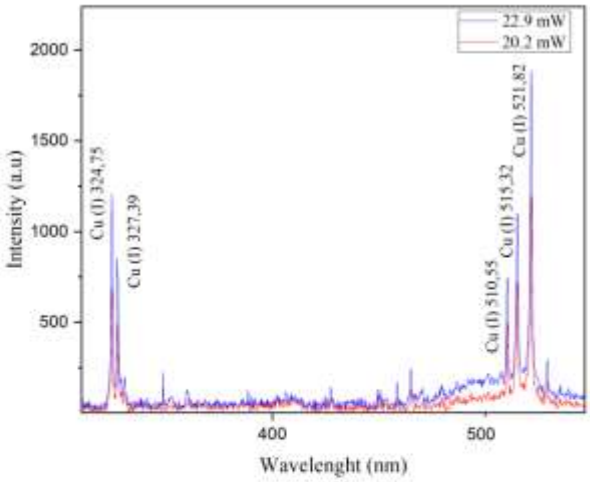
Hozirgi kunda lazer texnologiyalarining rivojlanishi moddalar bilan oʻzaro taʼsir jarayonlarini oʻrganish imkoniyatlarini kengaytirmoqda. Lazer nurlanishining qattiq modda sirtiga taʼsiri orqali turli fizik va kimyoviy jarayonlarni amalga oshirish, ayniqsa, **plazma hosil qilish[1], nanozarralar yaratish[2]**, **elementar tarkibni tahlil qilish** kabi sohalarda muhim ilmiy tadqiqotlar olib borilmoqda. Shuningdek, lazer yordamida **nanostrukturalar** shakllantirish[3] orqali material sirtining **optik**, **kimyoviy** va **mexanik xususiyatlarini oʻzgartirish** imkoniyatlari oʻrganilmoqda[4].

Tadqiqotda impuls davomiyligi 28 ps va toʻlqin uzunligi 1064 nm boʻlgan Nd:YAG lazer nurlanishidan foydalanildi. Eksperiment uchun namunaviy material sifatida qalinligi 63,1 mkm boʻlgan mis folga tanlandi. Lazer nurlanishining quvvati 20,2 mW va 22,9 mW qiymatlarida, 25 sm fokus masofali yigʻuvchi linza yordamida normal atmosfera sharoitida namunaga tik perpendikulyar yoʻnaltrilgan.

Pikosekund impulsli lazer nurlanishi taʼsirida mis folga sirtida hosil qilingan plazmaning spektrida Cu elementining (I) bir zaryadli ionlariga xos ion oʻtishlari mavjudligi aniqlangan (1-rasm). Plazma spektriga mos keluvchi mis ionlari uchun ion oʻtish chiziqlarini aniqlashda NIST dan foydalanildi. Mis folga sirtida krater shakllantrish jarayonida hosil boʻlgan plazmaning emissiyasi nur tolali optik spektrofotometr (Ocean Optics HR-4000) yordamida qayd qilindi. Plazma emmisiyasini qayd qilish uchun spektral qurilma namunaga 45^0 burchak ostida joylashtirildi.

Spektrofotometr plazma spektrini 200 nm dan 1100 nm gacha bo'lgan diapozondagi ion o'tishlarini o'rganish imkonini beradi.



1-rasm. Lazer nurlanish quvvati 20.2 mW va 22.9 mW bo'lganda Cu folganing plazma emissiya spektrlari

Plazma sohasidagi elktronlar zichligini aniqlashda **Shtark kengayish usuli** qo'llanildi. Shtark kengayishi plazmadagi elektr maydonlari ta'sirida spektr chiziqlarining **kengayishi va siljishi**ni ifodalovchi hodisa bo'lib, erkin elektronlar zichligi to'g'risida **miqdoriy ma'lumot** olish imkonini beradi. Lokal termodinamik muvozanat sharoitida plazmadagi zarrachalar guruhining (uyg'ongan holatlar) energetik sathi Boltsmanning taqsimot qonuni bilan ifodalanadi[5].

$$\frac{n_{k,Z}}{n_Z} = \frac{g_{k,Z}}{P_Z}\exp\left(-\frac{E_{k,Z}}{k_B T}\right) \qquad (1)$$

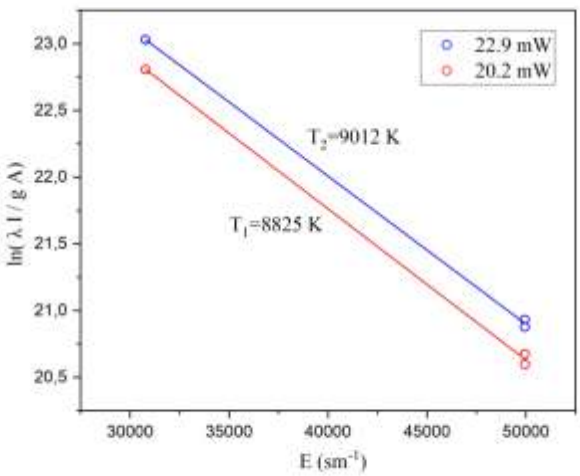
Agar ushbu chiziqli tenglamaning (Boltsman tenglamasi deb ataladi)[17] chap tomoni $\ln\left(\frac{I_Z \lambda_{ki,Z}}{g_{k,Z} A_{ki,Z}}\right)$ yuqori sathda bir necha qayta o'tishlar uchun **Z** ionlanish bosqichidagi zarrachalarning energiyasini ifodalasa, u holda o'rnatilgan qiyalik **T** ning teskari qiymatiga $-\frac{1}{k_B T}$ teng bo'ladi. Bu esa plazma temperaturasini aniqlash imkonini beradi.. Jadvalni tayyorlashda

NIST ma'lumotlar bazasidan foydalanildi[6].

Jadval-1

Atom/ion	*To'lqin uzunligi $\lambda_{ki, z}$, (nm)*	*Quyi sath energiyasi E_i, (sm^{-1})*	*Yuqori sath energiyasi E_k, (sm^{-1})*	*Yuqori sath energiya darajasi g_k*	*O'tish extimoligi A_{ki}, (s^{-1})*
Cu (I)	324.75	0	30783.697	4	$1.39*10^8$
Cu (I)	327.39	0	30535.324	2	$1.376*10^8$
Cu (I)	510.55	11202.618	30783.697	4	$2*10^6$
Cu (I)	515.32	30535.324	49935.195	4	$6*10^7$
Cu (I)	521.82	30783.697	49942.051	6	$7.5*10^7$

Plazma sohasidagi elektronlar temperaturasini aniqlashda 1-**jadvalda** keltirilgan optik kattaliklardan foydalanildi.



2-rasm. *Cu (I) ion o'tish emissiya spektr chiziqlarini Bolsman taqsimot grafigi. Qiyalik a) lazer nurlanish quvvati 20.2 mW bo'lganda T_1= 8825 K va b) lazer nurlanish quvvati 22.9 mW bo'lganda T_2=9012 K plazma elektron temperaturasi*

Lazer nurlanish quvvati oshgani sari plazma harorati ham oshadi, chunki energiya zarrachalarga uzatiladi va ionlanish kuchayadi. Biroq, bu bog'lanish to'g'ridan-to'g'ri emas, chunki energiya yo'qotish mexanizmlari va plazmaning boshqa xususiyatlari (masalan, zichlik, hajm) bu jarayonga ta'sir qiladi.

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LAZER NURLANISHI TA'SIRIDA MIS FOLGA YUZASIDA SHAKLLANGAN PLAZMANING ELEKTRON ZICHLIGINI ANIQLASH

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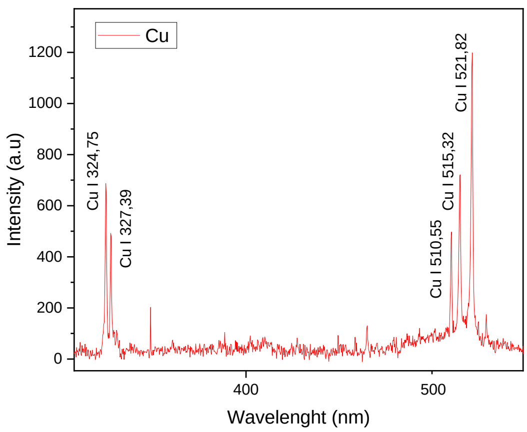
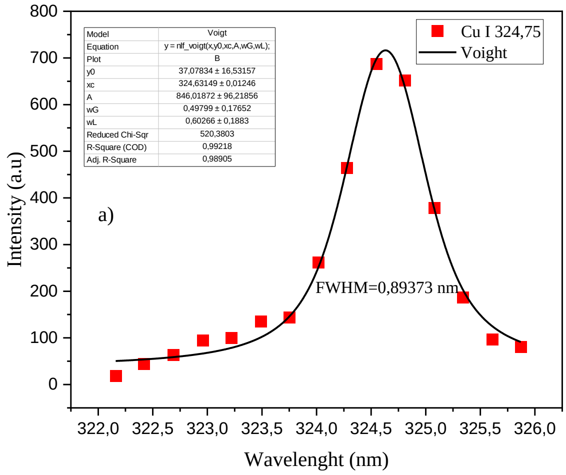
Lazer va modda o'zaro ta'siri hozirgi zamon ilm-fanining yuqori energiyali fizikasi, materialshunoslik va nanofotonika sohalarida eng faol rivojlanayotgan yo'nalishlardan biridir. Ayniqsa, ultraqisqa impulsli lazerlar (femtosekund va pikosekund diapazonidagi) yordamida material sirtining lokal qizishi, erishi va bug'lanishi natijasida yuzada plazma hosil bo'lishi hamda kraterlar va nano/mikro tuzilmalar shakllanishi dolzarb tadqiqot mavzularidandir[1-3].

Lazer nurlanishi ta'sirida xosil bo'lgan plazmani o'rganishda elektronlar zichligini aniqlash muhim o'rin tutadi. Elektronlar zichligini aniqlashda Shtark kengayish usulidan foydalanildi. Shtark kengayishi – bu plazmadagi elektr maydonlari ta'sirida spektr chiziqlarining kengayishi va siljishini ifodalashda muhim hodisa bo'lib, erkin elektronlar zichligini miqdoriy baholash imkonini beradi.



1-rasm. Cu folganing plazma emissiya spektri

Mis neytral atomlarining o'tish chiziqlarini o'rganish natijasida plazma parametrlari aniq tavsiflandi, bu esa lazer ablatsiyasi va unga bog'liq jarayonlarni chuqurroq tushunishga zamin yaratdi.



3-rasm. Lazer nurlanish quvvati 20.2 mW ta'sirida Cu sirtida hosil bo'lgan plazmaning λ=324.75 nm spektr chizig'ini Voight impulsi bilan moslashtirish.

Vodorodsimon bo'lmagan atomlar uchun elektron zichligi va spektr chiziqlari yarim kengligi (FWHM) o'rtasidagi bog'liqlik Shtark kengayishi orqali belgilandi[4]

$$\Delta\lambda_{\frac{1}{2}} = 2W\left(\frac{n_e}{10^{16}}\right)\overset{0}{A}. \quad (1)$$

$\Delta\lambda_{\frac{1}{2}}$=FWHM spektr yarim kengligi, n_e-elektron zichligi, **W** – elektron ta'sir parametri. Shtark kengayish usuli yordamida Cu I atom o'tishlariga mos keluvchi spektr to'lqin uzunliklari asosida elektron zichliklari aniqlandi (1-jadval). Spektr chiziqlari yarim kengligi (FWHM) Voigt impulsiga moslashtirilib topildi (3-rasm). Bir-biriga yaqin joylashgan atom o'tishlar ajratilib, alohida hisoblandi. Elektronlarning o'zaro ta'sir parametri **W** dan foydalanilib [5], elektronlar zichligi hisoblab chiqildi.

1-jadval

Atom/ion	*To'lqin uzunligi λ, (nm)*	*Elektron konfiguratsiyasi*	*FWHM (nm)*	***Elektron ta'sir kengligi** w (Å)*	*Elektrolar zichligi n_e, $(10^{18})cm^{-3}$*
Cu I	324.75	$3d^{10}4p \rightarrow 3d^{10}4s$	*0.89373*	0.00301	14.84
Cu I	327.39	$3d^{10}4p \rightarrow 3d^{10}4s$	0.70788	0.00301	11.76
Cu I	510.55	$3d^{10}4p \rightarrow 3d^{9}4s^{2}$	0.75101	0.043	0.87
Cu I	515.32	$3d^{10}4p \rightarrow 3d^{10}4d$	1.05062	0.19	0.27
Cu I	521.82	$3d^{10}4p \rightarrow 3d^{10}4d$	1.0102	0.22	0.23

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UGLEROD SIRTIDA HOSIL QILINGAN LAZER PLAZMANING PARAMETRLARI TADQIQI.

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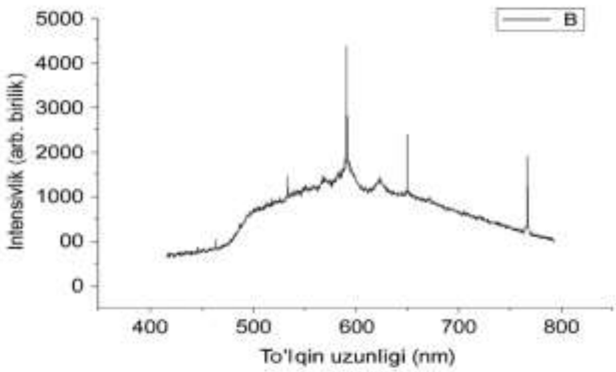
Hozirgi kunda metallar, qotishmalar, yarim o'tkazgichlar va uglerod asosidagi materiallar tarkibini tahlil qilishda LIBS usulidan foydalanish keng qo'llanilmoqda [1-3]. Ushbu usul lazer impulslari yordamida material yuzasida plazma hosil qilish va uning emissiya spektrlarini tahlil qilish orqali uning tarkibiy elementlarini aniqlash imkonini beradi [5]. Bugungi kunda uglerod va uning turli shakllari, xususan grafen, karbon nanotubalar va uglerod qora moddalari**,** quyosh batareyalarini ishlab chiqishda asosiy materiallardan biri sifatida ishlatilmoqda**.** Chunki uglerodning yuqori elektr o'tkazuvchanligi, nur yutish qobiliyati va yengil vazni quyosh energiyasini yuqori samaradorlik bilan yutish va elektr energiyasiga aylantirish imkonini beradi. Masalan, grafen asosidagi quyosh panellari oddiy kremniy asosidagi panellarga nisbatan ingichka, egiluvchan va yengil bo'lishi bilan ajralib turadi. Shuningdek, uglerod asosidagi materiallardan foydalanish ekologik jihatdan ham xavfsiz bo'lib, ularni ishlab chiqarish va qayta ishlash jarayonlari atrof-muhitga kam zarar yetkazadi[5-6].

1-rasm. *LIBS va Uglerodning quyosh batareyalarida qo'llanilishi.*

Uglerod asosidagi plazmalar yuqori elektr o‘tkazuvchanlikka va keng nurlanish diapazoniga ega bo‘ladi. Uglerodli materiallarga lazer tushganda, uning atomlari va molekulalari ionlashadi va nurlanish yuz beradi. Ushbu nurlanishlar bir element uchun o‘ziga xos to‘lqin uzunligida sodir bo‘ladi [6]. Uglerod elementi uchun LIBS (Laser-Induced Breakdown Spectroscopy) texnikasi orqali olingan emissiya spektri quyidagi grafikda aks ettirilgan.



2-rasm. Uglerod plazmasining emissiya spektri.

Plazmaning asosiy parametrlaridan biri bo‘lgan elektron zichligi aniqlangach ($n_e \approx 3 \times 10^{16}$ cm^{-3}), plazma holatini tavsiflovchi hosila parametrlar ham hisoblanadi. Debay uzunligi λ_D plazmadagi zaryadlangan zarralarning elektrostatik maydonlari ta’sir radiusini aniqlaydi va [6] quyidagi formula bilan

hisoblanadi : $$\lambda_D = \sqrt{\frac{\varepsilon_0 k T_e}{n_e e^2}} \quad (1)$$

Hisoblash natijasida uglerod plazmasi uchun:

$$\lambda_D \approx 1.4 \times 10^{-6} \text{ m} = 1.4 \ \mu\text{m}$$

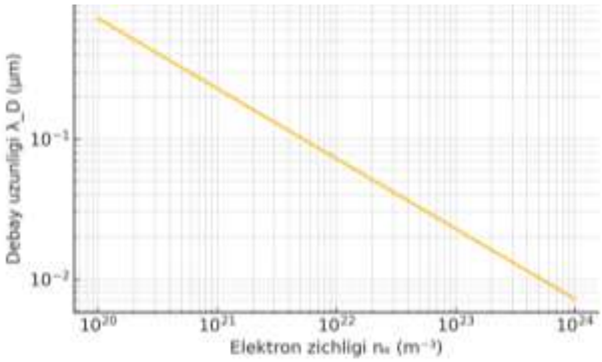
Plazma chastotasi (ω_p) erkin elektronlarning kollektiv tebranish chastotasi bo‘lib, quyidagi formula bilan hisoblanadi:

$$\omega_p = \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} \quad (2)$$

Hisoblash natijasida uglerod plazmasi uchun:

$$f_p = \frac{\omega_p}{2\pi} \approx 1.56 \times 10^{12}\ \text{Hz}\ (3)$$

Bu parametrlar plazmaning barqarorligini, to'lqin tarqalishini va lazer-plazma o'zaro ta'sir jarayonlarini tushunishda muhimdir. Spektral tahlil uchun ishlatilishi mumkin.



3- rasm: Debay uzunligining elektron zichlikka bog'liqligi grafigi.

Quyidagi jadvalda Debay uzunligi $\lambda_D$ning elektron zichligi (n_e) ga bog'liqligi grafik asosida taqdim etilgan. Bu ma'lumotlar plazma fizikasi bo'yicha hisob-kitoblar va laboratoriya ishlari uchun foydalanish imkonini beradi.

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2D Panjara tuzilishi asosida ikkinchi garmonik hosil bo‘lishining sonli tadqiqi

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Optikada Gauss nurlar keng tarqalgan bo`lib, lazer texnologiyasi, optik tolalar va boshqa sohalarda qo`llaniladi. Ushbu ishda Gauss nur profilining shaxmat uslubida ishlangan nochiziqli foton kristaldan o`tishida amplituda va chastota o`zgarishlarini tahlil qilishimiz mumkin.

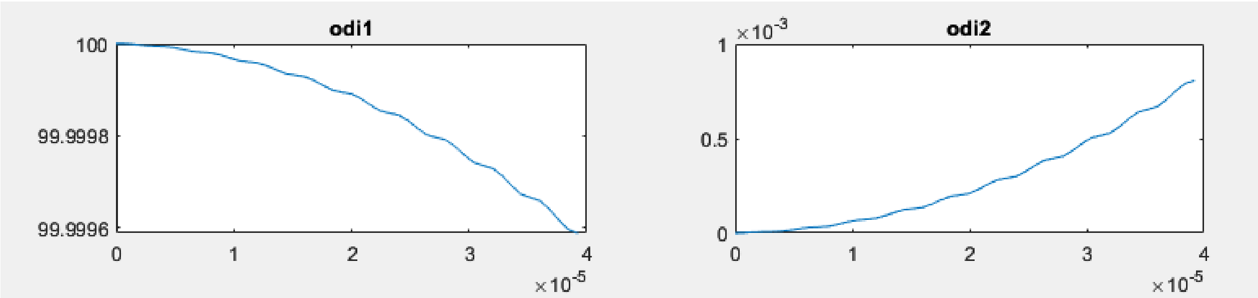
So‘nggi yillarda nolinear optika sohasida olib borilayotgan tadqiqotlar yorug‘lik chastotasini o‘zgartirish, yangi spektral diapazonlarni hosil qilish va yuqori samarali optik qurilmalar yaratishga qaratilgan. Bunda, ayniqsa, ikkinchi garmonik avlod (Second Harmonic Generation – SHG) jarayoni muhim o‘rin tutadi. SHG jarayonida asosiy lazer nurlanishining chastotasi ikki baravar oshib, yorug‘likning yarim to‘lqin uzunligi hosil qilinadi. Bu hodisa lazer texnologiyalarida, axborot uzatish tizimlarida hamda kvant optikada keng qo‘llaniladi.

SHG jarayonining samaradorligi fazaviy moslashuv shartiga bog‘liq. Fazaviy moslashuvni ta’minlash uchun turli usullar mavjud bo‘lib, ulardan eng samaralisi – optik panjara (grating) strukturalaridan foydalanishdir. Xususan, 2D panjara (ikki o‘lchamli grating) tuzilmalari fazaviy moslashuvni nafaqat bir yo‘nalishda, balki ikki yo‘nalishda ta’minlab, ikkinchi garmonik avlod intensivligini oshirish imkonini beradi.

Ushbu ishda MATLAB muhitida yozilgan dastur yordamida 2D panjara asosida SHG jarayonining sonli modellashtirilishi amalga oshirildi. Hisoblashlar natijasida panjara tuzilishi, z-o‘q bo‘yicha panjara periodikligi, energiya taqsimoti va chiqishdagi maydon intensivligi grafigi olindi.

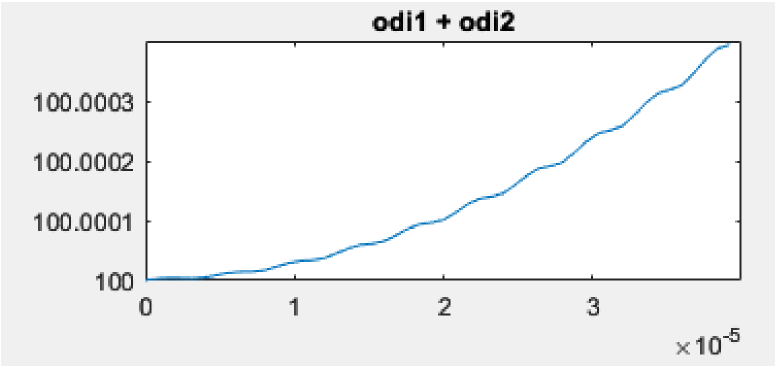
Natijalar panjara yordamida energiyaning samarali qayta taqsimlanishini hamda ikkilamchi garmonikning shakllanishini tasdiqlaydi.

Qurilgan modelda panjara "shaxmat doskasi" shaklida koʻrinadi. Bu yerda oq va qora kataklar fazaviy moslashuvni navbatma-navbat ta'minlovchi sohalarni ifodalaydi. Bunday panjara tuzilishi ikki oʻlchamda faza moslashuvini yaxshilab, SHG samaradorligini oshirish imkonini beradi. Panjara davriyligi y koordinata boʻyicha 8 ta elementdan tashkil topgan boʻlib, z-oʻq boʻyicha muntazam oʻsib boradi.



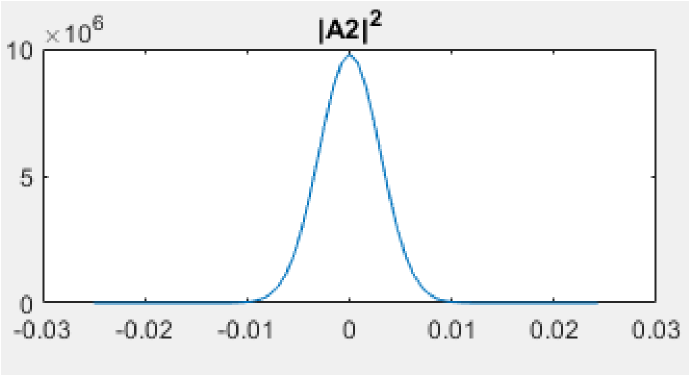
1 – rasm

Yuqoridagi 1 – rasmda **odi1** – asosiy toʻlqin (A1) intensivligi boʻlib, z boʻylab sekin kamayadi. . **odi2** – ikkinchi garmonik (A2) intensivligi, aksincha, oʻsib boradi.



2 – rasm

Yuqoridagi 2 – rasmda. **odi1 + odi2** – umumiy energiya yigʻindisi deyarli doimiy boʻlib qoladi. Bu energiya saqlanish qonuni bajarilishini va hisoblashlarning toʻgʻriligini isbotlaydi.



3-rasmda $|A2|^2$ ikkinchi garmonik intensivligi ham gaussga o'xshash shaklga ega, lekin amplitudasi ancha kichik. Bu panjara orqali asosiy to'lqindan ikkinchi garmonikga energiya samarali o'tishini ko'rsatadi.

Ushbu ishda ikkinchi garmonik avlod (SHG) jarayonining sonli modellashtirilishi amalga oshirildi. Tadqiqot natijalari shuni ko'rsatdiki, panjara asosidagi fazaviy moslashuv usuli SHG samaradorligini sezilarli darajada oshiradi. Modellash jarayonida asosiy to'lqin (A1) intensivligi z-o'qi bo'ylab asta-sekin kamayib borishi, ikkinchi garmonik (A2) intensivligi esa ortib borishi kuzatildi. Shu bilan birga, umumiy energiya yig'indisi (odi1 + odi2) deyarli o'zgarmay qolishi energiya saqlanish qonunining bajarilishini tasdiqlaydi.

Maydon intensivliklarining taqsimotlari ham muhim natijalarni ko'rsatdi. Asosiy to'lqin $|A1|^2$ va ikkinchi garmonik $|A2|^2$ gauss shaklida taqsimlandi. Bu natija panjara orqali o'tgan nur markaziy sohada maksimal qiymatga ega bo'lishini va energiyaning samarali tarzda qayta taqsimlanishini bildiradi. Ikkinchi garmonikning intensivligi kichikroq bo'lsa-da, bu uning asosiy to'lqindan hosil bo'layotganini ko'rsatadi.

Tadqiqot shuningdek shuni ko'rsatadiki, fazaviy moslashuvni to'g'ri tashkil etish orqali ikkilamchi garmonik hosil qilish samaradorligini oshirish mumkin. Optik panjara yordamida amalga oshirilgan bu jarayon yuqori samarali chastota ikki baravar oshiruvchi qurilmalarni loyihalashda qo'llanishi mumkin. Bunday qurilmalar lazer texnologiyalari, spektral diapazonlarni kengaytirish, axborot uzatish tizimlari va kvant optikada keng amaliy ahamiyatga ega.

Umuman olganda, olib borilgan modellashtirish ishlari panjara strukturalaridan foydalanib ikkilamchi garmonik avlod jarayonini chuqur o'rganish va amaliy qurilmalarga tadbiq etish uchun mustahkam nazariy asos yaratadi.

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TEXNOLOGIYA ASRIDA KVANT KOMMUNIKATSIYALARI, KVANT KOMPYUTERLARI VA ULARNING ISTIQBOLI

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Raqamli transformatsiya davrida insoniyat ilm-fan va texnologiyalarda yangi bosqichga qadam qo'ydi. Kvant texnologiyalari, xususan kvant kommunikatsiyalari va kvant kompyuterlari, XXI asr ilm-fanining eng dolzarb yo'nalishlari hisoblanadi. Ularning rivojlanishi axborot xavfsizligi, hisoblash texnikasi va ishlab chiqarish sohalarida tub burilish yasamoqda.

Kvant kommunikatsiyalari – bu axborot almashinuvi va uni himoya qilishda kvant mexanikasi qonunlariga asoslangan yangi avlod texnologiyalaridir. Asosiy ustunligi shundaki, uzatilayotgan ma'lumotni hech qanday klassik kriptografik usul bera olmaydigan darajada mutlaq xavfsizlik bilan himoyalaydi[1,2].

Asosiy prinsiplari:

1. Kvant kalitlarini taqsimlash (QKD – Quantum Key Distribution) – ikki tomon (masalan, A va B) o'zaro maxfiy kalit almashadi. Bu jarayon fotonlarning kvant holatlari orqali amalga oshiriladi. Agar uchinchi tomon (E) aralashishga harakat qilsa, fotonlarning kvant holati buziladi va darhol aniqlanadi.
2. No-klonlash teoremasi – kvant holatini nusxalash mumkin emas. Demak, josuslik qilish yoki kalitni yashirincha ko'paytirib olish imkonsiz.
3. O'lchashning buzuvchi xususiyati – kvant zarrachani o'lchash jarayonning o'zini o'zgartiradi. Shu sababli maxfiylik kafolatlanadi.

Amaliy natijalar quidagilardan iborat:

1. "Micius" sun'iy yo'ldoshi (Xitoy, 2017 y.) orqali 1200 km masofada kvant kalit almashinuvi amalga oshirildi. Bu tarixda birinchi marta global kvant aloqa tajribasi sifatida qayd etildi.

2. Yevropa Ittifoqi "EuroQCI" (European Quantum Communication Infrastructure) loyihasini boshlagan bo'lib, kelgusida butun qit'ani qamrab oluvchi kvant internetini yaratishni maqsad qilgan.

3. AQSh va Yaponiya ham milliy kvant aloqa tarmoqlarini yo'lga qo'yish bo'yicha faol ishlamoqda.

Ilmiy va amaliy qo'llanish sohalari

Milliy xavfsizlik**:** diplomatik, harbiy va hukumat aloqalarini mutlaq darajada himoya qilish.

Moliyaviy tizimlar**:** banklararo tranzaksiyalar va onlayn to'lovlarni xavfsiz amalga oshirish.

Sog'liqni saqlash: tibbiy ma'lumotlarni sir saqlash.

Bulutli hisoblash: kvant tarmoqlari orqali ma'lumot uzatishda yuqori darajadagi maxfiylik.

Kvant kommunikatsiyalarining eng yirik maqsadi – global kvant internetini barpo etishdir. Bu internetda:

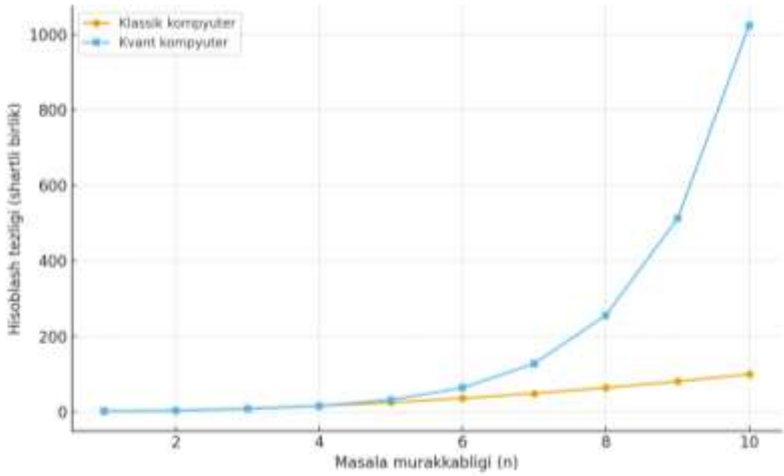
Kvant kalitlari orqali uzatilgan barcha ma'lumotlar mutlaq xavfsiz bo'ladi;

Kvant kompyuterlar o'zaro bog'lanib, murakkab masalalarni jamoaviy hisoblash imkoniyatiga ega bo'ladi;

Zamonaviy kriptografiya butunlay yangi bosqichga ko'tariladi.

Kvant kommunikatsiyalari bugungi kunda tajriba bosqichida bo'lsa-da, tez orada klassik aloqa tizimlarini siqib chiqarishi kutilmoqda. Bu texnologiya axborot xavfsizligini tubdan o'zgartiradi, davlatlararo munosabatlar va xalqaro iqtisodiy hamkorlikda hal qiluvchi rol o'ynaydi[3].

Quyida kvant texnologiyalarini tasvirlovchi grafik va chizmalar keltirilgan:



1-rasm. Klassik va kvant kompyuter tezliklarining taqqoslanishi.

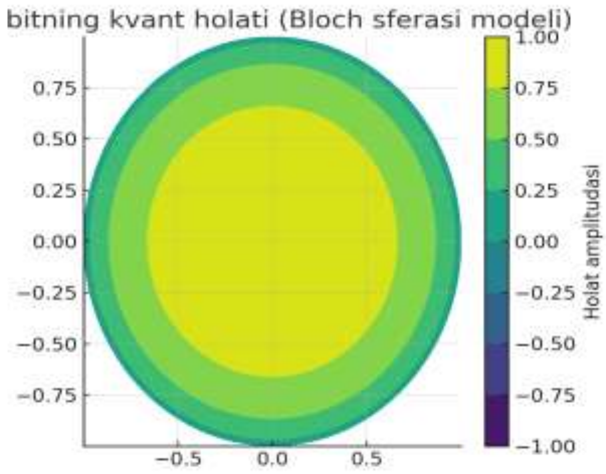
Kvant kompyuterlari hisoblash jarayonlarini kvant bitlari (kubits) orqali bajaradi. Kubitlar superpozitsiya va kvant bog'lanish (entanglement) hodisalari tufayli bir vaqtning o'zida ko'plab holatlarni ifodalay oladi. Kvant kompyuterlari klassik kompyuterlar uchun imkonsiz bo'lgan murakkab masalalarni qisqa vaqt ichida yechishi mumkin. Shor algoritmi yordamida katta sonlarni faktorlash, Grover algoritmi yordamida ma'lumot qidirishni tezlashtirish bunga misol bo'la oladi[4].

Quyida kvant texnologiyalarini tasvirlovchi grafik va chizmalar keltirilgan:

Amaliy qo'llanilishi:

Kvant texnologiyalarining amaliy imkoniyatlari juda keng:

- Farmatsevtikada yangi dori vositalarini ishlab chiqishda molekulyar modellashtirish;
- Transport va logistika sohasida optimal yo'l tarmoqlarini ishlab chiqish;
- Sun'iy intellekt va mashina o'qitishni yangi bosqichga ko'tarish;
- Energetika va materialshunoslikda samaradorlikni oshirish.



2-rasm. Kubitning kvant holati Bloch sferasi modeli orqali ifodalangan

Texnologiya asrida kvant kommunikatsiyalari va kvant kompyuterlari ilm-fan va jamiyat taraqqiyotini yangi bosqichga olib chiqmoqda. Kelgusida kvant internetining shakllanishi va kvant kompyuterlarning amaliyotga keng joriy etilishi insoniyatning axborot xavfsizligi, iqtisodiy rivojlanishi va ijtimoiy hayotiga bevosita ta'sir ko'rsatadi.

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ZAMONAVIY OPTIK TOLA VA OPTOELEKTRONIKA TEXNOLOGIYALARINING QO’LLANILISHI

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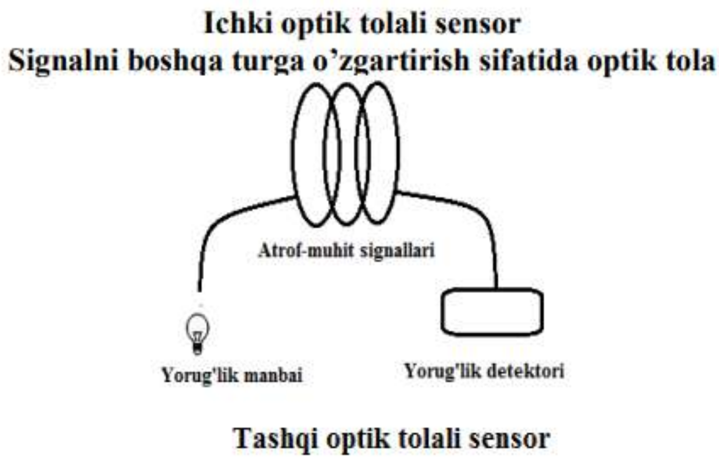
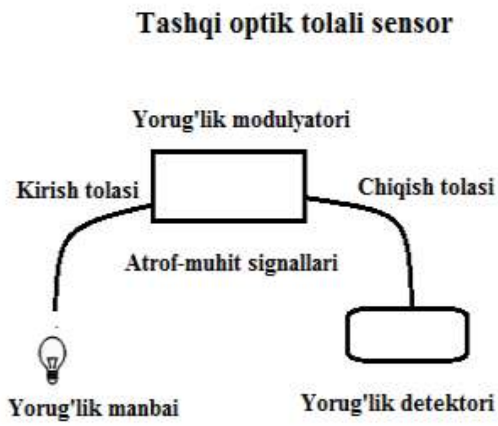
Optoelektronika texnologiyasi - bu fotonik texnologiya va elektron texnologiyalarning kombinatsiyasi natijasida hosil bo’lgan yangi texnologiya. Optoelektronika yorug’likni elektr signallariga va aksincha aylantiradigan qurilmalar va tizimlarni o’rganish va qo’llanishni o’z ichiga oladi. Optik tolalar quyosh batareyalarida, optoelektronikaning zamonaviy texnologiyalarida va global ishchi kuchida hal qiluvchi rol o’ynaydi.

Optik tolali va optoelektronika texnologiyalarining dinamik rivojlanishi iqtisodiyot hamda sanoatning ko’plab tarmoqlarida optik tolali va optik tolali datchiklarning tobora ko’proq qo’llanilishiga olib keldi: elektrotexnika va telekommunikatsiyalar, sanoat va robototexnika, tibbiyot va oziq-ovqat sanoati. Optik tolali texnologiya sohasidagi yechimlar asosan o’lchash va nazorat qilish uskunalari sohasida, shuningdek, uzatish vositasi shaklida qo’llaniladi. **O**ptik tolali sensor bu o’lchash yo’lining boshida joylashtirilgan transduser yoki transduserlar to’plamidan boshqa narsa emas. Ushbu transduserlar o’lchangan miqdorning qiymatini aniqlashi va uni chiqish signalining parametrlarini o’zgartirishga aylantirishi mumkin. Optik tolada oqayotgan yorug’lik to’lqinining ichki modulyatsiyasi tashqi omil to’g’ridan-to’g’ri optik tola bilan o’zaro ta’sir qilganda sodir bo’ladi. Biroq, tashqi modulyatsiya optik toladan olingan yorug’lik to’lqiniga ta’sir qiladi.

Optik tolali datchikning rivojlanishi [1] optoelektron va optik tolali aloqa sanoati bilan bog’liq texnologiyaning asosiy foydalanuvchisi bo’lgan. O’tgan o’n yillardan beri turli xil qurilmalar, shu jumladan optik tolali giroskoplar, harorat, bosim va tebranish sezgichlarini va kimyoviy zondlar optik tolali datchiklar texnologiyasini ishlab chiqish bosqichi takomillashdi. Optik tolali datchiklarning imkoniyati akustika, elektr va magnit maydonlarini o’lchash tarmoqlarida namoyon bo’ladi [2]. Optik tolali datchiklarning yutug’i shundaki, ular harorat, bosim, tezlanish, aylanish, namlik kabilarni aniqlovchi, kimyoviy o’lchovlarni amalga oshiruvchi asboblar vazifasini bajara oladi. Dielektrik xususiyati tufayli ular yuqori kuchlanishli, yuqori haroratli yoki korroziyali muhitda ishlatilishi mumkin. Bundan tashqari, bu datchiklar aloqa tizimlari bilan aloqada bo’ladi va masofadan boshqarish imkoniyatiga ega bo’ladi.



a)



b)

1-rasm. Optik tolali sensorlarning turlari. Ichki (a)va tashqi (b) qurilmalari

Optik tolali sensorlar robototexnika va avtomatlashtirish sohasidagi zamonaviy ilovalarda qo'llaniladi. Optik tolali texnologiya an'anaviy optik yechimlarga qaraganda beqiyos yaxshi bo'lib chiqdi. Uning afzalliklari quyidagilardan iborat: uni bezovta qiladigan EM maydonlariga sezgir bo'lmagan yorug'lik to'lqinlarining uzatilishi, minimal yo'qotishlar, shuningdek, modulyatsiyalangan yorug'lik nurlarining keng diapazonidan foydalanish imkoniyati [3-4].

Optik tolali datchik- bu o'lchangan ob'ektning holatini o'lchanadigan yorug'lik signaliga aylantiruvchi datchik. Optik tolali datchikning ishlash prinsipi shundaki, yorug'lik manbasidan tushadigan yorug'lik nurini optik tolalar orqali modulyatorga yuboradi va modulyatorda tashqi o'lchangan parametrlar bilan o'zaro ta'sir o'tkazib, yorug'likning yorug'lik intensivligi, to'lqin uzunligi kabi optik xususiyatlarini hosil qilib, chastota, faza, qutblanish holati va boshqalar aniqlanadi. U o'zgaradi va modulyatsiya qilingan optik signalga aylanadi, so'ngra optik tola orqali optoelektronik qurilmaga yuboriladi va o'lchov parametri demodulatordan so'ng olinadi. Butun jarayonda yorug'lik nurlari optik tolalar orqali kiritiladi, so'ngra modulator orqali o'tgandan keyin chiqariladi. Optik tolaning vazifasi birinchi navbatda yorug'lik nurini uzatish, ikkinchidan optik modulyator vazifasini bajaradi [5].

Xulosa-hozirgi paytga kelib optik tolaga asoslangan texnologiya va ilovalarning rivojlanishi juda tez rivojlanib bormoqda. Shunday qilib, u o'lcham va shakldagi o'zgarishlarni va optik (sinishi indeksi, rejimni konvertatsiya qilish) o'zgarishlarning tabiati va kattaligiga qarab katta yoki kichik darajada o'zgaradi. Aloqa ilovasi har doim ishonchli bo'lishi va uzatiladigan signallarga har xil ta'sirini kamaytirish juda muhim. Boshqa tomondan, optik tolali datchiklarda sezilarli joyni tekshirish va tashqi ta'sirga javoban ataylab kuchaytiriladi, natijada optik nurlanishning o'zgarishi tashqi buzilishning o'lchovi sifatida ishlatilishi mumkin.

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TEXNOLOGIYA ASRI: KVANT ALOQA VOSITALARI VA KVANT KOMPYUTERLARI.

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Dunyo bo’ylab bejizga XXI asrni “Axborot va texnologiyalar asri” deb nomlashmaydi. Insoniyat taraqqiyoti tobora yangi bosqichlarga ko‘tarilib, ilgari imkonsizdek tuyulgan g‘oyalar haqiqatga ylanmoqda. Bugungi kunda fan va texnika oldida turgan eng dolzarb masalalardan biri — hisoblash quvvatini oshirish va axborot xavfsizligini ta’minlashdir. Shu bois, dunyoning yetakchi ilmiy markazlari va kompaniyalari kvant texnologiyalarini amaliyotga joriy etishga katta e’tibor qaratmoqda. Ularning eng muhim yutuqlari sifatida kvant aloqa vositalari va kvant kompyuterlarini ko‘rsatish mumkin.

Kvant texnologiyalarining paydo bo‘lishi va rivojlanish omillari. Kvant texnologiyalari XX asr boshlarida shakllangan kvant mexanikasi nazariyalariga asoslanadi. Maxsus nurlanish nazariyasi, Geisenbergning noaniqlik prinsipi, Shredinger tenglamalari kabi ilmiy yutuqlar elektronlar, fotonlar va boshqa mikro zarralarning noodatiy xususiyatlarini ochib berdi. Bugungi kunda kvant mexanikasi nazariyalari amaliy texnologiyalar asosiga aylanib, quyidagi yo‘nalishlarda rivojlanmoqda:

Kvant hisoblash (Quantum Computing);

Kvant aloqa (Quantum Communication);

Kvant simulyatsiya;

Kvant sensorlari va metrologiyasi.

Bu yo‘nalishlar orasida hisoblash va aloqa tizimlarining kvant texnologiyalariga asoslanishi jamiyat va iqtisodiyot uchun eng muhim o‘zgarishlarni keltirib chiqarishi kutilmoqda.

Kvant aloqa vositalari: an’anaviy aloqa tizimlarida yuborilgan signallar shifrlansada, ularni maxsus algoritmlar yordamida buzish mumkin.

Shu sababli axborot xavfsizligi global miqyosda dolzarb muammo bo'lib qolmoqda. Kvant aloqa voaitalari esa bu muammoni mutlaqo yangi darajada hal qiladi. Kvant mexanikasida mavjud superpozisiya va noaniqlik prinsipi asosida uzatilayotgan fotonlarning holatini yashirincha o'lchash mumkin emas. Har qanday tashqi aralashuv signaldagi o'zgarish orqali darhol aniqlanadi. Bu esa kelajakda mutlaq xavfsiz aloqa tarmoqlarini yaratish imkonini beradi.

Amaliy misol: 2016-yilda Xitoy "Micius" nomli kvant sun'iy yo'ldoshini orbitaga chiqarib, dunyoda birinchi marta uzoq masofaga xavfsiz kvant aloqa kanalini o'rnatdi. Bu tajriba kelajakdagi kvant interneti uchun asosiy poydevor bo'ldi.

Kvant kompyuterlari: hisoblash quvvatida yangi bosqich. Klassik kompyuterlar 0 va 1 raqamlariga asoslangan bo'lsa, kvant kompyuterlari kubitlardan foydalanadi. Kubitlarning o'ziga xosligi shundaki, ular bir vaqtning o'zida bir nechta holatda bo'lishi mumkin (superpozitsiya) va ular o'zaro chalkashlik (entanglement) orqali bog'lanadi. Buning natijasida kvant kompyuterlari oddiy kompyuterlar uchun imkonsiz bo'lgan hisob-kitoblarni nihoyatda tez bajaradi.

Ilmiy va amaliy imkoniyatlari:

- Kriptografiya: an'anaviy shifrlash tizimlarini qisqa vaqtda buzish; yangi, yanada ishonchli kvant shifrlash usullarini yaratish.
- Kimyo va biologiya: murakkab molekulalarni modellashtirish orqali yangi dori vositalari yaratish.
- Sun'iy intellekt: katta hajmdagi ma'lumotlarni qayta ishlashni tezlashtirish.
- Logistika va iqtisodiyot: optimal resurs taqsimoti masalalarini tez hal qilish.

Amaliy misol: 2019-yilda Google kompaniyasi "Sycamore" kvant protsessori yordamida klassik superkompyuter 10 ming yil davomida bajaradigan hisobni 200 soniyada amalga oshirdi. Bu hodisa "kvant ustunligi" (Quantum Supremacy) deb nomlanib, fan tarixida muhim bosqich bo‘ldi.

Fan va texnologiyaga ta’siri. Kvant texnologiyalarining rivojlanishi nafaqat hisoblash va aloqa tizimlarini, balki butun jamiyatning rivojlanish paradigmasini o‘zgartiradi.

Tibbiyotda yangi dorilar va diagnostika usullari yaratiladi.

Kosmik tadqiqotlarda murakkab jarayonlarni tez hisoblash imkoniyati tug‘iladi.

Iqtisodiyotda xavfsiz moliyaviy tranzaksiyalar amalga oshiriladi.

Davlat boshqaruvida axborot xavfsizligi eng yuqori darajaga ko‘tariladi.

Xulosa. XXI asr ilm-fanida kvant texnologiyalari eng dolzarb yo‘nalishlardan biri hisoblanadi. Kvant kommunikatsiyalari insoniyatni mutlaq xavfsiz aloqa tizimlari bilan ta’minlasa, kvant kompyuterlari hisoblash quvvatini keskin oshiradi. Hozirgi bosqichda bu texnologiyalar hali to‘liq amaliyotga joriy etilmagan bo‘lsa-da, ularning kelajakdagi ta’siri beqiyos bo‘lishi shubhasiz.

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POLIMER NANOSTRUKURALARDA GRAFEN HOSIL BO'LISHINING TERMIK VA LAZERLI STIMULYATSIYA MEXANIZMLARI

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Ushbu ishda polimer materiallar ichida yuqori harorat va lazer energiyasining ta'siri ostida grafen qatlamlarining sintezi jarayonlari o'rganilgan. Termik stimulyatsiya jarayonida polimer molekulalarining yuqori haroratda karbonizatsiyalanishi va rekristallanishi natijasida ikki o'lchamli grafen strukturalari hosil bo'ladi. Tadqiqotlar bu jarayonlarning ilmiy asoslarini aniqlash va yangi yuqori samarali grafen asosidagi nanostrukturalar yaratish imkoniyatlarini kengaytirishga qaratilgan.

Ushbu ishda pikosoniyali lazer spektrining turli energiya oqimlarida, PI sirtida temperature o'zgarishini COMSOL Multiphysics dasturiy ta'minoti vositasida modeli qurilgan, mavjud texnologiyalar va lazer-polimer o'zaro ta'sir mexanizmlarini yanada chuqurroq anglashga qaratilgan. Lazer parametrlari va PI yuzasidagi sirt termal effekti o'zgarishlari batafsil tahlil qilinadi. Ushbu tadqiqotlar lazer texnologiyalaridan foydalangan holda PI bazasidagi materiallarning funksional xususiyatlarini boshqarish, ularning elektron qurilmalardagi ilovalarini optimallashtirish uchun asos bo'lishi mumkin[1-3].

Ushbu tadqiqotda poliimid (PI) yuzasida pikosoniyali lazer spektri yordamida yuzaga keladigan termal o'zgarishlarni aniqlash maqsad qilib qo'yildi. Tadqiqot jarayoni COMSOL Multiphysics dasturiy ta'minoti yordamida modellashtirish asosida olib borildi. Simulyatsiya jarayonida pikosoniyali lazerning turli energiya oqimlari va ularning PI yuzasiga ta'siri o'rganildi. Lazer va materialning o'zaro ta'siri mexanizmi modellashtirilgach, PI yuzasida yuzaga kelgan temperaturaning vaqt va joy bo‘yicha taqsimoti tahlil qilindi.

Natijalar polimerlarning lazer bilan ishlov berilishi jarayonlarini optimallashtirish va elektron qurilmalardagi PI asosidagi materiallarning sifatini yaxshilash uchun amaliy tavsiyalar shaklida qo‘llanilishi mumkin.
Ushbu tadqiqotning asosiy metodlari va vositalari quyidagilarni o‘z ichiga oladi:

COMSOL Multiphysics dasturi orqali issiqlik tarqalishini modellashtirish;

Lazer impulsi parametrlarini aniqlash va ularni modellashtirishga kiritish;

PI materialinin issiqlik va fizik xususiyatlarini hisobga olish;

Termal ta’sir va uning yuzaning mikrostrukturalariga ta’sirini tahlil qilish.

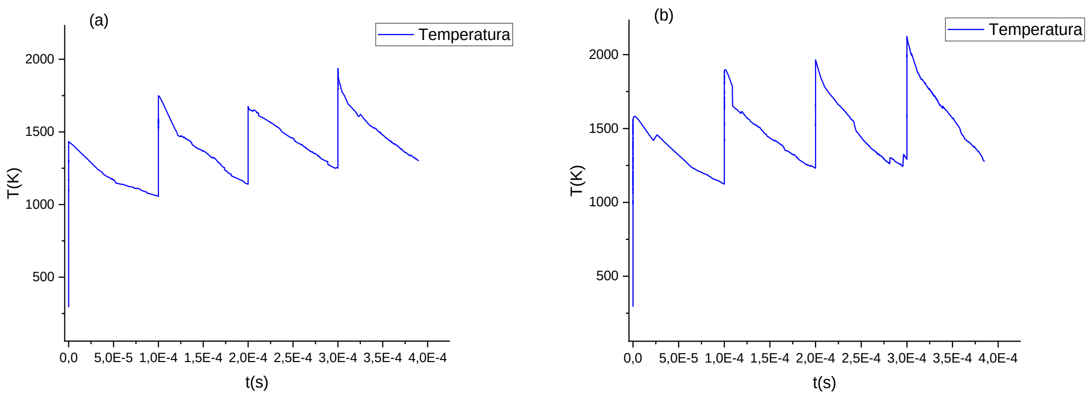
1-jadval. Lazerli ishlov berish parametrlari

Belgilanishi	*Qiymati*	*Lazer nurlanishini parametrik kattaliklari*
f	10[kHz]	Chostatasi
E_p	125-160 [mkJ]	Impuls energiyasi
P_w	50[fs]	Impuls davomiyligi
D	150 [mkm]	Nur diametri
ε	0.8	Yutulish koeffitsiyenti
x_r	100[mkm]	Yo’naltiruvchi nuqta lazer nurining markazini ifodalaydi
x_d	100 [mkm]	Gauss lazer nurining standart og‘ishi
v	700 mm/s	Lazerli skanerlash tezligi

2-jadval. Polimid materialining dastlabki parametrlari

Belgilanishi	*Qiymati*	*Termal kattaliklar*
T_m	723 [K]	Erish temperaturasi
T_v	1173 [K]	Bug'lanish harorati
L_m	250 [J/g]	Erishning yashirin issiqligi
L_v	5000 [J/g]	Bug'lanishning yashirin issiqligi
β	5e-5 [1/K]	Termal kengayish koeffitsienti
γ	-3e-4 [N/m/K]	Sirt tarangligining harorat hosilasi
h_1	17 [W/m^2/ K]	Issiqlik uzatish koeffitsienti
ΔT	30 [K]	Egri chiziqning yarmi kengligi
T_a	293.15 [K]	Atrof-muhit harorati
T_i	293.15 [K]	Dastlabki harorat
H	193[µm]	Oddiy balandligi
W	750 [µm]	Oddiy kenglik
A	0.8	Lazer nurini yutish koeffitsienti

Natijalar va tahlil. Modellashtirish uchun polimidning parametrlari COMSOLE dasturiga kiritilgan. Kiritilgan parametrlar 2-jadvalda keltirilgan.



3-Rasm. *(a) 0,7 J/sm², (c) 0,9 J/sm² lazer oqimlari uchun o'zgaruvchan to'qnashuvlar bilan to'rtta impulsli nurlanish paytidagi harorat o'zgarishlarini tasvirlaydi.*

Poliimid (PI) yuzasida lazer energiyasi oqimining 0.7 J/sm² dan 0.9 J/sm² gacha o'zgarishi natijasida yuzaga kelgan haroratning maksimal qiymati, 2000 K dan 2100 K gacha ko'tarilishi polimer sirtida yuzaga keladigan fizik-kimyoviy jarayonlarga sezilarli ta'sir ko'rsatadi. Bu ko'tarilgan haroratlarda PI yuzasida grafen hosil bo'lishi va karbonizatsiya jarayonlari faol amalga oshadi.

Pikosoniyali lazer spektrining 0.7 J/sm² va 0.9 J/sm² energiya oqimlari ostida polimid (PI) sirtida yuzaga kelgan maksimal haroratlarning 2000 K va 2100 K ga ko'tariilishi natijasida yuzaga kelgan jarayonlar tizimi murakkab termik va kimyoviy o'zgarishlarni o'z ichiga oladi. Ushbu harorat diapazonida PI sirtida karbonizatsiya va grafen qatlamlarining sintezi uchun zarur bo'lgan energiya sharoiti yaratiladi.

2000 K atrofida yuzaga kelgan harorat karbonizatsiyani boshlash va polimer molekulalarining termik parchalanishini faollashtirish uchun yetarli hisoblanadi. Bu jarayonda polimid molekulalaridagi kislorod va boshqa elementlar yo'qolib, yadro uglerod atomlari zichligining oshishi va qayta tashkil etilishi sodir bo'ladi. Bu termik jarayonlar natijasida yuqori sifatli, qattiq va ikki o‘lchamli grafen qatlamlari yuzaga keladi, ular nanometr o‘lchamda sirt bo‘ylab tarqaladi.

Natijada, pikosoniyali lazer spektrining optimal energiya oqimi va intensivligi PI sirtida yuqori sifatli grafen hosil bo‘lishini ta’minlab, elektron qurilmalardagi materiallarning barqarorligi va ishlash muddatini uzaytirishda muhim ahamiyat kasb etadi. Bu tadqiqot lazer asosidagi materiallarni modifikatsiyalash texnologiyalarini rivojlantirish va yangi avlod nanoelektronika vositalarini yaratishda ilmiy va amaliy ahamiyatga ega bo‘ladi.

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LAZER PLAZMASI HOSIL BO‘LISHIDA YUZAGA KELADIGAN FIZIK JARAYONLARNI MODELLASHTIRISH

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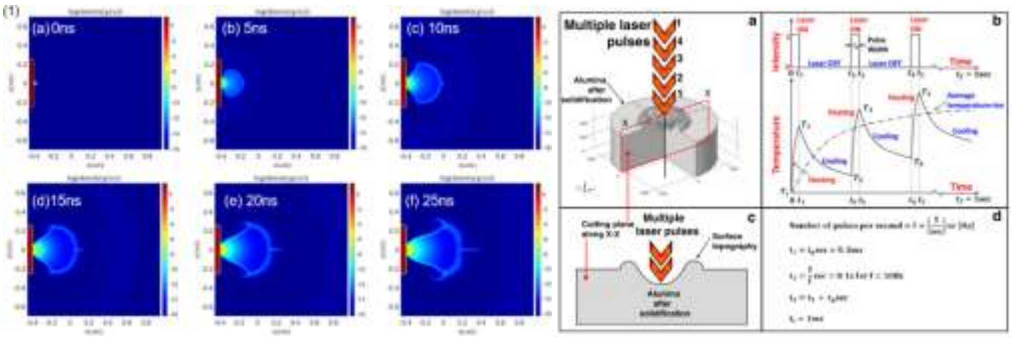
Buguni kunda lazer nurlanishini moddalar bilan o‘zaro ta’sirlashuvi natijasida yuzaga keladigan fizik jarayonlarni aniqlash va fizik ma’nolarini tushinishga qaratilgan ko‘plab tadqiqotlar olib borilmoqda. Yuqori quvvatli, qisqa impulsli lazer nurlanishi bilan qattiq agregat holatdagi moddalarga ta’sir qilish orqali plazma hosil bo‘lishi va shu plazmaning optik husosiyatlarini o‘rganish, moddani sifat va miqdoriy jihatdan tahlil qilishga imkoniyat beradi. Lazer nurlanishi bilan sirtga ishlov berish, sirtni yangi optik, o‘tkazuvchanlik, namlanish kabi fizik husosiyatlarini ochishi bilan nanotexnologiyada keng qo‘llanilmoqda



1-rasm. Lazer pazmasini hosil bo‘lishi va sirt morfologiyasini o‘zgarishining fizik modellari. [1][2]

Lazer plazmasini hosil bo‘lishidagi fizik jarayonlarni modellashtirish (1-rasm) , samarali plazma hosil bo‘lishi uchun lazer parametrlarini optimallashtirish, plazma harorati va zichligini nazorat qilish, elementlarni sifat va miqdor jihatdan tahlil qilish uchun lazer spektroskopiyasidek (LIBS) analitik usullarni takomillashtirish kabi asosiy imkoniyatlarni taqdim etadi. Shuningdek, u materiallarni qayta ishlash usullarini, shu jumladan lazerli ablatsiyasi va nanostrukturalarni shakllantrishni yaxshilaydi. Bundan tashqari, modellashtirish litografiya uchun samarali plazma manbalarini ishlab chiqishni qo'llab-quvvatlaydi, ilg'or tezlatgichlar uchun plazma dinamikasini tushunishni osonlashtiradi va keng ko'lamli fizik tajribalar o'rniga bashoratli simulyatsiyalarni amalga oshirish orqali eksperimental xarajatlarni kamaytiradi. Ushbu yutuqlar birgalikda lazerdan foydalanish spektroskopiya, materialshunoslik, nanotexnologiya va sanoatni taraqqiyotga olib keladi.

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PARAMETRIC SENSITIVITY OF HFO_2-BASED MEMRISTORS: COMSOL–MATLAB MODELING OF I–V CHARACTERISTICS

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Abstract

HfO_2-based memristors are promising candidates for next-generation non-volatile memory and neuromorphic computing. Their switching behavior, however, is highly variable due to sensitivity to material, thermal, and geometric parameters. In this study, we develop a free-energy–based numerical model of resistive switching using a hybrid COMSOL Multiphysics–MATLAB LiveLink framework. The model self-consistently solves coupled electrostatic and thermal fields and determines stable filament configurations through free-energy minimization.

1. Introduction

Earlier ion-drift and tunneling models captured partial aspects of the switching mechanism but lacked predictive accuracy [1-3]. A thermodynamic free-energy framework [5] has provided a more consistent description by incorporating both electronic and thermal contributions. Building on this approach, we employ a hybrid COMSOL Multiphysics–MATLAB LiveLink implementation to systematically analyze how electrical conductivity (EC) and specific heat capacity (SHC) govern resistive switching in HfO_2 memristors.

2. Methods

Resistive switching was described as a sequence of phase transitions governed by free-energy minimization. The total free energy of the system was expressed as:

$$F = \iiint \rho C_p \Delta T dV + \frac{1}{2}\iiint \epsilon |E|^2 dV + 2\pi r h \sigma_s + \pi r^2 h \Delta\mu$$

where ρ is density, C_p is specific heat capacity, ΔT the temperature rise, ϵ dielectric permittivity, E electric field, r and h filament radius and length, σ_s interfacial energy, and Δμ the chemical potential difference. These terms represent thermal, electrostatic, surface, and chemical contributions, respectively. Minimization of F with respect to filament radius (SET) or gap length (RESET) yields stable states [4].

The simulated device was a TiN/Hf/HfO_2/TiN stack with oxide thickness 5-10 nm and lateral radius 10 nm under axisymmetric geometry. COMSOL solved electric and thermal fields at each voltage step, and results were transferred to MATLAB via LiveLink. MATLAB minimized the free-energy functional and returned stable filament/gap configurations. Device current was then computed from the effective filament cross-section, and voltage sweeps in both polarities were used to reconstruct I–V loops.

Figure 1. The

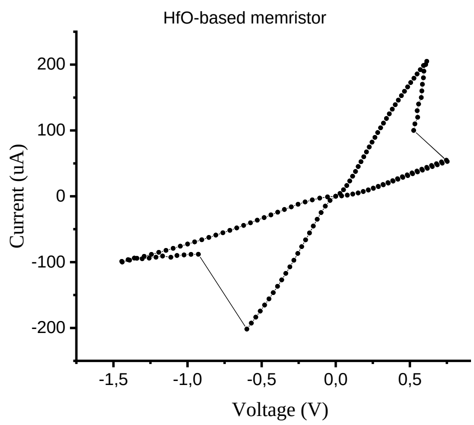


Figure 2. The experimental IV of HfO

Electrical transport was solved using:

$$\nabla \cdot \boldsymbol{J} = 0, \quad \boldsymbol{J} = \sigma \boldsymbol{E}, \quad \boldsymbol{E} = -\nabla V,$$

and thermal transport with Joule heating was described by:

$$\rho C_p \frac{\partial T}{\partial t} - \nabla \cdot (k \nabla T) = \boldsymbol{J} \cdot \boldsymbol{E}$$

where *k* is thermal conductivity.

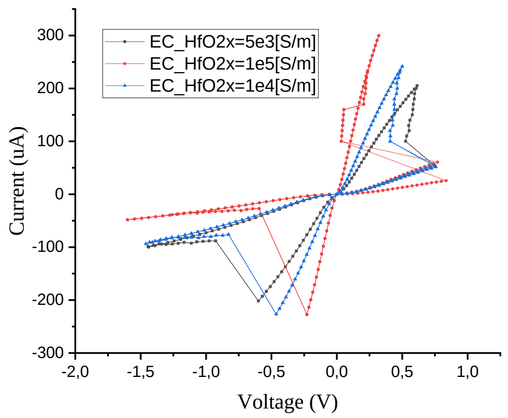
These PDEs were implemented in COMSOL Multiphysics.

geometry of device. based memristor

Figure 1 illustrates the geometry of the simulated device, while **Figure 2** presents the experimental I–V characteristics of HfO_2-based memristors reported in the literature [1]. These experimental data serve as a reference for validating our numerical results.

3. Results and Discussion

Figure 3 shows the simulated I–V characteristics of HfO_2 memristors for different values of oxide electrical conductivity (EC). Increasing EC significantly reduces the SET voltage and steepens the ON-state current rise. Physically, higher conductivity enhances local Joule heating at lower voltages, thereby lowering the energy barrier for filament nucleation. The RESET transition also shifts, but to a smaller extent, indicating that RESET is influenced by both conduction and heat dissipation. Importantly, at high EC values the hysteresis window narrows, suggesting that excessive conductivity compromises the stability between ON and OFF states. Figure 4 illustrates the influence of the specific heat capacity (SHC) of HfO_2 and sub-stoichiometric HfO_{2-x} (The unit is J/(kg*K)). Larger SHC values delay SET switching and increase threshold voltages, while lower SHC accelerates switching at reduced voltages. This occurs because higher SHC increases the thermal inertia of the oxide: more energy is required to raise the local temperature sufficiently for vacancy migration and filament growth. In contrast, low SHC allows rapid temperature rise under Joule heating, resulting in earlier switching. The RESET process also broadens at higher SHC values, reflecting slower thermal relaxation.



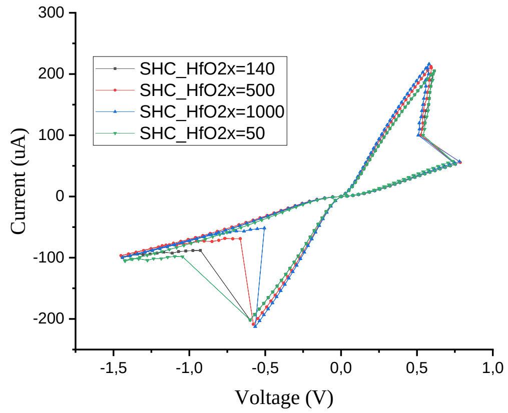


Figure 3. Simulated I–V curves for different values of electrical conductivity (EC) in HfO_2.

Figure 4. Simulated I–V curves for different values of specific heat capacity (SHC) in HfO_2 and HfO_{2-x}.

5. Conclusion

The study shows that electrical conductivity (EC) and specific heat capacity (SHC) are decisive factors in resistive switching. Higher EC lowers SET voltages by enhancing Joule heating, while higher SHC delays switching through thermal buffering. Their interplay explains both efficiency and variability observed in experiments. Controlling oxide conductivity and heat capacity is therefore as critical as ionic mobility for achieving stable and reproducible memristor performance.

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OPTOELEKTRONIKA TEXNOLOGIYASINING HOZIRGI KUNDAGI AHAMIYATI

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Optoelektronika texnologiyasi - bu fotonik texnologiya va elektron texnologiyalarning kombinatsiyasi natijasida hosil bo'lgan yangi texnologiya hisoblanadi. Bular optik aloqa, optoelektron displey, yarimo'tkazgichli yoritish, optik saqlash, lazerlar va boshqa qo'llash sohalarini o'z ichiga olgan materiyadagi yorug'lik va elektronlarning gigant o'zaro ta'sirini va uning energiya konversiyasini o'rganish bilan bog'liq texnologiya axborot va aloqaning asosiy texnologiyalaridir.

Kundalik hayotda eng keng tarqalgan narsa bu LED displeydir. Ko’p LED mahsulot seriyasi mavjud. Foydalanish muhitiga ko’ra, u ikki toifaga bo’linadi: ichki biologi va tashqi biologi; Yashil va ko’k (RGB) uch rangli to’liq rangli ekran va boshqalar; displeyni boshqarish usuliga ko’ra, u aloqa ekrani va video biologi ekraniga bo’linadi. Bundan tashqari, LED displeylar chiziqli ekranlar, nuqta matritsali ekranlar, nuqta matritsali raqamli gibrid ekranlar va yo’l harakati o’zgaruvchan ma’lumot taxtalari kabi foydalanish xususiyatlariga ko’ra tasniflanishi mumkin. Turli xil ko’rsatkichlarga ega bo’lgan LED displeylarning har xil turlari moddiy tarkibi, ishlab chiqarish jarayoni va nazorat qilish texnologiyasi jihatidan juda farq qiladi va texnik ma’nodagi farq ham aniq [1].

LEDlar ko’pincha jamiyatimizning ish va hayotida qo’llaniladi:

- Qimmatli qog’ozlar savdosi, moliyaviy ma’lumotlar displeyi. Ushbu sohada ishlatiladigan LED biologi ekrani eng katta talabga ega bo’lib, LED biologi ekrani bozor ulushining deyarli 50 foizini tashkil qiladi va hali ham katta talab mavjud.

- Aeroportlar, stansiyalar va portlarda yo‘lovchilarga yo‘l-yo‘riq ko'rsatuvchi ma'lumotlarni ko'rsatish. Aeroport parvozi dinamik ma'lumotlarini ko'rsatish. Mening mamlakatimning fuqarolik aviatsiyasi aeroporti qurilishida biologi ekranlari uchun juda aniq talablar mavjud va LED biologi ekranlari parvozlarni ko'rsatish tizimlari uchun birinchi tanlovdir. Asosiy korpus sifatida LED displeyli axborot va radioeshittirish tizimi, poezdning kelishi va jo'nashini eslatish tizimi va chiptalar haqida ma'lumot tizimidan iborat bo'lgan yo'lovchi tashish markazining avtomatlashtirish tizimi texnologik rivojlanishning muhim qismiga aylandi va mening mamlakatimning temir yo'l stantsiyalari va portlarini o'zgartirish.

- Reklama vositalari. Reklama vositasi sifatida bitta katta ichki va tashqi LED displeyga qo'shimcha ravishda, klasterli LED displeyli biologi tizimlari va poezdning LED displeyli biologi tizimlari ham qabul qilindi va targ'ib qilindi.

- Performans va biologi. Keng ko'lamli LED displeylar ommaviy va siyosiy maqsadlarda jonli video eshittirishlar uchun tobora ko'proq foydalanilmoqda, jonli efirda va biologi ma'lumotlarini tarqatishda muhim rol o'ynaydi [2].

Hozirgi vaqtda optoelektronik texnologiya jadal rivojlanmoqda va ko'plab yangi chegara yo'nalishlari paydo bo'ldi, masalan, o'ta aniqlikdagi optika, hisoblash optikasi, mikro-nanooptika va boshqalar "va "kosmosni aniqlash", "okeanlarni aniqlash", "fotoelektrik biologi", "tibbiy salomatlik", "aqlli shahar" va boshqa sohalar keng ko'lamli ilovalarga ega bo'lib, ular milliy xavfsizlikni saqlash, ilmiy-texnikaviy taraqqiyotni rag'batlantirish va ijtimoiy iqtisodiyotni rivojlantirishda muhim rol o'ynaydi.

Sun'iy biologic kiberxavfsizlikni, tasvirni aniqlash dasturini, onlayn xarid qilish tajribasini va raqamli ravishda amalga oshiriladigan har qanday boshqa ilovalarni keskin yaxshilashi mumkin bo'lgan mashinani o'rganish vositalarining asosiy elementidir. Smart soatlar, ko'zoynaklar va tibbiy monitorlar kabi aqlli qurilmalar televizor va maishiy texnika kabi odamlarning kundalik hayotining muhim qismiga aylanib bormoqda. Odamlar ushbu aqlli qurilmalarga kunlik minimal qadamlar soniga rioya qilishlari, keraklidan kamroq kaloriya iste'mol qilishlari va ekran vaqtini cheklashlari uchun ishonishadi [3].

Rasm. Optroelektronika mahsulotlari.

Kelgusi yechimlar ushbu qurilmalarni yanada aqlli qiladi. Yo'naltirilgan tadqiqotga muhtoj bo'lgan ikkita yo'nalishga mobil qurilmalar uchun chipli o'lchovli integratsiyalangan spektrometrlar (spektrometrlar yorug'lik intensivligi-dagi o'zgarishlarni o'lchaydigan va tahlil qiluvchi asboblar) va robotli jarrohlik ilovalari uchun miniatyura 3D sensorlar va tasvirlash echimlarini o'z ichiga oladi. Optik ilovalar front-end zondlash va ishlab chiqarishga qaratilgan. Sanoat sohasida xarajatlarni pasaytirish, samaradorlikni oshirish va aqlli ishlab chiqarish talablarini qondirish uchun butun ta'minot zanjiri mustaqil nazoratini amalga oshirish biolog bilan birga sanoat ko'rish va sanoat kabi ilg'or mahsulotlarni qo'llashni jadallashtirish kerak. Sanoat stsenariylarida lazer uskunalari.

Chiplar ishlab chiqarish sohasidagi eng yirik kompaniyalar mijozlar talabini qondirish va chiplarning navbatdagi global taqchilligini oldini olish uchun bir nechta mintaqalarga yirik investitsiyalar e'lon qilishdi. 2022 yilda chip ishlab chiqarish sanoatining xarajatlari biolog ko'rsatkich bo'lib, global chip ishlab chiqaruvchilar to'liq yillik kapital xarajatlar uchun 150 milliard dollardan ko'p sarflashadi [4].

Optoelektronika texnologiyasi harbiy dasturlarda katta salohiyatga ega, ba'zilari paydo bo'ldi, ba'zilari hali ham kontseptual tadqiqot bosqichida va men ko'proq ishlab chiqilmaganidan qo'rqaman. Misol uchun, lazerlar tug'ilganda harbiylar tomonidan o'ylangan va tez orada tadqiqotga sarmoya kiritgan lazer qurollari. 1983 yilda AQSh prezidenti Ronald Reygan "Yulduzli urushlar" rejasini taklif qildi va lazer quroli ustuvor energiya quroli sifatida katta miqdorda sarmoya kiritildi. Lidar tadqiqotlari uzoq tarixga ega. Ko'plab prototiplar va tajribalar, shuningdek, ko'plab ilmiy tadqiqot mahsulotlari mavjud. Lazerlar va tegishli texnologiyalarning rivojlanishi bilan turli xil harbiy Lidarlar paydo bo'lishi kutilmoqda. Masalan, 3D tasvirlash lidar, kimyoviy va biologik urush agentlarini aniqlash radarlari, nishonni aniqlash lidarlari va boshqalar [5].

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KVANT TEXNOLOGIYALARINING SHAKLLANISHI VA RIVOJLANISH OMILLARI

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Bugungi kunda kvant kommunikatsiyalari va kvant kompyuterlari nafaqat ilmiy doiralar, balki global iqtisodiyot, milliy xavfsizlik va raqamli jamiyatni rivojlantirishda muhim rol o'ynay boshladi. Kvant texnologiyalarning rivojlanishiga quyidagi omillar turtki bo'ldi:

- Raqamli texnologiyalarning murakkablashishi va yangi hisoblash quvvatlariga ehtiyoj.
- Global axborot xavfsizligini mustahkamlash zarurati.
- Nanotexnologiya va yuqori aniqlikdagi tajribalar asosida kvant effektlarini boshqarish imkoniyati.

Kvant kommunikatsiyalari kvant kriptografiyasi prinsiplari asosida shakllanadi. Ularning asosi bo'lib kvant superpozitsiyasi va kvant chalkashligi (entanglement) hodisalari xizmat qiladi. Kvant kommunikatsiyalari QKD (Quantum Key Distribution) – kvant kalitlarini taqsimlash orqali mutlaq xavfsizlikka ega aloqa kanallarini yaratish, kvant internet – kelajakda kvant tugunlari orqali global xavfsiz axborot tarmog'ini shakllantirish, harbiy va davlat sirlarini himoyalash – klassik kriptografiyani buzib bo'ladigan sharoitlarda ham barqarorlik ta'minlash maqsadida qo'llaniladi [1].

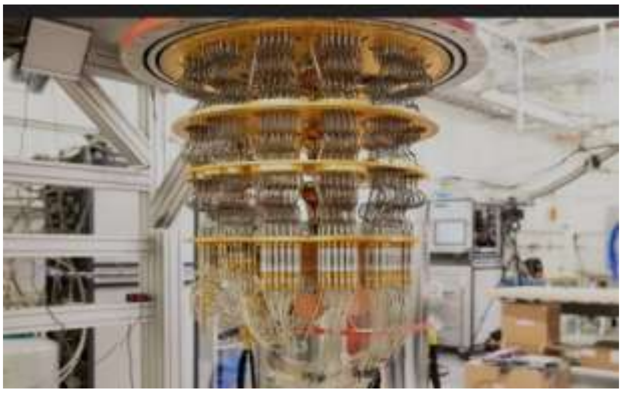
Xitoyning 2016-yilda uchirilgan Micius sun'iy yo'ldoshi dunyodagi birinchi kvant aloqa tarmog'i loyihasidir. Kvant kompyuterlarning asosiy elementi kubит bo'lib, u klassik bitdan farqli ravishda "0" va "1" holatlarda bir vaqtda bo'lishi mumkin. Kvant kompyuterlari - kvant hisoblashlarga asoslangan zamonaviy kompyuterlardir. Kvant kompyuterlari, masalan, kriptografiyada juda keng qo'llanadigan katta sonlarni tub ko'paytuvchilarga ajratish kabi ma'lum bir muammo va masalalarni oddiy kompyuterlariga nisbatan ancha tez bajaradi.

Mashhur amerikalik fizik Richard Feynman hisob-kitoblarni amalga oshirish uchun kvant hodisalaridan foydalanishni XX asrning oʻrtalaridayoq taklif qilgan edi, ammo oʻsha paytda bunday kompyuter, albatta, faqat chiroyli futuristik nazariya edi.

Deyarli barcha ma'lum kompyuterlar Tyuring nazariyasidan foydalanadi va aynan Benioff Tyuring kvant mashinasini yaratish mumkinligini nazariy jihatdan birinchi boʻlib asoslab bergan. Rus fizigi Yuriy Ivanovich Manin ham kelajakda ishlab chiqilishi mumkin boʻlgan kubit kompyuteriga oʻz hissasini qoʻshgan — kvant hisoblashlar gʻoyasini taklif qilgan va kengaytirgan. Ammo ishga yaroqli birinchi prototipni yaratish uchun oʻn yildan koʻproq vaqt kerak boʻldi. 1997-yilda olimlar Isaak Chuang, Nil Gershenfeld va Mark Kubinets hisoblashlarni bajara oladigan kvant kompyuterining taqdimotini oʻtkazdi. U Shor algoritmi va yadro-magnit rezonansi tamoyillariga asoslangan. Kvantning birinchi modeli taqdim etilgandan soʻng koʻplab taniqli ilmiy va texnologik tashkilotlar oʻz prototiplarini ishlab chiqishni boshladi. Har bir olim va muhandislar jamoasining maqsadi kvant ustunligiga erishish edi. Kvant ustunligi — oddiy kompyuter yordamida bajarib boʻlmaydigan vazifalarga kvant kompyuteri yordamida yechim topish. Kvant ustunligi amallarning yuqori tezlikda bajarilishi ekanini tushunish kerak [2].

Bugungi kunga kelib kvant hisoblashlar shunchaki chiroyli "kelajak manzarasi" emas. Dunyodagi yetakchi texnologik kompaniyalar eng qiyin vazifalarni muvaffaqiyatli bajara oladigan mashinalarini taqdim etmoqda. Kvant hisoblash mashinalari poygasi ba'zida qurollanish poygasini eslatib yuboradigan darajada keskinlashadi. Har bir jamoa yanada kuchli va takomillashgan modelni taqdim etib, boshqalarni "quvib oʻtishga" harakat qilmoqda. Rossiya texnologiya sanoati 2024-yilning fevral oyida "Rosatom"

20 kubitli kompyuterni taqdim etdi. Uning aniqligi 95% ni tashkil etadi [3].



Rasm. Kvant kompyuteri.

Kvant kompyuterining keng qo'llanishiga to'sqinlik qilayotgan yana bir muammo — **dekogerensiya**. Zarrachalar odatdagi tashqi sharoitda o'z xususiyat-larini osongina yo'qotadi va bu hisoblash jarayonini buzadi. Atrof-muhit haroratining o'zgarishi vazifalarning bajarilishiga xavf soladi, shuning uchun olim va muhandislar kompyuterlarni tashqi dunyodan ajratishga majburdir. Hozircha buning uchun kuchli sovutishdan foydalaniladi: hech bir narsa zarrachalarni superpozitsiyadan chiqarib yubormasligi uchun tizim ichidagi harorat sun'iy ravishda mutlaq nolga tushiriladi. Olimlar kvant kompyuterlarini takomillashtirishni davom ettirmoqda, shunday ekan ular yanada ixcham va oddiy bo'lishi ehtimoldan yiroq emas [4].

Olimlarning barcha sa'y-harakatlari, kashfiyotlar, qozonilgan yutuqlarga qaramay, kvant hisoblash hali ham ommabop variant bo'la olmadi. Bu ko'proq qiziqarli texnologik yangilik bo'lib, uning asosiy salohiyati kelajakda namoyon bo'ladi. Ammo kun sayin kelajak tobora yaqinlashib kelmoqda. Masalan, Rossiya Fanlar akademiyasining Sibir bo'limidagi A.V.Rjanov nomidagi yarimo'tkazgichlar fizikasi instituti direktori Aleksandr Vasilyevich Latishevning fikriga ko'ra, qattiq tanali yarimo'tkazgich qurilmalarga o'tish kvant hisoblashni ekzotikadan samarali vositaga aylantiradi. Supero'tkazgichlarda ishlaydigan kvant kompyuterlari maxsus harorat sharoitlariga, murakkab va noqulay boshqaruv tizimlariga muhtoj. Aleksandr Vasilyevichning so‘zlariga ko‘ra, hozirgi vaqtda mikroelektronika qattiq tanali nanofotonika bilan tobora birlashib bormoqda. Nanofotonika — fotonlarning nanometrli obyektlar bilan o‘zaro ta’siri natijasida yuzaga keladigan fizik hodisalarni o‘rganadigan faol rivojlanayotgan fan. Bu fanning amaliy jihati qattiq tanali va organik lazerlarni ishlab chiqish bilan bog‘liq.

Yarimo‘tkazgichlar fizikasi institutida kvant hisoblashlar bazasini yaratish borasida ishlar olib borilmoqda. Masalan, bu yerda kvant kompyuterining kubitlari sifatida sovutilgan yakka atomlar ishlatiladi. Rubidiy atomi bilan muvaffaqiyatli tajribalar o‘tkazishga erishilgan. Kelajakda “ommaga” chiqarish uchun kvant mashinasini yaratishni soddalashtirish va uni arzonlashtirish imkoni tug‘iladi [5].

Texnologiya asrida kvant kommunikatsiyalari va kvant kompyuterlari insoniyatni yangi sivilizatsion bosqichga olib chiqmoqda. Ularning amaliy qo‘llanilishi axborot xavfsizligi, hisoblash quvvatlari va ilmiy izlanishlarda ulkan imkoniyatlar yaratadi. Shu bilan birga, ularni rivojlantirish katta ilmiy va moliyaviy resurslarni talab qiladi.

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"YORUG'LIKNING ASOSIY TARKIBI"

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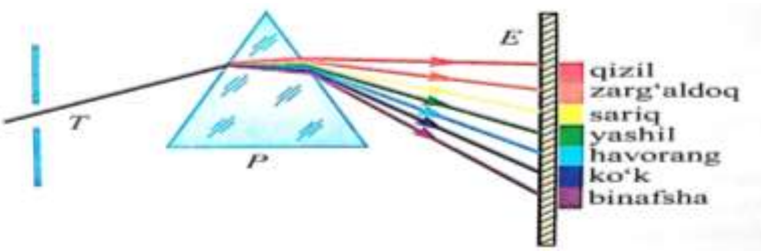
Yorug'lik manbai, bu biz uchun sodda qilib aytganda Quyosh hisoblanadi. Inson hayoti uchun eng yaqin va eng zararli yorug'lik tabiatidagi energiya turlari ichida ba'zi nurlar (rentgen va h.o) hisoblanadi. Uzoq yillar davomida yorug'likning xossalari va ularni xosil qiladigan manbalarning xususiyatlari borasida bir qator ilmiy jumboqlarga duch kelingan.

Fotometriyada quyidagi kattaliklardan foydalaniladi:

– energetik kattaliklar: bunda yorug'likning energetik xarakteristikalari uning qabul qiluvchiga ta'sirini e'tiborga olinmay qaraladi;

– yorug'lik xarakteristikalari: bunda yorug'likning ko'zga yoki boshqa qabul qiluvchilarga fiziologik ta'siri e'tiborga olinib, uning kuchi aynan shu ta'sirga asosan baholanadi.

Yorug'lik nurlarini o'rganish borasida buyuk ingliz fizigi Issak N'yuton ham bir qanca ishlarni amalga oshirgan va ajoyib natijalarga erishgan. N'yotonning bu yorug'lik xossalarini o'rganishga bo'lgan qiziqishga Dekart (1620-1630 yillar) o'tkazgan tajriba sabab bo'ldi va e'tiborini tortdi.



U yorug'likni shisha prizmaga yo'naltirgan va prizmadan 5 cm uzoq'likda ekran vazifasini bajaruvci oq qog'ozda yorug'lik ikkiga (qizg'ish va sariq) ajralganini ko'rgan. Sh bilan Dekart yorug'likning sinish qonunini ifodalab berdi.

Bu tajribani kuzatgan N'yuton asosiy e'tiborini prizma va ekran vazifasini bajargan oq qog'z oralig'idagi ya'ni, obektlar orasidagi masofaga qaratdi. N'yuton o'z tajribasida qorong'ulashtirilgan xonaga tirqish orqali yorug'lik nurini kiritdi va unga prizmani tutdi. Prizma va ekran (devor) oraliginin 5-6 metrgacha uzoqlashtirdi. Shunda prizmadan chiqayotgan nur ekran(devor)da 7 xil rangga ajraganligini kuzatdi. Yorug'lik prizmadan o'tganda paydo bo'lgan har xil ranglar to'plamini N'yuton spektr (lotinca spectrum- ko'rish) deb atadi. (1-rasm)

Asosiy ranglar va ularning xususiyatlari

Qizil (≈700 nm) – eng katta to'lqin uzunligiga ega, energiyasi kichikroq. Issiqlikni ko'proq ifodalaydi.

To'q sariq (≈620 nm) – iliqlik va yorqinlik ramzi.

Sariq (≈580 nm) – ko'zga eng sezilarli ranglardan biri.

Yashil (≈530 nm) – tabiatda eng ko'p uchraydigan rang, ko'z uchun eng qulay.

Ko'k (≈470 nm) – sokinlik va sovuqlik ramzi.

Havo rang (indigo) (≈440 nm) – qisqa to'lqinli yorug'lik.

Binafsha (≈380 nm) – eng kichik to'lqin uzunligiga ega, energiyasi eng katta.

N'yuton tirqishni qizil rangli shisha bilan berkitganda devorda faqat qizil rang dog'ini, yashil shisha bilan berkitganda devorda faqat yashil dog' bo'lishini kuzatdi. Shu bois u nurlarning sinishini ham o'rgandi. Buning sababini N'yuton bilmasada lekin, bu tajribada oq rang murakkab rang ekanligini ko'rsatdi. Spektr (ranglar dastasi) 7 xil rangdan iborat ekan: qizil, zarg'aldoq, sariq, yashil, havorang, ko'k va binafsha. N'yuton oq rang murakkabligini isbotlovchi ko'plab tajribalarni o'tkazgan. Bu tajribalarning zamonaviy taxlilini quyidagicha tushintirish mumkun; birinchi prizmadan o’tib ranglarga ajralgan yorug’lik yo’liga birinchi prizmaga nisbatan 180^0 ga burilgan ikkinchi prizma qo’yilsa, bu prizma yig’uvci linza vazifasini bajarib, undan chiqayotgan yorug’lik dastasi to’plangan nuqta oq rangga aylanadi.

XVII asrning oxorida yorug’likning tabiati haqida ikkita o’zaro qarama-qarshi nazariya maydonga keldi: bulardan biri Nyuton yaratgan ko’rpuskuliyar nazariya va ikkinchisi: Gyuygensning to’lqin nazariyasidir. Yoruqlikning ko’rpuskuliyar nazariyasiga binoan, yorug’lik juda kata tejlik bilan tarqaluvchi juda kichik moddiy zarralar (korpuskulalar) oqimidan iboratdir. Yorug;likning rang ta’siri ko’rpuskulalarning oqimi bilan tushuntirilgan: Eng yirik ko’rpuskulalar qizil ranglinurni, eng maydalari esa binafsha rangli nurni hosil qiladi.

1873- yilda ingliz olimi J. Maksvell yorug’likning $c=3*10^8$ m/s tezlik bilan tarqaladigan elektromagnit to’lqinlardan iborat ekanligini nazariy jixatdan isbotladi. Bu nazariyani H. Hertz tajriba yo’li bilan tas-diqlab berdi.

Bu soxada nemis fizigi Vilgelm Vin ning qo’lga kiritgan yutuqlari juda samaralidir. 1893-yilda u o’zining qizigan jism nurlanishini *spektrlar bo’yica* taqsimlanishi to’g’risidagi ilmiy ishlarini e’lon qildi. V. Vin qizigan jismlarning temteraturasi ortishi bilan nurlanish rangi ham o’zgara borishini matematik ifodalar bilan ko’rsatib berdi.

Yoruglikni o’rganish bo’yica buyuk nimis Albert Eynshteyn 1905-yilda dadil qadam qo’ydi. Taniqli fizik M. Plank yorug’likni alohida-alohida portsiyalardan iborat ko’rinishda tarqalishi to’g’risidagi fikrni olg’a surgan bo’lsa, A. Eynshteyn yorug’likni kvant tizimiga ega ekanligini va bu narsa yorug’lik kvanti oqimi (fotonlar)dan iboratligini ko’rsatib berdi.

1928- yilda Hindistondagi Kalkutta universiteti ilmiy xodimi Candrasekxara Raman o’z shogirdlari bilan yorug’likning turli moddalardan o’tgandan keying spektri tarkibini o’rganish davomida asosiy spektrdagi qizil va ko'k ranglarga yaqin joyda yangi spetr ciziqlari paydo bo'lganligini aniqlagan. Keyinchalik bu fizik hodisa <<Raman effekti>> deb nomlangan.

Yorug'likning yangi xossalarini o'rganish borasidagi kashfiyotlar e'tiborsiz qolmadi. 1911-yil V. Vin, 1918-yil M. Plank, 1921-yil A. Eynshteyn, 1923-til R. Milleken, 1927-yil A. Kompton va 1930-yil C. Ramanlar yorug'likning xossalarini o'rganish bo'yicha yaratgan buyuk kashfiyotlari ucun fizika sohasidagi Nobel mukofotiga sazovor bo'ldilar.

Yorug'lik bilan bog'liq yangi kashfiyot va ixtirolar yaratish borasidagi izlanishlar hozirgi kunda ham davom etib kelmoqda. Duntoning barcha mamlakatlarida, shu jumladan, O'zbekistonda ham bu borada katta ishlar amalga oshirilmoqda.

Ushbu yorug'likni o'rganish borasida yozilgan ilmiy maqola, yorug'lik xossalari va tabiatiga qiziquvci o'quvchilarning o'qib o'rganishlari ucun tavsiya etiladi.

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DESIGN AND ANALYSIS OF A PHOTONIC CRYSTAL FIBER-BASED BIOSENSOR FOR REFRACTIVE INDEX DETECTION

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Abstract. This paper explores the design and analysis of a photonic crystal fiber (PCF)-based biosensor for refractive index (RI) detection. The study emphasizes structural modifications and their effects on key optical properties such as confinement loss and dispersion. Utilizing COMSOL Multiphysics for simulations [8], the results demonstrate the sensor's capability for RI detection, particularly for analytes with an RI of 1.39. Graphical representations of the confinement loss and dispersion relationship are provided to illustrate the findings[1].

Figure 1. Cross-sectional view of the sensor

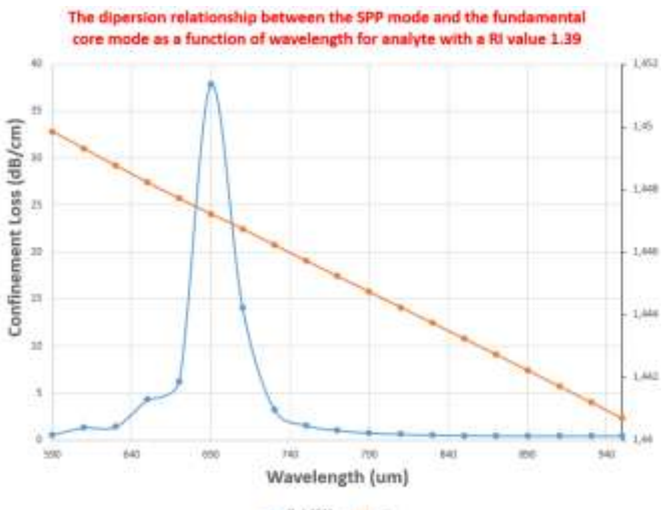

Figure 3. The dispersion relationship fundamental core mode as a function of wavelength for an analyte with a RI value of 1.39

I. Introduction. Photonic crystal fibers (PCFs) have become pivotal in sensing applications due to their versatile design and ability to guide light effectively. PCF-based biosensors are especially useful in detecting changes in the RI of analytes, which is critical for biochemical, environmental, and industrial applications[2,3]. This paper presents a modified PCF structure designed to improve sensitivity and reduce loss, with a focus on its geometrical and material parameters (Figure 1).

II. Sensor Structure. The biosensor is based on a hexagonal PCF structure with an asymmetric arrangement of air holes and a designated analyte channel. The structural modifications include variations in the air hole diameters and spacing to optimize light guidance and interaction with the analyte region. The dimensions and arrangement of the air holes directly influence the confinement of the fundamental core mode, which is critical for accurate RI detection. Key parameters defining the PCF structure are summarized in Table 1. These include the dimensions of the air holes, the pitch (spacing between air holes), and the analyte channel's location [4].

Table 1. Key Geometrical Parameters

Parameter	Value	Description
Air hole radius	2.0 µm	Radius of air holes in the cladding
Pitch (Λ)	5.5 µm	Distance between adjacent air holes
Analyte channel	Center	Region for RI measurement

III. Simulation Results

The fundamental core modes for x and y polarizations were simulated and analyzed using COMSOL Multiphysics. The results indicate strong confinement of light within the core, with minimal leakage into the surrounding cladding. This confinement is essential for enhancing the sensor's accuracy and sensitivity (Figure 2).

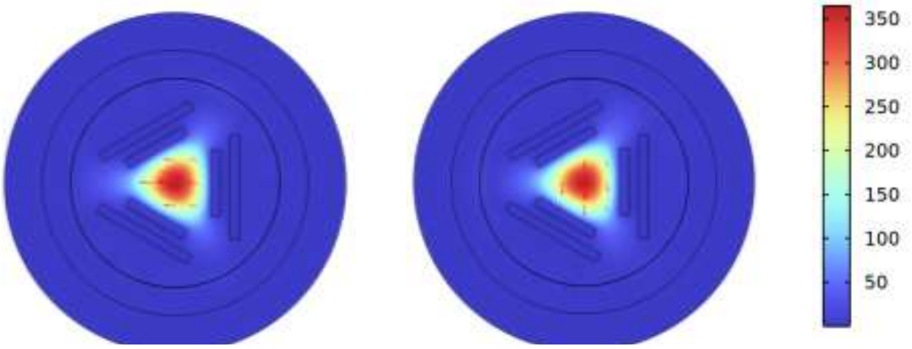

Figure 2. The fundamental core mode for both x and y polarizations

For the purpose of modeling the dispersion of the supplementary material, fused silica, the Sellmeier dispersion formula has been used (1):

$$n(\lambda) = \sqrt{1 + \frac{B_1\lambda^2}{\lambda^2 - C_1} + \frac{B_2\lambda^2}{\lambda^2 - C_2} + \frac{B_3\lambda^2}{\lambda^2 - C_3}} \qquad (1)$$

The dispersion relationship of the fundamental core mode as a function of wavelength was examined for an analyte with an RI of 1.39. The results, depicted in Figure 1, highlight the wavelength-dependent phase velocity of the core mode, demonstrating the sensor's ability to detect subtle RI variations (Figure 3). Confinement loss was evaluated to quantify the attenuation of the guided mode. Figure 2 shows the confinement loss spectrum, where a distinct trend is observed for the analyte with an RI of 1.39. The modified structure exhibits reduced confinement loss compared to earlier designs, showcasing the effectiveness of the structural adjustments [5] (Figure 3). The simulation results demonstrate that the modified PCF structure effectively confines the fundamental core mode while maintaining low confinement loss. The dispersion relationship further validates the design's suitability for RI detection. These findings suggest that the proposed sensor can be employed in various applications requiring high sensitivity and precision.

IV. Conclusion. A PCF-based biosensor with structural modifications was designed and analyzed for RI detection. The study focused on the fundamental core mode and dispersion relationship, achieving promising results for an analyte with an RI of 1.39. Future work could involve experimental validation and extending the design for multi-parameter sensing.

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KVANT HISOBLASH VA SPAM FILTRLASH ALGORITMLARI

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Annotatsiya: Spam xabarlar zamonaviy raqamli muhitdagi asosiy xavfsizlik muammolaridan biri bo‘lib, millionlab foydalanuvchilarning ma’lumot xavfsizligiga tahdid soladi. Hozirda spamni aniqlash uchun an’anaviy sun’iy intellekt va mashina o‘rganish algoritmlari qo‘llanilmoqda. Shu bilan birga, kvant hisoblash texnologiyalarining rivojlanishi bu sohada sifat jihatdan yangi imkoniyatlarni ochib bermoqda. Ushbu tezis kvant hisoblashning spam filtrlash algoritmlariga ta’siri va potensialini tahlil qiladi.

Kalit so‘zlar: spam, superpozitsiya, kvbit, Deep Learning, Machine Learning, QML algoritmlar.

Kvant hisoblash — bu an’anaviy (klassik) kompyuterlarning cheklovlarini yengib o‘tishga qaratilgan yangi avlod hisoblash paradigmasi bo‘lib, **kvant** mexanikasi qonunlariga asoslanadi. Uning asosiy maqsadi: ma'lumotlarni qayta ishlash va hisoblash jarayonlarini tezlashtirish [1].

1-jadval

Kvant kompyuterlari va klassik kompyuterlar husus iyatlari

Xususiyat	Klassik kompyuter	Kvant kompyuter
Birlik elementi	Bit (0 yoki 1)	Qubit (0 va 1 holatda bir vaqtda)
Hisoblash printsipi	Deterministik	Ehtimollik asosida

		(probabilistik)
Parallelizm	Cheklangan	Eksponentsial darajada
Misol	Core i7 protsessori	IBM Quantum, Google Sycamore

Spam xabarlar — zamonaviy aloqa tizimlarida eng ko‘p uchraydigan xavflardan biri. Bu xabarlar orasida phishing (firibgarlik), zararli dasturlar, reklama yoki aldovli havolalar bo‘lishi mumkin. Hozirgi paytda spamni aniqlashda an’anaviy mashina o‘rganish (ML) usullari qo‘llaniladi. Lekin, kvant hisoblash va ayniqsa Quantum Machine Learning (QML) bu sohaga yangi imkoniyatlar olib kelmoqda.

QML — bu kvant hisoblash texnologiyalari bilan birlashtirilgan mashina o‘rganish algoritmlari majmuasidir. Unda klassik kompyuter o‘rniga kvant kompyuter ishlatiladi yoki aralash (gibrid) yondashuv qo‘llaniladi [2,3].

QML asosiy afzalliklari:

- Ko‘p o‘lchamli (high-dimensional) ma’lumotlarni tezda tahlil qilish.
- Noaniq yoki shovqinli ma’lumotlar ustida ishlashga qobiliyat.
- Parallelizm orqali hisoblash tezligini oshirish.

QML yondashuvlari spam filtrlashda qanday ishlaydi?

Misollar:

2-jadval

QML yondashuvlari spam filtrlash

QML modeli	Qisqacha tavsif	Afzalliklari
Quantum Support Vector Machine	Spam va no-spam xabarlarni kvant fazoda tasniflaydi	Ko‘p o‘lchamli tasniflashda tezroq

(QSVM)		ishlaydi
Quantum k-Nearest Neighbors (Qk-NN)	O'xshash e-mail xabarlarni taqqoslaydi	Aniq spamlarni tez topadi
Quantum Neural Networks (QNN)	Spamni kontekst asosida aniqlash uchun chuqur o'rganishni ta'minlaydi	So'zlar o'rtasidagi murakkab bog'liqlikni tushunadi

QML modelining ishlash bosqichlari (spam misolida):

- Ma'lumotlarni tayyorlash. E-mail xabarlar matnli formatda olinadi va vektorlashtiriladi (TF-IDF yoki Word Embedding orqali).
- Qubitga kodlash (Encoding). Ma'lumotlar kvant holatiga o'tkaziladi (Amplitude encoding, Angle encoding, va h.k.).
- QML modelini qurish. QSVM, QNN yoki QkNN algoritmlaridan biri tanlanadi.
- Modelni o'qitish va sinovdan o'tkazish. Ma'lumotlar asosida model o'qitiladi va keyin yangi xabarlarni tasniflashda sinovdan o'tkaziladi.
- Natijalarni baholash. Aniqlik (accuracy), chaqqonlik (precision), yodga olish (recall), F1-score orqali baholanadi.

Afzalliklar va istiqbollar:

- Katta hajmdagi ma'lumotlar bilan tez ishlash.
- Spam xabarlar ichidagi gizli yoki yangi naqshlarni aniqlash.
- Noaniqlik bilan samarali ishlash.

Xulosa: Kvant mashina o'rganish (QML) texnologiyalari spam xabarlarni aniqlashda yangi bosqichni boshlab beradi. Ularning parallel hisoblash, ko'p o'lchamli tahlil va noaniqlik ustida ishlash qobiliyatlari yordamida spam filtrlash tizimlari:

- Yangi spam shakllariga moslashuvchan bo'ladi,

- Katta xatoliklar ehtimolini kamaytiradi,
- Foydalanuvchi xavfsizligini kuchaytiradi.

Kelajakda QML asosidagi tizimlar korxonalar va ijtimoiy platformalarning asosiy xavfsizlik mexanizmi bo'lib xizmat qilishi mumkin [4].

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KVANT MASHINA O'RGANISH (QUANTUM MACHINE LEARNING) VA SPAM FILTRLASH

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Spam xabarlar — zamonaviy raqamli muloqot tizimlarida keng tarqalgan va foydalanuvchilarga jiddiy xavf tug'diradigan noxush holatlardan biridir. Spamlar orasida zararli dasturlar, firibgarlik havolalari, yolg'on reklama va ma'lumot o'g'riligi singari turli tahdidlar mavjud. Bugungi kunda bu muammoni hal etishda sun'iy intellekt va mashina o'rganish texnologiyalaridan foydalanilmoqda. Biroq, ushbu klassik yondashuvlar katta hajmdagi va murakkab tuzilmali ma'lumotlar bilan ishlashda cheklovlarga ega.

Shu sababli, kvant hisoblash texnologiyalari bilan integratsiyalashgan Kvant mashina o'rganish (Quantum Machine Learning, QML) texnikasi yangi imkoniyatlarni taqdim etmoqda. Ushbu tezisda QML konsepsiyasi va uning spam filtrlashdagi potentsiali tahlil qilinadi.

Kvant mashina o'rganish tushunchasi

QML — bu klassik mashina o'rganish algoritmlarining kvant kompyuterlar asosida ishlab chiqilgan modifikatsiyasidir. U kvbitlar, superpozitsiya, kvant dolanma (entanglement) va interferensiya kabi kvant mexanikasi tamoyillaridan foydalanadi.

QML'ning asosiy ustunliklari quyidagilardan iborat:

- Parallel hisoblash imkoniyati orqali ko'p o'lchamli ma'lumotlarni tez tahlil qilish.
- Noaniq va shovqinli ma'lumotlar bilan samarali ishlash.
- Murakkab naqshlarni aniqlashda an'anaviy modellardan tezroq ishlash.

Spam filtrlashdagi hozirgi yondashuvlar

Spamni aniqlashda klassik mashina o'rganish algoritmlaridan foydalaniladi:

- Naive Bayes, Logistic Regression
- Support Vector Machines (SVM)
- Random Forest, Deep Neural Networks (DNN).

Ular asosan e-mail matnini vektorlashtirish (TF-IDF, bag-of-words, embedding) orqali o'rganiladi. Biroq, bu yondashuvlar katta o'lchamli ma'lumotlar bilan ishlaganda hisoblashga ko'p vaqt talab qiladi va yangi turdagi spamlarni aniqlashda zaiflikka ega [1,2].

QML modellarining spam filtrlashda qo'llanilishi.

1-jadval

Spam filtrlashda qo'llanilishi mumkin bo'lgan asosiy QML algoritmlari

Model	Vazifasi
Quantum Support Vector Machine (QSVM)	Spam va no-spam xabarlarni tasniflash
Quantum k-Nearest Neighbors (QkNN)	O'xshashlik asosida spamni aniqlash
Quantum Neural Networks (QNN)	Murakkab matn naqshlarini aniqlash

Ushbu modellar kvbitlar asosida ishlaydi va spam xabarlarni aniqlashda klassik modellar bilan teng yoki undan yuqori aniqlikka ega bo'lishi mumkin.

Afzalliklar:

- Tezlik: Katta ma'lumotlar ustida tezroq ishlaydi.
- Aniqlik: Murakkab spam naqshlarini samarali ajratadi.
- Moslashuvchanlik: Yangi spam turlariga oson moslasha oladi [3].

Kvant mashina o'rganish texnologiyalari — spam xabarlar muammosiga qarshi kurashda istiqbolli va kuchli yechimdir. Kvant fazoda ishlovchi modellar orqali spamni aniqlash samaradorligi ortadi, aniqlik va tezlik esa an'anaviy yondashuvlardan ustun bo'ladi. Kelajakda QML texnologiyalarining rivojlanishi bilan birga, spamga qarshi kurashda **intellektual va kvantga asoslangan xavfsizlik tizimlari** asosiy vositaga aylanishi kutilmoqda [4,5].

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IKKI ELEMENTLI LAZER PLAZMASI KO'P ZARYADLI IONLARINI TADQIQ QILISH

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Hozirgi kunda lazer nurlanishi ta'sirida vakuum sharoitida bir va ikki elementli nishonlar sirtida hosil bo'lgan plazmaning mass-spektrlarini tahlil qilish orqali, plazma ko'p zaryadli ionlarining hosil bo'lish va kengayish bosqichlarida, nishon tarkibiga qarab, ko'p zaryadli ionlarning ionlashuvi, rekombinatsiyasi va tezlashuvining fizik jarayonlarini o'rganish juda dolzarb masalalardan hisoblanadi. Bunday tadqiqotlarga bo'lgan ehtiyoj, ko'p zaryadli ionlarning hosil bo'lishi va inertsial kengayishining ushbu fizik jarayonlarining samaradorligi ko'p zaryadli ionlarning chiqishi, zaryadi, energiyasi va fazoviy taqsimotini aniqlaydi. Tadqiqotda olingan natijalar ikki elementli lazer plazmasida ion oqimining hosil bo'lish jarayonlarini tushuntirish imkoniyatini beradi.

Ushbu ishida lazerli ionlashgan mass-spektrometriya usuli yordamida tajriba yo'li bilan bir elementli (C, Cu,Ti, Zr) va yengil gaz atomlari kiritilgan ikki $(CH_2)_n$, Cu[H], Eu_2O_3) va ko'p elementli Ti[H,N], Zr[H,N] nishonlardan hosil bo'lgan lazer plazmasi ko'p zaryadli ionlarining shakllanishiga lazer nurlanishi parametrlari va nishon tarkibining ta'siri o'rganildi. Shuningdek, lazer plazmasi ko'p zaryadli ionlarining hosil bo'lishida sodir bo'ladigan fizik jarayonlarga nishonning tarkibi va lazer nurlanishi parametrlarining bo'gliqligi aniqlandi. Bu o'z navbatida ko'p zaryadli ionlar hosil bo'lish samaradorligini oshirishga hamda lazer nuri parametrlarini optimallashtirish va nishon tarkibini o'zgartirish orqali yuqori zaryadli ionlar intensivligini boshqarish imkonini beradi.

Olingan mono- va ikki elementli lazer plazmasining yo‘naltirilgan ion nurlari plazma lazerlarini, ko‘p zaryadli o‘tishga asoslangan lazerlarni yaratishga va yuqori tartibli garmonikalar hosil qilish uchun asos bo‘lishi hamda ulardan murakkab element tarkibiga ega bo‘lgan moddalarni lazerli-energiya-massa-analizatori sifatida, rentgen va neytron nurlarining, ko‘p zaryadli ionlarning samarali lazerli manbalari sifatida foydalanish mumkin. Shu bilan birga, lazer nurlanishidan foydalangan holda yuqori intensivlik va energiyaga ega yuqori fokusli ion nurlarini yaratish imkoniyati ham ko‘rsatildi. Bu ularni turli xil texnik va texnologik maqsadlarda qo‘llash imkonini beradi, masalan: yupqa qavatlarni cho‘ktirish, sirt qatlamlarini lazer bilan toblash, radiatsiyaviy bardoshlilikni aniqlash va boshqalar.

GRAVITATSION LINZALAR, QORA TUYNUKLAR VA PLAZMA TA'SIRINING OLIY TA'LIMDA TALABALARGA TUSHUNTIRISHNING PEDAGOGIK STRATEGIYALARI

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Annotatsiya. Biz mukammal suyuqlik qorong'i materiyasi mavjud bo'lgan holda, qora tuynuk atrofidagi bir xil va notekis taqsimlangan plazmaning gravitatsion zaif linzalashishga ta'sirini o'rgandik. Tadqiqotlarimizda olingan natijalar, ta'lim jarayonida turli pedagogik strategiyalarni qo'llashda qarama-qarshi ta'sirlarni tushunishning ahamiyatini ko'rsatadi. Masalan, mukammal suyuqlik qorong'i materiyasi va plazma parametrlarining ta'siri, zaif maydon rejimida o'quvchilarni yangi bilimlarga yo'naltirishda yuzaga keladigan qarama-qarshiliklarni tushunishga yordam beradi. Mukammal suyuqlik qorong'i materiyasi tasvir manbalarining umumiy kattalashishini pasaytirganidek, o'qituvchilar yangi mavzularni o'rgatishda, ba'zan ba'zi konseptsiyalarni soddalashtirish va murakkablashtirish zaruriyatini his qilishadi. Plazma esa teskari ta'sir ko'rsatib, kattalashishni oshirganidek, ta'limda turli metodlar va usullar orqali o'quvchilarning bilimlarini kengaytirish va chuqurlashtirish mumkinligini ko'rsatadi.

Kalit so'zilar: qora tuynuk, tortishish linzalari, zaif maydon rejimi, mukammal suyuqlik qorong'i materiya, pedagogik strategiyalar

Kirish. 1916-yilda Albert Eynshteyn tomonidan kashf etilgan umumiy nisbiylik nazariyasining eng muhim elementlaridan biri qora tuynuk soyasi va tortishish linzalarining (kuchli va zaif maydon rejimida) ta’siri hisoblanadi. Bu ta’sir fazo-vaqt egriligi tufayli tortishish obyekti yaqinida yorug‘lik nurlarining og‘ishiga asoslanadi. Umumiy nisbiylikdagi klassik tortishish linzalari keng miqyosda o‘rganilgan va sharhlarda batafsil tavsiflangan [1].

Pedagogik strategiyalarga kelsak, bu jarayonni o‘quvchilarga tushuntirishda yuqori darajadagi ilmiy mantiqni qo‘llash zarur. Masalan, egri fazo-vaqtdagi fotonlarning harakatini o‘rgatish jarayonida, o‘qituvchilar o‘quvchilarga tortishish linzalarining qanday ishlashini va bu jarayonning ilmiy nazariyalar bilan qanday bog‘lanishini ko‘rsatishi kerak. Bu yondashuv o‘quvchilarga murakkab ilmiy tushunchalarni tushunishda yordam beradi va ularni chuqurroq o‘rganishga rag‘batlantiradi. Bundan tashqari, ixcham obyekt atrofidagi plazma muhiti elektromagnit to‘lqin bilan o‘zaro ta’sir qilishi va natijada yorug‘lik nurlarining trayektoriyasiga ta’sir qilishi mumkin.

Xususan, Riflarda. [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12] olimlar turli fazo-vaqt metrikalaridagi fotonlar harakatini o‘rganishgan va ularning ba’zilari plazmaning tortishish kuchi bilan birga ta’sirini o‘rganishga bag‘ishlangan. foton harakati. Bundan tashqari, dolzarb mavzulardan biri vakuumda kuchli tortishish linzalari; yaqinda kuchli linzalarning nazariy tahlili Riflarda turli fazo-vaqt geometriyalari uchun bir nechta mualliflar tomonidan o‘rganiladi. [13, 14, 15].

Qorong‘i materiya yoki qorong‘i energiya mavjudligiga ba’zi dalillar mavjud va standart kosmologik modelga ko‘ra [16] bizning koinotimiz asosan 68% qorong‘i energiya, taxminan 27% qorong‘i materiya va 5% barion moddalarni o‘z ichiga oladi [16]. Qorong‘i materiya barion bo‘lmagan materiyadir. Shunday qilib, qorong‘i energiya yoki qorong‘i materiya ixcham obyektlar yaqinidagi astrofizik jarayonlarga ta'sir qiladimi degan savol tug'ilishi mumkin.

To'g'ri, qorong'i materiya ko'rinmas, shuning uchun uni sinab ko'rish qiyin, lekin biz qorong'i materiya yoki qorong'i energiyaning ta'sirini kuzatishdan his qilishimiz mumkin. Shu vaqtdan boshlab, qorong'i materiya qora tuynuk fizikasi xususiyatlarini o'rganish uchun juda muhimdir. Ma'lumki, qora tuynuk atrofida qorong'i materiya yoki qorong'i energiya ham mavjud, shuning uchun biz Koinotdagi qora tuynuk atrofida zarrachalarning harakatini o'rganganimizda, ularning hissasi har doim juda muhim va qiziqarli bo'ladi. Eng so'nggi parchalanishda qorong'i energiya kvintessensiyasi bilan o'ralgan qora tuynuk batafsilroq ko'rib chiqiladi [17]. Kvintessensiya bilan o'ralgan qora tuynuk atrofidagi fazoviy vaqtning boshqa xususiyatlari Riflarda o'rganilgan. [18, 19].

Qorong'i materiya uchun muqobil model [16] da taklif qilingan, bu yerda kvintessens skalyar maydoni mukammal suyuqlik qorong'i materiya sifatida qabul qilinadi. Mukammal suyuqlik qorong'i materiya bilan o'ralgan qora tuynuk yechimi metrik funksiyalarda paydo bo'ladigan logarifmik atamani $\lambda \ln(r/|\lambda|)$ o'z ichiga oladi, bu parametr orqali qorong'i materiyaning o'zgarmas hissasiga mos keladi. Qorong'i materiya zaif o'zaro ta'sir qiluvchi massiv zarrachalar orqali hosil bo'ladi, degan fikrdan keyin Rif. [20], u logarifmik atamani o'z ichiga olgan shunga o'xshash qora tuynuk yechimi olingan.

Mukammal suyuqlik qorong'i materiya bilan o'ralgan qora tuynuk atrofidagi fazo vaqtining xususiyatlari [21] da o'rganilgan. Ushbu maqolada olib borilgan tadqiqotning asosiy hisasi plazma muhiti mavjudligida ixcham obyekt atrofida foton harakati yordamida qorong'i materiya uchun mukammal suyuqlik qorong'i materiya modelini sinab ko'rishdir. Gravitatsion linzalar tufayli yorug'lik burilish burchagining kuzatiladigan xususiyatlari ixcham obyekt atrofidagi qorong'i materiyani tavsiflovchi model va nazariyaga cheklovlarni olishga yordam beradi. Binobarin, bu bizga qorong'i materiyaning tabiatini va qorong'i materiyaning ta'siri bilan bog'liq astrofizik jarayonlarni tushuntirishga yordam beradi. Xususan, ushbu maqolada biz mukammal suyuqlik qorong'i materiya bilan o'ralgan qora tuynuk atrofidagi foton harakatini ko'rib chiqdik.

Mukammal suyuqlik qorong'i materiyaning yorug'lik egilishiga ta'sirini tahlil qilib, biz Mukammal suyuqlik qorong'i materiya ning mavjudligi yorug'lik burilishini kamaytirishga olib kelishini aniqladik. Bu mukammal suyuqlik qorong'i materiyaning fotonlarga salbiy tortishish ta'siri sifatida talqin qilinishi mumkin, chunki mukammal suyuqlik qorong'i materiya markaziy obyekt va fotonlarni o'rab oladi. Mukammal suyuqlik qorong'i materiya va markaziy obyektning fotonlariga tortishish ta'siri bir-biriga qarama-qarshidir. Ish quyidagicha tartibga solinadi: Bo'l. 1 Biz Shvartsshild qora tuynugida mukammal suyuqlik qorong'i materiya mavjudligida plazmaning burilish burchagiga ta'sirini ko'rib chiqamiz. ichida. Biz mukammal suyuqlik qorong'i materiyaning turli parametrlari uchun tasvirni kattalashtirishni o'rganamiz.

Nihoyat, Biz olingan natijalarimizni muhokama qilamiz. Biz yorug'lik tezligini va tortishish doimiyligini (G = c = 1.) orqali aniqlaydigan birliklardan foydalandik.

1. Plazma borligida gravitatsion zaif linzalanish

Gravitatsion zaif linzalar, yorug'lik nurlarining tortishish kuchi ta'sirida egilishi hodisasi bo'lib, asosan qora tuynuklar va boshqa gravitatsion obyektlar atrofida kuzatiladi. Plazma borligi bu jarayonga qo'shimcha murakkablik kiritadi. Plazma, o'zining elektromagnit xususiyatlari bilan, yorug'lik nurlarining yo'nalishini o'zgartirish imkoniyatiga ega bo'lib, bu esa tortishish linzalarining kuchini o'zgartirishi mumkin.

Pedagogik strategiyalarni ko'rib chiqishda, o'quvchilarga plazma va tortishish linzalari o'rtasidagi o'zaro ta'sirni tushuntirishda aniq vizual materiallar va modellarni ishlatish zarur. Masalan, plazmaning gravitatsion linzalashishga ta’sirini o‘rgatishda, o‘quvchilarga elektron simulyatsiyalar yoki vizual yordamchilar orqali plazmaning yorug‘likning yo‘nalishiga qanday ta’sir ko‘rsatishini ko‘rsatish samarali bo‘ladi.

Bu metodlar o‘quvchilarning ilmiy tushunchalarni chuqurroq anglashlariga yordam beradi va murakkab ilmiy jarayonlarni soddalashtirishga imkon yaratadi.

1.1. Mukammal suyuqlik qorong‘i materiyada o‘lchov maydoni bilan minimal birlashtirilgan tortishish nazariyasi uchun harakat

Mukammal suyuqlik qorong‘i materiyasidagi o‘lchov maydoni bilan minimal birlashtirilgan tortishish nazariyasida harakat, o‘zining ilmiy ahamiyati bilan talabalar uchun murakkab, ammo qiziqarli mavzu hisoblanadi.

Ushbu nazariya, qora tuynuklar va boshqa gravitatsion obyektlar atrofidagi kuchli gravitatsion ta’sirlar bilan bog‘liq hodisalarni tushuntirishda muhim o‘rin tutadi. Ushbu jarayonni pedagogik strategiyalar yordamida tushuntirishda, o‘qituvchilar o‘quvchilarga tortishish kuchlarining o‘zgarishi va o‘lchov maydonining roli haqidagi tushunchalarni yaxshilab yetkazishlari kerak. Masalan, ilmiy modellar yoki simulyatsiyalar orqali, o‘quvchilar o‘lchov maydonidagi harakatlarni vizual tarzda kuzatishlari mumkin.

Bu usul o‘quvchilarning ilmiy konsepsiyalarni tezroq va samaraliroq anglashlariga yordam beradi. Mukammal suyuqlik qorong‘i materiyadagi o‘lchov maydoni bilan minimal birlashtirilgan tortishish nazariyasi uchun quyidagicha yoziladi [17]

$$\mathcal{Z} = \int dx^4 \sqrt{-g}\left(\frac{1}{16\pi G} R + \mathcal{L}_{DM}\right) \qquad (1)$$

Bu yerda $g = \det(g_{ab})$ metrik tensorning determinanti, R esa Ricci skalyari, G esa Nyutonning tortishish doimiysi va $\mathcal{L}_{DM}$ mukammal suyuqlik qorong'i materiya uchun Lagranj zichligi.

Shvartsshild koordinatalarida (t, r, θ, φ) mukammal suyuqlik qorong'i materiyaga botgan statik va sferik simmetrik qora tuynukni tavsiflovchi metrik [20] tomonidan berilgan.

$$ds^2 = -f(r)dt^2 + f(r)^{-1}dr^2 + r^2 + r^2 d\Omega^2 \quad (2)$$

Dan

$$f(r) = 1 - \frac{2M}{r} + \frac{\lambda}{r} ln \frac{r}{|\lambda|} \quad (3)$$

Bu yerda M qora tuynukning massasi va λ parametri qorong'i materiyaning zichligi va bosimi bilan bog'liq [20].

Quyida ko'rsatilgandek aniqlangan zaif maydonning taxminiyligini ko'rib chiqamiz:

$$g_{\alpha\beta} = \eta_{\alpha\beta} + h_{\alpha\beta} \quad (4)$$

Bu yerda $\eta_{\alpha\beta}$ yassi geometriyaning ifodasi va $h_{\alpha\beta}$ quyidagi umumiy xususiyatlarga ega bo'lgan tekis fazo-vaqt geometriyasining egilishidir[5]:

$$\eta_{\alpha\beta} = diag(-1,1,1,1) \quad (5)$$

$$h_{\alpha\beta} \ll 1,\ h_{\alpha\beta} \to 0\ keyin\ x^i \to \infty \quad (6)$$

$$g^{\alpha\beta} = \eta^{\alpha\beta} - h^{\alpha\beta},\ h^{\alpha\beta} = h_{\alpha\beta} \quad (7)$$

Bu yerda biz Shvartsshild fazoviy geometriyasida mukammal suyuqlik qorong'i materiya ishtirokida plazmaning tortishish burilish burchagiga ta'sirini o'rganamiz.

Plazma muhiti ishtirokidagi burilish burchagining asosiy ifodasini ko'rib chiqing [5, 8]

$$\hat{\alpha}_k = \frac{1}{2}\int_{-\infty}^{\infty}(h_{33} + \frac{h_{00}\omega^2 - K_e N(x^i)}{\omega^2 - \omega_2^2})_k dz \quad (8)$$

bu yerda $N(x^i)$ plazmadagi zaryadlangan zarrachalar konsentratsiyasi, ω va ω_e mos ravishda foton va plazma chastotalari. $K_e = \frac{4\pi e^2}{m_e}$ plazma zarrasining doimiy qiymati.

Boshqa tomondan, yuqordagi tenglamani boshqa ko'rinishda [5] sifatida qayta yozish mumkin:

$$\hat{\alpha}_b = \frac{1}{2}\int_{-\infty}^{\infty} \frac{b}{r}\left(\frac{dh_{33}}{dr} + \frac{1}{1-\omega_e^2/\omega^2}\frac{dh_{00}}{dr} - \frac{K_e}{\omega^2-\omega_2^2}\frac{dN}{dr}\right) dz \qquad (9)$$

$\hat{\alpha}_b$ qiymati ham manfiy (ixcham obyektga qarab) va musbat (ixcham obyektdan uzoqda) bo'lishi mumkin.

Kuchsiz maydon rejimida mukammal suyuqlik qorong'i materiya bilan o'ralgan ixcham obyektdan katta masofada r masofada fazoviy vaqt ko'rsatkichi quyidagicha ifodalanishi mumkin.

$$ds^2 = ds_0^2 + \left(\frac{R_s}{r} - \frac{\lambda}{r} ln\frac{r}{|\lambda|}\right) dt^2 + \left(\frac{R_s}{r} - \frac{\lambda}{r} ln\frac{r}{|\lambda|}\right) dr^2 \qquad (10)$$

bu yerda $ds_0^2 = -dt^2 + dr^2 + r^2(d\theta^2 + sin^2\theta d\phi^2)$ tekis fazodagi chiziq elementi va biz $R_s = 2M$ yozuvidan foydalandik.

Tenglamani hisoblash uchun. (7) dekart koordinatalaridagi h_{ab} komponentlarini ko'rinishda qayta yozish mumkin

$$h_{00} = \left(\frac{R_s}{r} - \frac{\lambda}{r} ln\frac{r}{|\lambda|}\right) \qquad (11)$$

$$h_{ik} = \left(\frac{R_s}{r} - \frac{\lambda}{r} ln\frac{r}{|\lambda|}\right) n_i n_k \qquad (12)$$

$$h_{33} = \left(\frac{R_s}{r} - \frac{\lambda}{r} ln\frac{r}{|\lambda|}\right) cos^2\mathcal{X} \qquad (13)$$

bu yerda yangi $cos^2\mathcal{X} = z^2/(b^2 + z^2)$ va $r^2 = b^2 + z^2$ yozuvlari kiritiladi. h_{00} va h_{33} ning hosilasini osongina hisoblash va olish mumkin.

$$\frac{dh_{33}}{dr} = -\frac{3z^2R_s}{r^4} - \frac{\lambda z^2}{r^4} + \frac{3\lambda z^2 ln\left(\frac{r}{|\lambda|}\right)}{r^4} \qquad (14)$$

$$\frac{dh_{00}}{dr} = -\frac{\lambda}{r^2} + \frac{\lambda ln\left(\frac{r}{|\lambda|}\right)}{r^2} - \frac{R_S}{r^2} \qquad (15)$$

Endi burilish burchagi ifodasini quyidagi shakldа ajratish mumkin [8]:

$$\hat{\alpha}_b = \hat{\alpha}_1 + \hat{\alpha}_2 + \hat{\alpha}_3 \qquad (16)$$

bilan

$$\hat{\alpha}_1 = \frac{1}{2}\int_{-\infty}^{\infty} \frac{b}{r}\frac{dh_{33}}{dr} dz \qquad (17)$$

$$\hat{\alpha}_2 = \frac{1}{2}\int_{-\infty}^{\infty} \frac{b}{r}\left(\frac{1}{1-\omega_e^2/\omega^2}\frac{dh_{00}}{dr}\right) dz \qquad (18)$$

$$\hat{\alpha}_3 = \frac{1}{2}\int_{-\infty}^{\infty} \frac{b}{r}\left(-\frac{K_e}{\omega^2-\omega_e^2}\frac{dN}{dr}\right) dz \qquad (19)$$

Bu yerda yangi belgilar $\hat{\alpha}_1, \hat{\alpha}_2\ va\ \hat{\alpha}_3$ mos ravishda tortishish, bir xil va bir jinsli plazma muhiti ta'sirida burilish burchagi hissasiga to'g'ri keladi.

Plazma muhitining burilish burchagiga ta'sirini o'rganish uchun biz (10) tenglamadan foydalanamiz.

1.2 Burilish burchagiga bir jinsli plazmaning ta'siri

Bu yerda $\hat{\alpha}_{uni1}\ va\ \hat{\alpha}_{uni2}$ bir jinsli plazma tufayli burilish burchagiga hissa sifatida talqin qilinishi mumkin va plazmaning bir xil taqsimlanishi tufayli $\hat{\alpha}_{uni3} = 0$ (10), (9) va (12) tenglamalardan foydalanib, bir xil plazma va mukammal suyuqlik qorong'i materiya bilan o'ralgan ixcham obyekt atrofidagi fotonlar uchun burilish burchagi formulasini osongina olish mumkin:

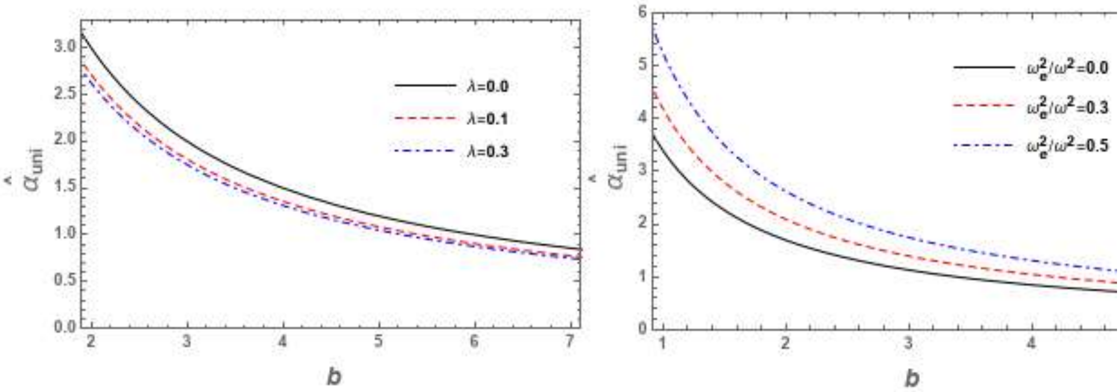
$$\hat{\alpha}_{uni} = -\left(\frac{\lambda}{b} + \frac{\lambda ln\frac{1}{|2\lambda|}}{b} - \frac{R_S}{r}\right) - \left(\frac{\lambda ln\frac{1}{|2\lambda|}}{b} - \frac{R_S}{r}\right)\left(\frac{\omega^2}{\omega^2-\omega_e^2}\right) \qquad (20)$$

1-rasmda Mukammal suyuqlik qorong'i materiya va plazma parametrlarining turli qiymatlari uchun burilish burchagining fotonlarning b parametriga bog'liqligi ko'rsatilgan.

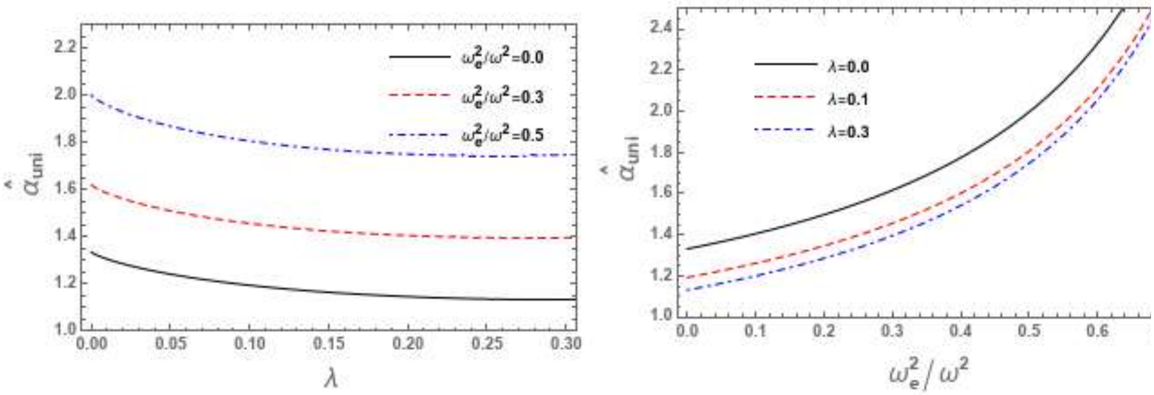
2-rasmda burilish burchagi shaklining plazma va qorong'i materiya parametrlarining sobit qiymatlari uchun bog'liqligi ko'rsatilgan.

Rasmlardan. 1 va 2 da Mukammal suyuqlik qorong‘i materiya parametrining ortishi bilan burilish burchagi pasayganini ko‘rish mumkin.

Boshqa tomondan, plazma muhitining mavjudligi fotonlarning tortishish burchagini oshiradi. E’tibor bering, burilish burchagi b parametrining oshishi bilan nolga intiladi.



Rasm. 1. Mukammal suyuqlik qorong‘i materiya parametri l (chap panel) va plazma muhiti (o‘ng panel) ning turli qiymatlari uchun burilish burchagi $\hat{\alpha}_{uni}$ ning b parametriga bog‘liqligi.



Rasm. 2. Ta’sir parametrining belgilangan qiymati uchun $\hat{\alpha}_{uni}$ Burilish burchagi $\hat{\alpha}_{uni}$mukammal suyuqlik qorong‘i materiya parametri l (chap

panel) va plazma muhiti (o'ng panel) ga bog'liqligi b

2. Gravitatsion linzalar va qora tuynuklar mavzusini ta'lim jarayonida qo'llash

2.1 Vaziyatli muammolar qo'yish

Talabalarga yuqoridagi va quyidagi kabi savollar orqali muammoli vaziyat yaratish mumkin: "Agar yorug'lik nuri qora tuynuk yaqinidan o'tsa, uning yo'nalishi qanday o'zgaradi?" yoki "Nega uzoq galaktikalar tasviri linza shaklida ko'rinadi?"

Bunday savollar muhokama va ilmiy izlanishga undaydi.

2.2 Vizual ta'sir vositalari

Simulyatsiyalar: Gravitatsion linzalarni va yorug'likning qora tuynuk yaqinida egilish jarayonini ko'rsatish uchun Stellarium, GeoGebra, MATLAB, Mathematica yoki Python (Matplotlib) boshqa vizual dasturlardan foydalanish.

Tasviriy materiallar: Hubble teleskopi orqali olingan gravitatsion linzalar tasvirlarini tahlil qilish.

Model yasash: Gravitatsion linzalarni oddiy optik linza yordamida sinovdan o'tkazish.

2.3 Matematik modellashtirish

Gravitatsion linza effektini oddiy formulalar orqali talabalarga tushuntirish mumkin. Yorug'lik burchagining egilishi formulalarini fizik tenglamalar asosida ko'rib chiqish. Qora tuynukning fazoviy strukturasi va yorug'lik trayektoriyasini differensial tenglamalar yordamida modellashtirish.

3. Plazma muhitining yorug'lik nurlari ta'siriga ta'limiy yondashuv

3.1 Laboratoriya mashg'ulotlari

Yorug'likning turli muhitlarda sochilishi va egilish jarayonini o'rganish uchun laboratoriya tajribalarini tashkil qilish.

Elektromagnit to'lqinlarning plazma muhitida qanday o'zgarishini modellashtirish.

3.2 O'quv loyihalari

Talabalarga mustaqil loyiha sifatida yorug'likning qora tuynuk atrofidagi trayektoriyasini hisoblash yoki plazma muhitining yorug'lik trayektoriyasiga ta'sirini simulyatsiya qilish topshirig'ini berish.

4. Ilmiy izlanish ko'nikmalarini rivojlantirish

4.1 Tadqiqot yondashuvi

Talabalarga mavzuni chuqurroq tushunish uchun ilmiy maqolalar bilan ishlash va olingan ma'lumotlarni tahlil qilish topshirig'ini berish. Maqolada muhokama qilingan mukammal suyuqlik qorong'u materiya modeli va plazma ta'sirini muhokama qilish yaxshi amaliyot bo'ladi.

4.2 Interaktiv muhokamalar

"Dark matter" yoki mukammal suyuqlik qorong'u materiya modellarining astrofizik jarayonlarga qanday ta'sir qilishini talabalarga turli nazariy yondashuvlar bilan tushuntirish.

4.3 Talabalar ilmiy loyihalari

Talabalarga quyidagi yo'nalishlarda ilmiy loyihalar berish mumkin. Gravitatsion linza modellarini dasturiy simulyatsiyalar yordamida ishlab chiqish. Plazma va qora tuynuklar ta'sirining yorug'lik trayektoriyasiga ta'sirini matematik modellashtirish.

Xulosa. Ushbu maqolada qora tuynuk atrofida plazma muhiti va mukammal suyuqlik qorong'i materiyaning gravitatsion linzalanish jarayoniga ta'siri tahlil qilindi. Tadqiqot natijalari shuni ko'rsatdiki, mukammal suyuqlik qorong'i materiya yorug'likning burilish burchagini kamaytirsa, plazma esa aksincha, bu burilish burchagini oshirish xususiyatiga ega. Bu esa, fazo-vaqt metrikalarining yorug'lik nurlari trayektoriyasiga qanday ta'sir qilishini chuqurroq tushunishga imkon yaratadi. Pedagogik nuqtayi nazardan qaralganda, bu ilmiy tushunchalarni talabalarga yetkazishda turli strategiyalardan foydalanish zarurati ta'kidlandi. Gravitatsion linzalar va qora tuynuklar mavzusini yuqori ta'lim tizimida o'qitishda quyidagi yondashuvlar samarali bo'lishi mumkin. Simulyatsiyalar, grafik tasvirlar va interaktiv modellar yordamida talabalar murakkab fizik hodisalarni tushunishlari osonlashadi. Yorug'lik nurlarining qora tuynuk atrofida qanday harakatlanishini differensial tenglamalar yordamida tushuntirish orqali talabalar fundamental ilmiy model va formulalarni qo'llashni o'rganadilar. Yorug'likning turli muhitlarda egilishi va plazma bilan o'zaro ta'siri bo'yicha laboratoriya tajribalarini o'tkazish talabalar bilimini mustahkamlaydi. Qiziquvchanlikni oshirish va ilmiy izlanish ko'nikmalarini shakllantirish uchun talabalar uchun muhokamalar va loyihalar tashkil qilish muhimdir. Umuman olganda, ushbu maqola orqali gravitatsion linzalar, qora tuynuklar va plazma ta'sirining nafaqat ilmiy jihatlari, balki pedagogik nuqtayi nazardan ham qanday tushuntirilishi mumkinligi haqida muhim xulosalar berildi. Bu esa, fizikani yuqori ta'lim tizimida yanada samarali o'qitish va talabalar ilmiy bilimlarini chuqurlashtirish uchun muhim vositalardan biri bo'lib xizmat qiladi.

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PICOSECOND LASER DRILLING OF STEEL FOIL: SURFACE MICROSTRUCTURE AND HEAT-AFFECTED ZONE

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Modern micro- and nanotechnologies for metal processing require highly precise methods with minimal thermal effects. Ultrafast lasers (pico- and femtosecond pulses) significantly outperform conventional techniques such as chemical etching or electrical discharge machining due to their non-contact nature, absence of reagents, and high reproducibility [1, 2]. Picosecond lasers with energies of ~1 mJ enable ablation within a thin near-surface layer before heat diffusion into the matrix occurs, thereby minimizing melting and cracking [3]. Unlike nanosecond lasers, where the threshold fluence for steel foil reaches 10–100 J/cm² producing holes >100 μm, picosecond pulses allow the formation of holes <50 μm at energies of 7–18 mJ. The aim of this work is to investigate the surface microstructure of steel foil during multi-pulse laser drilling and to assess the potential of this technology for industrial applications, particularly in the automotive sector.

Experiments were carried out under atmospheric conditions using a picosecond diode-pumped Nd:YAG laser (pulse duration ≈ 28 ps, repetition rate ≤ 50 Hz). The target material was stainless steel with the following composition: Fe (55.3%), Cr(10.2%), C(17.7%), O(15.8%). The setup included a CNC 3018 machine equipped with stepper motors, controlled by grblControl. The laser beam was focused onto the target surface and the resulting microstructure was analyzed using light and scanning electron microscopy. Figure 1 presents SEM images of a hole array in steel foil produced at 1064 nm. Processing parameters: pulse energy 7–40 mJ, 500 pulses per hole.

At UV irradiation (355 nm, 12 mJ), holes with diameters of ~32 μm were obtained. The actual hole size exceeded the theoretical focus diameter due to plasma shielding. A columnar microstructure was observed around the holes: elongated features 1–10 μm in width extending up to 150 μm from the edge. These were formed by the condensation of evaporated metal droplets in a pure ablation regime with negligible melting. The hole edges were partially melted, with droplets of resolidified material 1–5 μm in size dispersed within a radius approximately half that of the heat-affected zone (HAZ), which extended up to 500 μm.

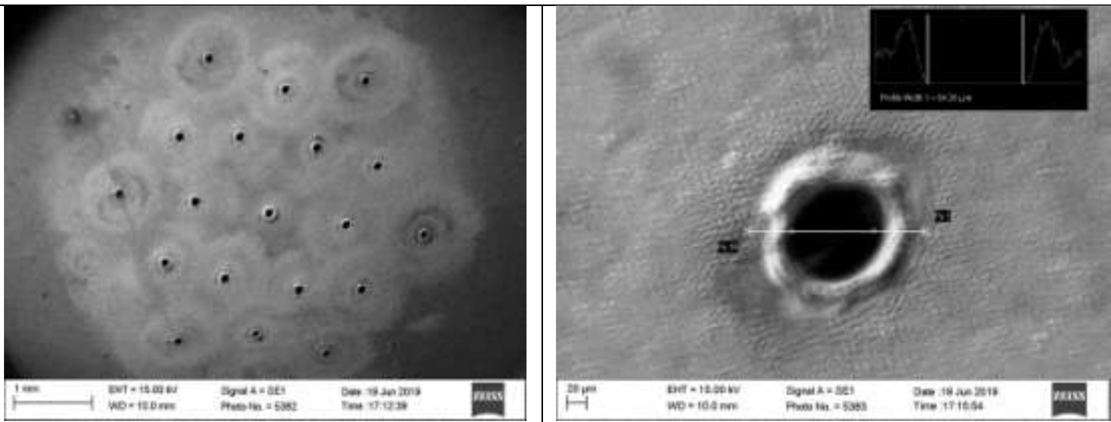

Figure 1. Micrographs of a hole array produced by automated picosecond laser drilling of steel foil (λ = 1064 nm, f = 50 Hz, pulse energy 13 mJ, 500 pulses) and the profile of a single hole.

The HAZ appeared as bright concentric rings with enhanced contrast due to laser-induced surface modification compared to the original granular steel structure. This confirms the advantages of picosecond pulses: the absorbed energy is first taken up by electrons and transferred to the lattice within 2–5 ps, thus reducing thermal diffusion [4-6].

Comparison with electrical discharge machining of injector membranes (hole diameter ~170 μm, rough edges) demonstrated the superiority of the laser technique: at λ = 1064 nm (13 mJ) the hole diameter was ~70 μm, while at λ = 355 nm it was ~40 μm, both with smooth walls. Automated drilling of a 19-hole array at 1064 nm required ~10 s per hole (500 pulses, 20 J), ensuring stable performance. The UV mode was faster (4 s per hole) but more energy-consuming (76 J), offering a 3.6-fold gain in energy efficiency at the expense of processing speed. The hole profiles (depth ~50 μm) showed minimal taper, which is crucial for fuel injectors, where membranes undergo thermochemical wear and need regular replacement. These findings are consistent with literature data on metal ablation [3, 10], but extend them to industrial alloys using UV harmonics, where the HAZ is significantly reduced compared to IR radiation.

The developed picosecond Nd:YAG laser-based technique enables automated drilling of microholes 10–100 μm in diameter in steel foil. The resulting columnar microstructure, formed by the condensation of ablated particles, ensures high-quality holes without pronounced thermal defects. Optimal parameters (pulse energy 7–18 mJ, 500 pulses, proper harmonic selection) minimize the HAZ and enhance productivity, making the method promising for mass production. The obtained results open up opportunities for applications in microelectronics, medicine, and fuel injection systems, where precision processing of metallic alloys is required.

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MODELING AND ANALYSIS OF TaO_x-BASED RESISTIVE SWITCHING: A SPACE-CHARGE LIMITED CURRENT PERSPECTIVE

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Abstract

Tantalum oxide (TaO_x) memristors are promising candidates for next-generation nonvolatile memory and neuromorphic systems due to their scalability, high speed, and low power consumption[1]. While multiphysics PDE-based models have provided detailed insights into filament dynamics, their complexity limits practical use. In this work, we implement a simplified space-charge-limited current (SCLC) model in COMSOL Multiphysics to simulate the I–V characteristics of TaO_x devices in the low-resistance state (LRS). The results show close agreement with PDE-based simulations, demonstrating that the SCLC framework can reliably capture the essential transport features of TaO_x memristors while offering computational efficiency.

Introduction

Resistive switching devices, or memristors, are promising candidates for next-generation nonvolatile memory and neuromorphic systems. Accurate modeling of their resistive switching mechanisms is essential for reliable device design and optimization. Among the proposed models, the coupled electronic–ionic transport framework based on partial differential equations (PDEs) is widely used, while the space-charge-limited current (SCLC) mechanism has been shown to describe conduction in TaOx-based structures. Unlike PDE approaches, which are computationally intensive, the SCLC model provides a simpler yet physically meaningful description of current transport that accounts for trap states and carrier injection effects[2,3]. Investigating its applicability to TaO_x memristors may offer an efficient alternative framework, bridging simplified analytical models and multiphysics simulations.

Method and Discussion

The numerical simulations were performed in COMSOL Multiphysics, with the device modeled as a metal–insulator–metal (MIM) stack containing a TaOx active layer. The electrical behavior was described by three coupled partial differential equations (PDEs) governing the evolution of state variables. The resulting I–V curve (Figure 2) shows excellent agreement between simulation (red line) and experiment (yellow points), reproducing the resistive switching behavior in both SET and RESET processes [2]. To capture the conduction mechanism, the space-charge-limited current (SCLC) framework was integrated into the PDE model, where transport is dominated by injected carriers and trap states in the dielectric. This combined approach yields a physically consistent description of charge transport and explains the nonlinear response in the low-resistance state.

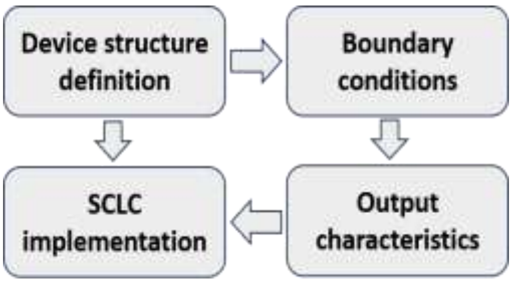

Figure 1. The simulation workflow.

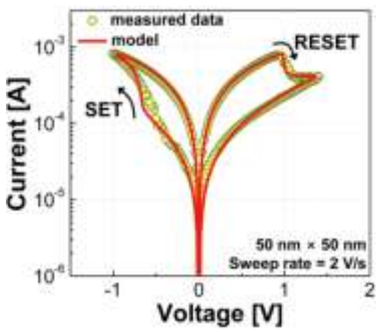

Figure 2. I-V characteristics of TaO_x based memristor simulated by PDEs.

The general form of the SCLC current density is expressed as:

$$J = \frac{9}{8}\,\mu\varepsilon\varepsilon_0\frac{V^3}{d^2}\theta$$

where μ is the carrier mobility, ε varepsilonε is the relative permittivity of the dielectric, ε_0 is the vacuum permittivity, d is the dielectric thickness, and θ represents the fraction of free carriers among the injected ones, determined by trap density and energy level [4].

Results and Discussion

To validate the modeling approach, the obtained I–V curves were compared with results reported by Kim et al.[2], who applied a PDE-based dynamic transport model to TaO_x memristors.

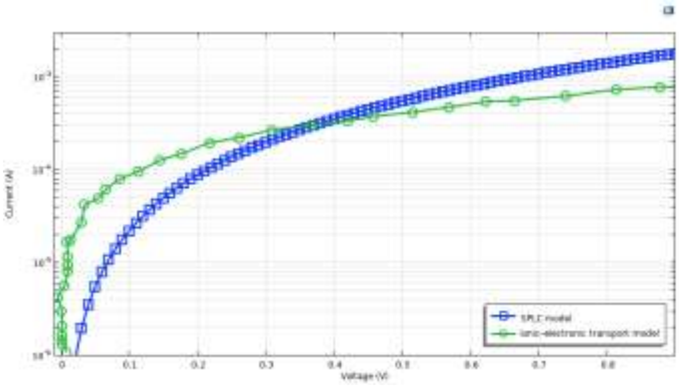

Figure 3. Comparison of current–voltage characteristics in LRS of TaO_x memristors obtained from SCLC and ionic–electronic transport models.

Despite the simplified assumptions, the SCLC model reproduced the essential features of the resistive switching behavior. In particular, the threshold voltages for transition and the general shape of the I–V curves in LRS showed close agreement with the PDE simulations (Figure 3).

The comparison highlights that while the PDE-based framework offers a more comprehensive physical description involving ionic drift, diffusion, and Joule heating, the SCLC model provides a computationally efficient alternative. The strong agreement between the two approaches suggests that the dominant transport in TaO_x memristors can be captured through trap-controlled space-charge-limited conduction. This result is consistent with prior findings in other dielectric memristors, such as TaO_x, where SCLC has been shown to describe charge transport in all resistance states.

Conclusion

In this study, we investigated charge transport in TaO_x-based memristors using the space-charge-limited current (SCLC) framework implemented in COMSOL Multiphysics. The simulated current–voltage characteristics low-resistance state (LRS) reproduced the typical nonlinear and ohmic-to-quadratic behaviors expected from trap-controlled conduction. Importantly, the obtained results showed close agreement with the comprehensive PDE-based dynamic model previously reported for TaO_x devices.

These findings demonstrate that the SCLC model, despite its relative simplicity, can reliably capture the essential transport mechanisms in TaO_x memristors. Compared with multiphysics PDE approaches, the SCLC framework requires fewer computational resources and parameters, while still providing accurate representation of switching behavior. This makes SCLC-based modeling an attractive tool for rapid device analysis and optimization.

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Impact of Different SiO_2 and HfO_2 Thickness Combinations on Short-Channel Effects in Nanosheet Transistors with an Effective Oxide Thickness of 0.7 nm: A Sentaurus Process Simulation Study

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Abstract

In this work, the effect of varying SiO_2 and HfO_2 thicknesses in nanosheet transistors was studied at a fixed EOT of 0.7 nm using Sentaurus Process simulations. The analysis shows that optimizing the dielectric stack is key to controlling short-channel effects like DIBL and SS, leading to improved device performance. This underlines the importance of dielectric engineering for nanosheet FET scaling in advanced nodes.

Relevance of the Study

The continuous scaling of CMOS technology has led to significant challenges in controlling short-channel effects (SCEs) in nanosheet transistors. Gate dielectric engineering plays a critical role in suppressing degradations such as drain-induced barrier lowering (DIBL) and subthreshold swing (SS). In particular, the combination of high-k dielectrics (HfO_2) with interfacial SiO_2 layers has become essential to achieve both low effective oxide thickness (EOT) and stable device performance. Therefore, investigating the impact of different SiO_2/HfO_2 thickness combinations on nanosheet transistor behavior remains highly relevant for future technology nodes.

Methodology

In this study, nanosheet transistors were modeled with Sentaurus Process, incorporating key fabrication steps for realistic device representation. Various SiO_2 and HfO_2 thickness combinations were tested at a fixed EOT of 0.7 nm, enabling systematic evaluation of their impact on short-channel effects like DIBL and SS.

Results

The device simulations were carried out for a nanosheet transistor with a channel size of 50 × 5 nm, where the ratio $R = \frac{T_{HfO2}}{T_{SiO_2}}$ was systematically varied under the condition of a fixed effective oxide thickness (EOT) of 0.7 nm. This approach allowed us to investigate how different dielectric stack configurations influence short-channel effects (SCEs) in aggressively scaled nanosheet devices.

The results indicate a strong dependence of both drain-induced barrier lowering (DIBL) and subthreshold swing (SS) on the dielectric thickness ratio R. As shown in Fig. 1, DIBL increases almost linearly with larger R, suggesting that a thicker HfO_2 layer relative to SiO_2 weakens gate control and enhances short-channel effects. This underlines the need for a proper balance between high-k and interfacial oxide thicknesses.

Similarly, Fig. 2 shows that SS also rises with increasing R, though less steeply than DIBL. This trend implies that higher R values degrade subthreshold characteristics, leading to less ideal switching behavior.

Overall, these findings confirm that while incorporating high-k HfO_2 is crucial for scaling the gate oxide to ultra-low EOT values, excessive reliance on thicker HfO_2 layers without sufficient SiO_2 interfacial support negatively impacts device electrostatics. Therefore, the optimization of the SiO_2/HfO_2 thickness ratio is a key design parameter to minimize short-channel effects and ensure reliable operation of nanosheet transistors in future technology nodes.

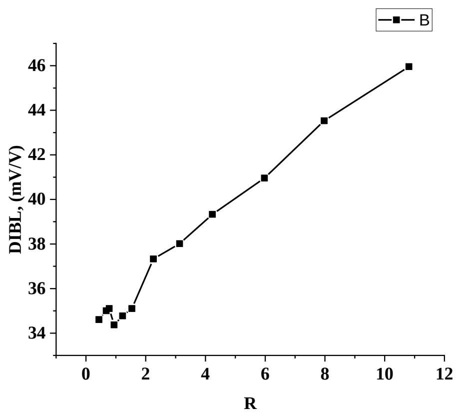

Fig. 1. Dependence of the drain-induced barrier lowering (DIBL) on the dielectric thickness ratio $R = \frac{T_{Hfo2}}{T_{SiO_2}}$ for a nanosheet transistor with a 50×5 nm channel size.

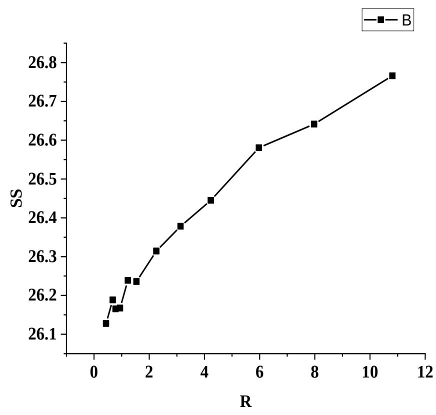

Fig. 2. Dependence of the subthreshold swing (SS) on the dielectric thickness ratio $R = \frac{T_{Hfo2}}{T_{SiO_2}}$ for a nanosheet transistor with a 50×5 nm channel size.

Explanation:

The electrostatic potential distribution along the channel provides insight into why both DIBL and SS increase with higher dielectric thickness ratio $R = \frac{T_{Hfo2}}{T_{SiO_2}}$. As R increases, the HfO_2 layer becomes relatively thicker, which reduces the gate's electrostatic control over the channel due to the weaker influence of the interfacial SiO_2 layer. This leads to a more pronounced penetration of the drain electric field into the channel region. As a result, the barrier potential at the source side is lowered more significantly under high drain bias, thereby increasing the drain-induced barrier lowering (DIBL). Similarly, the weakened gate control degrades the subthreshold characteristics, leading to an increase in the subthreshold swing (SS). The potential profiles in Fig. 3 clearly show that with increasing R, the channel potential becomes less confined, confirming the observed degradation of DIBL and SS.

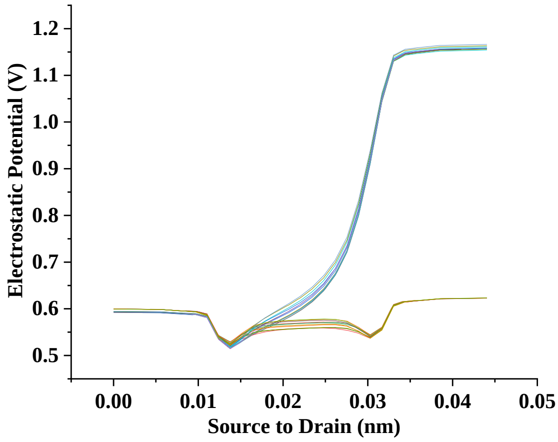

Fig. 3. Electrostatic potential distribution in a 50 × 5 nm nanosheet transistor at different dielectric thickness ratios R.

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INVESTIGATION OF SELF-HEATING PHENOMENA IN NANOSHEET FETS THROUGH TCAD-BASED PROCESS SIMULATIONS

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Abstract

This study investigates the self-heating effect (SHE) in 3-channel nanosheet field-effect transistors using TCAD-based Sentaurus Process simulations. The gate dielectric stack, composed of a SiO_2 interfacial layer and a HfO_2 high-k layer, was engineered while keeping the equivalent oxide thickness (EOT) constant. By defining the thickness ratio as $R = \frac{T_{Hfo2}}{T_{Sio2}}$, the impact of varying R[1] on self-heating was analyzed. Simulation results demonstrate that higher values of R intensify the self-heating effect due to reduced thermal conductivity, whereas optimized ratios help mitigate heat accumulation. These findings emphasize the importance of gate dielectric engineering for enhancing thermal management and device reliability in nanosheet FET technologies.

Results and Discussion

Fig.1 presents the variation of channel center temperature as a function of the dielectric thickness ratio $R = \frac{T_{Hfo2}}{T_{Sio2}}$ for the three stacked nanosheet channels. It is observed that the self-heating effect strongly depends on the gate dielectric configuration. At low values of R, corresponding to relatively thicker SiO_2 interfacial layers, the channel temperatures are higher due to the lower thermal conductivity of SiO_2, which restricts heat dissipation from the active region. Consequently, all three channels exhibit peak temperatures in this regime, with the top channel (Channel 3) experiencing the highest heating due to its reduced proximity to the substrate heat sink. In order to maintain a constant equivalent oxide thickness[2] (EOT), the physical thicknesses of the SiO_2 interfacial layer T_{SiO_2} and the HfO_2 high-k dielectric T_{HfO_2} were calculated (1) according to the well-known EOT relation:

$$\frac{1}{t_{eqv}} = \frac{\varepsilon_{HfO_2}}{\varepsilon_{SiO_2} t_{HfO_2} + \varepsilon_{HfO_2} t_{SiO_2}} \quad (1)$$

N	1	2	3	4	5	6	7	8	9	10	11
T_{SiO_2}	0.65	0.63	0.6	0.57	0.55	0.5	0.452	0.4	0.35	0.29	0.25
T_{HfO2}	0.282	0.395	0.564	0.733	0.846	1.128	1.399	1.692	1.974	2.313	2.5380.434
R	0.434	0.627	0.94	1.286	1.538	2.256	3.095	4.230	5.641	7.975	10.154

Table 1. Calculated values of T_{SiO_2},T_{HfO_2} and thickness ratio $R = \frac{T_{HfO2}}{T_{SiO2}}$ at constant equivalent oxide thickness (EOT).

As R increases, i.e., with a relatively thicker HfO_2 layer while maintaining constant EOT, a notable decrease in channel temperature is observed. This trend can be attributed to the improved thermal conduction pathways provided by the high-k dielectric, which facilitates more efficient heat dissipation. Among the three channels, Channel 1 (the bottom channel) consistently shows lower temperatures[3] compared to Channels 2 and 3, highlighting the stronger influence of substrate thermal coupling in reducing self-heating.

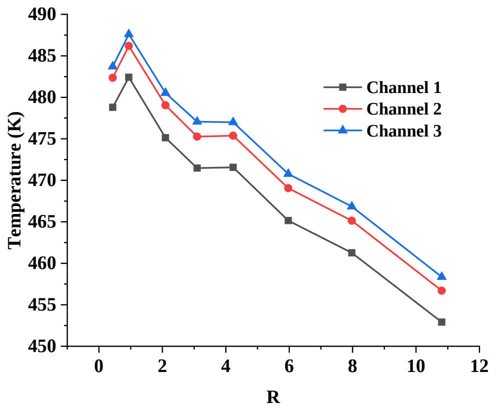

Fig. 1. Variation of channel center temperature with dielectric thickness ratio $R = \frac{T_{HfO2}}{T_{SiO2}}$ for three stacked nanosheet channels.

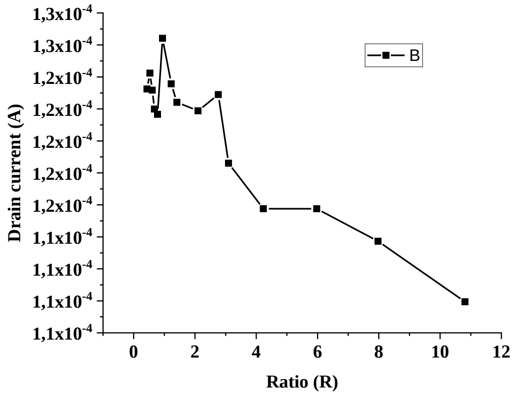

Fig. 2. Drain current variation as a function of dielectric thickness ratio $R = \frac{T_{HfO2}}{T_{SiO2}}$.

Overall, these results confirm that the dielectric thickness ratio plays a critical role in controlling self-heating in nanosheet FETs. Optimizing R not only reduces peak channel temperatures but also minimizes inter-channel temperature variations[5], which is essential for balanced device performance and reliability in multi-channel nanosheet architectures.

The variation of channel temperature with respect to the dielectric thickness ratio R can be directly explained by analyzing the drain current behavior shown in Fig2. At lower values of R, the drain current (I_D) is relatively high, which leads to increased Joule heating (2) within the channel. As a result, the channel center temperature rises, reaching its maximum around $R \approx 0 - 2$. This explains the peak observed in the temperature characteristics of all three channels.

$$Q = I^2 R t$$

(2)

As R increases, the drain current decreases significantly, thereby reducing the amount of generated Joule heat. Consequently, the channel temperature exhibits a gradual decline[4] with larger R. Furthermore, it is observed that Channel 1 (the bottom channel) consistently shows lower temperature values compared to Channels 2 and 3, owing to stronger thermal coupling with the substrate that facilitates more efficient heat dissipation.

These results clearly indicate that the temperature behavior in nanosheet FETs is strongly governed by the drain current profile[6]. High drain current at small R values results in enhanced self-heating, while reduced current at larger R effectively suppresses the thermal rise. This correlation highlights the crucial interplay between electrical and thermal phenomena in nanosheet transistor architectures.

Conclusion

This study analyzed the self-heating effect in 3-channel nanosheet FETs using TCAD simulations with different SiO_2/HfO_2 gate dielectric thickness ratios at fixed EOT. Results show that smaller R values lead to higher drain current and stronger Joule heating, causing elevated channel temperatures, while larger R values reduce heat generation and suppress self-heating. These findings confirm that optimizing the dielectric stack ratio is essential for improving thermal reliability and overall performance in nanosheet transistor technologies.

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SINUSOIDAL RADIAL 2D PANJARA ASOSIDA IKKINCHI GARMONIK HOSIL BO'LISHINING SONLI TADQIQI

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Annotatsiya

Ushbu ishda ikkinchi garmonik avlod (Second Harmonic Generation, SHG) jarayoni sinusoidal radial 2D panjara asosida sonli usulda modellashtirildi. Nolineylik xaritasi d_eff(x,y)=d33·g(x,y) ko'rinishida berildi va bu yerda $g(x,y)=\cos(2\pi R/\lambda_0)$ $(R=\sqrt{(x^2+y^2)})$ — kontsentrik halqalardan iborat sinusoidal modulyatsiya. Tarqalish Fresnel paraxial propagatori bilan 2D split-step FFT usulida, χ^(2) juftlashgan tenglamalar esa 4-qadamli Runge–Kutta (RK4) bilan yechildi. Lazer to'lqin uzunliklari $L_1=1064$ nm va $L_2=L_1/2$ bo'lib, $LiNbO_3$ uchun d33≈12.9 pm/V qabul qilindi. Natijalarda asosiy to'lqin $|A_1|^2$ taqsimoti Gauss shaklini saqlashi, ikkinchi garmonik $|A_2|^2$ esa panjara sinusoidal tuzilishiga mos halqasimon interferensiya tuzilmalari hosil qilishi kuzatildi. Energiya saqlanishi odi_1+odi_2 deyarli doimiy bo'lishi bilan tasdiqlandi.

Kalit so'zlar: ikkinchi garmonik avlod, SHG, kvazifaza-moslash, 2D panjara, sinusoidal modulyatsiya, Fresnel propagatori, split-step FFT, MATLAB.

I. Kirish

Nochiziqli optikada ikkinchi garmonik avlod (SHG) chastotani ikki baravar oshiruvchi eng samarali hodisalardan biridir. Jarayon samaradorligi fazaviy moslashuvga kuchli bog'liq; kvazifaza-moslash (QPM) bu muammoni dielektrikning nolineyer koeffitsientini fazoda davriy o‘zgartirish orqali hal qiladi. Avvalgi ishda panjara “shaxmat” (katak) ko‘rinishida ko‘rilgan bo‘lsa, bu ishda 2D sinusoidal radial panjara taklif qilinadi. Sinusoidal modulyatsiya diskret domen inversiyasiga nisbatan silliqroq spektr beradi hamda spektral moslashuvni boshqarish imkonini oshiradi.

II. Nazariy model va sonli usul

Modelda ikkita to‘lqin amplitudalari $A_1(x,y,z)$ va $A_2(x,y,z)$ uchun χ^(2) juftlashgan tenglamalar ishlatildi. Tarqalish qismi paraxial Fresnel propagatori bilan ifodalanadi:

$A_j(x,y,z+\Delta z) = \mathcal{F}^{-1}\{ \exp[-i\cdot k_\perp^2\cdot \Delta z/(2k_{0j})] \cdot \mathcal{F}\{A_j(x,y,z)\} \}$, $_j$=1,2,

bu yerda $k_{0j} = 2\pi n_j/\lambda_j$ va $k_\perp^2 = kx^2 + ky^2$. Nolinear qadamda (Δz ichida) quyidagi ko‘rinishdagi juftlashuv qo‘llandi:

$\partial A_1/\partial z = i\cdot \kappa_1\cdot d\_eff(x,y)\cdot A_2\cdot A_1^*\cdot e^{+i\Delta k z}$, $\partial A_2/\partial z =$

$i\cdot \kappa_2\cdot d\_eff(x,y)\cdot A_1^2\cdot e^{-i\Delta k z}$,

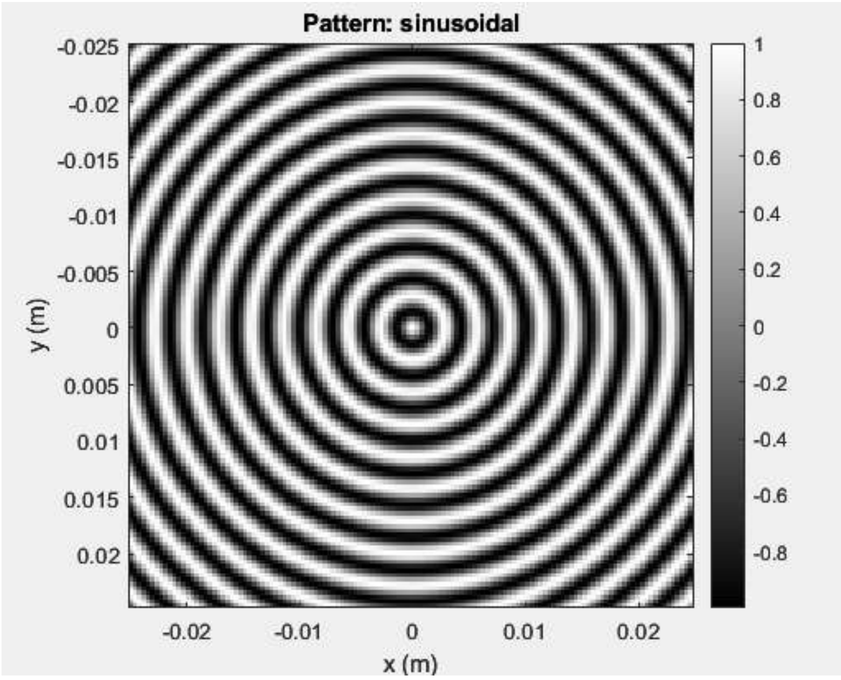
bu yerda $\Delta k = 2k_1 - k_2$, $d\_eff(x,y)=d33\cdot g(x,y)$ hamda $g(x,y)=\cos(2\pi R/\lambda_0)$. Nochiziqli qadam 4-qadamli Runge–Kutta (RK4) bilan yechildi. Boshlang‘ich maydon Gauss profilida tanlandi.

III. Hisoblash parametrlari

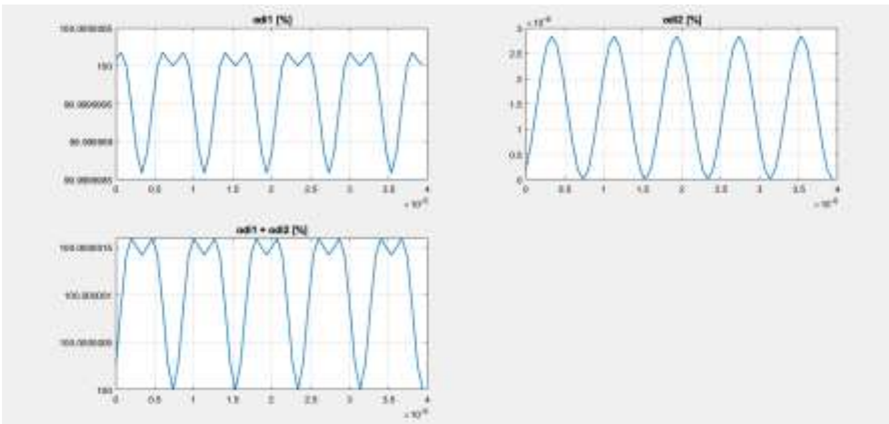
To‘lqin uzunliklari: L_1=1.064 μm, L_2=0.532 μm; refraksion ko‘rsatkichlar n_1, n_2 — ne_index(L) modeli orqali; nolineyer koeffitsient: d33≈12.9 pm/V ($LiNbO_3$); panjara: $g(x,y)=\cos(2\pi R/\lambda_0)$ va λ_0≈rad/3.5; panjara radiusi rad≈1 cm; hisob panjarasi: Nx=Ny=128; z yo‘nalishi bo‘yicha N=10, nm=6 qadam.

IV. Natijalar

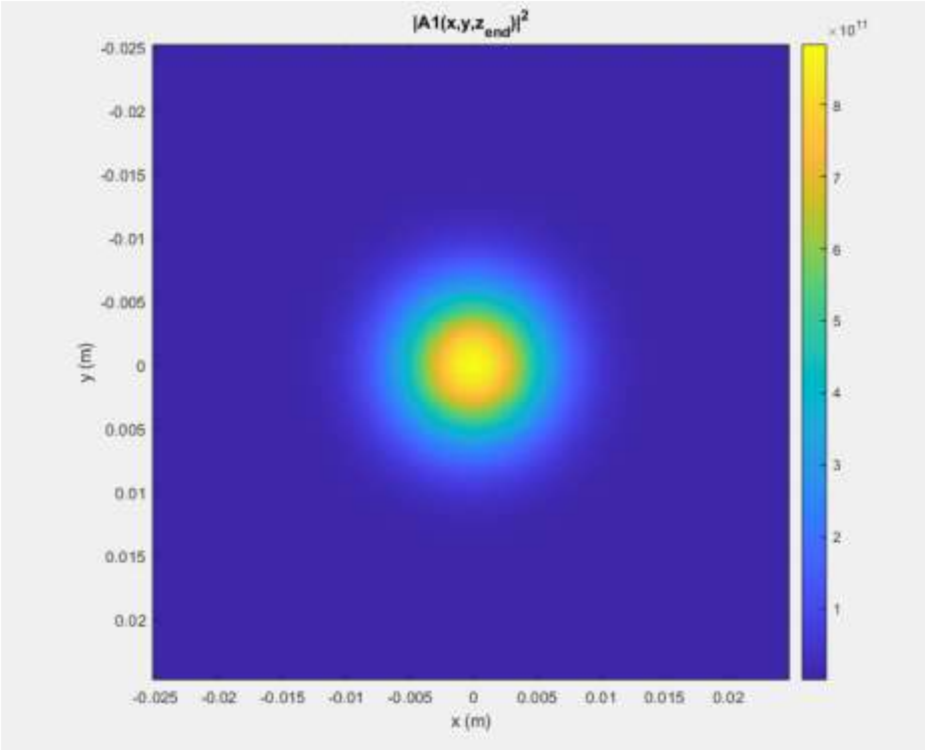
1-rasmda nolineylik xaritasi — sinusoidal kontsentrik halqalar ko‘rinadi. 2-rasmdagi graflarda asosiy to‘lqin (odi_1)ning biroz kamayishi va ikkinchi garmonik (odi_2)ning periodik o'sishi ko'rinadi; ularning yig'indisi (odi_1+odi_2) deyarli o'zgarmas bo'lib, energiya saqlanishini tasdiqlaydi. 3–4-rasmlar esa z = z_end nuqtasidagi maydon intensivliklarini beradi: $|A_1|^2$ Gaussga yaqin, $|A_2|^2$ esa panjara ta'sirida halqasimon tuzilma ko'rsatadi.



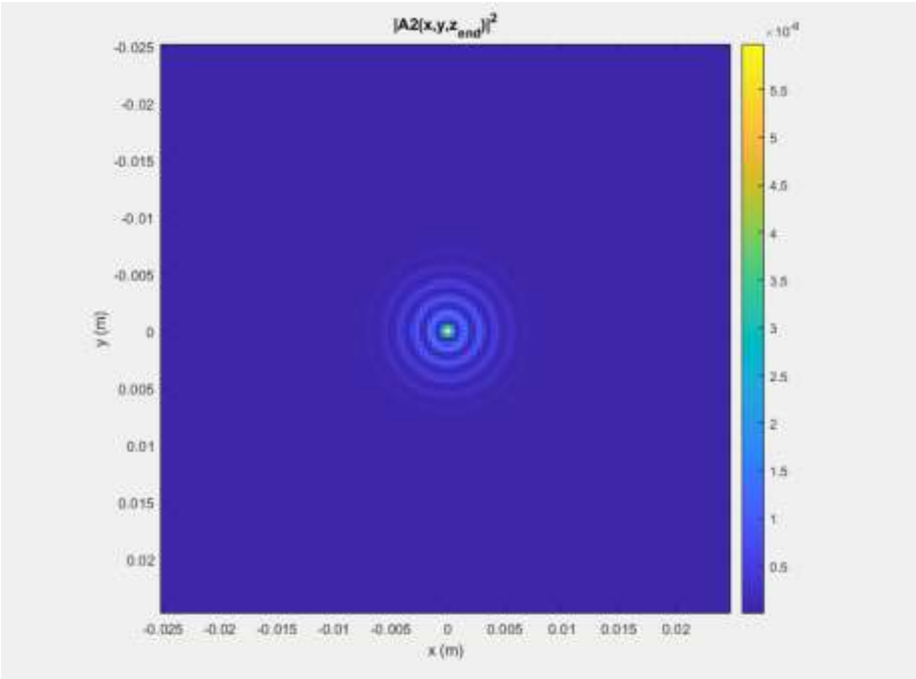
1-rasm. Sinusoidal radial panjara: $g(x,y)=cos(2\pi R/\lambda_0)$.



2-rasm. Energiya evolyutsiyasi: odi_1 (A_1), odi_2 (A_2) va ularning yig'indisi.



3-rasm. Chiqishdagi $|A_1(x,y)|^2$ taqsimoti



4-rasm. Chiqishdagi $|A_2(x,y)|^2$ taqsimoti.

V. Xulosalar

Sinusoidal radial 2D panjara yordamida SHG jarayonining 2D split-step FFT + RK4 asosidagi modellashtirilishi energiya almashinuvi va fazaviy moslashuvning silliq boshqarilishini ko'rsatdi. Natijalar sinusoidal modulyatsiya bilangina ham samarali ikkinchi garmonik hosil bo'lishi mumkinligini va $|A_2|^2$ taqsimotida halqasimon fazoviy xususiyatlar paydo bo'lishini tasdiqlaydi. Kelgusida chastota polosasini kengaytirish uchun chirplangan sinusoid ($\lambda_0=\lambda_0(R)$) yoki superpanjara (superlattice) yondashuvlari sinovdan o'tkazilishi mumkin.

VI. Foydalanilgan adabiyotlar

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LAZER PLAZMASI IONLANISH JARAYONLARI VA ULARNING FIZIK XUSUSIYATLARINI TADQIQ QILISH.

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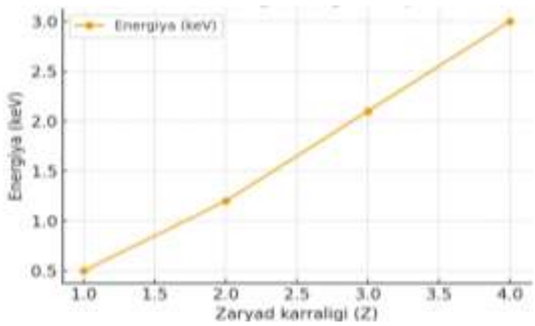
Hozirgi kunda lazer texnologiyalari yuqori energiyali fizik jarayonlarni o'rganishda keng qo'llanmoqda. Lazer plazmasida ko'p zaryadli ionlarning hosil bo'lish mexanizmlarini tadqiq qilish termoyadro reaksiyalari, rentgen-spektroskopiya, yuqori haroratli plazma modellashtirish va yangi turdagi lazer manbalarini yaratishda katta ahamiyatga ega. Ayniqsa, ionlanish va rekombinatsiya jarayonlarining chuqur tahlili lazer plazmasining asosiy fizik xususiyatlarini yoritib beradi. Quyida Al ionlarining energetik spektri va intensivlik taqsimlanishini ko'rsatuvchi grafiklar keltirilgan:



1-rasm. Al ionlarining energetik spektri (Z va energiya bog'lanishi).

Atomlarning ionlanishi lazerlar impulsining boshida boshlanadi,bunda u mo'ljal yuzasiga borib yetadi va natijada shu yuzada plazma qatlami hosil bo'ladi. Bu qatlamning optik qalinligi plazmada yorug'lik oqimi yutilmay qolguncha ortib boraveradi, bu bug'lanish tezligi kamayishiga olib keladi.Ionlanish tezlashishi vaqtining baholanishi [1-2] ishlarda amalga oshiriladi.[3] shuni ko'rsatadiki, elektronlar atomlar bilan to'qnashganda ionlanish sodir bo'ladi. Elektronlar konsentratsiyasi uchun quyidagi tenglama mos keladi.

$$\frac{dN}{dt}=\alpha_e(T_e)\,n_a n_e \quad (1)$$

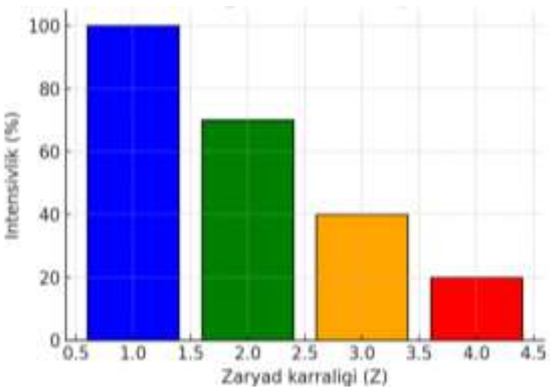
n_a-atomlar soni. Ionlanish tezligi konstantasi α_e [4] quyidagi ifoda orqali ifodalaniladi:

$$\alpha_e(T_e) = \sigma_e V_e \left(2+\frac{I}{kT_e}\right)\exp\left(\frac{I}{kT_e}\right) \quad (2)$$

Bu yerda $v_e = \sqrt{\frac{8kT_e}{nm_e}}$ – elektronning o'rtacha tezligi. I-ionlanish porensiali. σ_e-elektron uzilishi natijasida hosil bo'ladigan kesim. (1) ifodadan quyidagiga ega. T_e-vaqtga bog'liq bo'lganligi uchun n_e elektronlarning konsentratsiyasi ortishi oddiy bo'lmagan eksponensial qonunga asoslangan.Bu bog'liqliknianiqlash uchun elektronlar energiya balansini ko'rib chiqish kerak. Elektronlar nazariyasi yorug'likning yutilish koeffisienti uchun quyidagi ωifodani beradi.

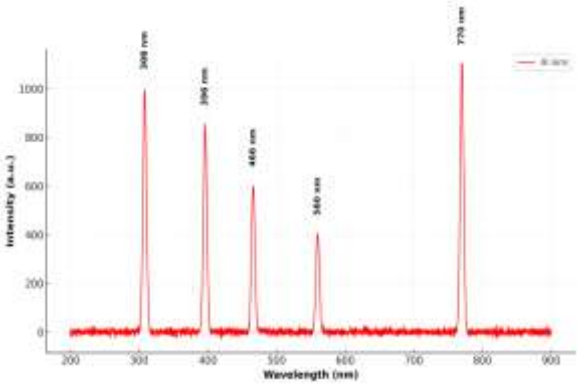
$$I=\frac{4\pi n_e e^2 \nu_{cT}}{m_e c(\omega^2+\nu^2{}_{cT})} \quad (3)$$

bu yerda,ν_{cT}-to'qnashishning effektiv chastotasi.



2-rasm. Al ionlarining intensivlik taqsimlanishi.

Eksperimentlarda bir kanalli mass-spektrometr va neodimli qattiq jismli lazer tizimi ishlatildi. Vakuum kamerasi yordamida lazer plazmasining turli burchaklarda shakllanishi kuzatildi. Ionlarning zaryad va energetik spektrlari qayd qilindi, bunda 1–13 karrali zaryadlar aniqlash imkoniyati yaratildi.



3-rasm. Lazer plazmasida Al ionlarining emissiya spektri.

Lazer plazmasida hosil bo‘lgan ionlarning massa-zaryad spektrlari va energetik spektrlari o‘rganildi. Ionlarning maksimal energiyasi ~3 keV gacha yetdi. Zaryad karraligi ortishi bilan ionlarning intensivligi kamayishi aniqlandi. Tadqiqotlar shuni ko‘rsatadiki, lazer plazmasi ionlanish jarayonlari va ko‘p zaryadli ionlarning xususiyatlarini o‘rganish nazariy va amaliy jihatdan dolzarbdir. Olingan natijalar materialshunoslik, plazma fizikasi, yuqori energiyali ion manbalari hamda zamonaviy lazer texnologiyalarida qo‘llash uchun ilmiy asos bo‘lib xizmat qiladi.

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TEMPERATURE SENSITIVITY OF OPTICAL FIBERS

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Abstract—This paper presents the results of an experimental study on the temperature sensitivity of optical fibers. The study focused on how optical fibers change under temperature influence, particularly in terms of light transmission power and loss variations. Experiments were conducted using a specialized laboratory setup, and it was observed that as the temperature increased, optical losses in the fiber significantly increased. The findings are important for developing temperature sensors based on optical fibers

Keywords— Optical fiber, temperature sensitivity, light transmission, dispersion, optical losses

I. INTRODUCTION

Optical fiber communication systems are widely used in modern telecommunications and sensor technologies. The temperature sensitivity of optical fibers plays a crucial role in various industries, including oil and gas pipeline monitoring, fire safety, and medical applications.

The main reasons for the temperature sensitivity of optical fibers are:

- Thermal expansion. Temperature changes affect the physical length of the fiber.
- Refractive index changes. Increasing or decreasing temperature alters the refractive index of optical materials.
- Increase in attenuation (losses). As the temperature rises, signal degradation within optical fibers increases.

Several studies have been conducted on the temperature sensitivity of optical fibers. For instance, Smith and Brown (2023) analyzed changes in the refractive index and dispersion of optical fibers under temperature influence. Their results showed that higher temperatures lead to increased optical losses [1].

Jones and Wilson (2022) investigated the impact of temperature on signal quality and transmission characteristics in optical fibers. Their research found that rising temperatures cause signal attenuation [2].

Uzbek researchers have also studied this field. For example, the textbook "Fundamentals of Optical Communication" by N. Yunusov and R. Isayev describes the key principles and technologies of optical communication systems [3].

Frank Payne, Zipei Song, Mohan Wang, and Julian A. J. Fells have conducted research on improving the temperature tolerance of optical waveguides. They have shown that temperature changes can also alter the propagation of light in optical fibers or other waveguides [4].

The primary goal of this study is to experimentally examine the temperature sensitivity of optical fibers and analyze their response to temperature variations.

II. METHODS

This study utilized a specialized laboratory setup, which included:

– A He-Ne laser (632.8 nm) or an infrared light source (1310/1550 nm),
– Optical fiber (single-mode or multi-mode),
– Electronic temperature control device (with PID control),
– Optical power meter,
– Optical spectrometer,
– Thermometer.

The experiment was conducted as follows:

1. The optical fiber was placed inside the temperature control device.
2. At an initial temperature of 27°C, the light power and spectrum were measured.
3. The temperature was gradually increased to 50°C, with light power recorded at every 5°C increment.
4. The signal recovery was analyzed as the temperature decreased.

Optical losses were calculated using the following formula (*Fig.1.*):

$$L = 10 * lg\left(\frac{p_{in}}{p_{out}}\right) \quad \text{(dB)} \qquad (1)$$

where:

p_{in}- is the input optical power,
p_{out}- is the output optical power,
L- represents the optical loss (dB)

Temperature sensitivity was determined using the equation (*Fig. 3.*):

$$s_T = \frac{\Delta P}{\Delta T} \quad \text{(dB)} \qquad (2)$$

where:

s_T- is the temperature sensitivity,
ΔP- is the power change (dB),

ΔT- is the temperature change (°C).

III. RESULTS

The experiment showed that as the fiber temperature increased, optical power decreased. Specifically, in the 27°C to 50°C range, optical losses increased by 2-3 dB. When the temperature exceeded 50°C, the system's automatic cooling mechanism was activated to prevent damage to the fiber and equipment.

Spectral shifts were observed in the 1310 nm and 1550 nm wavelength ranges.

Figure.1 illustrates the change in received optical power with increasing temperature.

Figure.2 shows the increase in optical losses due to temperature variations

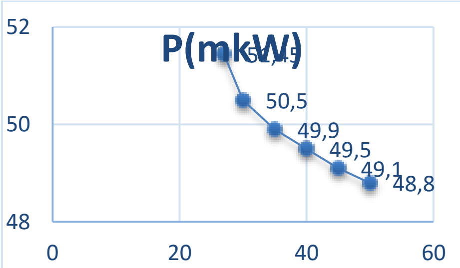

Fig. 1. Optical power is applied to the receiver with temperature.

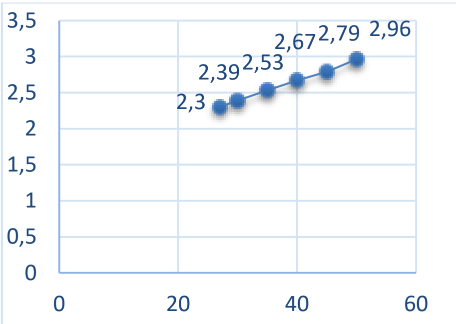

Fig. 2. Increased losses due to temperature

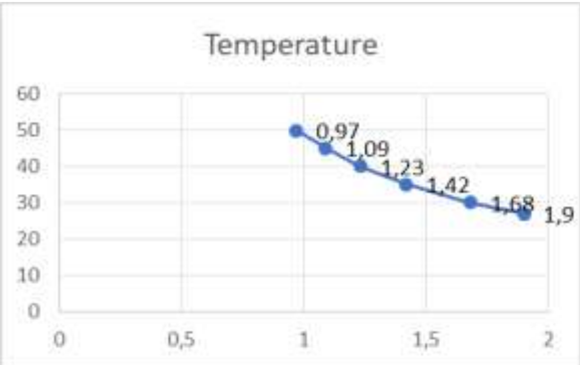

Fig. 3. Temperature sensitivity

IV. DISCUSSION AND CONCLUSION

The obtained results align with previous studies on the temperature sensitivity of optical fibers. Higher temperatures increase the refractive index, enhance optical losses, and degrade signal quality [1,2].

The temperature sensitivity of optical fibers plays a key role in various sensor technologies. These experimental results can be applied in fields such as oil and gas monitoring, medicine, and security systems [5], [6], [7].

The findings also indicate that temperature fluctuations can degrade signal quality. To mitigate this effect, heat-resistant optical fibers or stabilized materials should be used.

The temperature sensitivity of optical fibers was experimentally confirmed.

As the temperature increased, optical losses rose, and spectral shifts were observed.

These results are significant for the development of temperature-sensitive optical sensors.

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KREMNIY ASOSIDAGI IKKI O'TISHLI VERTIKAL QUYOSH ELEMENTLARI SAMARADORLIGINING BALANDLIGIGA BOG'LIQLIGINI MODELLASHTIRISH

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Annotatsiya

Mazkur tadqiqotda kremni asosidagi ikki o'tishli vertikal quyosh elementi (VTJ) samaradorligining qurilma balandligiga bog'liqligi TCAD Sentaurus dasturiy taminoti yordamida kompyuter modellashtirish asosida o'rganildi. Qurilma samaradorligini belgilovchi asosiy parametrlar – qisqa tutashuv toki zichligi (Jsc), ochiq kontur kuchlanishi (Voc), to'ldirish faktori (FF) va umumiy samaradorlik (η) balandlikka bog'liqligi tahlil qilindi. Natijalar samaradorlikning balandlikka nisbatan no-monoton bog'lanishga ega ekanligini ko'rsatdi.

Kirish

Quyosh elementlarini rivojlantirishdagi asosiy maqsad – samaradorlikni oshirish bilan birga ishlab chiqarish xarajatlarini kamaytirishdir. Shu sababli turli yangi yarimo'tkazgich materiallari taklif etilgan, jumladan organik yarimo'tkazgichlar va perovskitlar. Ular arzonligi va tayyorlash jarayonining soddaligi bilan ajralib turadi, ammo yuqori qarshilik, past o'tkazuvchanlik va tashuvchilarning past harakatchanligi kabi kamchiliklarga ega [1–3]. Perovskitlar istiqbolli bo'lsada, namlik, kislorod va ultrabinafsha nurlanishga sezgirligi, qo'rg'oshin tarkibi hamda yuqori haroratdagi beqarorligi ularni amaliy qo'llashni cheklaydi [4–7].

Shu bois e’tibor yana kremni asosidagi quyosh elementlariga qaratilmoqda. Kremni eng ko‘p o‘rganilgan va amalda keng ishlatiladigan yarimo‘tkazgich bo‘lib, ishlab chiqarish texnologiyalarining rivojlanishi tufayli uning narxi pasayib bormoqda. Ayniqsa, ko‘p-o’tishli kremni asosidagi quyosh elementlari yuqori samaradorlik ko‘rsatmoqda [8,9]. Vertikal ko‘p-o‘tishli qurilmalar nafaqat samaradorlikni oshiradi, balki qimmat material sarfini ham kamaytiradi [10].

Qurilma balandligining samaradorlikka ta’siri bo‘yicha tadqiqotlar mavjud, biroq ular cheklangan yorug’lik diapazonda olib borilgan [11]. Ushbu tadqiqotda esa Kremni asosidagi ikki o‘tishli vertikal quyosh elementlarining balandlikka bog‘liq xossalari keng yorug’lik diapazonda va turli quyosh konsentratsiyalari ostida tahlil qilinadi.

Tadqiqot metodikasi

O‘rganilgan kremni asosidagi ikki o‘tishli vertikal quyosh elementi (VTJ) tuzilishida ikkita p–n o‘tish ketma-ket ulanib, ular orasidagi bo’g’lanish tunnel o‘tish orqali ta’minlanadi. Tunnel o‘tish kuchli legirlangan p++–n++ qatlamlari asosida shakllantirilgan. Qurilmaning umumiy balandligi 5 μm dan 600 μm gacha o‘zgartirildi. Geometrik parametrlar va legirlanish konsentratsiyalari quyidagicha tanlandi: $p+ = 5\cdot10^{18}$ cm^{-3}, $n+ = 1\cdot10^{19}$ cm^{-3}, $n = 1\cdot10^{14}$ cm^{-3}, $p++ = 2\cdot10^{20}$ cm^{-3}, $n++ = 1.1\cdot10^{20}$ cm^{-3}. Qatlam qalinliklari mos ravishda W_{p+} = 5 μm, W_n = 185 μm, W_{n+} = 5 μm, W_{p++} = 0.02 μm va W_{n++} = 0.014 μm qilib olingan.

Hisoblash jarayonlari TCAD Sentaurus dasturi yordamida ikki o‘lchamli (2D) raqamli modellashtirish asosida bajarildi. Modellashtirishda drift-diffuziya transport modeli, legirlanishga bog‘liq harakatchanlik modellari hamda Shockley–Read–Hall (SRH) rekombinatsiya mexanizmlari qo‘llanildi. Tunnel o‘tish orqali tok o‘tishini hisoblash uchun Band-to-Band Tunneling (BTB) modeli ishlatildi. Bundan tashqari, qamralgan holatlar orqali tunnellanishni tavsiflovchi Schenk modeli SRH rekombinatsiya mexanizmi bilan integratsiya qilindi.

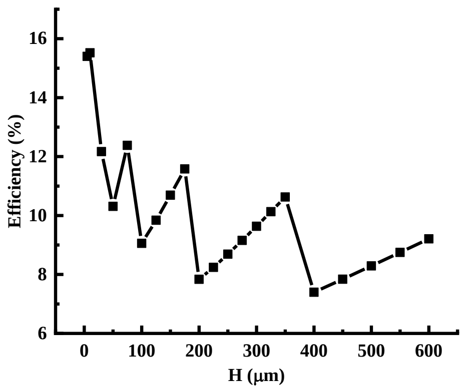
Qurilmada qo'llangan fizik modellar kalibrlash jarayonida eksperimental natijalar bilan taqqoslandi va yaxshi moslik kuzatildi. Faol ish rejimida tunnel o'tish kuchlanish yo'qotishi juda kichik bo'lib, ohmik kontakt kabi xususiyat namoyon etdi.

Natijalar va muhokama

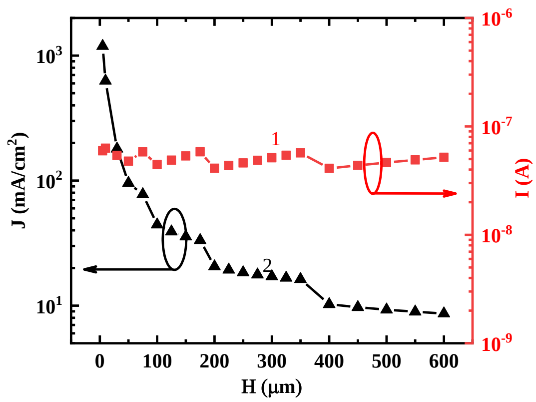
Hisoblash natijalari shuni ko'rsatdiki, balandlik ortishi bilan qurilma samaradorligi astasekin kamayadi, lekin "sakrash" tarzidagi no-monoton o'zgarishlar kuzatiladi (3-rasm). Bunday o'zgarishlar asosan qisqa tutashuv toki zichligi Jsc ning balandlik bo'yicha keskin kamayishi bilan bog'liq. Voc ham balandlik oshishi bilan kamayadi, FF esa uncha katta o'zgarish ko'rsatmaydi.

$$\eta = \frac{J_{SC} \cdot V_{OC} \cdot FF \cdot H}{P_{in} \cdot W} \quad (1)$$

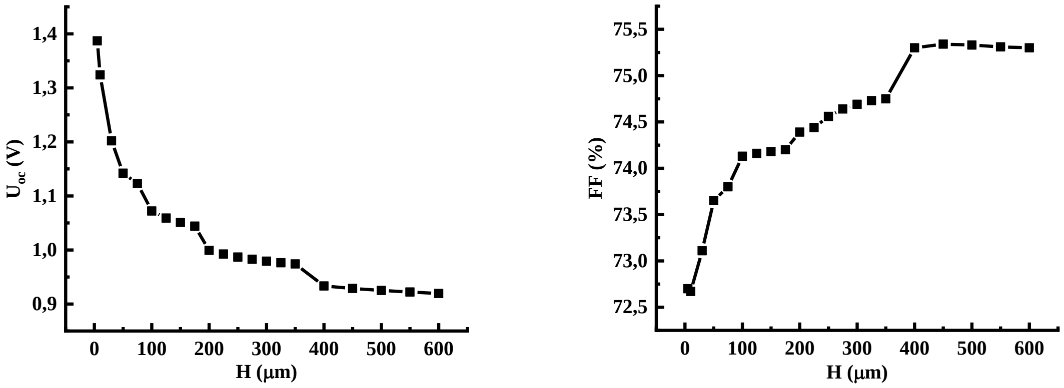
Formuladan ko'rinadiki, samaradorlikning kamayishiga asosiy sabab Jsc ning keskin pasayishidir. Bunga qurilma balandligi ortishi bilan tok oqimi yo'nalishiga perpendikulyar kesim yuzasining ortishi sabab bo'ladi.



(a)



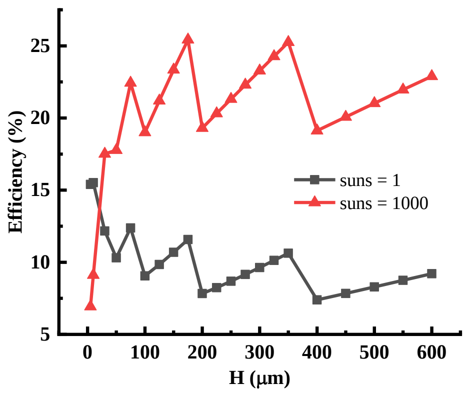
(b)



(c) (d)

3-rasm. Quyosh elementining samaradorligi (a), qisqa tutashuv toki va tok zichligi (b), ochiq kontur kuchlanishi (c) va to‘ldirish faktori (d) balandlikka bog‘liq holda (1 Quyosh yoritilishda).

Turli yorug‘lik konsentratsiyalarida ham samaradorlikning balandlikka bog‘liqligi sezilarli darajada farqlanadi. Xususan, balandlik 20 µm dan kichik bo‘lganda samaradorlik 1 Quyosh sharoitida yuqori bo‘lib, 1000 Quyosh ostida pasayadi (7-rasm). Bu holat yuqori konsentratsiyada tashuvchilar zichligi ortishi va rekombinatsiyaning kuchayishi bilan bog‘liqdir.



7-rasm. Samaradorlikning balandlikka bog‘liqligi turli quyosh konsentratsiyalarida.

Xulosa

O‘tkazilgan tadqiqotlar shuni ko‘rsatdiki, kremni asosidagi ikki o‘tishli vertikal quyosh elementining samaradorligi qurilma balandligiga kuchli bog‘liq. Samaradorlik balandlik ortishi bilan pasayadi, biroq ayrim balandliklarda "sakrash" tarzidagi oshishlar kuzatiladi. Kichik balandliklarda (20 μm dan kam) past konsentratsiyali yoritish samaradorligi yuqoriroq natija beradi, yuqori konsentratsiyada esa rekombinatsiya jarayonlari kuchayib, samaradorlik kamayadi.

Shunday qilib, kremni asosidagi VTJ quyosh elementlarida balandlikni optimal tanlash samaradorlikni oshirishda muhim omil hisoblanadi. Ushbu natijalar yuqori samarali mikrometr o‘lchamdagi quyosh elementlarini ishlab chiqishda amaliy ahamiyatga ega.

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O'ZBEKISTON MAKTAB VA UNIVERSITETLARIDA KVANT KOMPYUTERLARI TA'LIMI VA TADQIQOTLARIDAGI DOLZARBLIGI

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Annotatsiya Ushbu maqolada O'zbekiston ta'lim tizimida − xususan maktab va oliy ta'lim muassasalarida − kvant kompyuterlari sohasidagi bilimlarning dolzarbligi, mavjud salohiyat, kadrlar tayyorlash, ilmiy-tadqiqot yo'nalishlari va infratuzilma masalalari tahlil qilinadi. Hozirda butun dunyo kvant texnologiyalari, sun'iy intellekt va yuqori unumdor hisoblash tizimlariga o'tayotgan bir davrda, O'zbekiston ham bu sohalarda yetishmovchiliklarga qaramay, dastlabki qadamlarni qo'ymoqda. Maqolada xorijiy tajriba, milliy ta'lim siyosati, ilmiy loyihalar va istiqbolli yo'nalishlar muhokama qilinadi.

Kalit so'zlar: kvant kompyuter, ta'lim, O'zbekiston, STEM, universitet, informatika, ilmiy-tadqiqot, IT, yuksak texnologiyalar

Kirish. Kvant hisoblash texnologiyalari XXI-asrning eng muhim ilmiy-texnik yo'nalishlaridan biri hisoblanadi. AQSh, Xitoy, Yevropa Ittifoqi, Kanada va Yaponiya kabi davlatlar kvant texnologiyalarini strategik ustuvor yo'nalish deb e'tirof etgan va ularni ta'lim hamda tadqiqotga keng joriy qilmoqda. O'zbekistonda bu yo'nalish endi-endi shakllanmoqda. 2023-yildan boshlab, ayrim universitetlarda kvant fizikasiga oid kurslar taklif etila boshladi, biroq maktablarda bu tushunchalar umuman mavjud emas. Shunday ekan, quyidagi tahlillar O'zbekistonda kvant kompyuterlariga oid ta'lim va tadqiqotlar qanchalik dolzarb ekanligini asoslashga, mavjud muammolarni aniqlashga va istiqbolli yechimlarni taklif qilishga qaratilgan.

1-jadval

Tadqiqot usullari	**Tadqiqot natijalari**
Adabiyotlar tahlili	kvant kompyuterlari ta'limiga oid xalqaro maqolalar, loyiha hujjatlari, davlat strategiyalari o'rganildi.
So'rovnomalar	Toshkentdagi 3 ta universitet (M.Ulug'bek nomidagi O'zbekiston Milliy Universiteti, TATU, INHA universiteti) va 5 ta maktab o'qituvchilari o'rtasida mini-so'rovnoma o'tkazildi.
Taqqoslov tahlili	O'zbekiston ta'lim tizimi va xorijdagi tajriba (AQSh, Estoniya, Hindiston) taqqoslab o'rganildi.
SWOT tahlil	mavjud imkoniyatlar, zaif tomonlar, xavf va imkoniyatlar baholandi.

Kvant kompyuterlariga hozirgi kunda ishlatilayotgan sohalari:

Farmatsevtika, kriptografiya (shifrlash va xavfsizlik), sun'iy intellekt (AL), moliyaviy modellash (stock market simulation), iqlim modellashtirish (climate forecasting)

Xalqaro misollar:

IBM Quantum – kvant kompyuterlarga ochiq onlayn kirish platformasi (ibm quantum experience) orqali o'quvchilar va talabalar amaliyot o'tay olishadi.

Qiskit Global Summer School – butun dunyo bo'ylab o'tkaziladigan bepul onlayn kvant darslar.

Xitoy va Hindistonda – maktab darajasida STEM fanlariga kvant asoslari integratsiya qilinmoqda.

O'zbekistonda hozirgi kvant faoliyat holati Universitet va maktablar kesimida.

2-jadval

O'zMU	Fizika fakultetida kvant fizika fanlari mavjud, lekin kvant kompyuterlari bo'yicha maxsus kurs mavjud emas
TATU	Informatika va kriptografiya yo'nalishlarida kvant algoritmlari tilga olinadi, lekin chuqur kurslar mavjud emas
INHA	Sun'iy intellekt va algoritmlar doirasida kvant hisoblash mavzulari yuzaki o'rganiladi

3-jadval

Maktablarda	Fizika va informatika fanlarida kvant tushunchalari (superpozitsiya, kvant to'lqin) umuman yo'q yoki juda soddalashtirilgan.
	O'quv dasturlarida zamonaviy texnologiyalar haqida bilimlar yetarli emas.
	STEM yo'nalishi bo'yicha ilg'or sinflar bor, lekin kvant hisoblash yo'nalishi hali integratsiya qilinmagan.

Dolzarblik asoslari

4-jadval

Ta'lim sifatini oshirish	**Raqobatbardosh kadrlar tayyorlash**	**Ilmiy-tadqiqot salohiyatini oshirish**
Talabalarda zamonaviy texnologiyalarga qiziqish kuchayadi.	Kvant kriptografiya, AL, ma'lumotlar xavfsizligi kabi sohalarda mahalliy mutaxassislar	Kvant algoritmlari, fizikaviy modellashtirish va shifrlash kabi sohalarda ilmiy maqolalar, grantlar va

	yetishmovchiligi mavjud.	startaplar paydo bo‘lishiga zamin yaratiladi.
Informatika va fizika fanlariga amaliy yondashuv paydo bo‘ladi.	Yaxshi tayyorgarlikka ega yoshlar xorijiy dasturlarga osongina moslasha oladi.	
Global IT-kompaniyalar bilan integratsiyalash imkoniyati.		

O‘zbekiston ta’limidagi muammolar

1. Kadrlar yetishmasligi – kvant fizika, kvant hisoblash bo‘yicha yetarli o‘qituvchi yo‘q.

2. Moddiy-texnik baza – laboratoriya, simulyator, virtual muhitlar mavjud emas.

3. Darsliklar va metodika – o‘zbek tilida kvant kompyuterga oid o‘quv materiallar yo‘q.

4. Talabalarning tayyorgarligi – kvant tushunchalar uchun chuqur matematika va fizika asoslari talab qilinadi.

5. Raqamli tengsizlik – tuman va chekka hududlardagi maktablarda internet, kompyuter resurslari cheklangan.

Muammolarga yechim va takliflar:

Ta’lim dasturi: 10–11-sinflarda "Kvant texnologiyalar asoslari" fani kiritilishi. Universitet darajasi: "Kvant kompyuterlar", "Kvant algoritmlari" kabi kurslar yaratilishi. Kadrlar tayyorlash: IBM, Google, MIT, Qiskit orqali onlayn o‘quv kurslaridan o‘qituvchilarni o‘tkazish. Virtual infratuzilma:

IBM Quantum Experience, Qiskit, Microsoft Azure Quantum platformalari orqali laboratoriyalar. Ilmiy loyihalar: Magistr va PhD kabi ilmiy bosqichlarida kvant fizika yoki hisoblash bo'yicha tadqiqotlarni rag'batlantirish. Hamkorlik aloqalari: Germaniya, AQSh, Janubiy Koreya universitetlari bilan qo'shma kurslar, dual diplomlar.

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ZAMONAVIY FIZIKADA KVANT KOMMUNIKATSIYALARI VA KVANT KOMPYUTERLARI: ILMIY NAZARIYA VA AMALIY TADBIQLAR

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Annotatsiya. Kvant mexanikasining zamonaviy amaliy qo'llanmalari – kvant kommunikatsiyasi va kvant kompyuterlari fizikasining nazariy asoslari, matematik modellari va tajriba asosidagi rivoji yoritilgan. Asosan, kubitlar, superpozitsiya, o'zaro chalkashlik (entanglement), kvant teleportatsiyasi va Shor algoritmi kabi fundamental fizik tushunchalar atroflicha tahlil qilinadi. Shuningdek, kvant texnologiyalarining O'zbekistonda ilmiy rivojlanish istiqbollari va fizika ta'limi uchun ahamiyati ko'rsatib beriladi.

Kalit so'zlar. Kubit, superpozitsiya, entanglement, kvant mexanikasi, kvant kriptografiyasi, kvant holatlari, interferensiya, kvant algoritmlari, kvant ustunligi, kvant fizika ta'limi.

Kirish. Kvant fizikasining XX asrda paydo bo'lgan nazariy asoslari hozirgi kunda real texnologik yechimlarga aylanish bosqichida. Kvant mexanikasiga asoslangan qurilmalar – xususan, kvant kompyuterlari va kvant kommunikatsiyalari – fizik olimlar nazariyasi asosida real hayotga kirib kelmoqda. Fizika fanining zamonaviy yo'nalishi sifatida, kvant texnologiyalar nafaqat yangi ilmiy izlanishlar manbai, balki kompyuter texnikasi, tibbiyot, kriptografiya va telekommunikatsiya sohalarining asosiy tayanchi bo'lmoqda [1].

Kvant kommunikatsiyasining fizik asoslari

Kubitlar va kvant holatlari: Kvant axborotning asosiy birligi – bu kubit (quantum bit) bo'lib, klassik bitdan farqli o'laroq, kubit **superpozitsiya holatida** mavjud bo'ladi:

$$|\psi\rangle = \alpha\,|0\rangle + \beta|1\rangle, \quad |\alpha|^2 + |\beta|^2 = 1 \tag{1}$$

Bu holat kubitni istalgan kombinatsiyada aniqlash imkonini beradi. Bu interferensiya, superpozitsiya va o'zaro chalkashlik (entanglement) fenomenlari yordamida amalga oshadi.

Kvant o'zaro chalkashlik (Entanglement)

Entanglement: Bu ikkita kubit bir-biridan masofada joylashgan bo'lsa ham, o'zaro bog'langan holatda bo'lishi bo'lib, ulardan birini o'lchash ikkinchisining holatini ham aniqlaydi:

$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle) \tag{2}$$

Bu hodisa **EPR paradoksi** va **Bell tengsizliklari** orqali nazariy jihatdan isbotlangan bo'lsada, hozirda u tajriba asosida (Aspect, 1982; Yin, 2017 larda) ham tasdiqlangan [3].

Kvant kalit taqsimoti: Kvant kriptografiya fizik qonunlarga tayanadi: o'lchash kvant holatni o'zgartiradi. Shuning uchun kvant kalit taqsimoti (BB84 protokoli) orqali yuborilgan fotonlar kalit sifatida uzatilganda, agar ularni uchinchi shaxs o'qishga urinib ko'rsa, kvant holat buziladi va bu aniqlanadi [2].

BB84 protokolida Ali va Vali tasodifiy polarizatsiyalangan fotonlar orqali kalit hosil qiladi. Agar uchinchi ismli shaxs (josus) signalga aralashsa, **xatolik darajasi oshadi** va kalit rad etiladi.

Kvant kompyuterlari fizikasi:

1. Kvant darvozalari kvant kompyuterda klassik mantiqiy darvozalar o'rniga **kvant darvozalari** (Hadamard, CNOT, Pauli-X, Y, Z) ishlatiladi. Masalan: **Hadamard darvozasi** superpozitsiya hosil qiladi:

$$H|0\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) \tag{2}$$

2. Shor algoritmi va fizik tahdid Shor algoritmi 1994-yilda kvant algoritm sifatida taqdim etilgan bo'lib, sonlarni faktorizatsiya qilishni

eksponensial tezlikda bajaradi. Bu algoritmning kuchsizlanishiga olib keladi [5].

3. Kvant ustunligi jihatidan 2019-yilda Google kompaniyasi 53 kubitli Sycamore protsessori yordamida klassik superkompyuter 10 ming yilda bajaradigan vazifani 3daqiqa 20 soniyada bajardi [1].

Bu kvant ustunlik holati – fizik eksperiment asosida tasdiqlangan kvant kuchi sifatida tarixga kirdi.

Kvant texnologiyalarining fizik ta’limda o‘rni:

O‘zbekiston uchun kvant texnologiyalarining fizik jihatdan o‘rganilishi muhim ahamiyatga ega. Bu bo‘yicha quyidagi yo‘nalishlar tavsiya etiladi: Fizika ta’lim yo‘nalishlari bo‘yicha bakalavr va magistrlik dasturlariga **kvant informatika** kurslarini joriy etish

Oliy ta’lim muassasalarida fotonika, kvant optikasi kabi laboratoriyalar yaratish. Yurtimizda ilmiy-eksperimental markazlar tashkil etish orqali yosh fiziklar salohiyatini oshirish. Kvant kommunikatsiyalari va kvant kompyuterlari – bu zamonaviy fizikada nazariya va amaliyot qovushgan muhim yo‘nalishdir. Bu texnologiyalar kvant mexanikasining fundamental qonunlari – superpozitsiya, entanglement, o‘lchashning buzilishi – kabi tushunchalarga tayanadi. O‘zbekiston fizika sohasi uchun bu texnologiyalarni chuqur o‘rganish – xalqaro ilmiy maydonda raqobatbardosh bo‘lish uchun muhim qadam bo‘ladi. Bu borada ta’lim, fan va texnologik infratuzilmani rivojlantirish – bugungi kunning dolzarb vazifasidir.

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KVANT MEXANIKASI HAQIDA TUSHUNCHA

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Ma'lumki, klassik mexanikaga asosan har bir zarra aniq trayek- toriya bo'yicha harakatlanadi va zarralar oqimida hech qanday to'lqin jarayon ro'y bermaydi. Ammo tajribalar zarralarning to'lqin xususiyatlari mavjudligini ko'rsatadi. Shuning uchun ularning tabiatini klassik mexanika to'g'ri tavsiflay olmaydi. Zarralarning hamma xususiyatlarini aks ettiradigan nazariya ularning to'lqin xususiyatlarini ham hisobga olishi kerak. Bunday nazariya E. Shredinger, V. Geyzenberg, P. Dirak va boshqa olimlar tomonidan 1926- yilda **yaratilgan kvant mexanika** (uni **to'lqin mexanika** deb ham yuritiladi) hisoblanadi.

Kvant mexanikada atomlar, molekulalar va ularning kollektivi, xususan, kristallar, shuningdek, atom yadrolari va elementar zarralar fizikasi o'rganiladi. Bunda o'rganiladigan mikrodunyo obyektlarining o'lchami $10^{-8} \div 10^{-15}$ m tartibida. Agar zarralar $\vartheta \ll c$ tezlik bilan harakatlanayotgan bo'lsa, bunda c-yorug'likning vakuumdagi tezligi, u holda ***norelativistik kvant mexanika*** qo'llaniladi: agar bo'lsa, u holda ***relyativistik kvant mexanika*** qo'llaniladi.

Kvant mexanika asosida atomlar energiyasi o'zgarishining diskret xarakteri haqidagi Plank, fotonlar haqidagi Eynshteyn tasavvurlari, ma'lum sharoitlarda mikrodunyo zarralarining holatini xarakterlovchi ba'zi fizik kattaliklar (masalan, impuls va energiya)ning kvantlanganligi haqidagi ma'lumotlar yotadi.

Kvant mexanikada eng muhim g'oya shundan iboratki, yorug'lik uchun o'rnatilgan xossalarning korpuskulyar-to'lqin ikkilanmaligi universal xarakterga ega ekanligidir. Bu ikkilanmalik impulsga ega istalgan zarralarda namoyon bo‘ladi, ularning harakati qandaydir to'lqin jarayon bilan birga sodir bo‘ladi.

Kvant mexanikada fazoda vaqtning berilgan momentida zarraning holati **to'lqin funksiya** yoki **psi-funksiya** deb ataluvchi va y harfi bilan belgilanuvchi funksiya orqali tavsiflanadi. Bu funksiya koordinatalar va vaqtning funksiyasi hisoblanib, 1926- yilda Shredinger taklif etgan va uning nomi bilan ***Shredinger tenglamasi*** deb ataladigan tenglamaning yechimidan iboratdir.

Klassik mexanika asosida yotuvchi Nyuton harakat tenglamalari keltirib chiqarilmagani kabi, Shredinger tenglamasi ham keltirib chiqarilmaydi va postulat sifatida qabul qilinadi. Shredinger tenglamasining to'g'riligi atom va yadro fizikasida bu tenglama yordamida olingan kvant mexanika xulosalarining tajriba natijalariga yaxshi mos kelishi bilan isbotlanadi.

To'lqin funksiya va bu funksiya bilan tavsiflanadigan zarra orasidagi munosabat yorug'lik to'lqini bilan foton orasidagi munosabatga o'xshaydi. To'lqin tasavvurga asosan, biror sirtning yoritilganligi yorug'lik to'lqini amplitudasining kvadratiga proporsionaldir. Korpuskulyar nuqtayi nazardan yoritilganlik fotonlar oqimining zichligiga proporsionaldir. Demak, yorug'lik to'lqini amplitudasining kvadrati bilan fotonlar oqimining zichligi orasida to'g'ri proporsionallik mavjud: ***to'lqin amplitudasining kvadrati sirtning berilgan nuqtasiga fotonning kelib tushish ehtimolini aniqlaydi.***

Elementar zarralar uchun ham xudda shunday mulohaza yuritish mumkin: ***fazoning biror nuqtasi uchun to‘lqin funksiya modulining kvadrati fazoning shu nuqtasida zarraning bo‘lish ehtimolligini aniqlaydi.***

To'lqin funksiya mikroobyektlar holatining asosiy xarakteristikasi hisoblanadi. Bu funksiya vositasida shu funksiya tavsiflaydigan holatda turuvchi mikroobyektni xarakterlovchi fizik kattaliklarning o'rtacha qiymatlari hisoblab topiladi.

Shunday qilib, kvant mexanika statistik xarakterga ega bo'lib, u zarralarning haqiqiy tabiatini ochib beradi. Kvant mexanika bo'yicha zarraning fazodagi o'rnini yoki zarraning harakat trayektoriyasini aniqlash mumkin emas, chunki aniq trayektoriya bo'yicha bo'lgan harakat bilan to'lqin xususiyatlarini hech qachon birgalikda qarab bo'lmaydi. Kvant mexanikaga ko'ra faqat zarraning fazoning turli nuqtalarida qanday ehtimollikda bo'lishini to'lqin funksiya yordamida oldindan aytib berish mumkin.

Shunday ekan, bu holda elektronning ma'lum tezlik bilan ha- rakat qiladigan orbitasi to'g'risidagi tasavvur o'rinli bo'lmaydi, binobarin, atomda elektronni ma'lum trayektoriya bo'yicha harakatlanuvchi zarra deb tasavvur qilish qat'iy emas. Lekin shunga qaramay, elektronlarning atomda ma'lum orbitalar bo'yicha harakatlanishi haqidagi faraziyadan ma'lum darajada foydalanish mumkin. Ko'p hollarda bu faraziya taxminan to'g'ri natijalarga olib keladi.

Kvant fizikasi ko'plab texnologik yutuqlarga olib keldi va boshqa ta'lim sohalariga, jumladan kimyo, biologiya va materialshunoslikka ta'sir ko'rsatdi. Kvant fizikasining amaliy qo'llanilishiga bir nechta misollar: Lazerlar: Lazerlar - bu stimulyatsiya qilingan emissiya deb ataladigan jarayon orqali yorug'lik chiqaradigan qurilmalar. Lazerlarning rivojlanishi kvant mexanikasi tamoyillari tufayli mumkin bo'ldi.

Tranzistorlar: Tranzistorlar - bu kalit yoki kuchaytirgich sifatida ishlatilishi mumkin bo'lgan elektron qurilmalar. Tranzistorlarning rivojlanishi kvant mexanikasi tamoyillari tufayli mumkin bo'ldi.

Xulosa shunday, kvant mexanikada atomdagi elektron orbitasi deganda, elektronlarning eng katta ehtimollik bilan bo'lishi mumkin bo'lgan nuqtalarning geometrik o'rni tushuniladi. Xususan, normal holatdagi vodorod atomi uchun radiusi

$$r_n = n^2 \frac{\varepsilon_0 h^2}{\pi m_0 e^2}$$

formula bilan aniqlanadigan birinchi doiraviy Bor orbitasi shunday orbitadan iboratdir.

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KO'P O'TISHLI QUYOSH ELEMENTLARIDA QO'LLASH UCHUN KREMNIY TUNNEL O'TISHINI MODELLASHTIRISH

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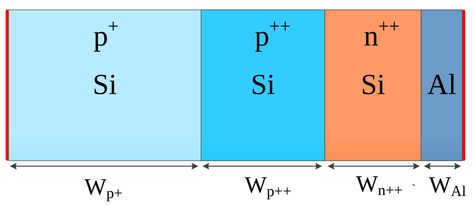
Quyoshning yorug'lik energiyasini elektr energiyasiga to'g'ridan-to'g'ri aylantirib beruvchi quyosh elementlarida asosiy muammo samaradorlikni oshirish va ishlab chiqarish xarajatlarini kamaytirishdir. Yangi materiallardan foydalanish [1] yoki optimal tuzilma yaratish orqali bu maqsadlarga erishish mumkin. Biroq, ko'plab yangi materiallar barqaror emas [2], qimmat [3] yoki xavfli [4]. Shu sababli kremniy materiali hozirgi kunda quyosh elementlari uchun eng ko'p qo'llaniladigan materiallardan biri bo'lib qolmoqda.

Tarkibida bir nechta p-n o'tishlardan iborat bo'lgan, ko'p o'tishli quyosh elementlari hozirgi kunda yuqori foydali ish koeffitsientiga ega bo'lgan quyosh elementlari sifatida qaralmoqda [5]. Ko'p o'tishli quyosh elementlari samarali ishlashi uchun p-n o'tishlarni o'zaro bog'laydigan kichik ketma-ket qarshilikli va yorug'lik nurlarini yaxshi o'tkazadigan kontaktlar zarur. Bu turdagi kontaktlar vazifasini dastlab metal kontaktlar bajargan bo'lsa, hozirgi kunda tunnel o'tishlar yordamida amalga oshirilmoqda. Masalan, davriy sistemadagi III-V guruh elementlari asosida tayyorlangan ko'p o'tishli quyosh elementlari ichidagi p-n o'tishlarni o'zaro bog'lash uchun tunnel o'tishlar qo'llanilgan [12]. Ammo ko'p o'tishli quyosh elementlarini III-V guruh elementlari asosida ishlab chiqarish kremniy materiali asosida ishlab chiqarishga qaraganda ancha qimmatga tushadi [13].

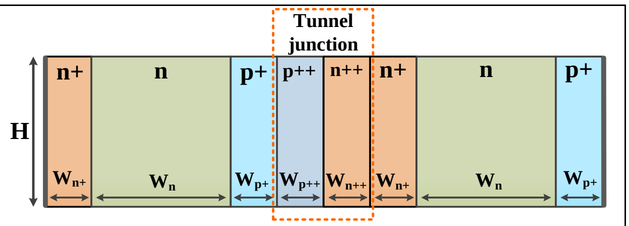
Kremniy tunnel o'tishlari izlanuvchilar tomonidan SOD (Spin-on dopant), RTA (Rapid thermal annealing), RTD (Rapid thermal diffusion) kabi bir nechta texnologiyalar yordamida ishlab chiqilgan [7] va ular hozirda ko‘plab tadqiqotlarda qo‘llanilmoqda [8]. Ammo modellashtirish orqali tunnel o‘tish xarakteristikalari kamroq o‘rganilgan. Shu sababli ushbu ishda biz Sentaurus TCAD dasturi yordamida turli tunnellanish modellarini tahlil qilib, ularning Si tunnel diodlari xususiyatlarini adekvat akslantirishini o‘rgandik [9].

Ushbu ishda kremniy asosidagi tunnel diod (TD) va tunnel o‘tish orqali bog‘langan vertikal ikki o‘tishli quyosh elementi Sentaurus TCAD platformasida modellashtirildi [10]. Ularning tuzilmalari 1- va 2-rasmlarda, asosiy parametrlar esa 1- va 2-jadvalda keltirilgan. TD parametrlari eksperimental namunaga mos ravishda tanlandi.

Modelni kalibrlash uchun avval izolyatsiyalangan p^{++}/n^{++} Si tunnel diod simulyatsiya qilindi va uning tok – kuchlanish xarakteristikasi [11] da berilgan tajriba ma’lumotlari bilan solishtirildi. Bu yondashuv simulyatsiya modelining aniqligini baholash imkonini berdi.



Rasm.1. Modellashtirilgan tunnel o‘tish strukturasi.



Rasm.2. Tunnel o‘tishli vertikal ikki qatlamli quyosh elementining tuzilishi.

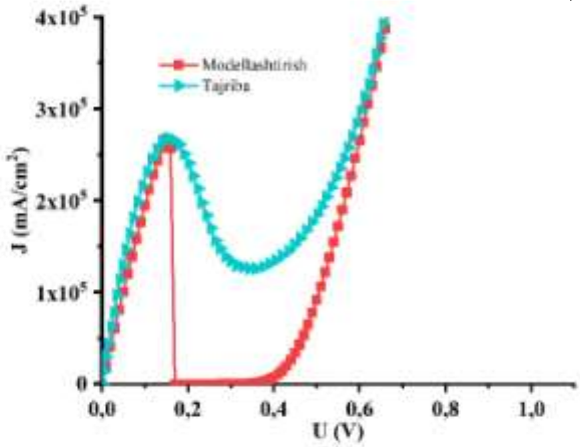
Tablitsa.1. Tunnel o‘tishni modellashtirishda qo‘llanilgan parametrlar

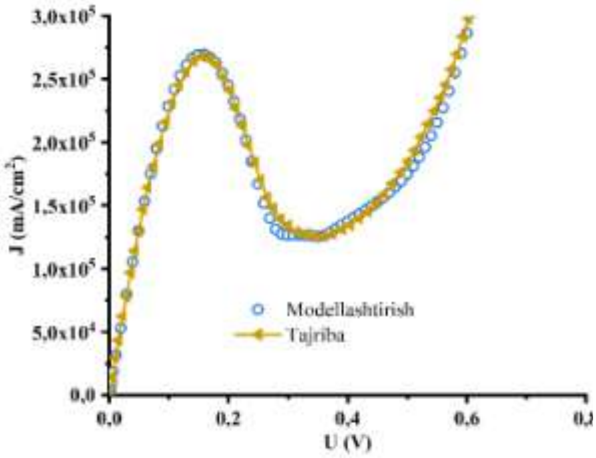
H (µm)	W_{p+} (µm)	W_{p++} (µm)	W_{n++} (µm)	W_{Al} (µm)	p^{+} (cm^{-3})	p^{++} (cm^{-3})	n^{++} (cm^{-3})
64	0.05	0.02	0.014	0.01	10^{18}	$3.6\cdot10^{20}$	$8\cdot10^{20}$

Tablitsa. 2. Tunnel o‘tishli vertikal ikki qatlamli quyosh elementining modellashtirish parametrlari

H (µm)	W_{n+} (µm)	W_n (µm)	W_{p+} (µm)	W_{p++} (µm)	W_{n++} (µm)	n^+ (cm^{-3})	n (cm^{-3})	p^+ (cm^{-3})	p^{++} (cm^{-3})	n^{++} (cm^{-3})
64	5	185	5	0.02	0.014	10^{19}	10^{14}	$5\cdot10^{18}$	$3.6\cdot10^{20}$	$8\cdot10^{20}$

Si materiali asosidagi tunnel o'tish Sentaurus TCAD da "*Nonlocal Tunneling*" va "*Dynamic Nonlocal Path Band-to-Band Recombination*" modellari asosida modellashtirildi. Modellashtirish jarayonida bu ikkala model aloxida aloxida o'rganilib, Si tunnel o'tishning tajribaviy J-V egri chizig'iga eng mos kelgan modellar va ularga mos parametrlar tanlab olindi (Rasm.1,2). Rasm.3,4 lardan ko'rinib turibdiki "*Dynamic Nonlocal Path Band-to-Band Recombination*" modeli va nuqsonlar konsentratsiyasini xisobga oladigan modellar birgalikda kombinatsiya qilinib qo'llanilsa Si tunnel o'tish tajribaga yetarlicha mos kelishi mumkinligini o'rganildi. Olingan eng mos modellar va ularga mos parametrlar vertikal ikki p-n o'tishli konsentratorli quyosh elementi uchun p-n o'tishlarni bog'lovchi tunnel o'tishni xosil qilishda foydalanildi va J-V egri chiziqlar olindi [Rasm.5].

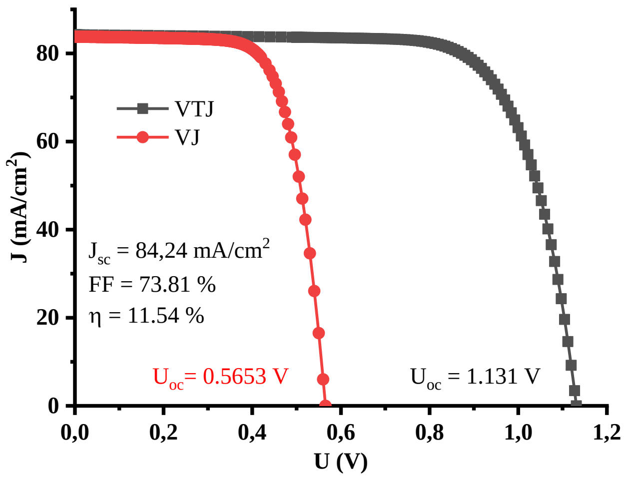




Rasm.3. Tajriba namunasi J–V xarakteristikasi va nolocal tunnellanish modeli (e/h BarrierTunneling "NLM" (Band2Band = UpsideDown)) asosida

Rasm.4. "*Dynamic Nonlocal Path Band-to-Band Recombination*" modeli va SRH modeli (Hurkx hamda kirishmaga bog'liq modellarni o'z ichiga olgan) kombinatsiyasi

olingan simulyatsiya natijalari, hamda Schenk tunnellanish modeli orqali Shockley–Read–Hall rekombinatsiyasi (Recombination (SRH (Tunneling))).	nuqson yordamidagi rekombinatsiya bilan tajriba J–V xarakteristikalari.



Rasm.5. Bitta o'tishli va ikki o'tishli quyosh elementlarining J–V egri chiziqlari.

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FOTON SANOVCHI DETEKTORLAR BILAN JIHOZLANGAN KOMPYUTER RENTGEN TOMOGRAFIYASI YORDAMIDA MATERIALLARNI KLASSIFIKATSIYA USULI

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Ikki energiyali KT ushbu sohada yangi izlanishlar amalga oshirish va bir qator cheklovlarni oldini olishga imkon yaratdi. Ba'zi materiallar, masalan, o'simta va tolali to'qimalar [1], yumshoq to'qimalar [2-4], suyuq moddalar va portlovchi moddalar [5] bir-biriga mos keladigan o'rtacha ChSKlarga ega bo'lishi mumkin, bu esa past kontrastli ma'lumotga olib keladi va yagona energiya KTning tasniflash samaradorligini sezilarli darajada cheklaydi. KT bu cheklovlarni minimallashtirishning eng yaxshi usuli sifatida paydo bo'ldi, bu past va yuqori energiya spektrlarida materiallarning ChSKni tekshirish va ularni elektron zichligi ρ_e va samarali atom raqami Z_{eff} ning energiyaga bog'liq bo'lmagan jismoniy parametrlariga aylantirish orqali paydo bo'ldi. Biz ushbu maqolada materiallarning samarali atom raqami Z_{eff} ni aniqlaymiz. Har xil elementlardan tashkil topgan i har biri bir necha atomga ega bo'lgan α_i birikma uchun o'rtacha atom raqamini hisoblash mumkin va samarali atom raqami, Z_{eff} deb ataladi, bu birikma va elementlarning atom raqamlariga bog'liq. Ularning tegishli miqdorlari bo'yicha Mayneord (1937) va Spiers (1946) sifatida belgilangan Z_{eff} ning klassik parametrlashini taklif qildi.

$$\boldsymbol{Z_{eff}} = \sqrt[1]{\sum_{i=1}^{N} r_i Z_i^l}, \qquad \textbf{(1)}$$

bu yerda r_i har bir elementning nisbiy elektron ulushi:

$$r_i = \frac{a_i Z_i}{\sum_{j=1}^{N} a_i Z_i},$$

bu yerda α_i - bir xil atom raqamiga ega bo'lgan atomlar soni Z_i, bu α_j va Z uchun ham amal qiladi.

Asosiy materiallarga misol sifatida ular polietilen (PE) va polivinilxlorid (PVX) dan foydalanganlar. Maksimal ehtimollik funksiyasi ishlab chiqaradigan ikkita asosiy materialning superpozitsiyasini topish uchun ishlatiladi.

Rentgen KT da materiallar ChSK μ tufayli farqlanadi. Har qanday skanerlangan materialning CHKK mos keladigan kattalikka ega bo'lgan bir nechta asosli materiallarning CHKK larning chiziqli birikmasiga ajralishi mumkin va bu asosiy material dekompozitsiyasi (BMD) modeli deb ataladi

$$\mu(E_k) = a_1\mu_1(E_k) + a_2\mu_2(E_k) + \cdots + a_N\mu_N(E_k), \qquad (2)$$

bu yerda $\mu i(Ek)$ (i = 1, 2, … , N; k = 1, 2, … , K) energiya qutisi Ek uchun asosiy materialning LAC ni i ni bildiradi, K larning umumiy soni bilan va energiya qutilari, mos ravishda. a_i asosiy material uchun fizik birliksiz o'lchamli kattalikni ifodalaydi

Biz tenglamani qayta shakllantiramiz. (2) asosiy materiallar uchun a_i kattaliklarni hisoblash uchun chiziqli tenglamalar tizimi sifatida:

$$(\overrightarrow{\mu_1} \ldots \overrightarrow{\mu_N}) \begin{pmatrix} a_1 \\ \vdots \\ a_N \end{pmatrix} = \begin{pmatrix} \mu(E_1) \\ \vdots \\ \mu(E_k) \end{pmatrix}, \qquad (3)$$

Moddiy xususiyatni kalibrlash va hisoblash

ChSKni ajratib olish va LACning asosiy materialini parchalashdan keyingi quvur liniyasidagi navbatdagi qadam kalibrlash bosqichi bo‘lib, unda mos yozuvlar to‘plami o‘lchanadi va nihoyat materialning Z_{eff}ini hisoblaydi. Baholash uchun polinom egri chizig‘ini o'rnatish texnikasidan foydalanish mumkin

Z_{eff} rentgen-spektrli KTni olishga asoslangan. f_{N} bilan belgilangan parchalanishdagi asosiy materiallar orasida eng yuqori Z_{eff} qiymatiga ega bo‘lgan asosiy material uchun hajm ulushi deb ataladigan narsa materiallarning Z_{eff} qiymatining monoton ravishda ortib borayotgan funktsiyasidir.

$$Z_{\mathrm{eff}} = c_0 + c_1 \cdot f_n + c_2 \cdot f_n^2 + c_3 \cdot f_n^3, (4)$$

Bu erda c - asosiy materiallar va parchalanishdagi energiya qutilari soniga va eksperimental o‘rnatish parametrlariga bog‘liq bo‘lgan polinom regressiya koeffitsientlari to‘plami, tenglamadan ko‘rinib turibdi.(3) Tajribalar Daniyadagi Daniya Texnika Universitetida joylashgan 3D tasvirlash markazida o‘tkazilgan. Tajriba parameterlari to‘g‘risidagi batafsil ma’lumotlarni [1,2] maqolalardan olishingiz mumkin.

Xulosa.

Biz ushbu maqolada yangilik sifatida tasniflash samaradorligini prognozlar soni, energiya kanallari soni va LAC parchalanishidagi asosiy materiallar sonining funktsiyasi sifatida o‘rganib chiqdik. Biz ikkita asosiy materialdan va bo‘shliqlarsiz 6 ta energiya kanalidan foydalangan holda usulni eng aniq deb topdik. Qayta qurish uchun proektsiyalar soni sezilarli darajada kamayishi mumkin, shu bilan birga LAClarni ajratib olish va shu bilan istalgan tasniflash aniqligini saqlab qolish uchun tasvir segmentatsiyasiga erishish mumkin. BMD usuli Z_{eff} ni baholash nuqtai nazaridan SIMCAD usuliga qaraganda plastik materiallarga nisbatan yaxshiroq mustahkamlikni ko'rsatishi aniqladik.

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CdTe(001)<110> SIRTIDA ION–ATOM TO‘QNASHUV MEXANIZMLARINI KOMPYUTER MODELLASHTIRISH ORQALI TAHLIL QILISH

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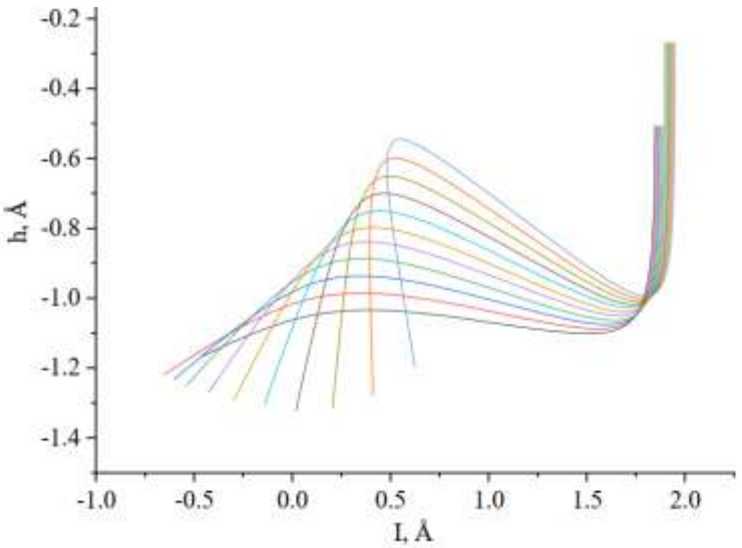
So‘nggi yillarda yuqori aniqlikdagi materialshunoslik va sirt fizikasi sohalarida ion sochilishi spektroskopiyasi (Ion Scattering Spectroscopy – ISS) keng qo‘llanilmoqda. Ushbu metod materiallarning sirt tuzilishini atomar darajada tahlil qilish imkonini beradi va ayniqsa yarimo‘tkazgich texnologiyalarida muhim ahamiyat kasb etadi [1–3]. Ion sochilishi jarayonida turli energiyaga ega zaryadlangan zarrachalar sirtga yuboriladi va ularning sochilgan traektoriyalari, energiya yo‘qotishlari va burchaklari o‘lchanadi. Ushbu ma’lumotlar yordamida materialning sirt qatlami, atomlarning joylashuvi va struktura xususiyatlari haqida muhim ilmiy xulosalar chiqarish mumkin[4-5].

Ionlarning sirt bilan o‘zaro ta’sirini modellashtirishda turli nazariy yondashuvlar ishlab chiqilgan. Klassik juft-to‘qnashuv modeli (pair collision model) ion–atom o‘zaro ta’sirini ikki zarracha orasidagi lokal to‘qnashuv sifatida ko‘rib chiqadi. Bu yondashuv ionlarning trayektoriyalarini, energiya taqsimotini va noelastik energiya yo‘qotishlarini hisoblashda samarali usul sifatida keng qo‘llanadi [6–7]. Shu bilan birga, ionlarning elastik o‘zaro ta’siri Ziegler–Biersack–Littmark (ZBL) potentsiali orqali, noelastik energiya yo‘qotishlari esa Firsov–Kishinevskiy modeli yordamida hisoblab chiqilishi mumkin [8–9].

Mazkur tadqiqotning dolzarbligi shundaki, CdTe(001)<110> kristall sirtida past energiyali Ar^+ ionlarining kichik sirpanma burchaklarda ($\psi = 3°$

va 7°) sochilishini kompyuter modellashtirish orqali tahlil qilish orqali sirt atomlarining joylashuvi va ionlarning implantatsiya xususiyatlarini aniqlash imkoniyati mavjud. Bu esa CdTe asosida yaratiladigan fotoelektrik va optoelektron qurilmalar samaradorligini oshirish uchun muhim nazariy asos bo‘lib xizmat qiladi.



1-rasm. Sochilgan ionlarning CdTe(001)<110> sirtining ψ=3° va E_0 = 1 keV sharoitidagi trayektoriyasi

Ionlarning qattiq jism sirti bilan o‘zaro ta’sirini tushuntirishda turli nazariy modellardan foydalaniladi. Ulardan eng ko‘p qo‘llaniladigani klassik juft-to‘qnashuv modeli (pair collision model) hisoblanadi. Ushbu yondashuvga ko‘ra, ion va sirt atomlari o‘rtasidagi o‘zaro ta’sir ikkita zarrachaning lokal to‘qnashuvi sifatida qaraladi. Agar ionning boshlang‘ich massasi M_1, atomning massasi M_2, ionning tezligi v_0 va boshlang‘ich energiyasi E_0 bo‘lsa, unda energiya va impulsni saqlanish qonunlari asosida ionning sochilish energiyasi E_1 va burchagi aniqlanadi [1]. Bu yondashuv kichik energiyali ionlar uchun ham, o‘rta energiya diapazonida ham samarali hisoblanadi.

Ionlarning elastik o‘zaro ta’siri Ziegler–Biersack–Littmark (ZBL) potentsiali orqali tavsiflanadi [2]. Ushbu potentsial atom yadrolari va elektron bulutlari o'rtasidagi Coulomb kuchini ekranga olish (screening) jarayonini hisobga oladi. ZBL potentsiali quyidagicha yoziladi:

$$U_r = \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0 r}\Phi\left(\frac{r}{a}\right)$$

bu yerda Z_1,Z_2 – ion va nishon atomining atom raqamlari, r – zarrachalar orasidagi masofa, Φ(r/a) – universal ekranga olish funksiyasi, a – Thomas–Fermi uzunligi. Ushbu model ionlarning sirt atomlari bilan to'qnashuvini turli burchaklarda va masofalarda aniq tasvirlash imkonini beradi.

Ionlarning noelastik energiya yo'qotishlari esa Firsov–Kishinevskiy modeli asosida hisoblandi [3]. Bu yondashuv ionlarning elektron bulut bilan o'zaro ta'siridan kelib chiqadigan energiya yo'qotishlarni baholash imkonini beradi. Noelastik yo'qotish kattaligi ionning tezligiga, atom raqamiga hamda to'qnashuv masofasiga bog'liq bo'lib, CdTe kabi yarimo'tkazgichlarda sezilarli darajada bo'ladi.

Mazkur tadqiqotda Cd va Te atomlaridan tashkil topgan CdTe(001)<110> sirtining ikki qatlamli yarimkanal (semichannel) tuzilmasi ko'rib chiqildi. Yarimkanalning kengligi va chuqurligi mos ravishda 4.64 Å va 2.28 Å ga teng bo'lib, bu tuzilma ionlarning sirt bo'ylab harakatini tahlil qilishda asosiy geometriya sifatida qabul qilindi. Ionlarning boshlang'ich energiyasi 1 keV bo'lib, burchak qiymatlari ψ = 3° va ψ = 7° da modellashtirildi.

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Kvant texnologiyalaridan biri bo'lgan optikaning signallarini kodlash va dekodlash jarayonlarini algoritmik modellar orqali ifodalash

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Kvant texnologiyalarining rivojlanishi bilan axborotni uzatish, saqlash va qayta ishlashda yuqori darajadagi xavfsizlik va samaradorlikka erishish mumkin bo'lmoqda. Ularning asosiy yo'nalishlaridan biri bu – kvant optikasi bo'lib, u yorug'likning kvantik xossalaridan (masalan, fotonlar holatlari) foydalanadi. Optik signallarni kodlash va dekodlash kvant axborot uzatish tizimlarida muhim o'rin tutadi. Bu jarayonlarni algoritmik modellar orqali ifodalash esa tizimlarning matematik asosda loyihalanishiga va amaliyotda qo'llashiga imkon yaratadi.

Kvant optik signal tushunchasi:

Optik kvant signallar – bu fotonlar orqali uzatiladigan axborot bo'lib, ularning holati (qutblanishi, fazasi, amplitudasi) orqali ma'lumot kodlanadi.

Fotonlar kvant bitlar (qubit) sifatida qaraladi.

Kvant superpozitsiya va intrikatsiya holatlari kodlashni murakkablashtiradi, lekin xavfsizlikni oshiradi.

2. Kodlash algoritmlari:

Kvant optik kodlash algoritmlari ma'lumotni foton holatlariga o'zgartiradi.

BB84 protokoli – kvant kriptografiyada eng mashhur algoritmlardan biri. Kodlashda to'rtta qutblanish holati ishlatiladi (0°, 90°, 45°, 135°).

Algoritmik model:

- Kirish: klassik bitlar ketma-ketligi (0 va 1).

- Chiqish: fotonlarning kodlangan holatlari (masalan, |0⟩, |1⟩, |+⟩, |−⟩).
- Algoritm:
  1. Har bir bit uchun tasodifiy baza tanlanadi (rectilinear yoki diagonal).
  2. Mos ravishda foton holati belgilanadi.
  3. Fotonlar kvant kanal orqali yuboriladi.

3. Dekodlash algoritmlari:

Qabul qiluvchi (masalan, Bob) har bir fotonni qabul qilganda, uni o'zi tanlagan bazaga nisbatan o'lchaydi.

To'g'ri baza tanlangan bo'lsa – to'g'ri bit olinadi, noto'g'ri baza holatida – natija tasodifiy.

Keyinchalik Alice va Bob baza tanlovlarini solishtirib, umumiy kalitni shakllantiradi.

Matematik model va ehtimollar tahlili

Har bir bitning noto'g'ri aniqlanish ehtimoli (error rate) modelini tuzish.

Kanal shovqini va xatolik modelini qo'shish: depolarizatsiya, g'orning dispersiyasi va foton yo'qolishi.

Entropiya, mutual information, Shannon informatsiya nazariyasi va kvant informatsiya nazariyasi elementlari.

Qabul qiluvchi va uzatuvchi o'rtasidagi xavfsizlik darajasini quyidagicha ifodalash:

$$I(A,B) > I(E,B)$$

Algoritmik model asosida ifodalanishi:

```
Algorithm KvantKodlash(bitlar):
   Baza = tasodifiy_baza(bitlar.uzunligi)
   Fotonlar = []
   for i in 0 to bitlar.uzunligi-1:
```

```
        if Baza[i] == "rectilinear":
            if bitlar[i] == 0: Fotonlar[i] = |0⟩
            else: Fotonlar[i] = |1⟩
        else:
            if bitlar[i] == 0: Fotonlar[i] = |+⟩
            else: Fotonlar[i] = |−⟩
    return Fotonlar, Baza
Algorithm KvantDekodlash(Fotonlar, QabulBaza):
    Bitlar = []
    for i in 0 to Fotonlar.uzunligi-1:
        Bitlar[i] = o'lchash(Fotonlar[i], QabulBaza[i])
    return Bitlar
```

Optik kvant signallarni kodlash va dekodlash jarayonlarini algoritmik modellar orqali ifodalash ularni simulyatsiya qilish, tahlil etish va amaliy tizimlarga joriy qilish imkonini beradi.

BB84 kabi algoritmlar xavfsiz aloqa kanallarini yaratishda asosiy vosita bo'lib xizmat qiladi.

Algoritmik modellashtirish yordamida kodlash va dekodlashdagi ehtimolliklar, xatoliklar va xavfsizlik darajasi baholanishi mumkin.

Bu sohada ishlash uchun kvant mexanikasi, ehtimollar nazariyasi va algoritmlarni chuqur o'rganish zarur.

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CdTe(001)<110> KRISTALL SIRTIDAGI YARIMKANALDA PAST ENERGIYALI AR$^+$ IONLARINING SOCHILISH TRAYEKTORIYALARINI KOMPYUTER MODELLASHTIRISH ASOSIDA O'RGANISH

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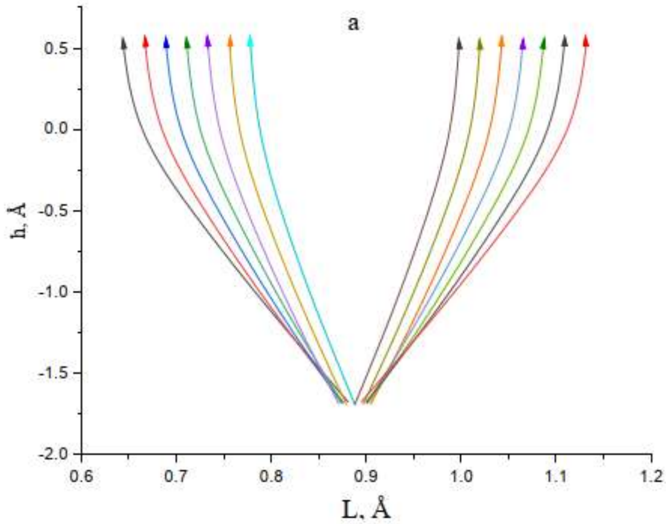
Ionlarning kristall sirtida sochilish jarayonlari hozirgi zamon materialshunoslik va nanoelektronika sohasida eng dolzarb masalalardan biri hisoblanadi. Chunki ionlarning kristall panjarasi bilan o'zaro ta'siri nafaqat nazariy fizika uchun muhim, balki amaliy jihatdan ham keng qo'llaniladi. Xususan, ion implantatsiyasi, sputtering, sirt modifikatsiyasi va nuqsonlar hosil bo'lish jarayonlarining samaradorligi va mexanizmini tushunishda ionlarning sirt bo'ylab harakati va ularning sochilish xususiyatlarini bilish muhim o'rin tutadi [1–3]. Shu bois ushbu yo'nalishda olib boriladigan tadqiqotlar yarim o'tkazgich texnologiyalari, ionli plazma asosidagi qurilmalar va optoelektronika elementlarini ishlab chiqishda katta ahamiyatga ega.

Mazkur ishda tadqiqot obyekti sifatida CdTe(001)<ī10> kristalli tanlandi. CdTe (kadmiy tellurid) yarim o'tkazgich material sifatida keng o'rganilgan bo'lib, u yuqori samarali quyosh batareyalari, optik datchiklar va ionlashtiruvchi nurlanish detektorlarida qo'llaniladi [4,5]. Ushbu materialning (001) yuza tuzilishi va <ī10> kristallografik yo'nalishida hosil bo'ladigan yarimkanallar ionlarning harakati va sochilishini o'rganishda qulay model hisoblanadi. Chunki bunday sirt strukturalari ionlarning kanallar bo'ylab yo'naltirilgan harakatini, ularning bloklanishini yoki fokuslanishini yaqqol namoyon etadi.

Tadqiqotda kompyuter modellashtirish usulidan foydalanildi. Hisoblash ishlari ionlarning kristall panjarasi bilan oʻzaro taʼsirini ifodalashda keng qoʻllaniladigan ikkilik toʻqnashuv approksimatsiyasi (Binary Collision Approximation, BCA) asosida olib borildi [6]. Ushbu metodning mohiyati ionlarning trayektoriyasini ularning kristall atomlari bilan ketma-ket amalga oshadigan juft toʻqnashuvlar sifatida koʻrib chiqishda yotadi. Hisob-kitoblarda ion–atom oʻzaro taʼsir kuchlarini tavsiflash uchun eng ishonchli modellardan biri boʻlgan Ziegler–Biersack–Litmark (ZBL) potensiali qoʻllanildi [7]. Bu yondashuv ionlarning energiya yoʻqotishi, burilish burchagi va kristall ichiga kirish chuqurligini aniq baholash imkonini beradi.



1-rasm. CdTe(001)<ī10> kristall yuzasida hosil boʻlgan yarimkanal tubidan sochilgan Ar^+ ionlarining xarakterli trayektoriyalari: ion tushish burchagi ψ=70° (a) va ψ=130° (b) boʻlganda, boshlangʻich energiya E_0=5 keV.

Natijalar shuni koʻrsatdiki, past energiyalarda (1 keV) ionlar yarimkanal tubidan sirt atomlari tomon qaytarilib, ularning energiya taqsimotida alohida choʻqqi (pik) kuzatilmaydi. Bunday ionlarning energiyasi asosiy pik qiymatlariga yaqin boʻlgani uchun ular umumiy taqsimotga qoʻshilib ketadi. Oraliq energiyalarda (3 keV) esa ionlarning trayektoriyalarida koʻplab past intensivlikdagi qoʻshimcha piksimon taqsimotlar hosil bo‘ldi. Bu esa ionlarning bir qismi sirt orqali qaytishini, boshqa bir qismi esa qisman implantatsiyalanishini ko‘rsatadi. Yuqori energiyalarda (5 keV) ionlarning sochilish xususiyati yanada murakkablashadi. Ular yarimkanal devorlari ta’sirida tubga yo‘naltirilib, qayta sochiladi va energiya taqsimotida past energiyali alohida qism paydo bo‘ladi.

Umuman olganda, tadqiqot shuni tasdiqlaydiki, ionlarning boshlang‘ich energiyasi va sirtga tushish burchagi ularning sochilish mexanizmini belgilovchi asosiy parametrlar hisoblanadi. Past energiyalarda ionlarning alohida piki kuzatilmasa-da, energiya ortishi bilan qo‘shimcha past intensivlikdagi cho‘qqilar hosil bo‘ladi. Ushbu natijalar ion fokuslanishi va bloklanishi mexanizmlarini chuqurroq tushunishga yordam beradi hamda ion implantatsiyasi va sirt modifikatsiyasi texnologiyalarini takomillashtirishda amaliy ahamiyat kasb etadi.

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FIZIKA VA INGLIZ TILI DARSLARIDA INTEGRATSIYALASHGAN TA'LIM IMKONIYATLARI

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Annotatsiya. Ushbu maqolada fizika fanini ingliz tili bilan integratsiya qilish imkoniyatlari yoritilgan. Dars jarayonida interfaol metodlar va axborot texnologiyalaridan foydalanish o'quvchilarning bilim olish jarayonini samarali qiladi. Fizika terminlarini ingliz tili bilan birgalikda o'rganish o'quvchilarning xorijiy tilga bo'lgan qiziqishini oshiradi va ilmiy manbalarni o'zlashtirish imkonini kengaytiradi.

Kalit so'zlar:fizika, ingliz tili, integratsiya, interfaol metod, axborot texnologiyalari, terminologiya, ta'lim samaradorligi.

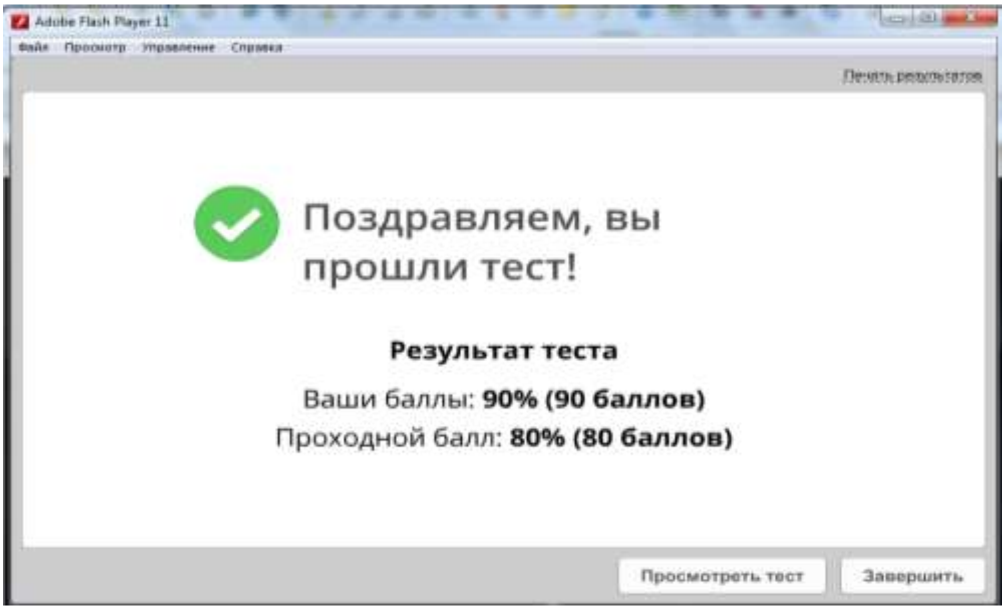
Dars jarayonida axborot texnologiyasi va interfaol metodlardan foydalanish hozirgi kunda dolzarb masalalardan biri bo'lib qolmoqda. Interfaol usulning mohiyati shundaki barcha o'quvchilar bilim olish jarayoniga jalb qilinadi, ular mavzuni o'z tafakkuri, o'z bilimlarini ishga solgan holda tushunish va anglash imkoniyatiga ega bo'ladilar. Shu bilan bir qatorda fizika fanida tushintiriladigan termin va parametrlarni ingliz tili fani bilan birga o'rganish o'quvchining dunyoqarashini oshirib, xorijiy tillarga bo'lgan qiziqishini rivojlantiradi.

Fizika darslarida mavzuga kerakli yoki, o'tilgan mavzularda tushuntirilgan terminlarni ingliz tilidagi tarjimalari bilan birga aytib borilishi o'quvchilarning ingliz tiliga bo'lgan dunyoqarashini oshiribgina qolmay, texnika taraqqiyotidagi eng sara ingliz tilidagi adabiyotlarni varaqlashga undaydi.

Fizika fanini ingliz tili bilan birlashtirib hamkorlikda darslarni tashkil qilish maqsadida iSpring Suite 8 dasturi asosida o'zbek tilidagi terminlarning ingliz tilidagi tarjimalarini mos holatda joylashtirib chiqish uchun quyidagi test tizimidan foydalanishimiz:

1-rasm. iSpring Suite 8 dasturida test ishlash

O'quvchi berilgan vaqt davomida ajratilgan terminlarni mos holda joylashtirgandan so'ng uning ingliz tili savodxonligini shu vaqtning o'zida bilib olish mumkin:



2-rasm. iSpring Suite 8 dasturida natijani chiqarish

iSpring Suite 8 dasturda berilgan so'zlarning qaysi birida xatolikka yo'l qo'yganini tekshirish uchun bajarib chiqqan savollarni qayta ko'rib chiqishi mumkin:

3-rasm. iSpring Suite 8 dasturida xatolarni qayta ko'rib chiqish

Fan texnika taraqqiyoti rivojlangan bu davrda dars davomida o'tkaziladigan test va savol javoblar orqali o'quvchilarimiz faqatgina o'zbek va rus tillari bilan chegaralanib qolmasdan xorijiy tillarni ham yaxshi o'zlashtira olishlariga ko'maklashgan bo'lar edik.

Maqolada fizika va ingliz tili fanlarini integratsiyalash orqali ta'lim samaradorligini oshirish masalalari yoritildi. Interfaol metodlar va axborot texnologiyalaridan foydalanish o'quvchilarni dars jarayoniga faol jalb etib, ularning mustaqil fikrlash va ilmiy terminologiyani o'zlashtirish ko'nikmalarini rivojlantiradi. Fizika terminlarini ingliz tilida o'rganish esa o'quvchilarda xorijiy tillarga bo'lgan qiziqishni kuchaytiradi va ularni ilmiy-texnik adabiyotlardan samarali foydalanishga yo'naltiradi. Shu bois fizika va ingliz tili fanlarini uyg'unlashtirish zamonaviy ta'limning dolzarb yo'nalishlaridan biri hisoblanadi.

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KVANT TEXNOLOGIYALARINING KOSMIK TADQIQOTLARDA QO'LLANISHI

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Annotatsiya: So'nggi yillarda kvant texnologiyalari fan va texnikaning eng ilg'or yo'nalishlaridan biri sifatida rivojlanmoqda. Ularning kosmik tadqiqotlarda qo'llanilishi alohida ahamiyat kasb etadi. Xususan, kvant kommunikatsiyalari yordamida fazoviy apparatlar va Yer stansiyalari o'rtasida xavfsiz axborot almashinuvi ta'minlanadi. Kvant sezgichlari va kvant radar tizimlari esa koinotdagi nozik o'zgarishlarni aniqlash imkonini beradi. Shuningdek, kvant kompyuterlari orbitadagi katta hajmdagi ma'lumotlarni tezkor qayta ishlashda samaradorlikni oshiradi. Ushbu tadqiqotda kvant texnologiyalarining kosmik izlanishlarga kiritayotgan yangiliklari va istiqbollari ilmiy jihatdan tahlil qilinadi.

Kalit so'zlar: kvant texnologiyalari, kosmik tadqiqotlar, kvant kommunikatsiyasi, kvant kompyuteri, kvant sezgichlari, kosmik xavfsizlik, ilmiy izlanishlar.

Abstract: In recent years, quantum technologies have been developing as one of the most advanced fields in science and technology. Their application in space research is of particular significance. Specifically, quantum communications enable secure information exchange between spacecraft and Earth stations. Quantum sensors and quantum radar systems allow for the detection of subtle changes in the cosmos. Additionally, quantum computers enhance efficiency in rapidly processing large volumes of data in orbit. This study scientifically analyzes the innovations and prospects that quantum technologies are introducing to space exploration.

Keywords: quantum technologies, space research, quantum communications, quantum computer, quantum sensors, space security,

scientific research.

Аннотация: В последние годы квантовые технологии развиваются как одно из самых передовых направлений науки и техники. Их применение в космических исследованиях имеет особое значение. В частности, с помощью квантовых коммуникаций обеспечивается безопасный обмен информацией между космическими аппаратами и наземными станциями. Квантовые датчики и квантовые радиолокационные системы позволяют обнаруживать тонкие изменения во Вселенной. Кроме того, квантовые компьютеры повышают эффективность быстрой обработки больших объемов данных на орбите. В данном исследовании научно анализируются инновации и перспективы, вносимые квантовыми технологиями в космические исследования.

Ключевые слова: квантовые технологии, космические исследования, квантовая коммуникация, квантовый компьютер, квантовые датчики, космическая безопасность, научные исследования.

Kirish. XXI asr ilm-fan taraqqiyotining muhim yo'nalishlaridan biri – bu kvant texnologiyalaridir. Mazkur texnologiyalar hozirgi kunda nafaqat axborot xavfsizligi, balki kosmik izlanishlar, astronomiya va astrofizika sohalarida ham katta imkoniyatlarni ochib bermoqda. Kosmosni o'rganish jarayonida mavjud an'anaviy usullar ma'lum chegaralarga ega bo'lib, ulardan foydalanishda yuqori aniqlik, tezkorlik va ishonchlilik yetarli darajada ta'minlanmaydi. Shu sababli kvant kommunikatsiyasi, kvant sezgichlari va kvant hisoblash texnologiyalarini joriy etish zamonaviy kosmik tadqiqotlarda muhim ahamiyat kasb etmoqda. Bu esa kosmik apparatlar o'rtasida mutlaq xavfsiz ma'lumot almashish, koinotdagi nozik fizik jarayonlarni aniqlash va katta hajmdagi ma'lumotlarni qayta ishlash imkoniyatini beradi. Shu tariqa, kvant texnologiyalarining kosmik tadqiqotlarga integratsiyasi kelajak ilmiy izlanishlari va kosmik xavfsizlikning yangi bosqichini belgilab bermoqda.

Asosiy qism. Bugungi globallashuv va texnologiyalar asrida kosmik tadqiqotlar insoniyat taraqqiyotining strategik yo‘nalishlaridan biri sifatida e’tirof etilmoqda. An’anaviy texnologiyalar asosida olib borilayotgan kosmik izlanishlar yuqori aniqlik va xavfsizlik talablariga doimo javob bera olmaydi. Shu nuqtai nazardan, kvant texnologiyalarining qo‘llanishi alohida dolzarblik kasb etmoqda. Kvant kommunikatsiyalari yordamida orbitadagi sun’iy yo‘ldoshlar bilan Yer stansiyalari o‘rtasida mutlaq xavfsiz axborot almashinuvi ta’minlanadi. Kvant sezgichlari esa koinotdagi gravitatsion to‘lqinlar, magnit maydonlar va boshqa fizik hodisalarni aniqlashda yangi imkoniyatlar ochadi. Shuningdek, kvant kompyuterlari yordamida katta hajmdagi kosmik ma’lumotlarni tezkor qayta ishlash va tahlil qilish imkoniyati mavjud. Bu esa insoniyatning kelajakda Mars va boshqa sayyoralarga uchish, koinot resurslaridan foydalanish hamda kosmik xavfsizlikni ta’minlash borasidagi sa’y-harakatlarini samarali amalga oshirishga zamin yaratadi. Shu bois mazkur mavzuning ilmiy va amaliy ahamiyati beqiyosdir.

Kvant kommunikatsiyalarining kosmik tadqiqotlarda qo‘llanilishi.

- sun’iy yo‘ldoshlar va Yer stansiyalari o‘rtasida mutlaq xavfsiz axborot almashinuvi imkonini beradi;
- kvant kriptografiyasi yordamida uchinchi tomon aralashuvi va axborot o‘g‘irlanishi ehtimoli yo‘q qilinadi;
- Xitoy, AQSH va Yevropa mamlakatlari kvant kommunikatsiya yo‘ldoshlari loyihalarini amalga oshirishmoqda (masalan, “Micius” yo‘ldoshi);

Kvant sezgichlari va ularning kosmosdagi ahamiyati.

- gravitatsion to‘lqinlarni aniqlashda yuqori aniqlikka erishish;
- kosmik kemalar navigatsiyasini mustaqil ravishda amalga oshirish;

- magnit maydon va vaqtning nozik o'zgarishlarini qayd etish orqali kosmik izlanishlarni chuqurlashtirish;

Kvant kompyuterlari va kosmik ma'lumotlarni qayta ishlash.

- orbitadan yig'iladigan katta hajmdagi ma'lumotlarni real vaqt rejimida tahlil qilish;
- astronomik kuzatuvlarda aniqlik va tezkorlikni oshirish;
- murakkab modellashtirish va prognozlash jarayonlarida samaradorlikni ta'minlash;

Kosmik xavfsizlik va kvant texnologiyalarining roli.

- fazoviy apparatlar harakatini kuzatishda xavfsizlikni mustahkamlash;
- kiberxavfsizlikni ta'minlashda yangi imkoniyatlar yaratish;
- harbiy va strategik kosmik faoliyatda kvant texnologiyalarining alohida ahamiyat kasb etishi;

Kvant texnologiyalarining istiqbollari.

- kelajakda Mars va boshqa sayyoralarga parvozlarda ishonchli aloqa tizimini yaratish;
- koinot resurslarini samarali o'zlashtirishda yuqori aniqlikdagi hisob-kitoblarni ta'minlash;
- yangi ilmiy kashfiyotlarga zamin yaratish va astrofizik tadqiqotlarda yangi bosqichni boshlab berish;

Kvant texnologiyalarining kosmik tadqiqotlarda qo'llanish yo'nalishlari

1-jadval:

Yo'nalish	Qo'llanish sohasi	Afzalligi
Kvant kommunikatsiyasi	Sun'iy yo'ldosh–Yer stansiyasi aloqa tizimlari	Mutlaq xavfsizlik, tezkorlik
Kvant sezgichlari	Gravitatsion to'lqin, magnit maydon aniqlash	Yuqori aniqlik va sezgirlik

Kvant kompyuterlari	Kosmik ma’lumotlarni qayta ishlash	Katta hajmli ma’lumotlarni tez tahlil
Kvant radar texnologiyalari	Fazoviy obyektlarni aniqlash	Past signalni ham qayd etish
Kvant metrologiyasi	Vaqt va masofa o‘lchovlari	Ultra-aniq o‘lchash imkoniyati

Kvant kriptografiyasi asosiy tenglamasi.

Kvant kalitlarni taqsimlashda **Shannon entropiyasi** tushunchasi ishlatiladi:

$$H(X) = -\sum_{i=1}^{n} p_i \log_2 p_i$$

Bu yerda:

$H(X)$ – ma’lumotning entropiyasi,

p_i – ehtimollik,

n – kvant tizimining mumkin bo‘lgan holatlari soni.

Muhokama: Kvant texnologiyalarining kosmik tadqiqotlarda qo‘llanishi bo‘yicha olib borilgan tahlillar shuni ko‘rsatadiki, mazkur yo‘nalish ilm-fan va texnika taraqqiyotining eng dolzarb sohalaridan biridir. Hozirgi kunda Xitoy, AQSH va Yevropa mamlakatlari kosmosda kvant kommunikatsiyalarini sinovdan o‘tkazib, amaliy natijalarga erishmoqda. Masalan, Xitoyning “Micius” kvant yo‘ldoshi yordamida Yerning ikki nuqtasi o‘rtasida mutlaq xavfsiz aloqa o‘rnatilgan. Bu esa xalqaro miqyosda kvant texnologiyalarining amaliy samaradorligini isbotlab berdi.

Shuningdek, kvant sezgichlari koinotdagi murakkab jarayonlarni, jumladan, gravitatsion to‘lqinlar va magnit maydonlarning nozik o‘zgarishlarini qayd etishda ulkan imkoniyatlar yaratmoqda. Bu esa kelgusida yangi astronomik kashfiyotlarga asos bo‘lishi mumkin. Kvant kompyuterlari esa kosmik kuzatuvlardan keladigan ulkan hajmdagi ma’lumotlarni real vaqt rejimida qayta ishlash imkonini beradi, natijada ilmiy izlanishlarning samaradorligi keskin ortadi.

Biroq mazkur texnologiyalarni keng joriy etishda qator muammolar ham mavjud. Jumladan, kvant tizimlarining yuqori sezgirligi sababli tashqi ta’sirlarga bardoshliligi past bo‘lishi, qurilmalarning murakkabligi va yuqori xarajatlarni talab qilishi asosiy to‘siqlardan biridir. Shu bilan birga, xalqaro hamkorlikning yetarli darajada rivojlanmaganligi ham kosmik izlanishlarda kvant texnologiyalaridan keng foydalanishga to‘sqinlik qilmoqda.

Demak, kvant texnologiyalarining kosmik tadqiqotlarda qo‘llanilishi katta istiqbolga ega bo‘lib, bu borada xalqaro hamkorlikni kengaytirish, ilmiy izlanishlarni chuqurlashtirish va texnologik muammolarni hal qilish zarur.

Xulosa va takliflar: Yuqoridagi tahlillardan kelib chiqib aytish mumkinki, kvant texnologiyalarining kosmik tadqiqotlarda qo‘llanilishi zamonaviy ilm-fan va texnikaning strategik ustuvor yo‘nalishlaridan biridir. Kvant kommunikatsiyalari kosmik apparatlar va Yer stansiyalari o‘rtasida mutlaq xavfsiz aloqa tizimini ta’minlasa, kvant sezgichlari koinotdagi eng nozik fizik jarayonlarni aniqlash imkonini beradi. Kvant kompyuterlari esa kosmik kuzatuvlardan keladigan ulkan hajmdagi ma’lumotlarni tezkor va samarali qayta ishlashga xizmat qiladi.

Shuningdek, mazkur texnologiyalar kosmik xavfsizlikni mustahkamlash, xalqaro kosmik hamkorlikni kengaytirish va kelajakdagi sayyoralararo parvozlarni amalga oshirishda hal qiluvchi ahamiyat kasb etadi. Shu bois kvant texnologiyalarining ilmiy asoslarini chuqur o‘rganish, amaliyotga tatbiq etish va bu yo‘nalishda xalqaro hamkorlikni kuchaytirish zarurdir. Umuman olganda, kvant texnologiyalarini kosmik tadqiqotlarga keng joriy etish insoniyatning koinotni chuqurroq o‘rganishi va kelajak avlodlar uchun yangi kashfiyotlarga yo‘l ochishi shubhasizdir.

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KVANT NUQTA VA ULARNING NOCHIZIQLI OPTIK XUSUSIYATLARI

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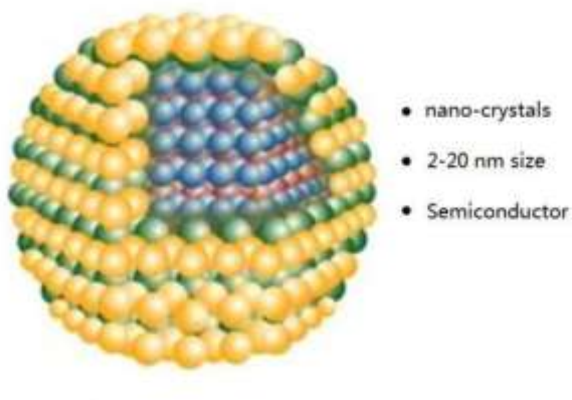
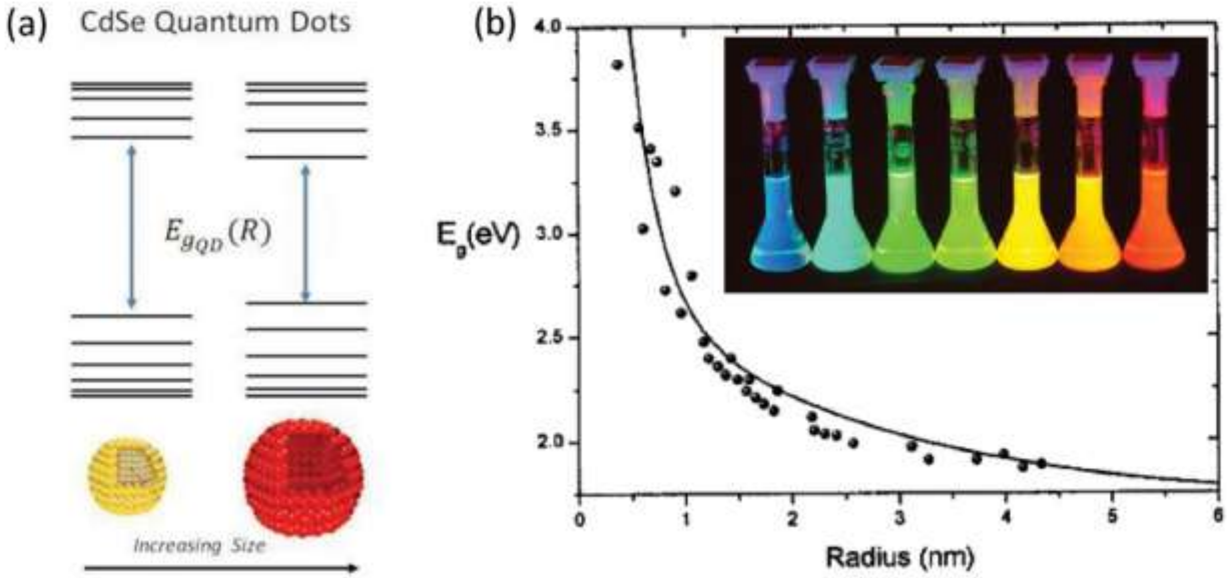
Bugungu kunda, yangi nanostrukturali, kompozit optik materiallar asosida lazer nurlanishi modifikatsiyasiga ega yuqori effektivlikdagi lazer sistemalarini ishlab chiqish va yasashning yangi imkoniyatlarini o’rganishga e’tibor kuchaymoqda, shuningdek turli energiya turlarini lazer nurlanishi energiyasiga almashtirishning samaradorligini oshirishga qaratilgan lazer fizikasining dolzarb masalalari bo’yicha ilmiy tadqiqot va innovatsion ishlar olib borilmoqda jumladan nanoo’lchamli strukturalar-kvant nuqtalari (1-rasm) va ularning bo’yoqlar bilan birikmalarining kvant o’lchamli effektlar sababli yuzaga keladigan, shuningdek komponentlarning kimyoviy tarkibini o’zgartirish orqali emas, balki sistemani tashkil etuvchi zarrachalarning o’lchami va shaklini tartibga solish orqali yangi materiallarni yaratish uchun keng imkoniyatlarning paydo bo’lishi ularning noyob elektron strukturalari va xossalari ularni sintez qilish va optik va nochiziqli optik xususiyatlarini tadqiq qilishga bo’lgan qiziqish ortib bormoqda (2-rasm).



Bu kabi yangi materiallarni turli xil masalalarda qo’llash, jumladan lazer fizikasi va nochiziqli optika sohasida ularning optik va nochiziqli optik xarakteristikalarini va turli spektral va vaqt diapazonlarida ularning optik javobini shakllanishini aniqlovchi mexanizmlarini o'rganishni talab qiladi. Shu nuqtai nazardan, kvant nuqtalari va ularning bo'yoqlar bilan birikmalarini o'z ichiga olgan eritmalarda ultraqisqa lazer impulslarining tarqalish jarayonida sodir bo'ladigan nochiziqli jarayonlar yuqori bo'lgan shunday aralashmalardagi optik cheklash jarayonini tadqiq qilish, ularning nochiziqli optik parametrlarini aniqlash muhim ahamiyatni kasb etadi [1].

1-rasm kvant nuqtalar (KN) yarimo'tkazgichli nanozarrachalar bo'lib, ular hajmi(o'lchami) va tarkibiga bog'liq ravishda o'ziga xos optik va elektronik (optoelektronik) xususiyatlarni namoyish etadi. KNlar juda kichik bo'lib, odatda 2 nm dan 10 nm gacha bo'lgan o'lchamlarga to'g'ri keladi, hamda bir necha yuz va minglab atomlardan tashkil topadi. KN fotodetektorlar, displeylar, biosensorlar, bioimijing, kvant kompyuterlar, quyosh panellari va lazer sohalarida keng qo'llaniladi.



2-a rasmda har xil o'lchamli CdSe kvant nuqtalarining zonali strukturasining sxematik tasviri. b) CdSe KN taqiqlangan zona kengiligning radiusiga bog'liqligi tasvirlangan.

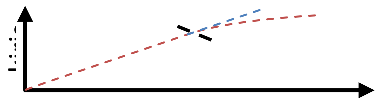
Kvant nuqtalarini yaratishning bir necha yo'li mavjud. Mumkin bo'lgan usullar orasida kolloid sintez, o'z-o'zini yig'ish va elektr to'siqlari mavjud.

(Kolloid - suyuqlikda suzib yurgan juda kichik zarrachalar (nanozarralar) tizimi. Bu zarrachalar suyuqlikda cho‘kmaydi va dispers holatda bo‘ladi). Kolloid kvant nuqta bu o‘lchami nanometr darajasida bo‘lgan yarimo‘tkazgich nanokristallari bo‘lib, ular kolloid shaklda, ya’ni suyuqlik muhitida tayyorlanadi). Ularni "kvant nuqtalar" deb atalishining sababi - o‘zining kvant cheklanish xossalariga ega bo‘lishidir. Ya’ni, o‘lchami juda kichik bo‘lgani sababli, ulardagi elektronlar harakati kvant mexanik qonunlariga bo‘ysunadi.

Kvant nuqtalari va ularning bo’yoqlar bilan birikmalarini o’z ichiga olgan eritmalarda ultraqisqa lazer imulslarining tarqalish jarayonida sodir bo’ladigan nochiziqli jarayonlarni (nochiziqli yutilish va nochiziqli sinish) koeffitsientlari yuqori bo’lgan shunday aralashmalardagi optik cheklash jarayonini tadqiq qilish, ularning nochiziqli optik parametrlarini aniqlash muhim ahamiyatni kasb etadi.

Nochiziqli optikaning paydo bo‘lishi XX asrning 60-yillarida quvvatli lazerlarning kashf etilishi bilan bog‘liq. Chunki o‘sha paytgacha ma’lum bo‘lgan yorug‘likning to‘g‘ri chiziq bo‘yicha tarqalishi, turli muhitlar chegarasida sinish va qaytish, muhitda tarqalayotgan yorug‘lik nurlarining mustaqillik qonuni kabi geometrik optikaning qonunlari juda kichik intensivlikli nurlanish uchun o‘rinli ekanligi ko‘rindi. Katta intensivlikli nurlanishlar diapazonida bu qonunlar bajarilmaydi. Odatiy simob lampasining intensivligi $I = 10^4 Vt/m^2$ ga teng bo‘lsa, standart impulsli lazerning intensivligi esa $I = 10^{14} Vt/m^2$ va o‘ta quvvatli lazer nurlanishining intensivligi $I = 10^{24} Vt/m^2$ ga teng. Bunday katta intensivlikli nurlanish ta’sirida yangi optik effektlar paydo bo‘ladi. Shunga ko‘ra kichik intensivlikli "chiziqli" o‘zaro ta’sirga qaraganda, katta intensivlikli o‘zaro ta’sir “nochiziqli”lik xarakteriga ega bo‘ladi (3-rasm). Ana shundan chiziqli va nochiziqli optika tushunchalari kelib chiqqan.

Chiziqli optikadan farqli ravishda nochiziqli optikada asosiy vazifani

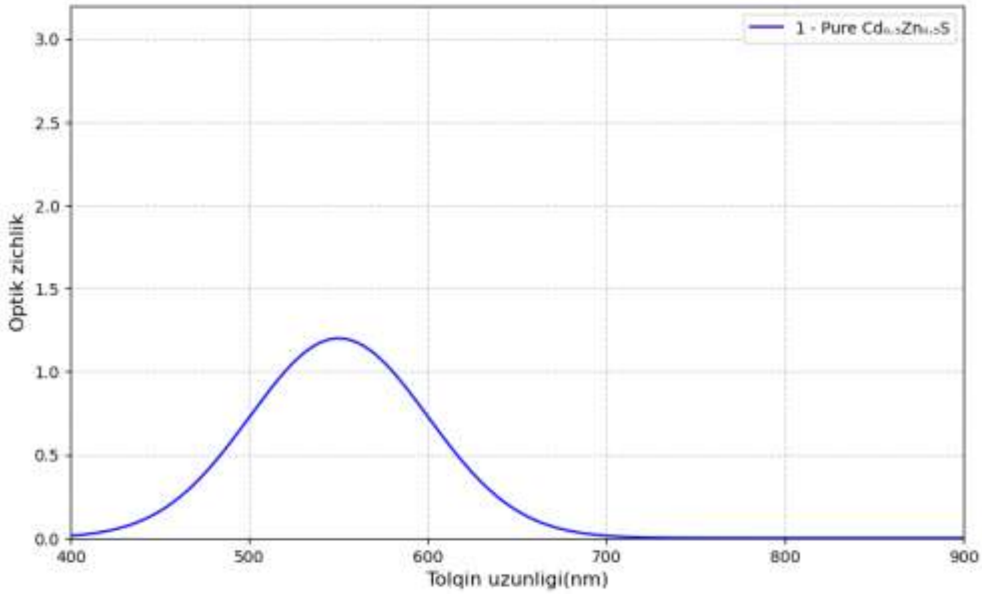


mikroskopik, atom darajasidagi hodisalar belgilaydi va superpozitsiya prinsipi bajarilmaydi. Unga ko‘ra chastotasi, yo‘nalishi, qutblanishi farqlanuvchi turli yorug‘lik to‘lqinlari bir-biridan mustaqil ravishda tarqaladi va muhit bilan o‘zaro ta’sirlashadi. Shunday qilib, nochiziqli optika-quvvatli yorug‘likning muhitda tarqalishi va modda bilan ta’sirlashuvi natijasida paydo bo‘lgan, xarakteri nurlanish intensivligiga bog‘liq bo‘lgan optik hodisalarni o‘rganuvchi fizikaviy optikaning bo‘limi hisoblanadi. Shunday qilib, nochiziqli optikada optik hodisalarning ro‘y berish jarayonini sifat va miqdor jihatidan o‘zgartiruvchi yorug‘likning intensivligining bo‘sag‘aviy qiymati mavjud bo‘ladi (4-rasm) [3].

Nochiziqli optik hodisalarning paydo bo‘lishiga olib keluvchi asosiy fizikaviy sabablar:

- optik jihatdan shaffof muhitdagi nochiziqli refraksiya, ya’ni muhit sindirish ko‘rsatkichining yorug‘lik maydoni amplitudasiga bog‘liq bo‘lishi;
- yorug‘lik maydoni intensivligining katta qiymatlarida yorug‘lik sochilishining nochiziqli xarakteri paydo bo‘lishi;
- kuchli intensivlikli optik nurlanish ta’sirida moddada ko‘p fotonli yutilish;
- yorug‘likni qayta nurlatishda yuqori garmonika generatsiyasi;

Yorug‘likning yutilishi - muhitdan o‘tayotgan yorug‘lik intensivligining muhitdagi zarralar bilan o‘zaro ta’siri natijasida kamayishidir. Bunda, odatda, muhit isishi, ionlanishi yoki atom va molekulalari g‘alayonlanishi mumkin. Yorug‘lik biror moddadan o‘tganda unda yorug‘likning bir qismi yutiladi. Yutilish selektivlik xarakteriga ega, ya’ni turli to‘lqin uzunliklariga tegishli yorug‘lik turlicha yutiladi. Bo‘yalmagan, shaffof jismlarda ko‘zga ko‘rinadigan nurlar intervaliga tegishli yorug‘lik to‘lqinlari juda kam yutiladi. Ko‘pchilik metallarning past bosimli bug‘larining (bunda atomlar oraligi ancha katta bulib, atomlar amalda yakkalangan deb xisoblanishi mumkin) yorug‘lik yutishi juda ajoyibdir Bunday bug‘larning yutish koeffitsienti deyarli xamma joyda juda kichik (nolga yaqin) va fakat juda ensiz (eni angstremning yuzdan bir necha ulushlaricha bo‘lgan) spektral soxalardagina keskin maksimumlarga ega buladi. Masalan kadmiy rux sulfidning ($Cd_{0.5}Zn_{0.5}S$) yutilish spektri [2].



Kadmiy rux sulfiding yutilish spektri ($Cd_{0.5}Zn_{0.5}S$)

Yorug‘lik bir muhitda ikkinchi muhitga o‘tganda yorug‘lik nur sindirish ko‘rsatkichi katta bo‘lgan muhitga og‘adi. Buger o‘z tajribasida nur sindirish ko‘rsatkichi va muhitning sindirish ko‘rsatkichi o‘zgarishini hisobga olmagan. Agar muhitga tushayotgan yorug‘lik nurining intinsivligi vaqt o‘tishi bilan o‘zgarib borsa, muhitning nur sindirish ham ko‘rsatkichi o‘zgaradi. Muhitning o‘z-o‘zini yoritishi (self-focusing) va o‘z-o‘zini qorong‘ulashtirishi (self-defocusing) - bu holatlar muhitning sinish ko‘rsatkichi yorug‘lik intensivligiga bog‘liq bo‘lganida yuzaga keladi. Tushayotgan yorug‘lik kuchining intinsivligi moddani tashkil etgan molekula atomlarining elektronlarini nochiziqli tebratadi, agar yorog‘lk kuchi yetralicha bo‘lmasa elektronlar chiziqli tebranadi va chizikli optik qonunlariga bo‘ysunadi. 6.a rasmda. Agar yorug‘lik intinsivligi yuqori bo‘lsa masalan attosekundli $(10^{-18}s)$ lazer nuri bilan yoritilsa atomlarining elektronlarini ionlanishiga sabab bo‘ladi va ekistremal nochiziqli jarayon kuzatiladi. Moddadan yorug‘lik o‘tayotganda to‘lqinning elektromagnitik maydoni tasirida muhitning elektronlari tebranadi va bu to‘lqin energiyasining bir qismi elektronlarni tebrantirishga sarf bo‘ladi.

Kuchli intensivlik ta’siri natijasida muhitda nochiziqli effektlar paydo bo‘ladi va ularni o‘rganidigan fizikaviy optikaning bo‘limi nochiziqli optika deb ataladi. Nochiziqli optikada, chiziqli optikadan farqli ravishda atom darajasidagi mikroskopik hodisalar alohida ahamiyatga ega bo‘lib, superpozitsiya prinsipi bajarilmaydi va natijada muhitda tarqalayotgan turli chastotali, qutblanishli va yo‘nalishga ega bo‘lgan yorug‘lik to‘lqinlari bir-biridan alohida holda muhit bilan ta’sirlashishi kuzatiladi.

Xulosa qilib aytganda kvant nuqtalar (KN) va ularning nochiziqli optik xususiyatlari batafsil o‘rganildi. KNlar o‘ziga xos elektron va optik xususiyatlarga ega bo‘lgan yarimo‘tkazgichli nanozarrachalar bo‘lib, ularning o‘lchami va shakli asosida yangi materiallar yaratish imkoniyati mavjudligi ta’kidlangan. Ayniqsa, KN va bo‘yoqlar bilan birikmalari asosida tuzilgan sistemalarda yuqori intensivlikdagi lazer impulslar ta’sirida sodir bo‘ladigan nochiziqli optik jarayonlar - nochiziqli yutilish, sinish, o‘z-o‘zini fokuslash kabi hodisalar muhim ahamiyat kasb etadi.

Nochiziqli optika lazer texnologiyalari rivoji natijasida yuzaga kelgan bo‘lib, bu sohada yorug‘likning intensivligi muhit xossalariga kuchli ta’sir ko'rsatadi. Natijada yorug'likning tarqalishi chiziqli qonunlarga bo'ysunmaydi. Shuning uchun kuchli lazer nurlari bilan ishlaydigan zamonaviy optik tizimlarda KNlarning nochiziqli optik ko'rsatkichlarini aniqlash, bu materiallarni samarali qo'llashda muhim hisoblanadi.

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THE INFLUENCE OF ABSORPTION ON THE PARAMETRIC AMPLIFICATION PROCESS OF LASER RADIATION IN MgO:LiTaO$_3$ CRYSTAL

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Abstract

Special attention is given to analyzing the influence of basic factors such as linear absorption and dispersion on the process efficiency. It is found that in the infrared spectral range, linear absorption and dispersion effects significantly affect the signal wave amplification coefficient, determining the energy redistribution dynamics and spectral characteristics of the resulting radiation. The study introduces a novel approach to optimizing domain length relative to coherence length, achieving up to 18% efficiency through precise tuning, which surpasses previously reported results for similar materials.

Key words: parametric amplification, nonlinear crystal MgO:LiTaO$_3$, infrared range, laser technologies, nonlinear optics, quasi-phase matching.

1. Introduction

The concept of parametric amplification, initially introduced through theoretical models in nonlinear optics, was later validated experimentally with the advent of laser technologies capable of producing high-intensity radiation. The primary motivation for investigating this effect was the development of lasers that could trigger pronounced nonlinear interactions within optical media [1-2]. From the first experimental realizations, parametric amplification has advanced considerably—shifting from conventional nonlinear crystals to state-of-the-art nanostructured materials.

Breakthroughs in material science, especially in nonlinear photonic crystal design and nanoscale fabrication techniques, have significantly broadened the scope of this phenomenon, opening new opportunities for light manipulation in optical systems [3].

2. Equations of Parametric Amplification under Nonstationary Conditions

The system of equations describing the evolution of complex amplitudes A_p, A_s, and A_i (for pump, signal, and idler waves, respectively) is [4]:

$$\frac{\partial A_p}{\partial z}+\frac{1}{v_p}\frac{\partial A_p}{\partial t}+\frac{\alpha_p}{2}A_p = -i\frac{\omega_p}{2n_p c}\chi^{(2)}A_s A_i \exp(i\Delta kz),$$
$$\frac{\partial A_s}{\partial z}+\frac{1}{v_s}\frac{\partial A_s}{\partial t}+\frac{\alpha_s}{2}A_s = -i\frac{\omega_s}{2n_s c}\chi^{(2)}A_p A_i^* \exp(-i\Delta kz),$$
$$\frac{\partial A_i}{\partial z}+\frac{1}{v_i}\frac{\partial A_i}{\partial t}+\frac{\alpha_i}{2}A_i = -i\frac{\omega_i}{2n_i c}\chi^{(2)}A_p A_s^* \exp(-i\Delta kz),$$

where:

2. Results and Discussion

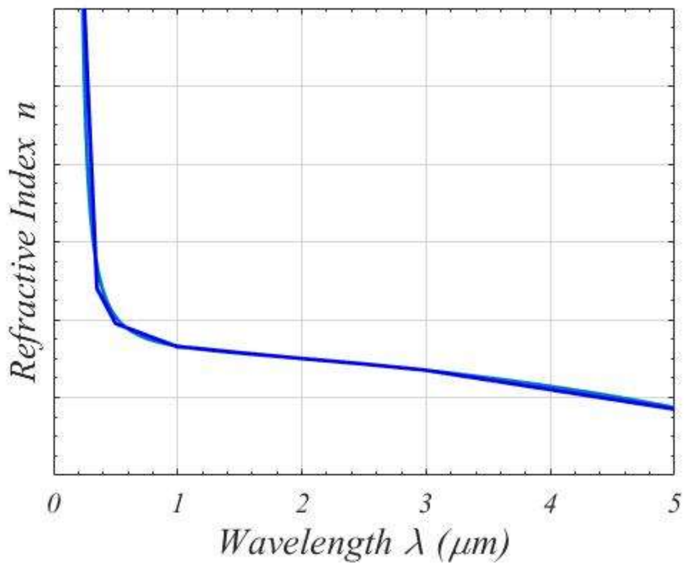

Fig.1. Dependence of refractive index on wavelength.

Figure 1 shows the dependence of the refractive index of this crystal on wavelength. Our calculations, based on the Sellmeier equations for the extraordinary wave (e-e-e interaction) as described in [5], agree with experimental data, confirming the reliability of our model. The refractive index was computed using the formula

Next, we studied the role of pulse duration in signal wave efficiency formation. We examined this at different input pulse durations (100 fs, 50 fs, and 10 fs). The results are shown in Figure 4. Pulse duration influences the interaction time and peak intensity of the waves, with shorter pulses (e.g., 10 fs) enhancing nonlinear effects due to higher intensity ($I \propto E^2/\tau$), but requiring careful domain tuning to mitigate dispersion, as quantified below.

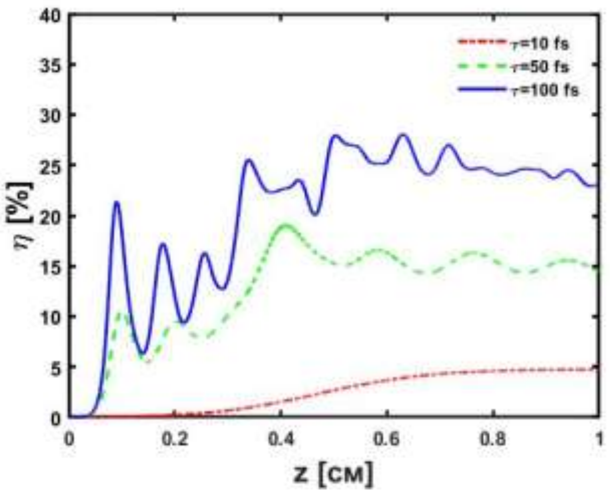

Fig.4. Numerical calculation results of signal wave generation efficiency, considering all limiting factors, at pulse durations of 100 fs, 50 fs, and 10 fs .

Figure 4 quantifies the combined effects of absorption and dispersion on signal wave formation. Here, the dependence of signal wave efficiency on crystal length with a regular domain structure is presented for different input pulse durations, denoted τ. The results indicate that dispersion limits signal wave efficiency only when the main pulse duration is less than 10 fs. Thus, achieving maximum efficiency requires considering dispersion effects and selecting an appropriate pulse duration. For this range, an optimal domain length must be used, as shorter pulses (10 fs) achieve peak efficiency of 15% with $d = 0.9L_c$, while longer pulses (100 fs, 50 fs) stabilize at 8–10% due to reduced dispersion but lower peak intensities.

4. Conclusion

Thus, this work studied the parametric amplification process of femtosecond pulses in MgO:LiTaO_3 crystals with periodic modulation of quadratic nonlinear susceptibility. By optimizing domain length to $0.9d_o$, we achieved a signal wave efficiency of 18%, a significant improvement over the baseline 4.8%, demonstrating the potential of precise domain tuning to mitigate dispersion and absorption effects.

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ASTRONOMIYA FANINING RIVOJLANISHIDA FOTONIKANI RO'LI.

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Annotatsiya: Ushbu maqolada astronomiyada osmon yoritgichlarini yulduz kattaliklarini aniqlashda fotonikani ro'li korsatilgan.

Kalit so'zlar: Fotonika, foton, lazer, astronomiya, optika, kvant, Elektromagnit to'lqinlar shkalasi, yulduz kattalik, FEU-fotoelektron ko'paytirgich.

XX asrning boshlarida yorug'lik elektromagnit to'lqinlarni kvantlar, fotonlardan iborat ekanligiga asos solindi. Optikani tarixiy rivojlanishiga fotonika qo'shilib ketdi. N.Bor postulatlari atomning nurlanishiga, Atomni nurlanishida Plankning elektromagnit to'lqinlarning kvantlanish nazariyasi, fotoeffekt uchun

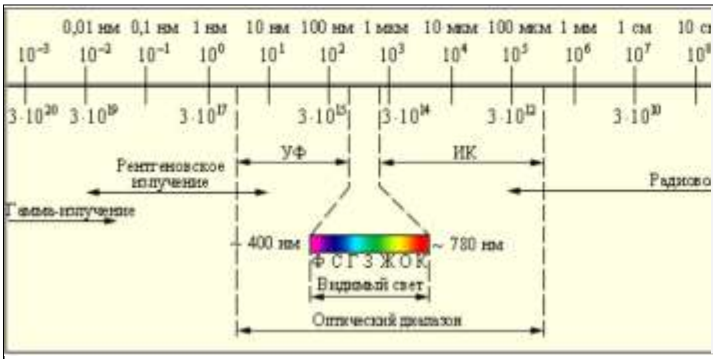
$$h\nu = \frac{m\vartheta^2}{2} + A$$

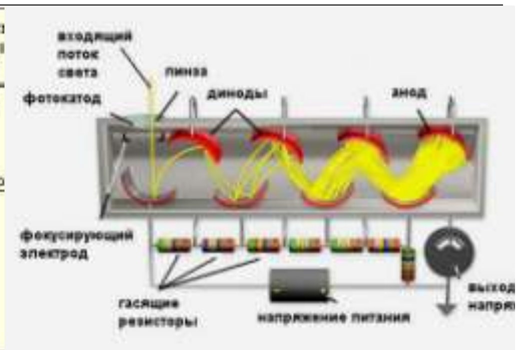
(1)

A.Eynshteyn formulasi, bular yorug'likni foton zarrasini asoslari edi. Ayniqsa 1960-yillar kvant generatorida amerikalik olimlar Ch.Taunis, T.Meyman, rus olimlari N.Basov va A.Proxorovlar tomonidan lazer nurlarini kashf qilinganligi fotonikaning keng rivojlanishiga olib keldi. Fotonika bu yorug'lik haqidagi fandir. Shunday ekan astronomiyada osmon jismlari, koinotni o'rganishda bu fan katta ahamiyatga egadir [1]. Osmon jismlardan bizga faqat yorug'lik kvantlari, fotonlar keladi. Mana shu yorug'lik kvantlari xossalariga qarab yulduzlar klassifikatsiyasi, ularni temperaturalari, ximiyaviy tarkibi, massasi, o‘lchamlari, uzoqligi xaqida ma’lumotlarga ega bo‘lamiz.

1-rasmda Elektromagnit to‘lqinlar shkalasi keltirilgan. Osmondagi obyektlar, yulduzlar, gallaktikalar, tumanliklar, qora o‘ralar, kvazarlarni spektrini o‘rganish, ulardan keladigan nurlanishlarda elektromagnit to‘lqinlar shkalasidagi barcha to‘lqin uzunlikdagi kvantlar mavjud ekanligini ko‘rsatdi.

Yulduzlarni ko‘rinma xolatini ko‘rib chiqaylik. Yulduzlardan kelayotgan yorug‘ligini o‘rganib, ularga ko‘rinma yulduz kattaliklar belgilandi [2]. Yulduzning Yer yuzidagi tekislikda yoritilganligi E har 1^m bir kattalikdagi yoritilganlik intervali 2,512 marta farq qiladi. Ya’ni $\frac{E_1}{E_2} = 2{,}512$ (2) bunda E_1 - biror $\propto_1$ yulduzni Yer sirtida yoritilganligi. $E_2 - \propto_2$ yulduzni yoritilganligi desak,





1-rasm. Elektromagnit to‘lqinlar shkalasi.	**2-rasm.Fotoelektron ko‘paytirgich.(FEU)**

va unii o‘nli logarifmik masshtabda ifodalasak

$$\lg\frac{E_1}{E_2} = \lg 2{,}512 = 0{,}4 \quad (3)$$ ifoda hosil bo‘ladi,

bundan 5^m yulduz kattalikka farq qilgan yulduzlarni yoritilganligi uchun

$$\frac{E_1}{E_5} = 100 \quad (4)$$ ifodani olish mumukin.

Shunday qilib yulduzlarni yoritilganligi yoki ularni charaqlab ko‘rinishiga qarab ko‘rinma yulduz kattaligi quyidagiga nisbiy belgilanadi.

-26^{m}, …-12^{m}, …-4^{m},-3^{m},-2^{m},-1^{m}, 0^{m}, $+1^{m}$,$+2^{m}$,$+3^{m}$,$+4^{m}$,$+5^{m}$…20^{m} [2].

Bunga Quyosh eng yorug', uni Yer sirtini yoritilganligi eng katta, uni yulduz kattaligi -26^{m} –deb qabul qilingan. To'lin Oyniki – 12^{m}, Veneraniki – 4^{m}, Yupiterniki -3^{m}, Marsniki -2^{m} va hakoza -1^{m} ,0^{m}, $+1^{m}$, $+3^{m}$, $+4^{m}$. Bu ketma ketlikdagi -4^{m} kattalikdagi yulduz eng xira, bizni ko'zimizga zo'rg'a ko'rinadi. $+5^{m}$ kattalikdagi va undan katta yulduzlarni biz yaxshi ko'rolmaymiz. (3)- formula umumiy ko'rinishda quyidagicha yoziladi $\lg\frac{E_1}{E_2}=-0{,}4(m_1 - m_2)$ (5) bunga Pagson formulasi deyiladi [2].

Agar $m_1 - m_2 =1$ bo'lsa ya'ni yulduz o'z kattaligi 1^{m} ga farq qilsa, ularni Yer yuzidagi E_1 va E_2 yoritilganligi nisbati o'nli logarifmga 0,4 ga teng va (2) formula kelib chiqadi. Astronomik xisoblashlarda 0^{m} – kattalikdan yulduz Yer yuzida $2{,}78*10^{-8}$ lyuks yoritilganlik beradi. Bu yulduz Yer sirtiga har sm^2 yuzaga 1 sekuntda 10^6 kvant (foton) beradi.[1. 197 bet]. Agar biz yulduz kattaligi $+5^{m}$ yulduzdan bizni ko'zimizga tushayotgan fotonlar sonini xisoblasak ko'zimizni gavhari qorachig'ini 1 cm^2 deb olsak Pagson (4) formulasidan $m_1 - m_2=5$ bundan $\lg\frac{E_0}{E_5}=2$ yoki $\frac{E_0}{E_5} = 100,$ kelib chiqadi. Agar $E_0=\frac{W}{S*t}$, ekanligidan $W=N h\nu$ bunda N-fotonlar soni. $h\nu$ –bitta kvant energiyasi. W-yulduzdan tushayotgan to'la energiya, 0^{m} kattalikdagi yulduzdan kelayotgan energiya $W_0=N_0 h\nu$,desak va $+5^{m}$ kattalikdagi yulduzdan kelayotgan energiya esa $W = Nh\nu$, bularni 4-formulaga qo'ysak Bunda N_0-0^{m} kattalikdagi yuluzdan kelayotgan fotonlar soni. N esa -5^{m} kattalikdagi yulduzdan kelayotgan fotonlar soni desak.

$100 = \frac{E_0}{E_5} = \frac{N_0 h\nu}{N h\nu} = \frac{N_0}{N}$; $\frac{N_0}{N} = 100$ (6) ifoda kelib chiqadi.

Bundan $N=\frac{N_0}{100} = \frac{10^6}{100} = 10^4 = 10000$

Bundan ko'rinadiki, yuqorida aytilgan bizni ko'zimiz eng xira $+5^m$ – kattalikdagi yulduzni ko'ra olmaydi. Demak $+5^m$ kattalikda yulduz ko'zimizni ko'rish chegarasi deb qarasak, shu kattalikdagi yulduzlardan bizni ko'zimizga har sekunda, 10000 ta foton tushar ekan. Xulosa qilsak, agar yulduzdan kelayotgan har sekunda fotonlar soni 10000 dan oshsa biz shu yulduzni ko'ramiz. Agar fotonlar soni 10000 dan kam bo'lsa, biz bu yulduzlarni ko'zimiz bilan vizual kuzata olmaymiz. Endi bizga fotonlarni qayd qiladigan asboblar kerak bo'ladi. Agar bu hisoblashni davom etsak $+10^m$ kattalikdagi yulduzdan bizni ko'zimizga kelayotgan fotonlar soni 10000:100=1000 ga teng bo'lib chiqadi. $+15^m$ kattalikdagi yulduzdan bizni ko'zimizga kelayotgan fotonlar soni 1000:100=10 ga teng bo'lib chiqadi. $+20^m$ kattalikdagi yulduzdan bizni ko'zimizga kelayotgan fotonlar soni 10:100=0,1 ga teng bo'lib chiqadi. Bu esa mavjud bolmaydi chunki foton butun bo'lishi kerak. Bunday kattalikdagi yulduzlarni kuzatish uchun spektral qurilmalardan foydalaniladi. Ularni ekspozitsiya vaqtini uzaytirish kerak boladi. Fotoko'paytirgich yordamida sanoqli fotonlarni ham qayd qilish mumkin (2-rasm).

2-rasmda fotoko'paytirgichni ishlash prinsipi ko'rsatilgan, unga ko'ra agar yoritkichdan sanoqli foton (kvant) unga tushsa ham uni million marta(keraklicha) ko'paytirib keyingi spektral qayd qilgich asboblarga uzatadi.

Xulosa qilib shuni aytish mumkinki, fotonikaning fizik nazariyasi asosida yaratilgan, qonunlari, qurilmalari astronomiya fanini rivojlanishida katta ro'li borligini ko'rish mumkin.

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ELEKTROMAGNETIZM FANIDAN TALABALARINING AMALIY KOMPETENTLIGINI RIVOJLANTIRISH

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Oliy ta'limda Elektromagnetizm fanidan ma'ruza, amaliy va talabaning mustaqil ta'lim mashg'ulotlari mazmunini takomillashtirish asosida oliy ta'lm muassasasida (OTM) tayyorlanayotgan mutaxassislarni elektromagnetizmning asosiy qonuniyatlari hamda nazariy va amaliy masalalarni bajarish uchun zarur bo'lgan fizikaviy bilimlar bilan tanishtirish, nazariy olgan bilimlarini amaliyotda qo'llay olish, talabaning mantiqiy fikrlash qobiliyatini rivojlanishi bilan birga, fanga oid amaliy kompetentligi rivojlanadi.

Masalan, ma'ruza davomida Om va Joul-Lens qonunlarining mazmun-mohiyati va matematik ifodasi yozilgandan so'ng, talaba ushbu mavzularni mukammal o'zlashtirib olishi uchun Om va Joul-Lens qonunlarining differensial ko'rinishini keltirilib chiqarilsa, maqsadga muvofiq bo'ladi, chunki bu qonunlarning differensial ko'rinishi umumiy o'rta ta'lim maktablari va akademik litseylar fizika fani dasturlarida kiritilmagan. Agar ma'ruza davomida bu ish bajarilsa, talabalar uchun ham yangilik, ham fanga qiziqish ortadi, buni quyidagicha amalga oshiramiz:

1. Om qonunining differensial ko'rinishini tok zichligi formulasidan keltirilib chiqariladi: tok zichligi – o'tkazgichning ko'ndalang kesimi yuzasidan oqib o'tgan tokning kuchi bilan ifodalanadi, ya'ni $J = \frac{I}{S}$ (1)

agar zanjir elektr yurituvchi kuchga ega bo'lmagan holda bo'lsa, tok kuchi $I = \frac{U}{R}$ ekanligini inobatga olsak, u holda → $J = \frac{U}{R \cdot S}$ bo'ladi. Shuningdek, o'tkazgich qarshiligi R = $\frac{\rho \cdot l}{S}$ ekanligini nazarda tutsak, shunda → J = $\frac{U \cdot S}{\rho \cdot l \cdot S}$ bo'ladi. Elektr maydon kuchlanganligi va potensial orasidagi bog'lanish uchun E = $\frac{U}{d}$ o'rinli bo'lsa, unda → J = $\frac{E \cdot d \cdot S}{\rho \cdot l \cdot S}$ ko'rinishga ega bo'ladi. Formuladagi o'xshash fizik kattaliklarni qisqartirib olsak, → J = $\frac{E}{\rho}$ matematik ifodaga ega bo'lamiz va solishtirma elektr o'tkazuvchanlik o'tkazgichning solishtirma qarshiligiga teskari proporsional, ya'ni $\sigma = \frac{1}{\rho}$ ekanligini bilgan holda $J = \sigma \cdot E$ (2)

tengligini ko'ramiz va bu Om qonunining differensial ko'rinishini beradi [1,2,3,].

2. Joul-Lens qonunining differensial ko'rinishini o'tkazgichdan elektr toki o'tganda undan ajralib chiqadigan issiqlik miqdori formulasidan keltirilib chiqariladi. Bunda o'tkazgichning birlik hajmidan birlik vaqt ichida ajralib chiqqan issiqlik miqdori hisoblaniladi, ya'ni $\omega = \frac{Q}{V \cdot t}$ (3)

→ agar o'tkazgichdan elektr toki o'tganda undan ajralib chiqqan issiqlik miqdori Q = $I^2 \cdot R \cdot t$ ekanligini e'tiborga olsak, → $\omega = \frac{I^2 \cdot R \cdot t}{V \cdot t}$ bo'ladi. agar zanjir elektr yurituvchi kuchga ega bo'lmagan holda tok kuchining I = $\frac{U}{R}$ ekanligini inobatga olsak va undan R = $\frac{U}{I}$ ga tengligidan → $\omega = \frac{I^2 \cdot U \cdot t}{V \cdot t \cdot I}$ bo'ladi. Ushbu formuladan o'xshash kattaliklarni qisqartirsak, u holda → $\omega = \frac{I \cdot U \cdot t}{V \cdot t}$ bo'ladi. Agar $V = S \cdot d$ teng bo'lsa, → $\omega = \frac{I \cdot U \cdot t}{S \cdot d \cdot t}$ ko'rinishga ega bo'ladi. Elektr maydon kuchlanganligi va potensial orasidagi bog'lanish E = $\frac{U}{d}$ bo'lsa, yuqoridagi formula quyidagi ko'rinishga ega bo'ladi: → $\omega = \frac{I \cdot E \cdot d}{S \cdot d}$ yoki

$\rightarrow \omega = \frac{I \cdot E}{S}$. tokning zichligi $j = \frac{I}{S}$ hamda uning differensial ko'rinishi j $= \sigma \cdot$ E ekanligi inobatga olinsa, $\rightarrow \omega = \sigma \cdot$ E·E yoki $\omega = \sigma \cdot E^2$ (4)

ko'rinishda bo'ladi va bunga Joul-Lens qonunining differensial ko'rinishi deyiladi [1,3].

Barcha amaliy mashg'ulotlarda nazariy jihatdan o'rganilgan mavzular isbotlanadi, tasdiqlanadi, barcha formulalarni matematik hisoblashlar orqali qonun va hodisalarni tasdiqlanishi ko'rsatiladi. Barcha talabalar amaliy mashg'ulotlarida fizik qonuniyatlarni amalda aniq qo'llash malakalari hosil bo'ladi. Demak, talabalarda amaliy kompetentlik to'liq shakllanadi, ya'ni yetuk mutaxassis bo'ladi.

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KO‘P O‘TISHLI QUYOSH ELEMENTLARIDA QO‘LLASH UCHUN KREMNIY TUNNEL O‘TISHINI MODELLASHTIRISH

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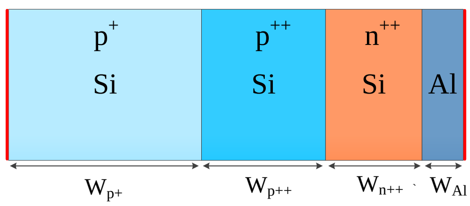
Quyoshning yorug‘lik energiyasini elektr energiyasiga to‘g‘ridan-to‘g‘ri aylantirib beruvchi quyosh elementlarida asosiy muammo samaradorlikni oshirish va ishlab chiqarish xarajatlarini kamaytirishdir. Yangi materiallardan foydalanish [1] yoki optimal tuzilma yaratish orqali bu maqsadlarga erishish mumkin. Biroq, ko‘plab yangi materiallar barqaror emas [2], qimmat [3] yoki xavfli [4]. Shu sababli kremniy materiali hozirgi kunda quyosh elementlari uchun eng ko‘p qo‘llaniladigan materiallardan biri bo‘lib qolmoqda.

Tarkibida bir nechta p-n o‘tishlardan iborat bo‘lgan, ko‘p o‘tishli quyosh elementlari hozirgi kunda yuqori foydali ish koeffitsientiga ega bo‘lgan quyosh elementlari sifatida qaralmoqda [5]. Ko‘p o‘tishli quyosh elementlari samarali ishlashi uchun p-n o‘tishlarni o‘zaro bog‘laydigan kichik ketma-ket qarshilikli va yorug‘lik nurlarini yaxshi o‘tkazadigan kontaktlar zarur. Bu turdagi kontaktlar vazifasini dastlab metal kontaktlar bajargan bo‘lsa, hozirgi kunda tunnel o‘tishlar yordamida amalga oshirilmoqda. Masalan, davriy sistemadagi III-V guruh elementlari asosida tayyorlangan ko‘p o‘tishli quyosh elementlari ichidagi p-n o‘tishlarni o‘zaro bog‘lash uchun tunnel o‘tishlar qo‘llanilgan [12]. Ammo ko‘p o‘tishli quyosh elementlarini III-V guruh elementlari asosida ishlab chiqarish kremniy materiali asosida ishlab chiqarishga qaraganda ancha qimmatga tushadi [13].

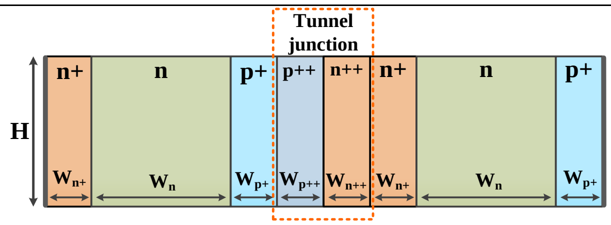
Kremniy tunnel o'tishlari izlanuvchilar tomonidan SOD (Spin-on dopant), RTA (Rapid thermal annealing), RTD (Rapid thermal diffusion) kabi bir nechta texnologiyalar yordamida ishlab chiqilgan [7] va ular hozirda ko'plab tadqiqotlarda qo'llanilmoqda [8]. Ammo modellashtirish orqali tunnel o'tish xarakteristikalari kamroq o'rganilgan. Shu sababli ushbu ishda biz Sentaurus TCAD dasturi yordamida turli tunnellanish modellarini tahlil qilib, ularning Si tunnel diodlari xususiyatlarini adekvat akslantirishini o'rgandik [9].

Ushbu ishda kremniy asosidagi tunnel diod (TD) va tunnel o'tish orqali bog'langan vertikal ikki o'tishli quyosh elementi Sentaurus TCAD platformasida modellashtirildi [10]. Ularning tuzilmalari 1- va 2-rasmlarda, asosiy parametrlar esa 1- va 2-jadvalda keltirilgan. TD parametrlari eksperimental namunaga mos ravishda tanlandi.

Modelni kalibrlash uchun avval izolyatsiyalangan p^{++}/n^{++} Si tunnel diod simulyatsiya qilindi va uning tok – kuchlanish xarakteristikasi [11] da berilgan tajriba ma'lumotlari bilan solishtirildi. Bu yondashuv simulyatsiya modelining aniqligini baholash imkonini berdi.



Rasm.1. Modellashtirilgan tunnel o'tish strukturasi.



Rasm.2. Tunnel o'tishli vertikal ikki qatlamli quyosh elementining tuzilishi.

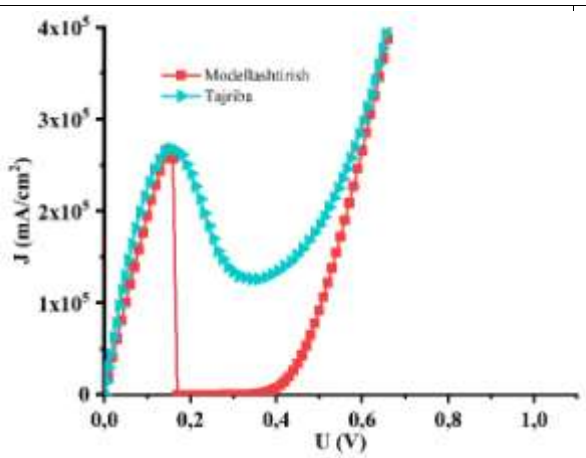
Tablitsa.1. Tunnel o'tishni modellashtirishda qo'llanilgan parametrlar

H (μm)	W_{p+} (μm)	W_{p++} (μm)	W_{n++} (μm)	W_{Al} (μm)	p^{+} (cm^{-3})	p^{++} (cm^{-3})	n^{++} (cm^{-3})
64	0.05	0.02	0.014	0.01	10^{18}	$3.6 \cdot 10^{20}$	$8 \cdot 10^{20}$

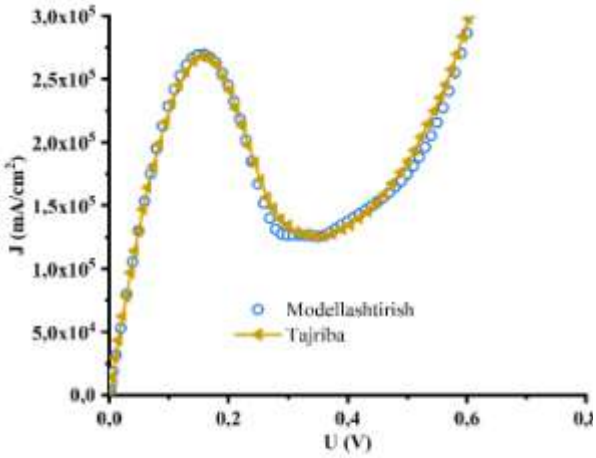
Tablitsa. 2. Tunnel oʻtishli vertikal ikki qatlamli quyosh elementining modellashtirish parametrlari

H (μm)	W_{n+} (μm)	W_n (μm)	W_{p+} (μm)	W_{p++} (μm)	W_{n++} (μm)	n^+ (cm^{-3})	n (cm^{-3})	p^+ (cm^{-3})	p^{++} (cm^{-3})	n^{++} (cm^{-3})
64	5	185	5	0.02	0.014	10^{19}	10^{14}	$5\cdot10^{18}$	$3.6\cdot10^{20}$	$8\cdot10^{20}$

Si materiali asosidagi tunnel oʻtish Sentaurus TCAD da "*Nonlocal Tunneling*" va "*Dynamic Nonlocal Path Band-to-Band Recombination*" modellari asosida modellashtirildi. Modellashtirish jarayonida bu ikkala model aloxida aloxida oʻrganilib, Si tunnel oʻtishning tajribaviy J-V egri chizigʻiga eng mos kelgan modellar va ularga mos parametrlar tanlab olindi (Rasm.1,2). Rasm.3,4 lardan koʻrinib turibdiki "*Dynamic Nonlocal Path Band-to-Band Recombination*" modeli va nuqsonlar konsentratsiyasini xisobga oladigan modellar birgalikda kombinatsiya qilinib qoʻllanilsa Si tunnel oʻtish tajribaga yetarlicha mos kelishi mumkinligini oʻrganildi. Olingan eng mos modellar va ularga mos parametrlar vertikal ikki p-n oʻtishli konsentratorli quyosh elementi uchun p-n oʻtishlarni bogʻlovchi tunnel oʻtishni xosil qilishda foydalanildi va J-V egri chiziqlar olindi [Rasm.5].

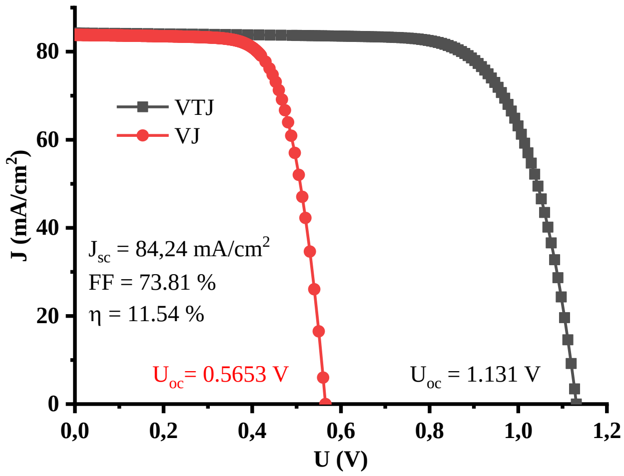


Rasm.3. Tajriba namunasi J–V xarakteristikasi va nolocal tunnellanish modeli (e/h BarrierTunneling "NLM" (Band2Band =



Rasm.4. "*Dynamic Nonlocal Path Band-to-Band Recombination*" modeli va SRH modeli (Hurkx hamda kirishmaga bogʻliq modellarni

UpsideDown)) asosida olingan simulyatsiya natijalari, hamda Schenk tunnellanish modeli orqali Shockley–Read–Hall rekombinatsiyasi (Recombination (SRH (Tunneling))).	o'z ichiga olgan) kombinatsiyasi nuqson yordamidagi rekombinatsiya bilan tajriba J–V xarakteristikalari.



Rasm.5. Bitta o'tishli va ikki o'tishli quyosh elementlarining J–V egri chiziqlari.

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MOLEKULALARNI O'RGANISHDA SUN'IY INTELLEKT VA KVANT HISOBLASH TEXNOLOGIYALAR

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Annatatsiya: Maqolada molekulalarning fazoviy va energetik tuzilishi ularning kimyoviy xossalari, reaktivligi va biologik faoliyatini belgilovchi asosiy omillardan biridir. An'anaviy hisoblash yondashuvlari, jumladan molekulyar dinamika simulyatsiyalari va kvant kimyo metodlari, kichik molekulalarni modellashtirish va ularning strukturasini tahlil qilishda samarali vosita sifatida xizmat qiladi. Biroq, murakkab molekulalar, oqsillar va biologik tizimlarning energetik landshaftlarini aniqlashda ushbu klassik metodlarning hisoblash resurslari va vaqt talablari sezilarli darajada oshadi, bu esa ularning amaliy qo'llanilishini cheklaydi. Ushbu yondashuv katta ma'lumotlar bazasini o'rganish orqali molekulalarning optimal konformatsiyalarini aniqlash, energetik barqarorlikni baholash va yangi kimyoviy tizimlarni modellashtirishda samarali vosita sifatida namoyon bo'lmoqda.

Kalit so'zlar: molekula strukturalari, sun'iy intellekt, kvant hisoblash, molekulyar modellashtirish, kvant kimyo

Molekulalar tuzilishi va ularning xossalari kimyoviy reaksiyalar, biologik jarayonlar va materialshunoslik sohalarida markaziy ahamiyatga ega. Molekula tuzilishi – bu molekulani tashkil qiluvchi atomlar, ularning o'zaro kimyoviy bog'lanishlari va fazoviy (uch o'lchovli) joylashuvini ifodalaydi. Molekula tuzilishi uning kimyoviy, fizik va biologik xossalarini belgilovchi eng muhim omil hisoblanadi.

Molekulalar atomlarning bir-biri bilan bog'lanishi orqali hosil bo'ladi. Molekuladagi bog'lanishlar turlicha bo'lishi mumkin: kovalent, ion, vodorod va dispersiya bog'lanishlari molekulaning barqarorligini va xossalarini belgilaydi. Atomlar molekula ichida uch o'lchovli shaklda joylashadi va bu ularning fazoviy konfiguratsiyasini belgilaydi. Masalan, suv (H_2O) molekulasi burchak shaklga ega bo'lsa, uglerod(IV) oksidi (CO_2) to'g'ri chiziqli shaklga ega.

Molekula har bir konfiguratsiyada o'z energiyasiga ega bo'ladi va eng barqaror tuzilish minimal energiya holatida aniqlanadi. Molekuladagi atomlar va bog'lanishlarning joylashuvi uning reaktsiyaga kirish qobiliyatini belgilaydi. Shuningdek, elektronlar taqsimoti molekulani qutbli yoki qutbsiz qiladi va molekulaning optik xossalari, jumladan nurni yutish yoki so'ndirish qobiliyatiga ta'sir ko'rsatadi.

Zamonaviy yondashuvlarda, xususan chuqur o'rganish algoritmlari, molekulalarning optimal konformatsiyasini bashorat qilish va katta ma'lumotlar bazasini tahlil qilish imkonini beradi. Shu bilan birga, kvant hisoblash texnologiyalari molekulalarning energiya landshaftini tezkor va samarali tahlil qilish imkonini yaratadi. Bu yondashuvlar molekulalarning tuzilishini o'rganish, ularning xossalarini aniqlash va yangi kimyoviy tizimlarni modellashtirishda muhim vosita hisoblanadi. Molekulalarning tuzilishi va xossalarini aniqlash turli ilmiy va sanoat sohalarida muhim ahamiyatga ega.

Molekulalar tuzilishi ularning kimyoviy, fizik va biologik xossalarini belgilovchi asosiy omil bo'lib, kimyo, biologiya va materialshunoslik sohalarida markaziy o'rinni egallaydi. Farmatsevtika sohasida dorivor moddalar molekulalarining uchlamchi va energetik tuzilishi ularning biologik faolligi hamda farmakologik xususiyatlarini belgilaydi. Molekulyar modellashtirish va kompyuter hisoblash metodlari dorilarning samaradorligini oshirish, ularning maqsadli biomakromolekulalar bilan o'zaro ta'sirini prognoz qilish hamda yangi dori birikmalarini yaratishda muhim vosita hisoblanadi. Bu yondashuv farmatsevtika sanoatida yangi avlod dorilarini ishlab chiqishda nazariy asos bo'lib xizmat qiladi [1].

Materialshunoslikda molekulalar tuzilishini aniqlash va modellashtirish yangi materiallar, polimerlar hamda kompozitlarni loyihalashda asosiy ahamiyatga ega. Molekulalarning fazoviy konfiguratsiyasi va kimyoviy bog‘lanishlari materiallarning mexanik, termal va optik xossalarini belgilaydi. Shu sababli materialshunoslikda molekulyar darajadagi tadqiqotlar yuqori samarali, barqaror va funksional materiallarni yaratishga yo‘naltirilgan [2].

Bioinformatika sohasida esa oqsil va nuklein kislotalar kabi murakkab biomakromolekulalarning strukturasini modellashtirish molekulyar biologiya, genomika va proteomika tadqiqotlarida katta ahamiyat kasb etadi. Molekulalarning uchlamchi tuzilishini aniqlash biologik funksiyalarni chuqur tushunish, yangi terapevtik maqsadlarni belgilash hamda biomolekulyar tizimlarni yuqori aniqlikda simulyatsiya qilish imkonini beradi. Bu esa biologik jarayonlarni yanada kengroq anglash va tibbiyotda innovatsion yechimlar yaratishga xizmat qiladi.

Molekulalar tuzilishi haqidagi bilimlar kimyo, biologiya va materialshunoslikning rivojlanishida asosiy o‘rin tutadi. Ularning fazoviy va energetik konfiguratsiyasini o‘rganish nafaqat nazariy fan, balki farmatsevtika, yangi materiallar yaratish va bioinformatika kabi amaliy yo‘nalishlarda ham beqiyos ahamiyatga ega. Sun’iy intellekt va kvant hisoblash texnologiyalarining rivojlanishi murakkab molekulalarning strukturaviy tahlilini tezkor va aniq bajarish imkoniyatini yaratib, ilm-fan va texnologiyalarning yangi ufqlarini ochmoqda.

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A NEW COMPUTING PARADIGM: THE IMPACT OF QUANTUM ADVANCES ON ARTIFICIAL INTELLIGENCE

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Subject: A strategic overview of recent, tangible breakthroughs in quantum computing and their immediate implications for Artificial Intelligence and industry.

Introduction: A Critical Inflection Point

The period from 2024 to 2025 marks a critical inflection point for quantum computing, defined by two parallel and significant developments that have moved the field from theoretical promise to engineering reality. The first is the dawn of **Quantum Utility**, where current-generation quantum processors have delivered the first documented instances of commercial advantage. The second is a foundational breakthrough on the path to **Fault Tolerance**, characterized by a strategic pivot in error-correction architecture. This abstract summarizes these state-of-the-art advances and their transformative impact on the future of Artificial Intelligence.

Key Finding: The Emergence of Quantum Utility

The primary breakthrough of 2025 is the demonstration of tangible value from noisy, intermediate-scale quantum (NISQ) hardware. Landmark trials, such as the **IBM and HSBC collaboration in algorithmic bond trading**, have shown performance improvements of up to 34% by using quantum processors as specialized co-processors in hybrid classical- quantum workflows. This is complemented by new application-centric benchmarks, like **IonQ's #AQ 64**, which directly link hardware performance to the ability to solve commercially relevant problems in finance, logistics, and drug discovery. These results prove that the era of extracting business value from quantum computers has begun.

Qubit Counts of Leading Platforms (2024-2025)

IBM "Heron" (2024)

[~133 Qubits]
IonQ "Tempo" (2025)
[#AQ 64]
Quandela (2025)
[~4,000 Qubits]
<---- Scale (Each ≈ 100 Qubits) >

This chart visually represents the massive leap in computational scale, which, combined with improved quality, underpins the new era of Quantum Utility.

Key Area: The Quantum-AI Symbiosis

The most promising application of this new hardware is in augmenting Artificial Intelligence. State-of-the-art research in Quantum Machine Learning (QML) has shifted to addressing key training challenges. The most innovative mitigation strategies for the "barren plateau" problem now involve a powerful symbiosis, using **classical AI—specifically Large Language Models (LLMs) and Reinforcement Learning**—to intelligently initialize the parameters of quantum circuits, dramatically improving their trainability.

The table below outlines the leading QML algorithms being unlocked by these advances:

Algorithm	How It Works & Its Quantum Advantage	Potential Impact (1-10)	Near-Term Viability (1-10)
VQE (Variational Quantum Eigensolver)	Finds the lowest energy state of a molecule using a hybrid quantum-classical loop. **Advantage:** Simulates nature with quantum-native precision, far beyond classical methods. Ideal for drug and material discovery.	9	8
QSVM (Quantum Support Vector Machine)	Maps data into a massive quantum feature space to find optimal classification boundaries. **Advantage:** Identifies subtle, non- linear patterns invisible to classical SVMs. Crucial for advanced fraud detection and risk analysis.	7	7
Quantum PCA (Principal Component Analysis)	Uses quantum algorithms to find the most significant features within a complex dataset exponentially faster than classical PCA. **Advantage:** Drastic speedup in dimensionality reduction, essential for feature extraction in medical diagnostics.	9	7
Quantum Generative Models	Leverages quantum circuits to learn a probability distribution from data and generate new samples. **Advantage:** Potential to create more powerful and efficient generative models for financial modeling and synthetic data generation.	8	6

Foundational Breakthrough: The New Architecture for Fault Tolerance

The long-term viability of quantum computing depends on error correction. The definitive breakthrough of this era is a strategic pivot in Quantum Error Correction (QEC) architecture. Industry leaders like **IBM have moved from the resource-intensive surface code to novel, highly efficient quantum low-density parity-check (qLDPC) codes**. This new approach promises an **order-of-magnitude reduction in qubit overhead**, fundamentally reshaping hardware roadmaps toward modular, long-range connected systems and creating a more viable path to a large-scale, fault-tolerant quantum computer by 2029.

Conclusion & Outlook

The convergence of near-term Quantum Utility and a credible path to long-term Fault Tolerance signals the maturation of the quantum industry. The implications for sectors reliant on complex simulation, optimization, and AI are profound. The era of passive observation is over; organizations must now actively develop quantum-readiness strategies to harness this new computational paradigm.

LASER-INDUKSIYALANGAN PLASMA YORDAMIDA TAYYORLANGAN ($Cu_{1–x}$:Al_x) QOTISHMALARIDA PLAZMA PARAMETRLARINI HISOBLASH

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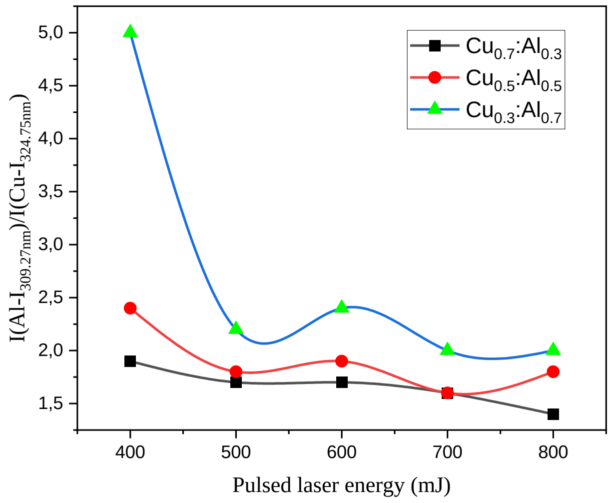
Lazer-induksiyalangan plazma (LIP) nanomateriallar sintezida samarali va nazorat qilinadigan usullardan biri hisoblanadi. Ushbu jarayonda hosil bo‘ladigan plazmaning asosiy parametrlari elektron zichligi (n_e) va elektron harorati (T_e) ablyatsiya jarayonining intensivligi hamda yakuniy nanostrukturalarning morfologiyasi va kristallik darajasini belgilaydi [1,2]. Shuning uchun lazer energiyasi va target (nishon) tarkibining plazma parametrlariga ta’sirini o‘rganish nanokompozitlarning fizik-mexanik xossalarini nazorat qilishda muhim ahamiyatga ega. Mazkur tadqiqotda turli nisbatlardagi mis-alyuminiy (Cu:Al) qotishmalari (x = 0.3, 0.5, 0.7) yuzasida Nd:YAG lazeri (λ = 1064 nm, E = 400–800 mJ) yordamida hosil qilingan plazma parametrlarini aniqlash hamda ularning nanokristallit o‘lchamlariga ta’siri o‘rganildi. Eksperimentda optik emissiya spektroskopiyasi (OES) usuli qo‘llanilib, Cu I, Cu II, Al I va Al II spektral chiziqlari tahlil qilindi.

Plazma harorati Boltsman grafik usuli bilan, elektron zichlik esa Stark kengayishi asosida aniqlangan [3]. Hosil bo‘lgan nanostrukturalar XRD yordamida tahlil qilinib, Debye–Scherrer tenglamasi asosida kristal o‘lchamlari hisoblab chiqildi [4]. Lazer energiyasi oshishi bilan T_e va n_e muntazam o‘sdi: $Cu_{0.7}$:$Al_{0.3}$ namunasi uchun T_e 0.36 eV dan 0.63 eV gacha, n_e esa 2.12×10^{18} sm^{-3} dan 2.88×10^{18} sm^{-3} gacha ortdi. $Cu_{0.3}$:$Al_{0.7}$ namunalarida esa T_e 0.46 eV dan 0.73 eV gacha, n_e esa 2.71×10^{18} sm^{-3} dan 3.30×10^{18} sm^{-3} gacha yetdi. Bu natijalar alyuminiy miqdori ortishi plazmaning yuqori ionlashuviga olib kelishini ko‘rsatadi [5]. Alyuminiy nisbati yuqori bo‘lgan $Cu_{0.3}$:$Al_{0.7}$ namunalarida T_e va n_e qiymatlari boshqa nisbatlarga qaraganda yuqoriroq qayd etildi. Bu farq materiallarning ishchi funksiyasi bilan bog'liq: alyuminiyning ishchi funksiyasi (4.3 eV) misnikiga (4.7 eV) qaraganda past bo'lib, u kamroq energiya bilan elektron emissiyasini boshlaydi [6].



1-rasm: Aralash nishonlar (Cu:Al)ning turli nisbatlarida impulsli lazer energiyasi ta'sirida Al-I (309,27 nm) va Cu-I (324,75 nm) chiziqlari intensivlik nisbatining o'zgarishi.

Al I (309.27 nm) va Cu I (324.75 nm) chiziqlari intensivligi nisbati (I_{Al}/I_{Cu}) > 1 bo'lgani kuzatildi. Bu natija Al tarkibi ko'proq bo'lgan namunada lazer energiyasi past bo'lganda ham alyuminiy chiziqlari kuchliroq bo'lishini tasdiqlaydi [7]. XRD natijalariga ko'ra, kristallit o'lchamlari plazma harorati bilan to'g'ridan-to'g'ri bog'liq ravishda o'sdi. Alyuminiy kristallitlari 12.4-21.0 nm gacha, mis kristallitlari esa 12.3-29.1 nm diapazonida o'sdi. $Cu_{0.7}:Al_{0.3}$ va $Cu_{0.5}:Al_{0.5}$ namunalarida mis kristallitlari kattaroq bo'lsa, $Cu_{0.3}:Al_{0.7}$ da alyuminiy kristallitlari ustunlik qildi. Bu lazer nurlanishining target tarkibidagi elementlar bilan turlicha o'zaro ta'siri bilan izohlanadi [8]. Lazer energiyasi oshishi ablatsiya jarayonini kuchaytirib, ko'proq atom va ionlarni hosil qildi. Elektronlarning zarrachalar bilan ko'plab to'qnashuvi kristallanish jarayonini tezlashtirdi va yuqori kristall tuzilishga ega nanomateriallarning hosil bo'lishiga olib keldi [9]. Tadqiqot shuni ko'rsatadiki, lazer-plazma parametrlarini nazorat qilish orqali hosil bo'layotgan nanostrukturalarning kristallik darajasi va zarracha o'lchamini boshqarish mumkin.

Ayniqsa, alyuminiy ulushi yuqori bo'lgan Cu-Al qotishmalari yuqori ionlashuv darajasiga ega bo'lib, bu nanokristallarning o'sishini jadallashtiradi. Demak, lazer energiyasi + nishon tarkibi kombinatsiyasi materiallarning yakuniy faza va morfologiyasini belgilovchi asosiy omillardir. Olingan natijalar Cu-Al nanokompozitlari sintezida zarracha o'lchamini va kristallanish darajasini boshqarish imkonini beradi. Bu yondashuv kelajakda nanoelektronika, yupqa plyonkali qoplamalar va energiya saqlash texnologiyalarida samarali qo'llanilishi mumkin.

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APPLICATION OF NANOTECHNOLOGY IN SUPER CAPACITORS

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Abstract

Supercapacitors are high-capacity devices with 10 to 150 times more energy per unit volume or mass than traditional capacitors. Integration of nanotechnology with supercapacitors lead to better results compared to supercapacitors. The present article describes a review of synthesis and characterization of nanomaterials that are doped with transition metals and its application in nano supercapacitors which are widely used in electronics, electric vehicles, UPS, smart meters, solid state devices, energy harvesters in solar cells, IoT sensors, energy grid stabilization.

1. Introduction

Super capacitors present lower energy densities (4–5 Wh/kg) than traditional batteries (30–40 Wh/kg) but with a virtually infinite life time, rapid charge, a wider temperature range, safety and higher reliability. With the developments in nanoscience and technology, nanosuper capacitors whose energy and power densities of 262 Wh/kg and tens of kW/kg to over 400 kW/kg were reported compared to the available traditional super capacitors with energy density of 4–5 Wh/kg and power density of 10–20 kW/kg. The integration of nanotechnology with the principles of supercapacitor create advanced energy storage devices that combine the high power density of conventional capacitors with the high energy density of batteries by utilizing nanotubes and nanosheets due to its extremely high surface area in the electrodes. Enhanced surface area leads to increased capacitance and faster charge/discharge rates that facilitates rapid energy delivery.

1.1Synthesis of nanomaterials for Supercapacitors

Common techniques such as hydrothermal, solvothermal, co-precipitation, sol-gel method and various chemical or physical approaches are suggested to synthesize nanomaterials with dopants such as Manganese, Nickel, Cobalt, Nitrogen, Sulfur, Boron, Vanadium etc into the host materials to alter their intrinsic electrical and chemical properties. Nanosuper capacitor materials possess modified concentration of charge carriers, increased conductivity and energy storage capacity and enhanced electro catalytic activity and thereby enhancing performance in applications like supercapacitors and batteries. Synthesis of Fe doped NiO nanoparticles (1) for super capacitor applications can be found.

1.2 Materials and Methods

Iron (III) nitrate nonahydrate ($Fe(NO_3)_3.9H_2O$), Nickel (II) nitrate hexahydrate ($Ni\ (No_3)_2.6H_2O$), and Sodium hydroxide (NaOH) were used. The co-precipitation process was used to create NiO nanoparticles doped with Fe. 100 ml of double-distilled water is used to dissolve 0.3 M of Nickel Nitrate hexahydrate and 10 wt% of Iron (III) nitrate nonahydrate is then added. Subsequent washing, dying at 150 C and calcination resulted in the final product of Fe doped NiO Nano powder. The detailed description of the synthesis and characterization are reported (1)

1.3 Characterization Techniques

1. EDS Spectra – For elemental analysis
2. X-ray diffraction - The crystal structures and phase purity of both undoped and doped nanomaterialscan be analyzed using XRD patterns
3. FTIR (Fourier Transform Infrared Spectroscopy) - to analyze samples and identify their chemical composition.
4. SEM (Scanning Electron Microscopy) - for detailed surface analysis by generating high-resolution, magnified images of a specimen's topography and composition using an electron beam.
5. HR-SEM (High-Resolution Scanning Electron Microscopy) - for ultra-detailed images of a sample's surface and composition with sub-nanometer resolution.
6. EDX (Energy-Dispersive X – Ray spectroscopy) - the composition and the quantity of the heavy metal ions of the nanoparticles, which are placed near or at the surface of a sample, can be measured.
7. BET (Brunauer, Emmett and Teller) - to measure high specific surface area and porosity.
8. GCD (Galvanostatic Charge-Discharge) - common electrochemical test used to evaluate the energy storage performance of materials for devices like supercapacitors and batteries.

9. EIS (Electrochemical Impedance Spectroscopy) - To analyze the electrochemical properties of nanomaterial-modified interfaces and understand phenomena like charge transfer, diffusion, and adsorption.

Few earlier Results and Discussion

The role of nanomaterials in redox-based supercapacitors for next generation energy storage devices is reported (2). Development of high-performance supercapacitors based on carbon nanomaterials (3). Supercapacitor electrodes based on nanopolyaniline deposited on hollow carbon spheres derived from cross-linked co-polymers (4). Ultrathin NiCo-MOF nanosheets for highperformance supercapacitor electrodes (5); Asymmetric supercapacitors with high energy density and high specific capacitance based on NiCo-Mn multiphase metal structure MOF (6); photocatalytic performance and supercapacitor applications of undoped and Cu-doped ZnO nanoparticles . (7); Design of composite cathodes for sulfide-based all-solid-state batteries (8); Design and synthesis of hybrid Mo-doped Bi_2O_3 nanomaterials as an efficient electrode for high-performance supercapacitors (9). Tuning barrier height and enhancing electrical properties of MOS heterojunctions using Fe2O3 doped MoO3 nanocomposite interlayer on Ni/ Cr/n-GaN for optoelectronic devices (10). Our future work focusses on the development of efficient and inexpensive, doped nanosupercapacitors for a better performance than the earlier reports.

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8-OKSIXINOLIN BILAN MODIFIKASIYANLANGAN ASETATSELLULOZA YORDAMIDA LITIY IONINI ANIQLASH

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Dolzarbligi: Litiy ionlarini aniqlash texnologiyalari bugungi kunda juda dolzarb hisoblanadi, chunki Li^+ ionlari energiya saqlash qurilmalari, farmatsevtika va ekologik nazorat sohalarida keng qo‘llaniladi. Ayniqsa, litiy-ion batareyalarining global qo‘llanilishi bu elementning sezgir va selektiv aniqlanishini taqozo etadi [1]. Litiy kontsentratsiyasini aniqlashning an’anaviy metodlari (atom-absorbsion spektroskopiya, ion-selektiv elektrodlari va ICP-MS) yuqori aniqlikka ega bo‘lsa-da, ular qimmat, ko‘p vaqt talab qiladi va murakkab namunalarni tayyorlash bosqichlariga ega. Shu bois, optik va lyuminessent asosidagi oddiy, arzon va yuqori sezgir usullar ishlab chiqilishi zamonaviy analitik kimyo yo‘nalishlaridan biridir.

Asetatsellyuloza yuqori barqarorlik, yaxshi ishlov berish imkoniyati va modifikatsiyaga qulayligi tufayli analitik maqsadlarda qo‘llanilmoqda [2]. Uning gidroksil guruhlari 8-oksixinolin kabi ligandlar bilan kovalent yoki ko‘prik hosil qiluvchi bog‘lanishlar orqali immobilizatsiyalanadi. Natijada yuzada metall ionlari bilan kompleks hosil qila oladigan faol markazlar paydo bo‘ladi.

8-Oksixinolin (8-HQ) N va O donor atomlari orqali turli metall ionlari, jumladan litiy bilan ham kompleks hosil qiladi. Bu komplekslar odatda yaxshi barqarorlikka ega bo‘lib, fotofizik xossalarini o‘zgartiradi va lyuminessent signallarni kuchaytiradi [3]. 8-HQ modifikatsiyasi natijasida hosil bo‘lgan asetatsellyuloza sorbentida litiy ionlari bilan selektiv o‘zaro ta’sir sodir bo‘ladi, bu esa fluoressensiya asosida aniqlash imkoniyatini beradi. Li^+ ionlari 8-oksixinolin bilan bog‘langanda xelat kompleks hosil bo‘ladi. Bu jarayon ligandning elektron tuzilishini o‘zgartirib, fluoressensiya intensivligini oshiradi yoki spektral siljishga olib keladi. Natijada, sorbent materialida litiy mavjudligi sezilarli ravishda aniqlanadi. Bunday usul yuqori sezgirlikka ega bo‘lib, mikro- va pikomolyar diapazonda aniqlash imkonini beradi. Bundan tashqari, 8-HQ asosidagi sensorlar arzon, portativ va tezkor monitoring uchun qulay hisoblanadi [4].

Maqsad: Asetatselluloza asosida 8-oksixinolin bilan modifikatsiyalangan sorbent sintez qilib, uni lyuminessent usulda litiy ionlarini aniqlashda qo'llash.

Usul va uslublar: Asetatsellyulozani 1mikron kattalikda maydalab, unga 1% li 8-oksixinolinning spirtdagi eritmasi qo`shildi va 1 soatga qoldirildi. Keyin eritma filtrlanib olindi va 8-oksixinolinning konsentratsiyasi spektrofotometr yordamida aniqlandi. Sorbsiya qiymati topildi. Uni spirtda yuvib tashlab, uni quritilib, tabletka holatiga olib kelindi va unga litiy xlorid eritmasi solinib, qattiq fazada fluoressensiya intensivliklari aniqlandi.

Natija: 8-HQ Li^+ ionlari bilan 1:1 stexiometrik nisbatda kompleks hosil qildi. Bu jarayon polimer yuzasida immobilizatsiyalangan ligandlar orqali tez sodir bo'lib, fluoressensiya intensivligini sezilarli oshirdi. Li^+ konsentratsiyasi ortishi bilan fluoressensiya intensivligi chiziqli ravishda oshib bordi.

$AC–8HQ+Li^+ \longrightarrow [AC–8HQ–Li]$ (xelat kompleks)

Bu yerda Li^+ 8-HQ ning N va O donor atomlari bilan ikki koordinatsion bog` hosil qilib barqarorlashadi.

Na^+, K^+, Mg^{2+} va Ca^{2+} ionlari ishtirokida ham sinov o'tkazildi. Boshqa ionlar fluoressensiya intensivligida sezilarli o'zgarish bermadi. Bu esa Li^+ uchun yuqori selektivlikni isbotladi.

Xulosa: Asetatsellyuloza asosidagi 8-HQ modifikatsiyalangan materiallarning asosiy afzalliklari yuqori selektivlik, past aniqlash chegarasi, biosamaradorlik va ekologik xavfsizlik, tayyorlashning soddaligi va iqtisodiyligidir. Asetatsellyulozani 8-oksixinolin bilan modifikasiyalash orqali yaratilgan sorbentlar litiy ionini aniqlashda samarali lyuminessent sensor vazifasini bajaradi. Ushbu materiallar arzon, ekologik xavfsiz va yuqori sezgirlikka ega bo'lib, zamonaviy analitik kimyoning istiqbolli yo'nalishlaridan biridir.

Adabiyotlar

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