ISNN:2181-1296

SHAROF RASHIDOV NOMIDAGI
SAMARQAND DAVLAT UNIVERSITETI

САМАРКАНДСКИЙ ГОСУДАРСТВЕННЫЙ
УНИВЕРСИТЕТ ИМЕНИ ШАРОФА РАШИДОВА

SAMARKAND STATE UNIVERSITY NAMED
AFTER SHAROF RASHIDOV

ILMIY AXBOROTNOMA

НАУЧНЫЙ ВЕСТНИК
SCIENTIFIC JOURNAL

ANIQ VA TABIIY FANLAR SERIYASI

Matematika, Mexanika, Informatika
Fizika, Kimyo, Biologiya, Geografiya

№ 1/2 (155)
2026

ISSN 2181-1296

ILMIY AXBOROTNOMA

НАУЧНЫЙ ВЕСТНИК SCIENTIFIC JOURNAL

2026-yil, 1-son (155/2) ANIQ VA TABIIY FANLAR SERIYASI

Matematika, Mexanika, Informatika, Fizika, Kimyo, Biologiya, Geografiya

Samarqand viloyat matbuot boshqarmasida ro‘yxatdan o‘tish tartibi 09-25.
Jurnal 1999-yildan chop qilina boshlagan va OAK ro‘yxatiga kiritilgan.

BOSH MUHARRIR **R. I. XALMURADOV, t.f.d., professor**
BOSH MUHARRIR O‘RINBOSARLARI: **H.A. XUSHVAQTOV, f-m.f.d., dotsent**

TAHRIRIYAT KENGASHI:

Sh.A.Alimov	- O‘zFA akademigi	**M.X.Ashurov**	- O‘zFA akademigi
S.N.Lakayev	- O‘zFA akademigi (SamDU)	**B.J.Axmedov**	- O‘zFA akademigi
M.M.Kamilov	- O‘zFA akademigi	**Q.G‘.G‘ulomov**	- O‘zFA akademigi
A.G.Yagola	- Moskva davlat universiteti professori (Rossiya)	**A.A.Zaxidov**	-Texas Nanotexnologiya instituti professori (AQSh)
Alberto Del Bimbo	-Florensiya universiteti professori (Italiya)	**N.B. Ferapontov**	- Moskva davlat universiteti professori (Rossiya)
Sh.Tugizov	-Kaliforniya universiteti professori (AQSh)	**V.L.Popov**	-Berlin texnika universiteti professori (Germaniya)
A.S.Soleev	- f.-m.f.d., professor (SamDU)	**N.F.Bunkin**	- Moskva davlat texnika universiteti professori (Rossiya)
I.A.Ikromov	- f.-m.f.d., professor (SamDU)	**Haji Akber Aisa**	-Xinjiang tibbiyot universiteti professori (Xitoy)
B.X.Xo‘jayarov	- f.-m.f.d., professor (SamDU)	**E. A. Abduraxmonov**	- k.f.d., professor (SamDU)
L.Sabirov	-f.-m.f.d., professor (SamDU)	**N. K. Muxamadiyev**	- k.f.d., professor (SamDU)
A.Jumaboyev	-f.-m.f.d., professor (SamDU)	**L. A. Bulavin**	- Kiev milliy universiteti
X.Bozorov	-k.f.d., professor (SamDU)	**X. Q. Xaydarov**	- b.f.d., professor (SamDU)
O.Q.Quvondiqov	-f.-m.f.d. professor (SamDU)	**Z. I. Izzatullayev**	- b.f.d., professor (SamDU)
A.Z.Xasanov	-f.-m.f.d. professor (SamDU)	**A.B.Hasanov**	-tex.f.d., professor (SamDU)
Muhammad Suzuri bin Hitam	- Terengganu universiteti professori (Malayziya)	**Sh. T. Xoliqulov**	- q.-x.f.d., professor (SamDU)
K.D.Kuliyev	- f.-m.f .n. professor (SamDU)	**S. B. Abbosov**	- g.f.d., professor (SamDU)
A.M.Xolxo‘jayev	-f.-m.f.d., professor (SamDU)	**M.E. Mo‘minov**	-f.-m.f.d., professor (SamDU)
J.Abdullayev	-f.-m.f.d., professor (SamDU)	**I.I.Jumanov**	-tex.f.d., professor (SamDU)
A.R.Axatov	-tex.f.d., professor (SamDU)	**N.S.Mamatov**	-tex.f.d., professor (TIQXMMI)
D.B.Xursanov	- g.f.f.d., dotsent (SamDU)	**A.Sh.Yarmuxamedov**	-f-m.f.n., dotsent (SamDU)
F.Nazarov	-tex.f.d., dotsent (SamDU)	**X.S.Xaydarov**	-f-m.f.n., dotsent (SamDU)

Obuna indeksi – yakka tartibdagi obunachilar uchun **- 5583,**
tashkilot, korxonalar uchun **- 5584**

M U N D A R I J A
C O N T E N T S

№	Maqola nomi	Article title	Bet/ page
1.	Yuqori chastotali II-turdagi radio portlash spektral kuzatuvlaridan foydalanib magnit maydon kuchini baholash **Pulatov D., Mirtoshev Z.**	Estimation Of The Coronal Magnetic Field Strength Using High-Frequency Type Ii Radio Burst Observations **Pulatov D., Mirtoshev Z.**	**5-11**
2.	Rayxon (OCIMUM) o‘simligi efir moyi kimyoviy tarkibiga iqlim omillarining ta’sirini GX–MS usulida tadqiq etish **Siddikova Y., Saifullaeva Sh., Mukhamadiyev A., N.Fazlieva, Nayimova B., Muhamadiyev N.**	Study of the influence of climate factors on the chemical composition of basil (ocimum) essential oil using the GH–MS method **Siddikova Y., Saifullaeva Sh., Mukhamadiev A., N.Fazlieva, Nayimova B., Muhamadiev N.**	**12-20**
3.	Bentonitni montmorillonit bilan boyitishning samarali usullari va termal ishlov berishning kation almashinuvi quvvatiga ta'siri **Mamadoliev I., Abdikamalova A., Ruzieva S.**	Effective methods for bentonite enrichment with montmorillonite and the impact of thermal treatment on cation exchange capacity **Mamadoliev I., Abdikamalova A., Ruzieva S.**	**21-28**
4.	$KPbBr_3$ asosidagi peroled tuzilmalarida zaryad tashish mexanizmlari va energetik sathlarning moslashuvi **Rahmonova M., Muxamadiyev N.**	Charge transport mechanisms and energy level alignment in $KPbBr_3$ -based peroled structures **Rahmonova M., Mukhamadiev N.**	**29-36**
5.	*N*-(4-(((7-Nitroxinazolin-4-il) amino) metil)fenil) siklogeksankarboksamid sintezi **Gaybullaev Sh., Takhirov Y., Chao Niu, Bozorov Kh.**	Synthesis of N-(4-(((7-nitroquinazolin-4-YL) amino) methyl) phenyl) cyclohexanecarboxamide **Gaybullaev Sh., Takhirov Y., Chao Niu, Bozorov Kh.**	**37-41**
6.	3-brom-pirido[2,3-*d*]pirimidinonlarning sintezi **Khushnazarov Z., Turgunov D., Bozorov Kh.**	synthesis of 3-bromo-pyrido[2,3-d]pyrimidinones **Khushnazarov Z., Turgunov D., Bozorov Kh.**	**42-46**
7.	Zarrachalar tezlatkichlarida materiallarning aktivatsiyasi va radiatsion xavflar **Temirov J., Khasanov Sh., Safarov A., Karimberganova Q.**	Material activation and radiological hazards in particle accelerators **Temirov J., Khasanov Sh., Safarov A., Karimberganova Q.**	**47-57**
8.	Geoinformatsion dasturlar yordamida demografik atlaslar yaratishning afzalliklariga nazar **Tukhtamishev Sh., Khudoyarova Sh., Shirinboyev D.**	Advantages of creating demographic atlases using geoinformation software **Tukhtamishev Sh., Khudoyarova Sh., Shirinboev D.**	**58-62**
9.	Siklopropilatsetilen asosida atsetilen spirtlari sintezi, ularning nazariy energetik xarakteristikalari va nadfoksidaza oqsili (7U8G) bilan molekulyar birikish tahlili **Ziyadullaev M.E., Nurmanov S.E., Buriev F.Kh., Abdukhalikov F.J.**	Synthesis of acetylenic alcohols based on cyclopropylacetylene, their theoretical energetic characterization, and molecular docking analysis with nadph oxidase (7U8G) protein **Ziyadullaev M.E., Nurmanov S.E., Buriev F.Kh., Abdukhalikov F.J.**	**63-71**
10.	Tetratsiklik tieno[3,2-*d*]pirimidinonlarning siklooksigenaza-2 ingibitorlari sifatida *in silico* tadqiqi **Nasrullaev A., Buronov A., Gaybullaev Sh., Bozorov Kh.**	In silico evaluation of tetracyclic thieno[3,2-d]pyrimidinones as potential cyclooxygenase-2 inhibitors **Nasrullaev A., Buronov A., Gaybullaev Sh., Bozorov Kh.**	**72-76**
11.	H3PO4, KOH va ZnCl2 yordamida olingan faollashtirilgan ko‘mirning morfologik va strukturaviy xususiyatlarining qiyosiy tahlili **Ergasheva D., Mukhamadiyev A., Mukhamadiyev N., Uzokov J.**	Comparative analysis of the morphological and structural properties of activated carbon prepared using H_3PO_4, KOH, and $ZnCl_2$ **Ergasheva D., Mukhamadiev A., Mukhamadiev N., Uzokov J.**	**77-81**
12.	CO_2 NI quyosh nuri ta’sirida samarali konversiyalashni ta’minlovchi g-C_3N_4/$CoNi_2S_4$ geterotuzilmali nanomateriallar sintezi va fizik-kimyoviy xossalari **Samiev A., Nizamov U.N., Mirzaev Sh., Ruzimuradov O., Nasimov A.**	Synthesis and physicochemical properties of γ-C3N4/CoNi2S4 heterostructured anomaterials providing efficient conversion of CO2 under the influence of sunlight **Samiev A., Nizamov U.N., Mirzaev Sh., Ruzimuradov O., Nasimov A.**	**82-87**

№	Maqola nomi	Article title	Bet/ page
13.	Atrof muhitdagi ammiak mikrokensentratsiyasini monigitori uchun gibrid perovskit $MA_xFA_{1-x}PbI_3$ fluoressent sensori tayyorlash **Eshmuradova G.B., Tashpulatov Kh.Sh., Khursandov J.M., Normuradov O.U., Norboyev Q.M., Toshpulatov D.T.**	Preparation of hybride perovskite $MA_xFA_{1-x}PbI_3$-fluorescent sensor for the monitoring of ammonia microconcentration in environment **Eshmuradova G.B., Tashpulatov Kh.Sh., Khursandov J.M., Normuradov O.U., Norboev Q.M., Toshpulatov D.T.**	**88-92**
14.	Al^{3+} bilan modifikatsiyalangan shpinel tuzilishga ega $Li_{1.33}Al_XMn_{1.67-X}O_4$ ($0 \leq x < 0.7$) tarkibli adsorbentlarning zol-gel sintezi va fizik-kimyoviy xossalari **Begimkulova Sh.A., Nematova Sh.Sh., Baxriev I.S., Mirzaev Sh.E., Ruzimuradov O.N., Nasimov A.M.**	Sol-gel synthesis and physicochemical properties of adsorbents consisting of Al^{3+} modified spinel structure $LI_{1.33}Al_XMn_{1.67-X}O_4$ ($0 \leq X < 0.7$) **Begimkulova Sh.A., Nematova Sh.Sh., Baxriev I.S., Mirzaev Sh.E., Ruzimuradov O.N., Nasimov A.M.**	**93-99**
15.	CdCr2Se4 va CuCr4Se4 magnitli yarimo‘tkazgichda magnit-optik effektlar **Dosmurodov G.**, **Kurbaniyazov A.**, **Boboqambarova G.**	Magneto-optical effects in the magnetic semiconductor CdCr2Se4 AND CuCr4Se4 **Dosmurodov G.**, **Kurbaniyazov A.**, **Bobokambarova G.**	**100-104**
16.	Sophora lehmanni va Cicer mogoltavikum o‘simliklari yer ustki qismilarining flavonoidlari **Gafurov A.Zh, Botirov E. Kh.**	Flavonoids of aerial parts of sophora lehmannii and cicer mogoltavicum **Gafurov A.Zh, Botirov E. Kh.**	**105-109**
17.	Buxoro viloyatining balneologik resurslari va ularning aholi salomatligini yaxshilashdagi ahamiyati **Zaynutdinova D.K., Nematova Kh. Kh.**	Balneological resources of the bukhara region and their significance in improving public health **Zaynutdinova D.K., Nematova Kh. Kh.**	**110-116**
18.	Tabiiy cho‘kuvchan gruntlarni polimer-kompozitsion eritmalar bilan inyeksion mustahkamlash texnologiyasini matematik rejalashtirish **Bakhriyev N.F., Kholiqulov O.O., Nurmatova R.K.**	Mathematical planning of injection strengthening technology of natural collapsible soils using polymer-composite solutions **Bakhriyev N.F., Kholikulov O.O., Nurmatova R.K.**	**117-125**
19.	Adgezion kontaktlarda ishqalanish koeffitsiyentiga geometrik parametrlar hamda tashqi yuk ta’sirining tahlili **Bekmamatova G., Xoliqulov O., Tojinorov M.**	Analysis of geometric parameters and external load on the friction coefficient in adhesive contacts **Bekmamatova G., Xolikulov O., Tojinorov M.**	**126-131**
20.	Markaziy Osiyo iqlim sharoitida sorbsion sovutgichlardan biogaz komplekslari bilan simbiozda foydalanish istiqbollari **Abdusamiyev F., Bahriev S., Sattarov S.**	Prospects for using sorption refrigerators in symbiosis with biogas complexes in the climatic conditions of Central Asia **Abdusamiev F., Bahriev S., Sattarov S.**	**132-136**
21.	Maple tizimida algebraik ko’pxilliklarni ratsional parametrlashining nazariy asoslari va kompyuterda amalga oshirilishi **Usmonova N.**	Theoretical foundations and computer implementation of rational parameterization of algebraic manifolds in the maple system **Usmonova N.**	**137-142**
22.	$Fe_5Ga_6Gd_2YZr$ ko‘p komponentli kristallining element tarkibi va tebranish xossalarini rentgen-fluoresans (XRF) va raman spektroskopiyasi yordamida tadqiq etish **Nasirova N., Fayziyev Sh., Saidov Q., Qaxorova Sh., Sharipov M., Djuraev D.**	Investigation of the elemental composition and vibrational properties of the multicomponent crystal Fe5Ga6Gd2YZr using X-RAY fluorescence (XRF) and raman spectroscopy **Nasirova N., Fayziyev Sh., Saidov Q., Qaxorova Sh., Sharipov M., Djuraev D.**	**143-152**
23.	Xofp tipidagi tenglamalar sistemasi uchun Koshi masalasi **Erkinova D. A.**, **Imomnazarov Kh. Kh.**	Cauchy problem for a Hopf-type system **Erkinova D. A.**, **Imomnazarov Kh. Kh.**	**153-157**
24.	Ar va HCl izotopologlari o‘rtasida hosil bo‘lgan komplekslarning kvant-kimyoviy tahlili: AIM, RDG va NCI usullari yordamida solvatatsiya effektlarini o‘rganish **Khujamov U.**	Quantum-chemical analysis of complexes formed between Ar and HCL isotopologues: studying solvation effects using AIM, RDG, and NCI methods **Khujamov U.**	**158-167**

UDC: 544.526:544.72:620.3 https://doi.org/10.59251/2181-3973.2025.v1.138.1.3826

SYNTHESIS AND PHYSICOCHEMICAL PROPERTIES OF γ-C3N4/CoNi2S4 HETEROSTRUCTURED ANOMATERIALS PROVIDING EFFICIENT CONVERSION OF CO2 UNDER THE INFLUENCE OF SUNLIGHT

A. Samiev[1], U.N.Nizamov[1], Sh.Mirzaev[1], O.Ruzimuradov[2], A.Nasimov[1]
[1] Samarkand State University named after Sharof Rashidov, Samarkand, Uzbekistan.
[2] Turin Polytechnic University in Tashkent, Tashkent, Uzbekistan.

A. Samiev Samarkand State University named after Sharof Rashidov, Samarkand, Uzbekistan.

Received: 17.01.2026
Revised: 24.01.2026
Accepted: 12.02.2026
Published: 30.03.2026

Publisher: Samarkand State University named after Sharof Rashidov.

Abstract. In this study, a g-CN–VN/$CoNi_2S_4$ nanocomposite material with a layer-by-layer architecture was successfully synthesized to improve the photocatalytic conversion efficiency of CO_2. The material consists of a nitrogen-rich g-C_3N_4 matrix and $CoNi_2S_4$ nanoparticles, which are aimed at ensuring effective charge carrier separation through interface engineering. It is known that the use of cocatalysts is a widely used strategy in photocatalytic systems, but weak interface bonds can lead to rapid recombination of electron-hole pairs. These strong interface bonds accelerate electron migration and increase the efficiency of charge carrier separation. As a result, the synthesized nanocomposite exhibited high activity and stability in the photocatalytic reduction of CO_2. The obtained results indicate that the creation of heterostructured photocatalysts based on interface engineering is a promising approach for converting CO_2 into useful products using solar energy.

Keywords: Photocatalysis, Nitrogen vacancies, g-C_3N_4, Nanoparticle, In situ, $CoNi_2S_4$, g-C_3N_4–V_N/$CoNi_2S_4$, CO_2 conversion.

CO_2 NI quyosh nuri ta’sirida samarali konversiyalashni ta’minlovchi g-C_3N_4/$CoNi_2S_4$ geterotuzilmali nanomateriallar sintezi va fizik-kimyoviy xossalari

Annotatsiya. Ushbu tadqiqotda CO_2 ning fotokatalitik konversiya samaradorligini oshirish maqsadida qatlamma-qatlam arxitekturaga ega bo‘lgan CN–VN/$CoNi_2S_4$ nanokompozit materiali muvaffaqiyatli sintez qilindi. Material azotga boy g-C_3N_4 matritsasi hamda $CoNi_2S_4$ nanozarrachalaridan tashkil topgan bo‘lib, interfeys muhandisligi orqali zaryad tashuvchilarning samarali ajralishini ta’minlashga qaratilgan. Ma’lumki, kokatalizatorlardan foydalanish fotokatalitik tizimlarda keng qo‘llaniladigan strategiya hisoblanadi, biroq zaif interfeys bog‘lanishlar elektron kovak juftlarining tez rekombinatsiyasiga olib kelishi mumkin. Ushbu mustahkam interfeys aloqalari elektron migratsiyasini tezlashtirib, zaryad tashuvchilarning ajralish samaradorligini oshiradi. Natijada, sintez qilingan nanokompozit CO_2 ning fotokatalitik reduksiya jarayonida yuqori faollik va barqarorlik namoyon etdi. Olingan natijalar interfeys muhandisligi asosida geterotuzilmali fotokatalizatorlar yaratish CO_2 ni quyosh energiyasi yordamida foydali mahsulotlarga aylantirishda istiqbolli yondashuv ekanligini ko‘rsatadi.

Kalit so‘zlar: fotokataliz, azot bo‘shliqlari, g-C_3N_4, nanozarracha, **in situ**, $CoNi_2S_4$, CN–VN/$CoNi_2S_4$, CO_2 konversiyasi.

Синтез и физико-химические свойства гетероструктурированных аноматериалов g-C_3N_4/$CoNi_2S_4$, обеспечивающих эффективное преобразование CO_2 под воздействием солнечного света

Аннотация. В данном исследовании был успешно синтезирован нанокомпозитный материал g-CN–VN/$CoNi_2S_4$ с послойной архитектурой для повышения эффективности фотокаталитического превращения CO_2. Материал состоит из богатой азотом матрицы g-C_3N_4 и наночастиц $CoNi_2S_4$, что обеспечивает эффективное разделение носителей заряда за счет инженерии межфазных границ. Известно, что использование сокатализаторов является широко распространенной стратегией в фотокаталитических системах, но слабые межфазные связи могут приводить к быстрой рекомбинации электронно-дырочных пар. Эти сильные межфазные связи ускоряют миграцию электронов и повышают эффективность разделения носителей заряда. В результате синтезированный нанокомпозит продемонстрировал высокую активность и стабильность в фотокаталитическом восстановлении CO_2. Полученные результаты показывают, что создание гетероструктурированных фотокатализаторов на основе инженерии межфазных границ является перспективным подходом к превращению CO_2 в полезные продукты с использованием солнечной энергии.

Ключевые Слова: Фотокатализ, азотные вакансии, g-C_3N_4, наночастица, in situ, $CoNi_2S_4$, CN–VN/$CoNi_2S_4$, CO_2 конверсия.

Introduction. The large-scale use of fossil fuels has greatly increased the amount of CO_2 in the atmosphere, making it a major cause of environmental problems. The continued rise of CO_2 strengthens the greenhouse effect, speeds up climate change, and disrupts marine ecosystems by causing ocean acidification[1]. In response to the escalating environmental challenges associated with excessive fossil fuel consumption, significant attention has been directed toward the development of renewable and sustainable energy technologies. One of the most attractive strategies is photocatalytic CO_2 reduction, which offers a green pathway for transforming CO_2 into high-value carbon-based fuels such as CO, CH_4, C_2H_4, and CH_3CHO. This process operates under mild conditions and utilizes solar energy as a clean and inexhaustible power source, making it a highly promising approach for achieving carbon neutrality and sustainable energy conversion[2]. Several photocatalytic materials have been used for CO_2 reduction, such as metal–organic frameworks (MOF), plasmonic metals (Au, Ag), and semiconductors including In_2O_3, and $ZnIn_2S_4$. These materials can absorb light and help convert CO_2 into useful products. [3], have been investigated for CO_2 reduction applications[4] has attracted much attention due to its visible light sensitivity, tunable electronic band structure, and high chemical stability. For example, Lee et al. developed ordered crystalline g-C_3N_4 enriched with specific defect sites to improve CO_2 conversion [5]. The improved crystallinity provides efficient transport of charge carriers, while the cyano and carboxyl functional groups on the surface enhance light harvesting, surface charge accumulation, and CO_2 adsorption capacity, thereby synergistically improving the photocatalytic performance[6]. Although g-C_3N_4 offers many benefits, it suffers from intrinsic drawbacks, including a small specific surface area and fast recombination of photogenerated electrons and holes, which reduce its photocatalytic performance. To address these issues, incorporating cocatalysts has become a common approach to enhance charge separation and speed up redox reactions on the surface. [7]. Nevertheless, conventional cocatalysts made of noble metals like Pt, Pd, and Au face challenges due to their high price and scarcity, restricting their large-scale use. In recent years, bimetallic sulfides based on transition metals have attracted attention as more cost-effective and abundant alternatives [8], which are characterized by multiple valence states of their

constituent metal ions, have attracted increasing interest as cost-effective and highly efficient cocatalysts [9]. $CoNi_2S_4$ stands out due to its high electrical conductivity, which helps electrons generated in the photoexcited semiconductor move quickly. In addition, the presence of multiple oxidation states offers many active sites for CO_2 adsorption and stabilizing reaction intermediates, thereby speeding up the surface reaction process. [10]. Despite being more affordable and catalytically efficient than noble metal-based systems, bimetallic sulfide-modified photocatalysts still face a major challenge: the transfer of charges across the interface is often insufficient. [11]. In this work, a g-C_3N_4-VN/$CoNi_2S_4$ nanocomposite was deliberately fabricated using an in situ growth method, achieving a CO_2 conversion rate of 124.8 $\mu mol \cdot g^{-1} \cdot h^{-1}$ without the need for sacrificial agents. The improved photocatalytic stability is attributed to the formation of strong interfacial bonds that effectively inhibit photocorrosion. Importantly, the in situ growth strategy enables the creation of interfacial Ni–N linkages, which enhance electron transfer and provide numerous active sites for CO_2 adsorption. These interfacial interactions also alter the reaction mechanism by reducing the activation energy for key intermediates and shifting the rate-limiting step from intermediate formation to CO desorption. Consequently, the overall photocatalytic performance is greatly improved. This study underscores the critical importance of engineering the surface and interface microenvironment in photocatalytic systems and offers a rational approach for designing highly efficient photocatalysts for sustainable solar-to-fuel conversion[12].

Experiment. Synthesis of g-C_3N_4-V_N

The synthesis of g-C_3N_4/VN involved a two-step thermal treatment of melamine. In the first step, 9 g of melamine was placed in a closed crucible and heated at 550,5 °C for 122 minutes in a muffle furnace, yielding a solid product denoted as g-C_3N_4 (Fig1). After thorough grinding, 1.3 g of the obtained g-C_3N_4 was transferred into a sealed ceramic boat and further heated at 650 °C for 9 hours under a N_2 atmosphere in a tubular furnace. The final product was labeled as g-C_3N_4-VN.

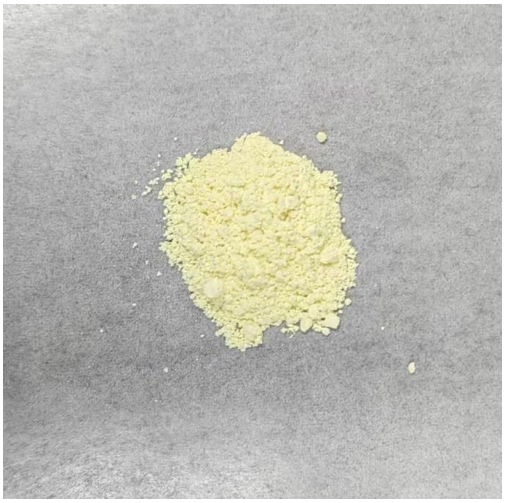

fig1. Sample of g-C_3N_4

Synthesis of g-C_3N_4-V_N/CoNi

100 mg of synthesized CN–VN was dispersed uniformly in 40 ml of a mixed solvent composed of ethylene glycol and polyethylene glycol (1:1. Once a stable suspension was formed, 3 mg of $Co(NO_3)_2 \cdot 6H_2O$, 3.1 mg of $Ni(NO_3)_2 \cdot 6H_2O$, and 1.2 mg of $C_2H_3NaO_2$ were sequentially added under continuous stirring. The mixture was stirred for 30 minutes to ensure thorough mixing and coordination of the metal ions. The resulting suspension was then transferred into a 50 ml Teflon lined stainless steel autoclave and subjected to hydrothermal treatment at 200 °C for 20 hours. After naturally cooling to room temperature, the solid product was collected by centrifugation, washed several times with deionized water and ethanol to remove residual species, and finally freeze-dried to obtain the g-C_3N_4–VN/CoNi composite.

Synthesis of g-C_3N_4-V_N/$CoNi_2S_4$

60 mg of g-C_3N_4–VN/CoNi precursor and 8 mg of C_2H_5NS (thioacetamide) were dissolved in 40 mL of ethanol and stirred magnetically for 10 min to form a homogeneous suspension. The prepared mixture was then placed in a 45 ml Teflon-lined stainless steel autoclave and kept under hydrothermal

conditions at 25 °C for 25 h. After the reaction was completed, the autoclave was naturally cooled to room temperature. The resulting solid product was separated by centrifugation, washed with deionized water and ethanol several times to remove remaining residues, and finally freeze-dried to obtain the final material. The prepared sample was named g-C_3N_4–VN/$CoNi_2S_4$-3 (Fig. 2). To prepare composites with different composition ratios, the mass ratios of $Co(NO_3)_2 \cdot 6H_2O$, $Ni(NO_3)_2 \cdot 6H_2O$, and g-C_3N_4/VN were systematically changed during the precursor synthesis step. At the same time, the amount of sulfur source (thioacetamide) during the sulfidation process was adjusted according to the relative composition of Co and Ni. The resulting products were designated g-C_3N_4–VN/$CoNi_2S_4$-1 and g-C_3N_4–VN/$CoNi_2S_4$-3, respectively.

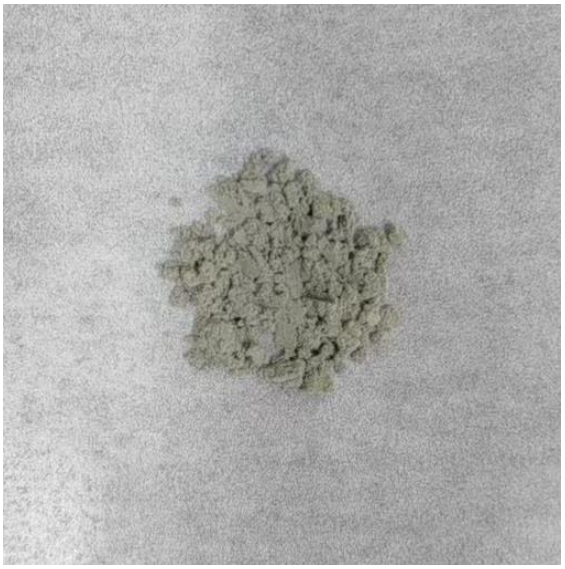

Fig 2. Sample of g-C_3N_4-V_N/$CoNi_2S_4$

Photocatalytic properties. The photocatalytic CO_2 reduction experiments were conducted in a completely sealed gas–solid reaction system. A quartz reactor with an effective volume of 440 ml was used, and a 300 W xenon arc lamp simulating the solar spectrum served as the light source. The light intensity on the catalyst surface was set to 2000 $mW \cdot cm^{-2}$. The lamp emitted light over a wavelength range of 325–800 nm, allowing efficient activation under both ultraviolet and visible light. Before illumination, 1 mg of the photocatalyst powder was evenly spread on a membrane support and placed inside the reactor. To create a humid environment and provide protons for the reaction, 0.45 ml of deionized water was added. Prior to starting the photoreaction, the reactor was purged with high-purity CO_2 gas (≥99.998%) for 25 minutes to eliminate residual air and establish a CO_2 rich closed system. During the reaction, gaseous products were sampled every hour using a 1 ml gas-tight syringe. The collected gases were analyzed by gas chromatography to determine the composition and quantify the amount of products formed.

Results and discussion. The g-C_3N_4-VN/$CoNi_2S_4$ composite was synthesized using an in situ growth strategy designed to establish strong interfacial interactions and enhance charge transfer across the interface. Initially, graphitic carbon nitride (g-C_3N_4) was thermally treated to generate VN (nitrogen vacancy) defects within its structure. This controlled thermal modification created active sites in the g-C_3N_4 framework, which later served as preferential nucleation centers for the deposition of metal sulfide nanoparticles. Subsequently, $CoNi_2S_4$ nanoparticles were directly grown on the g-C_3N_4-VN substrate. The g-C_3N_4-VN/$CoNi_2S_4$ composite was synthesized using an in situ growth strategy designed to establish strong interfacial interactions and enhance charge transfer across the interface. Initially, graphitic carbon nitride (g-C_3N_4) was thermally treated to generate VN (nitrogen vacancy) defects within its structure. This controlled thermal modification created active sites in the g-C_3N_4 framework, which later served as preferential nucleation centers for the deposition of metal sulfide nanoparticles. Subsequently, $CoNi_2S_4$ nanoparticles were directly grown on the g-C_3N_4-VN substrate. The synthesized samples were carefully characterized to study their morphology and microstructure using scanning electron microscopy (SEM). SEM observations provided information on surface features and particle size distribution, while X-ray diffraction (XRD) analysis offered

insights into nanoparticle dispersion, interfacial boundaries, and lattice structure. These results confirmed the successful formation of the g-C_3N_4–VN/$CoNi_2S_4$ heterostructure.

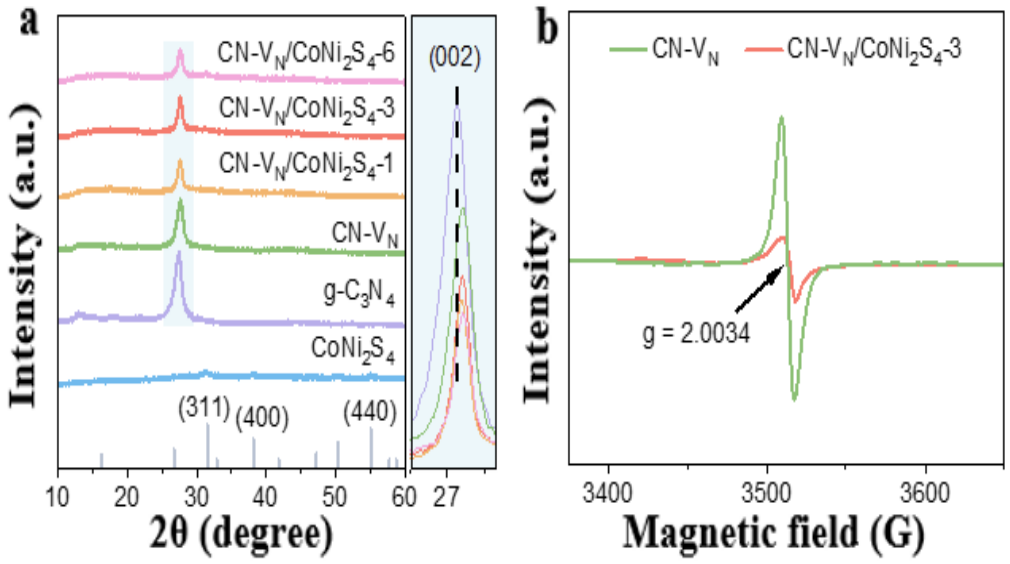

Fig 3. (a) XRD patterns of $CoNi_2S_4$, g-C_3N_4, g-C_3N_4-VN, and g-C_3N_4-VN/$CoNi_2S_4$ with different $CoNi_2S_4$ contents were examined (b) Electron spin resonance (ESR) spectra of g-C_3N_4-VN and g-C_3N_4-VN/$CoNi_2S_4$-3 were recorded.

X-ray diffraction (XRD) analyses were performed to determine the crystal phase, structural order, and interface properties of the synthesized nanomaterials. As shown in Fig.3, the g-C_3N_4/VN sample exhibits characteristic diffraction peaks at 12.8° and 27.4°, which represent the flat-layered tri-s-triazine units of g-C_3N_4 and the interlayer stacking state, respectively. Interestingly, the (002) peak of g-C_3N_4-VN is slightly shifted to the right compared to that of pure g-C_3N_4, indicating the reduction of the interlayer distance, the successful incorporation of VN, and the change in electron density. At the same time, the $CoNi_2S_4$ sample showed diffraction peaks corresponding to the cubic crystal phase. No separate peaks characteristic of Co and Ni elements were detected in XRD analyses, which indicates that they do not exist independently on the surface of $CoNi_2S_4$ and are evenly distributed within the nanostructure. In all the prepared g-C_3N_4-VN/$CoNi_2S_4$ nanocomposites, the peaks characteristic of g-C_3N_4 and $CoNi_2S_4$ are clearly observed, which confirms the successful combination of the two components and the stability of the interface. Meanwhile, the electron spin resonance (ESR) spectra of g-C_3N_4/VN and g-C_3N_4-VN/$CoNi_2S_4$ (Fig. b) show a signal with a γ-value of 2.0034, which clearly confirms the presence of VN. It is noteworthy that the signal in the g-C_3N_4-VN/$CoNi_2S_4$ spectrum is significantly attenuated compared to that of g-C_3N_4/VN, indicating that some of the VN sites are occupied by CoNi2S4 nanoparticles. The unsaturated coordination centers near the VN defects chemically bond with the Ni roofs, causing structural rearrangement at the interface. This indicates that the VN sites in g-C_3N_4-VN act as effective “solidification” points for the $CoNi_2S_4$ nanoparticles, and there is a strong chemical and electronic interaction between them. Thus, the g-C_3N_4-VN/$CoNi_2S_4$ nanocomposite demonstrates the important role of VN defects in enhancing the photocatalytic CO_2 conversion and provides the high photofunctional efficiency of the material.

Conclusions. In this work, a g-C_3N_4-VN/$CoNi_2S_4$ nanocomposite was successfully synthesized using a VN-mediated in situ growth strategy and exhibited high-efficiency photocatalytic CO_2 conversion. The optimized photocatalyst exhibited a CO_2 production rate of 124.8 $\mu mol \cdot g^{-1} \cdot h^{-1}$, which represents a three-fold increase in efficiency compared with the original g-C_3N_4-VN sample. This high photocatalytic activity is mainly attributed to the multifunctional synergistic effect of chemical bonds at the interface modulated by nitrogen vacancies. These bond extend light into the visible and near-infrared range, effectively facilitate charge transfer through the electron bridging effect, and create additional active sites for CO_2 adsorption. Most importantly, these chemical bonds at the interface play a central role in the photocatalytic mechanism and effectively modulate the rate-determining step (RDS) from COOH formation to CO_2 desorption This study not only demonstrates an

efficient nanocomposite synthesis method, but also provides key insights into the optimized design of heterostructure photocatalysts for solar-powered CO_2 conversion.

References

1. Li, H., Gao, W., Ma, K., Lei, J., Ruzimuradov, O., Samiev, A., ... & Li, Y. (2026). Interfacial Ni–N bond in g-C_3N_4/$CoNi_2S_4$ for enhanced photocatalytic CO_2 conversion. Chinese Journal of Catalysis, 82, 266-277. https://doi.org/10.1016/S1872-2067(25)64923-0.
2. Liu, L., Wang, Z., Zhang, J., Ruzimuradov, O., Dai, K., & Low, J. (2023). Tunable interfacial charge transfer in a 2D–2D composite for efficient visible-light-driven CO_2 conversion. Advanced Materials, 35(26), 2300643. https://doi.org/10.1002/adma.202300643.
3. Li, X. H., Wang, X., & Antonietti, M. (2012). Mesoporous gC_3N_4 nanorods as multifunctional supports of ultrafine metal nanoparticles: hydrogen generation from water and reduction of nitrophenol with tandem catalysis in one step. Chemical Science, 3(6), 2170-2174.
4. Shen, R., Zhang, L., Li, N., Lou, Z., Ma, T., Zhang, P., ... & Li, X. (2022). W–N bonds precisely boost Z-scheme interfacial charge transfer in g-C_3N_4/WO_3 heterojunctions for enhanced photocatalytic H2 evolution. ACS Catalysis, 12(16), 9994-10003.
5. Zhang, Y., Wen, D., Sun, W., Peng, J., Yu, D., Li, X., ... & Jiang, J. (2024). State-of-the-art evolution of g-C_3N_4-based photocatalytic applications: A critical review. Chinese Journal of Structural Chemistry, 43(12), 100469.6. L. Chen, M. A. Maigbay, M. Li, X. Qiu, Adv. Powder Mater., **2024**, 3, 100150. https://doi.org/10.1016/j.cjsc.2024.100469
7. Xia, P., Antonietti, M., Zhu, B., Heil, T., Yu, J., & Cao, S. (2019). Designing defective crystalline carbon nitride to enable selective CO_2 photoreduction in the gas phase. Advanced Functional Materials, 29(15), 1900093.
8. A.A.Samiyev, Sh.E.Mirzayev, D.B.Boyqobilov, A.M.Nasimov, CO_2 konversiyasi uchun anodlash usulida La qo‘shilgan TiO_2 asosidagi nanotuzilishli materiallar sintezi//Samarqand davlat Universiteti Ilmiy Axborotnomasi №5.1(147), 2024. B.79-83
9. Boykobilov, D., Thakur, S., Samiev, A., Nasimov, A., Turaev, K., Nurmanov, S., Ruzimuradov, O Electrochemical synthesis and modification of novel TiO_2 nanotubes: Chemistry and role of key synthesis parameters for photocatalytic applications in energy and environment //Inorganic Chemistry Communications. – 2024. – P. 113419.
10. Zhang, Q., Gong, W., Che, H., Liu, B., & Ao, Y. (2023). S doping induces to promoted spatial separation of charge carriers on carbon nitride for efficiently photocatalytic degradation of atrazine. Chinese Journal of Structural Chemistry, 42(12), 100205. https://doi.org/10.1016/j.cjsc.2023.100205.
11. Zhou, Z., Guo, W., Yang, T., Zheng, D., Fang, Y., Lin, X., ... & Wang, S. (2024). Defect and nanostructure engineering of polymeric carbon nitride for visible-light-driven CO_2 reduction. Chinese Journal of Structural Chemistry, 43(3), 100245. https://doi.org/10.1016/j.cjsc.2024.100245.
12. Zhao, Y., Gao, K., Li, J., Liu, H., Chen, F., Wang, W., ... & Hu, Y. (2025). Engineering of Lewis acid–base interfaces in Cu_2S/$ZnIn_2S_4$ hollow hetero-nanocages for enhanced photocatalytic CO_2 reduction. Nanoscale Horizons, 10(9), 2045-2054.

SAMARQAND DAVLAT UNIVERSITETI ILMIY AXBOROTNOMASI

НАУЧНЫЙ ВЕСТНИК SCIENTIFIC REPORTS

Texnik muharrir **Sh.Xoliqulov**

Muharrirlar:

I.Sulaymonov - fil.f.d., dotsent
E.Arziqulov - f.-m.f.d., dotsent
O.Yusupova - fil.f.n., dotsent

Mas'ul muharrir:

A. Sh. Yarmuxamedov - f.-m.f.n.

Muassis: Samarqand davlat universiteti Manzil: 140104,
Samarqand shahri, Universitet xiyoboni, 15.
Telefon: (0 366) 240-38-47, Faks: (0 366) 239-13-87 e-mail:
axborotnoma.uz
SamDU «Ilmiy axborotnoma» jurnali tahririyati kompyuterida terildi. Bosishga 30.03.2026-yilda ruxsat etildi. Qog'oz o'lchami A-4. Nashriyot hisob tabog'i 10,00
Buyurtma raqami 833. Adadi 30 nusxa.

ISSN 2181-1296