UDC 621.31 https://doi.org/10.33619/2414-2948/81/25

RESEARCH PROGRESS OF TYPE P COPPER (I) OXIDE IN THE FIELD OF LIGHT ENERGY UTILIZATION

©**Ren Bingbing,** *Jiangsu University of Science and Technology, Zhenjiang, China, 425442183@qq.com*
©**Mindrov K.,** *Ogarev Mordovia State University, Saransk, Russia*

ПРОГРЕСС В ИССЛЕДОВАНИЯХ ОКСИДА МЕДИ (I) ТИПА P В ОБЛАСТИ ИСПОЛЬЗОВАНИЯ СВЕТОВОЙ ЭНЕРГИИ

©**Жэнь Бинбин,** *Цзянсуский университет науки и технологии, Чжэньцзян, Китай*
©**Миндров К. А.,** *Национальный исследовательский Мордовский государственный университет имени Н.П. Огарева, г. Саранск, Россия*

Abstract. Copper (I) oxide Cu_2O, as a representative intrinsic P-type inorganic semiconductor material, has been widely used in the field of optical energy utilization, such as photovoltaic, photocatalysis, photodegradation and other fields, and has an extremely important position. For a long time, the literature on Cu_2O's application technology in the field of light energy utilization is relatively scattered and independent, resulting in a certain degree of obstacles and difficulties to obtain relevant technical knowledge and have a deep understanding of its internal principles. According to the application of Cu_2O in the field of light energy utilization in recent years, it is mainly divided into three modules (photovoltaic, photocatalysis, photodegradation, photodegradation), and mainly summarizes the classification, principle and characteristics of Cu_2O application in the field of light energy and prospects the optimization method and development direction of the application in the field of Cu_2O light energy. This review aims to provide reference and guidance for the optical energy applications of Cu_2O and other related inorganic oxide semiconductors.

Аннотация. Оксид меди (I) Cu_2O, как типичный неорганический полупроводниковый материал P-типа, широко используется в области использования оптической энергии, такой как фотоэлектрика, фотокатализ, фотодеградация и другие области, и занимает чрезвычайно важное положение. Долгое время литература по технологии применения Cu_2O в области использования световой энергии была относительно разрозненной и независимой, что приводит к определенной степени препятствий и трудностей при получении соответствующих технических знаний и глубокого понимания его внутренних принципов. В соответствии с применением Cu_2O в области использования световой энергии в последние годы, он в основном разделен на три модуля (фотоэлектрический, фотокатализ, фотодеградация, фотодеградация) и в основном обобщает классификацию, принцип и характеристики применения Cu_2O в области световой энергии и перспективы метода оптимизации и направления развития применения в области световой энергии Cu_2O. Цель этого обзора — предоставить справочные материалы и рекомендации по применению Cu_2O и других родственных неорганических оксидных полупроводников в оптической энергии.

Keywords: cuprous oxide, inorganic oxide, light energy utilization, research progress.
Ключевые слова: оксид меди, неорганический оксид, использование световой энергии, ход исследований.

Cu_2O is a promising p-type semiconductor material, with a direct bandgap structure of 2.17eV, high electrical conductivity, high carrier mobility, non-toxic and rich content and other properties that make Cu_2O is widely used in various industries [1-6].

In the photovoltaic field, Cu_2O is mainly used as the hole transmission material and light absorption material in solar cells [7-12]. Due to the direct band-gap structure of Cu_2O, Cu_2O can effectively absorb in the visible light range of the solar spectrum. At the same time [13], compared with the side effects of dilution, transfer, transformation, oxidation and ozone treatment measures of traditional pollution treatment measures, nano copper oxide in photocatalysts that degrade organic pollutants has been attracting attention to in the field of photocatalysis industry due to its strong oxidation ability [14-18], high catalytic activity and good stability. Photodegradation refers to the phenomenon of pollutant decomposition caused by the action of light. These include photochemical degradation, polymer photodegradation, photodegradable plastics, and photodegradable photosensitive polymers. However, Cu_2O is mainly used in [19-23] photochemical degradation and polymer photodegradation.

As a traditional inorganic oxide semiconductor material proposed and applied as early as 1926 [24], although the previous literature has been introduced and summarized to a certain extent, but the content is relatively scattered and independent, and the explanation of the process and mechanism is relatively simple. This paper will systematically classify, summarize, and summarize the various kinds of Cu_2O in the field of light energy utilization, and advance the various technical schemes

Line analysis and summary, aiming to play an enlightening and synergistic role in the application of Cu_2O.

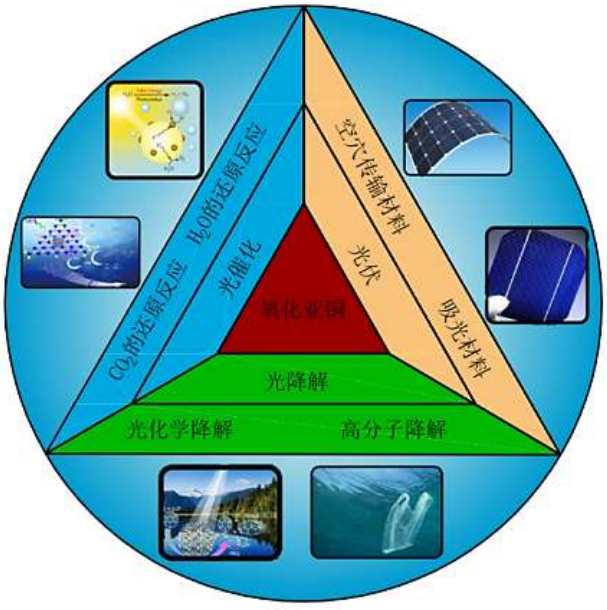


Figure 1. Application neighborhood of cuprous oxide

Solar photovoltaic effect, hereinafter referred to as photovoltaic (PV), refers to the phenomenon of potential difference between uneven semiconductor or semiconductor and metal combination during light. Photovoltaic technology has many advantages, such as no mechanical

Т. 8. №8. 2022
https://doi.org/10.33619/2414-2948/81

operating parts; no other, except sunlight; fuel, working in both direct and oblique sunlight. Among them, nano-copper oxide has the advantages of rich raw materials, high theoretical conversion efficiency and direct energy band structure, which has become a relatively potential solar cell material in recent years [24-27].

Cu_2O, as a hole transmission material, can improve the open circuit voltage, short circuit current and photocurrent of solar cells, thus improving the efficiency and stability of solar cells by [8, 28]. In 2015, Hossain [29] used wxAMPS and SCAPS software to calculate key features of CH3NH3PbI3-based solar cells. The results showed that solar cells containing Cu_2O as the HTM outperformed all other organic or inorganic HTM devices tested to date. The obtained power conversion efficiency exceeded 24%. Moreover, the use of Cu_2O is expected to provide moisture protection for perovskite, thus improving the performance of the device. These results suggest that, by replacing the expensive and water-sensitive spiro-OMETAD with Cu_2O, it promises to further improve the performance of perovskite cells and reduce their cost. In the same year, Yu [1] prepared perovskite layers with 11.0% PCE under AM1.5G nano-Cu_2O film (5 nm) HTM illumination.

In addition, the ultra-thin properties of Cu_2O films help reduce the material consumption and manufacturing costs of large-scale production of perovskite solar cells. The thickness and performance of the Cu_2O layer must be precisely adjusted to achieve optimal solar cell performance. In 2016, Nejand [30] introduced inorganic sandwich perovskite solar cells, with a PCE value of 8.93%.The use of Cu_2O as the HTM on the pinhole and needle-free perovskite layers yields high values of power conversion efficiency, especially when the pinhole-free perovskite layers are used.According to photoluminescence studies, Cu_2O shows better hole pumping capacity (hole-extraction) com- pared to Spiro-OMeTAD, proving that it is a promising candidate for alternatives to expensive organic HTMs in perovskite solar cells.

Moreover, in 2017, Guo [31] et al. synthesized Cu_2O films through reactive magnetron sputtering at room temperature (Figure 2a). The maximum power conversion efficiency of the OSCs based on the classic PTB7: PC71BM active layer is 8.61% (Figure 2b), 15% higher than the OSCs (solar cell) in the standard PEDOT: PSSHTM layer. Devices based on cuu oxide HTM exhibit better energy level alignment, reduced series resistance, and therefore improved charge extraction capab- ility. The results show that high mobility, low series resistance and better band energy alignment are related to improving the pumping capacity of the device, improving the performance of the short-circuit current density and filling factor in the Cu oxide solar cells.

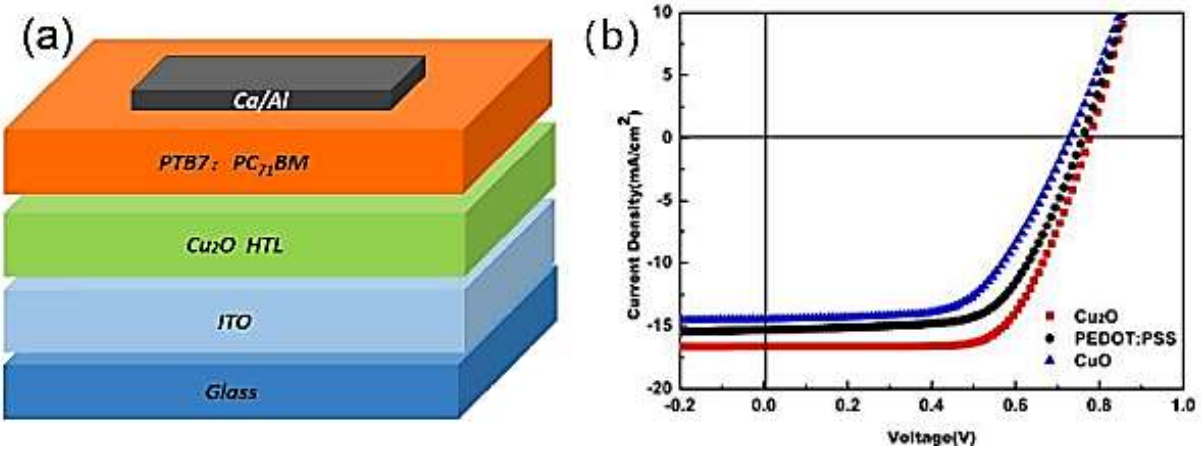


Figure 2. (a) Schematic diagram of planar body heterojunction solar cell. (b) OsCS power conversion efficiency diagram based on PTB7:PC71BM system [31]

Т. 8. №8. 2022
https://doi.org/10.33619/2414-2948/81

Later, in 2019, Elseman [32] provided a p-type hole transport layer (HTL) for a regularly structured nano-Cu_2O (p-i-p) perovskite solar cell. This work is the first to use this treated Cu_2O nanocubic solution as a top layer in perovskite solar cells. He prepared (100) crystal surfaces of 60 to 80 n m without surfactant and template and found that Cu_2O nanocrystalline were not easy to reunite. The synergistic effect of different Cu_2O nanocubic concentrations on the photovoltaic performance was investigated, and the optimized Cu_2O-based PSC was 17.23% higher than the device PCE where P3HT is HTL. The Cu_2O nanocubes showed more stability at room temperature compared to P3HT.The results show that the Cu_2O nanocubes can be used to prepare highly efficient and stable PSCs, and they are a very promising hole transport layer.

Cu_2O began to be studied as a photoele- ctric conversion material in the 1970s. At present, many heterojunctions solar cells combined with n-type semiconductors such as ZnO, CdO, and ITO have been reported, among which the theoretical conversion efficiency of Cu_2O/ZnO solar cells can reach 20% [33]. The conversion efficiency of Cu_2O/ZnO heterojunction solar cells is significantly improved by doping and interface control, but the current experimental data only show a conversion efficiency of about 2% [34]. Meanwhile, different thicknesses also affect the optical response properties of Cu_2O films. In 2012, Gershon [35] proposed a new approach to overcome the limitations of low long-wavelength absorption and short charge transport length in electrodeposited bilayer ZnO/Cu_2O solar cells. Here, the Gershon reduces the thickness of the Cu_2O to the transport length of about a few charge carriers and covers a thin film of a semiconductor polymer between the Cu_2O and the top electrode. Experiments show that the ZnO/Cu_2O photoabsorption layer of 2.7 m thickness shows the best light absorption at the Cu_2O thickness of 0.85 m. We show that achieving the ratio of optical absorption to film thickness is a promising way to overcome the charge transport difference and low-wavelength absorption in copper oxide electrodeposited films.

In 2015, Soundaram [34] successfully prepared the ZnO/Cu_2O/ITO heterostructures deposited by SILAR. The study showed that the SITAR method improved Voc and reached 0.297 and 4.841, respectively. It is also demonstrated that the maximum transmittance of ZnO films is 80% as the Cu_2O film thickness increases. The solar cell efficiency of the Cu_2O/ZnO structure was measured and found to increase with the Cu_2O membrane thickness.

In the same year, Yu [36] used electroch- emical deposition method to synthesize Cu_2O films with high electron and optical properties with different fluorine (F) content on ITO glass (Figure 3A), especially when the molar ratio of F/Cu was 1:2.The sample has a unique mesh microstructure, with the optimal visible light absorption performance (Figure 3C), and its electron concentration (Figure 3B) is more than 10 times that of pure Cu_2O. Moreover, it has the lowest resistivity (Figure 3D), which favors the light-generation charge transfer and a reduction of the electron-hole pair composite. F-doped Cu_2O films were prepared into Cu_2O homogeneous junction solar cells by continuous electrochemical deposition. The conversion efficiency of F-doped Cu_2O in homogeneous junction solar cells (Figure 3E) is nearly 8 times that of pure Cu_2O as the n-type layer. The application of F-doped Cu_2O to homogenous junction solar cells will provide inspiration for the development of another cheap, environmentally friendly solar cell.

The photocatalytic technology using solar energy is a new technology and has a broad application prospect, which is very suitable for physical adsorption, chemical oxidation and other traditional methods that cannot degrade or degrade inefficient organic matter. Among them, Cu_2O is favored by [37, 38] in the field of photocatalysis. Usually, Cu_2O and other inorganic semiconductor electrons are coupled to make the photocatalytic material [39-41].

Т. 8. №8. 2022
https://doi.org/10.33619/2414-2948/81

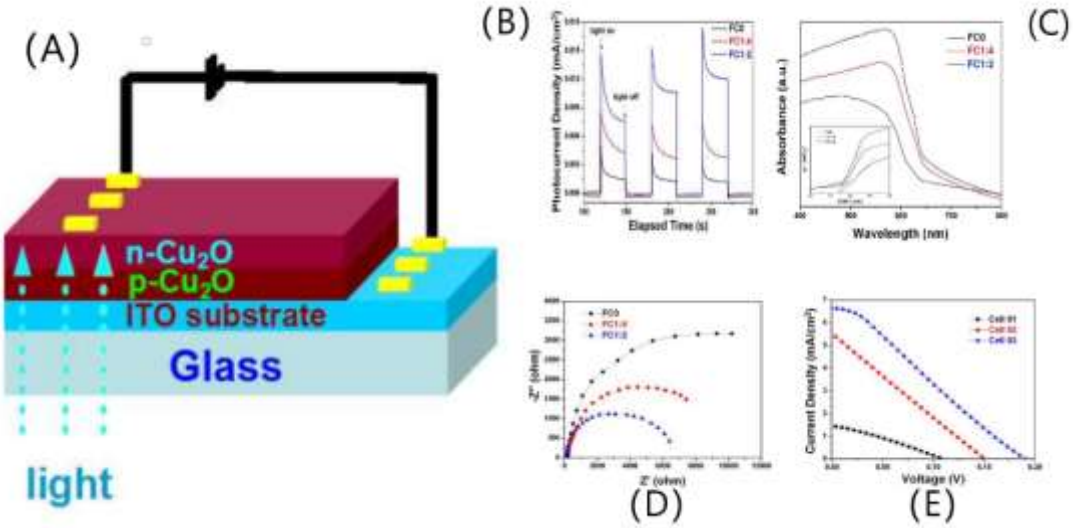


Figure 3 (A) Assembly schematic diagram of P-N Cu_2O homogeneous junction solar cell. (B) Photocurrent density of the sample doped with F Cu_2O under visible light irradiation and optical switching cycle. (C) UV-Vis diffuse reflectance spectra of Fe-doped Cu2O samples with different molar ratios of Fe/Cu. (D) Electrochemical Impedance Spectrometry of F-doped Cu2O electrode measured in Na_2SO_4 aqueous solution (0.02 M) under dark conditions. (E) I-V curves of three kinds of p-N Cu_2O homojunction solar cells under AM 1.5 illumination [36]

The release of CO_2 into the environment is one of the worst problems caused by the greenhouse effect. Photocatalytic reduction of CO_2 using solar energy is a promising approach to address the problem of greenhouse gases and to convert CO_2 into a reusable hydrocarbon resource [42, 43]. When two semiconductor electrons are coupled, their photocatalytic properties can greatly improve the [44-47]. In 2020, Ojha [48] used a solvent thermal reactor to form heterostructures between Cu_2O and SnS_2/SnO_2 nanocompo- sites, which generate CO, H_2 and CH_4 by H_2O-reducing CO_2 at room temperature. With the addition of Cu_2O, the apparent quantum yield for measuring the photoactivity was increased from 7.16% to 8.62%. Meanwhile, the selectivity of CH_4 for CO was about 1.8-fold higher than that for SnS_2/SnO_2.The resultant catalyst is capable of fixing N_2 to the NH_3 under light conditions. In the absence of the sacrificial agent, the NH_4^+ generation rate of $Cu_2O/SnS_2/SnO_2$ of 66.35 $molg^{-1}h^{-1}$ was 1.9 times that of SnS_2/SnO. The p-n heterojunction formed between the Cu_2O and the SnS_2/SnO nanocomposites has a good photoreduction potential and a high stability.

As early as 2014, Li [49] prepared cuprous oxide/red iron nanotubes (Cu_2O/ Fe_2O_3NTs) by using the constant potential electrodeposition method. Among them, materials with a double-layer copper oxide sphere (Cu_2O/Fe_2O_3NTs-30) show excellent PEC performance, with a suitable band gap (1.96eV) and a minimum superpotential (180mV). In addition, Cu_2O/Fe_2O_3NTs-30 shows two synergies in CO_2 reduction by PEC: (i) between electrocatalysis and photocatalysis, and (ii) between cuproxide and Fe_2O_3NTs. After 6 hours, the efficiency and methanol yield of the Faraday method reached 93% and 4.94 mmol L-1cm2, respectively.

In 2018, to achieve 24-hour photocatalysis, Lu [50] successfully designed and built a Cu_2O nanocryststal/TiO_2 microsphere (Cu_2O NCs/M-TiO_2) rotating disk reactor assisted by long afterglow phosphobodies, with the mechanism diagram shown in Figure 4. Experiments show that the composite expands the light response region and improves the quantum efficiency. It improves the light utilization yield of the photocatalytic system by keeping the catalyst hovering and avoiding the

Т. 8. №8. 2022
https://doi.org/10.33619/2414-2948/81

solution shading effect. Finally, 24h photocatalysis was achieved with the help of long afterglow phosphoomes.

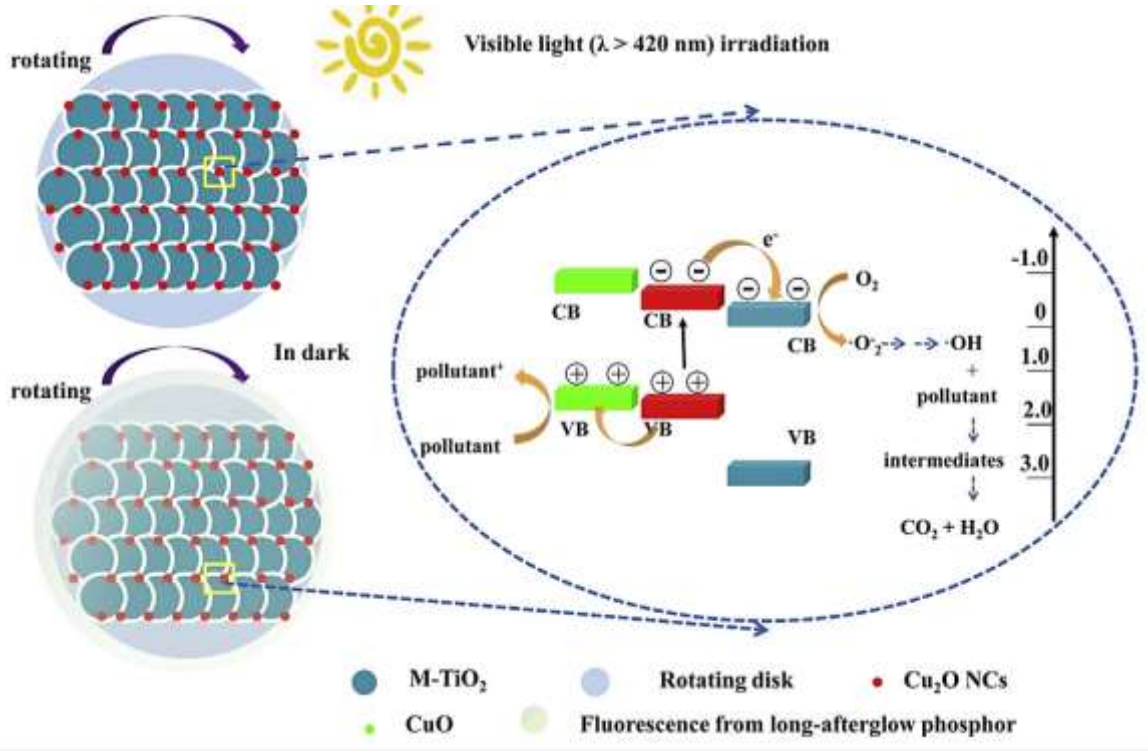


Figure 4. Degradation mechanism of pollutants in Cu2O NCS /M-TiO2 rotating disc reactor assisted by long-afterglow phosphor [50]

In addition, in 2018, Li [51] synthesized the Cu_2O/TiO_2 complex by rapid chemical reduction. Use as a thin-film electrode raw material for carbon dioxide photoreduction. The composite was then tested as a thin film electrode in the photoreduction of CO_2 in the cathode chamber in different fresh solutions (250mL) at different pH values of 2.0,7.0, and 12.0. CO_2 photoreduction and visible photoactivation of Cu_2O/TiO_2 composite showed excellent performance at pH of 12. The methanol yield was 1.635 mg/L after 4 h of CO_2 reduction, and CO_2 passed through formaldehyde intermediates. The surface properties of the Cu_2O/TiO_2 composite have good effects on the band coupling to obtain efficient photocatalytic properties.

Also in 2018, Kulandaivalu [52] synthe- sized blue, fluorescent carbon quantum dots (CQDs) through a simple top-down hydrothermal method, using biochar as the carbon source. The synthetic CQD is combined with the commercial copper (I) oxide (ferrous copper oxide) nanoparticles to form the CQD/Cu_2O nanocomposites. The CQD, Cu_2O, and CQD/Cu_2O nanocomposites were then applied for gas-phase photocatalytic CO_2 reduction. The experimental results showed that the photocatalytic activity of the CQDs/Cu_2O nanocomposite photocatalysts was increased by 54% when compared to the original Cu_2O.

Some advanced oxidation processes (AOP) are characterized by a special chemical feature: the ability to use the high reactivity of the OH free radicals in driving the oxidation processes. These free radicals are suitable for achieving complete emission reduction, including even mineralized [53-55] with less reactive contaminants. In 2005, Carrier [56] used a photocatalytic process to degrade imazapal, a herbicide of the imimazolinone family. It has been shown to rapidly and extensively photodegrade in aqueous solutions. The effect of dissolved metal ions on the

Т. 8. №8. 2022
https://doi.org/10.33619/2414-2948/81

photocatalytic degradation rate of titanium dioxide powder is investigated. The results can be summarized as follows: For low concentrations of Cu^{2+} and Ni^{2+}, the rate constant decreases. At higher concentrations, the plateau was reached. Phototon reactions at higher concentrations reduced negative effects such as photodeposition of CuO and Cu_2O and recombination of h^+/e^-. In 2020, Omrani [3] demonstrated that for individual Cu_2O or CdS semiconductors, the coupling of Cu_2O and CdS nanoparticles (NPs) showed enhanced photocatalytic activity in the degradation of sulfamalazine (SSZ) in aqueous solution. Experiments show that the improved photocatalytic activity of the Cu_2O-CdS composite is associated with a better charge transfer between the charge carriers in the composite.

As early as 2013, Wang [57] deposited Cu_2O/TiO_2p-n heterojunction photoelectrodes on n-type titanium dioxide nanotubes (Figure 5A.C.D). Loading of copper oxide nanoparticles enhanced the visible light response of titanium dioxide NTAs. The photocatalysts with a small amount of copper oxide nanoparticles loaded on Ti 2 nanotubes showed the maximum photoflow and photoconversion efficiency under both UV and visible light irradiation, as well as the highest visible photocatalytic degradation rate of RhB, and the degradation mechanism diagram is shown in Figure 5B. In particular, when the 0.5V bias potential is applied, the Cu_2O/TiO_2NTA photoelectrode has a superior photocatalytic efficiency due to the synergistic effect of electrical and visible light irradiation, and thus it is one of the candidates for environmental applications of wastewater treatment and water light-induced splitting into hydrogen.

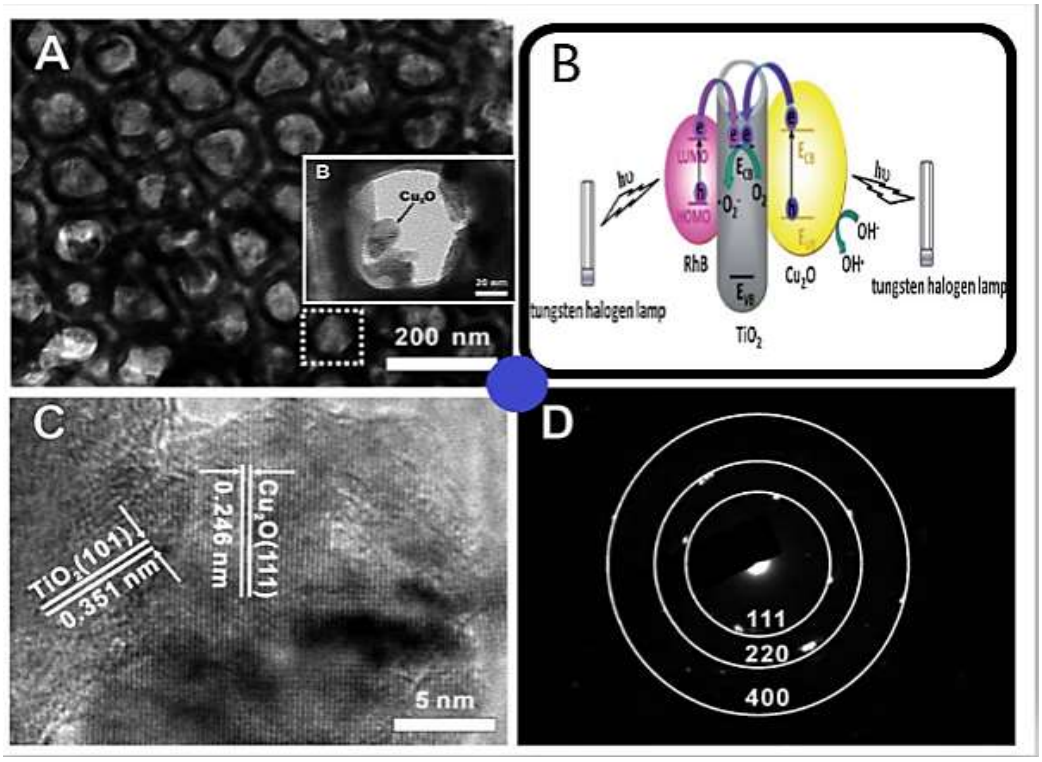


Figure 5. (A) Low magnification TEM image of Cu_2O/TiO_2 NTAS prepared by ultrasound-assisted S-CBD for 4 min (top view). (B) Schematic diagram of photocatalytic degradation of RHB by Cu_2O/TiO_2 NTAS under visible light (C) High-resolution TEM images of Cu_2O/TiO_2 NTAS. (D) Cu_2O is selected from the Region Electron Diffraction (SAED) mode of (C) nanoparticles [57]

Later, by 2020, Wang [58] prepared the Cu_2O-Pt/SiC/IrOx composite by controlled photodeposition and used the Nafion membrane as an artificial photosynthetic system to separate

Т. 8. №8. 2022
https://doi.org/10.33619/2414-2948/81

reduction and oxidation. To find out the optimal co-catalyst content, they tested the photocatalytic activity of the sample on the reaction of CO_2 with H_2O under visible light irradiation and found that HCOOH was the main product of all the photocatalysts. When IrOx and Cu2O were deposited simultaneously on the optimal Pt/SiC, the HCOOH yield was highest at an IrOx content of ~ 2.2 wt% and a Cu_2O content of ~ 1.8 wt%, respectively. The deposition of a too-thick Cu2O layer rather than that on the surface of the Pt was unfavorable at a Cu_2O content higher than 1.8 wt%. The HCOOH yield was almost 37 times more abundant than the naked SiC activity under the optimal Cu_2O-Pt/SiC/IrOx conditions. This artificial system showed excellent photocatalytic performance in CO_2 reduction to HCOOH and the oxidation of H_2O to O_2 under visible light irradiation. The yields of HCOOH and O_2 essentially coincided with the stoichiometry, being as high as 896.7 and 440.7 μmol g-1 h-1, respectively. The high efficiency of CO_2 reduction and H_2O oxidation in the artificial system is attributed to the direct z-format electronic structure of the Cu_2O-Pt/SiC/IrOx and the spatially separated indirect z-format reduction and oxidation units. This greatly extends the service life of photogenerated electrons and holes and prevents the reverse reaction of the products. This study provides an effective and feasible strategy to improve artificial photosynthetic efficiency.

In recent years, metal oxide semiconductors have received increasing attention as a catalyst for photocatalytic degradation of organic pollutants in water, which is conducive to solving environmental problems related to wastewater [59-62].

Photochemical degradation refers to the reaction of organic compounds into homologues with less carbon atoms under the action of light. In 2012, An [63] used a combination of catalysts (FeCu and Cu_2O) to degrade five commonly used drugs and personal care products (PPCPs). The current between Cu and Fe increases the dissolution rate of the anode iron as compared to the internal microcircuit of Fe/C. Moreover, due to the photochemical properties, Cu_2O can accelerate the degradation process of PPCPs under visible light irradiation.

Also in 2012, Zhu [64] successfully prepared the Cu_2O/AS composites by using a simple deposition method (Figure 6C). Acid-treated silica (AS) fibers are excellent carriers for Cu_2O particles (Figure 6A). AS improves the optical properties of Cu_2O and redshifts the band gap, thus improving the use of visible light, and thus effectively improving the photocatalytic activity of Cu_2O. The Cu_2O/AS composites showed excellent photo- catalytic properties in the degradation of red water (Figure 6B). The 87.0% red water can be photocatalyzed degraded by Cu_2O/AS 5h after irradiation, and most of the organic com- ponents of red water were degraded except 1,3,5-trinitrobenzene.

Cu_2O is a low-cost semiconductor with narrow band gap, high absorption coefficient and suitable conduction band, but it has low charge mobility, poor quantum yield and poor catalytic performance. However, in 2017, Zhang [65] greatly improved the catalytic capacity of Cu_2O for the degradation of fire-resistant pollutants with a simple and effective strategy. Using a synergistic effect of photocatalysis and Fenton, Scheme I propose a novel and highly efficient photocatalytic-driven Fenton system for the PFC. The Cu_2O/nano C mix was used and experimentally verified. The synergistic PFC is highly dependent on nanoscale C and facilitates the wastewater removal of rhodamine B and p-nitrophenol, two typical fire-resistant contaminants.

Antibiotics and heavy metals often coexist in the polluted environment, and the harm of compound pollution is greater than that of a single pollution. In 2019, Huang [66] synthesized a series of graphene-loaded p-n heterojunction rGO@Cu_2O/$BiVO_4$ composites, doped with different Cu_2O, for the simultaneous detoxification of Cr (VI) and antibiotics. In this study, a series of p-n heterojunction composite materials, rGO@Cu_2O/$BiVO_4$, was applied to the efficient reduction and SMZ oxidation of Cr (VI) under LED light. With the increase of the Cu_2O load, the photoabsorption

Т. 8. №8. 2022
https://doi.org/10.33619/2414-2948/81

performance of LED improves, and the appropriate band gap of the p-n heterojunction enables its effective electron/hole separation, ensuring the photocatalytic activity of LED. This work provides a new method for the coexistence of Cr (VI) and antibiotic pollutants in wastewater treated by rGO@Cu_2O/$BiVO_4$ p-n heterojunction compound synthesis.

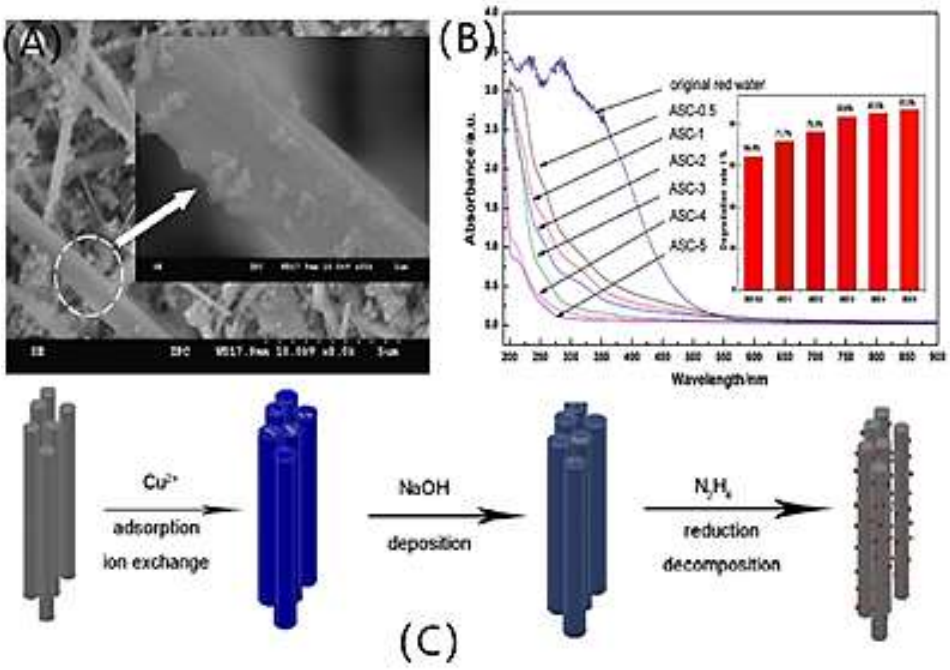
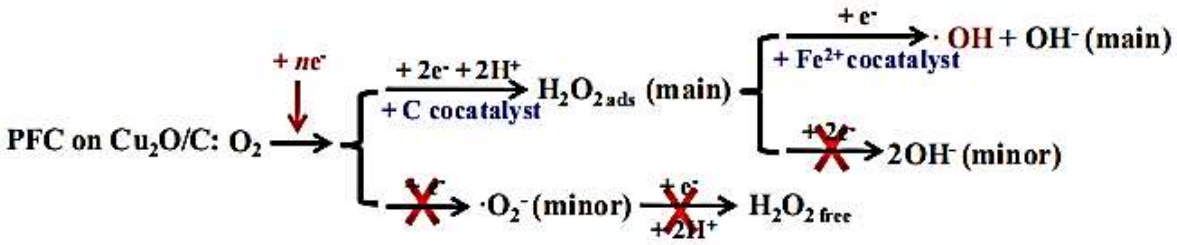


Figure 6. (A) SEM images of different Cu_2O/ As samples. (B) UV-Vis spectra of residual red water treated with different photocatalysts for 5 h. (C) Cu_2O/As preparation process schematic diagram [64]

The synergistic O_2 continuous reduction pathway of PFC by Cu_2O and Cu_2O/Nano-C complexes under visible light irradiation ($\lambda > 420$ nm)



Polymer photodegradation is one of the research advances in the field of light energy. With the deepening of the research in the field of light energy, polymer photodegradation has increasingly attracted the attention of researchers. In the process of applying this method, many problems have become highlighted, and the discussion on polymer photodegradation is becoming increasingly fierce.

Back in 2015, Falah [67] introduced the synthesis of spherical Cu_2O nanoparticles and a composite of P25 TiO_2 with aluminsilicate inorganic polymer (ground polymer), and XRD and FTIR confirmed that the addition of Cu_2O/TiO_2 nanoparticles had no effect on the formation of the polymer matrix. But experiments under dark conditions and under UV irradiation show that the composite removes the MB dye through a combination of adsorption and photodegradation without

Т. 8. №8. 2022
https://doi.org/10.33619/2414-2948/81

disrupting the structure of the polymer. The combination of nanometer Cu_2O particles and photoreactive P25 titanium in an aluminosilicate inorganic polymer substrate under UV irradiation is a more effective photocatalyst than a single oxide under UV irradiation. It can effectively remove the model organic contaminant methylene blue dye in solution.

Later, in 2016, Zhang [68] synthesized a new copu oxide nanocomposite (Cu_2O@3D-rGO@NCS) by one-step in situ reduction (Figure 7a). The Cu_2O@3D-rGO@NCS has an excellent photocatalytic capability, thanks to the high porosity of the 3D-rGO, the efficient charge transfer from the Cu_2O to the rGO, and the high adsorption capacity of the NCS (Figure 7d). XPS, SEM, and TEM show that Cu_2O nanospheres and NCS particles are evenly distributed on 3D-rGO sheets. The porous and mesh structure of 3D-rGO not only improves the high load of Cu_2O and improves the adsorption capacity of dye molecules, but also promotes the rapid transfer of optoelectronics (Figure 7b). The Cu_2O@3D rGOwas@NCSimproved RhB PGs efficiency compared to the Cu_2O nanosphere and Cu_2O@3D-rGO nanocomposites and the nanocomposites, respectively (Figure 7c.e.f). Interestingly, the simple method proposed in this study may be extended to the synthesis of other nanocomposites with various functions grown on 3D-rGO sheets.

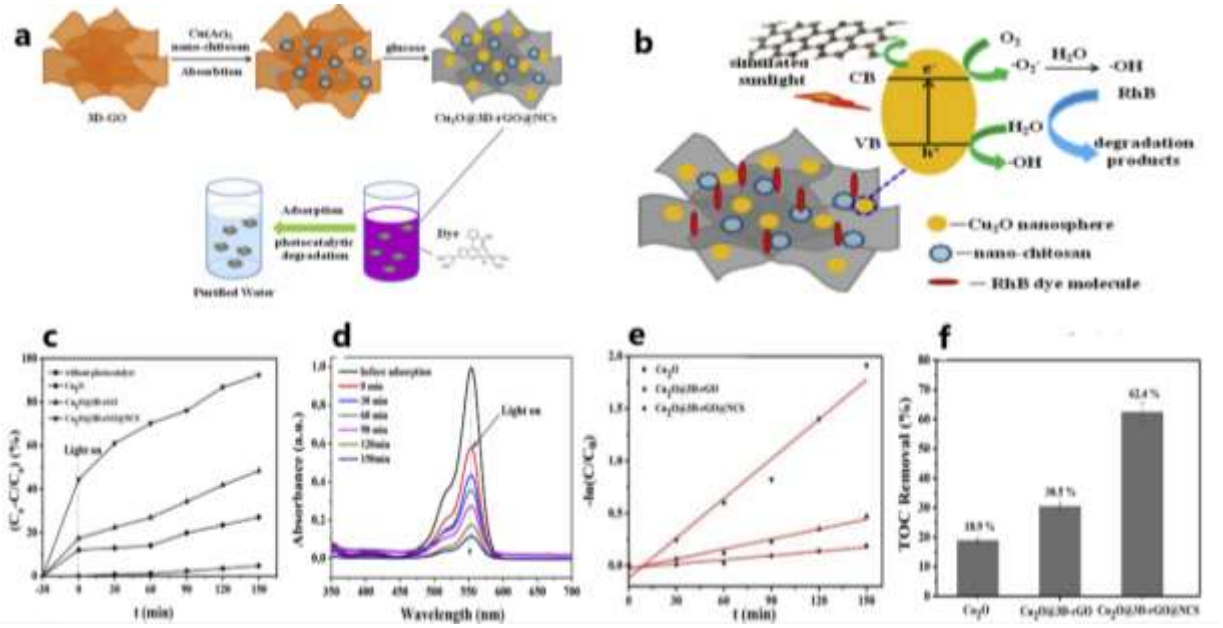


Figure 7. (a) A schematic diagram of photocatalytic degradation of RhB using the developed Cu_2O@3D-rGO@NCS nanocomposite as a photocatalyst. (b) Using Cu_2O @3D-rGO@NCS nanocomposite as photocatalyst, the schematic diagram of charge separation and photodegradation mechanism of RhB dye of @NCS nanocomposite under solar irradiation was simulated. (c) The presence of Cu_2O nanospheres, Cu_2O @3D-rGO, and Acr@NCs in simulated sunlight, and the elimination of RhB in the absence of photocatalyst.(d) UV-Vis absorption spectra of RhB in the presence of Cu_2O @3D-rGO@NCS nanocomposites.(E) The change curve of eln(C/C_0) in photodegradation of RhB aqueous solution with simulated illumination time in the presence of Cu_2O, Cu_2O @3D-rGO and FeN@NCS.(f) The percentage of TOC in RhB aqueous solution was removed by Cu_2O, Cu_2O @3D-rGO and NaNi@NCS [68]

In addition, in 2018, Anku [69] proposed the biolorization of acrylic acid (Gg) grafted acrylic acid (AA) and acrylamide (AAm) (Cu_2O/Gg AAm AA) as nano Cu_2O particles. The results show that Cu_2O/Gg AAm AA is a good photocatalyst to effectively remove naphthol blue-black dye from water. The procedure has an optimal pH value of 6. The photodecolorization process enhanced with increasing catalyst concentration but showed a decreasing trend above 0.3 g L-1. The excellent

Т. 8. №8. 2022
https://doi.org/10.33619/2414-2948/81

photodegradation efficiency of the nanocomposite is attributed to the excellent dye molecule adsorption capacity of the Gg AAm AA polymer matrix, as well as the high visible photoactivity and photocatalytic properties of the Cu_2O nanoparticles. The recyclability studies show that Cu_2O/Gg AAm AA nanocomposites can be efficiently recycled and reused.

In 2019, Razmara [70] synthesized the [Cu_2(μ-ox)2(pyz)3]n (Pyz = pyrazine + ox = oxalate) supramolecular coordination complex under ultrasound irradiation. Studies of the complex show that the complex has good thermal stability and is a weak ferromagnet. After characterization with various techniques, octahedral Cu_2O nanoparticles with edge lengths of 5-80 nm were produced by calcination at 600 °C. The adsorption capacity and photocatalytic activity of octahedral Cu_2O nanoparticles at room temperature were investigated. The final results indicate that octahedral Cu_2O nanoparticles play an important role in the degradation and adsorption of RB, with a maximum degradation efficiency of 91.7% and a maximum adsorption capacity of 83.3 mg/g at 40 min.

Also in 2019, Xu [71] prepared Cu_2O/ PLA composite nanofibers through surface modification induced by electron beam irradiation by using PLA fibers as a carrier for Cu_2O nanoparticles. Based on the FTIR spectroscopy, the binding of the Cu_2O nanoparticles and the PLA particles can be attributed to the strong hydrogen bonds between them, so that the Cu_2O nanoparticles can be uniformly dispersed on the PLA fragments to form a composite membrane. The obtained Cu_2O/PLA nanofibers showed excellent photocatalytic properties in the organic pollutants of soil and water systems (e. g., MO and bran ether). Antimicrobial tests show that the prepared composites can enhance the antimicrobial properties. This provides an idea to constructing bifunctional composites for effective degradation of organic pollutants in soil and water systems.

It has abundant raw materials, high theoretical conversion efficiency, high efficiency photoelectric catalytic performance, proper band gap of p-n heterojunction, strong oxidation capacity and good stability; both as nanomaterials to improve the performance of solar cells, and as composite materials to help decompose environmental pollutants. With the deepening of relevant research, more and more excellent properties of nano copper oxide will be explored and developed. It is believed that in the near future, these products will be widely used in real life, and they will play a decisive role in solving the problem of human living resources and living environment.

References:

1. Yu, W., Li, F., Wang, H., Alarousu, E., Chen, Y., Lin, B., ... & Wu, T. (2016). Ultrathin Cu_2O as an efficient inorganic hole transporting material for perovskite solar cells. *Nanoscale*, *8*(11), 6173–6179. https://doi.org/10.1039/C5NR07758C

2. Gusain, R., Kumar, P., Sharma, O. P., Jain, S. L., & Khatri, O. P. (2016). Reduced graphene oxide–CuO nanocomposites for photocatalytic conversion of CO_2 into methanol under visible light irradiation. *Applied Catalysis B: Environmental*, *181*, 352–362. https://doi.org/10.1016/j.apcatb.2015.08.012

3. Omrani, N., & Nezamzadeh-Ejhieh, A. (2020). Focus on scavengers' effects and GC-MASS analysis of photodegradation intermediates of sulfasalazine by Cu_2O/CdS nanocomposite. *Separation and Purification Technology*, *235*, 116228. https://doi.org/10.1016/j.seppur.2019.116228

4. Izaki, M., Shinagawa, T., Mizuno, K. T., Ida, Y., Inaba, M., & Tasaka, A. (2007). Electrochemically constructed p-Cu_2O/n-ZnO heterojunction diode for photovoltaic device. *Journal of Physics D: Applied Physics*, *40*(11), 3326.

5. Ali, S., Lee, J., Kim, H., Hwang, Y., Razzaq, A., Jung, J. W., ... & In, S. I. (2020). Sustained, photocatalytic CO_2 reduction to CH_4 in a continuous flow reactor by earth-abundant

materials: Reduced titania-Cu_2O Z-scheme heterostructures. *Applied Catalysis B: Environmental*, *279*, 119344. https://doi.org/10.1016/j.apcatb.2020.119344

6. Chen, J., Liu, X., Zhang, H., Liu, P., Li, G., An, T., & Zhao, H. (2016). Soft-template assisted synthesis of mesoporous CuO/Cu_2O composite hollow microspheres as efficient visible-light photocatalyst. *Materials Letters*, *182*, 47-51. https://doi.org/10.1016/j.matlet.2016.06.077

7. Chen, S., Lin, L., Liu, J., Lv, P., Wu, X., Zheng, W., ... & Lai, F. (2015). An electrochemical constructed p-Cu_2O/n-ZnO heterojunction for solar cell. *Journal of Alloys and Compounds*, *644*, 378-382. https://doi.org/10.1016/j.jallcom.2015.02.230

8. Zuo, C., & Ding, L. (2015). Solution□processed Cu_2O and CuO as hole transport materials for efficient perovskite solar cells. *Small*, *11*(41), 5528–5532. https://doi.org/10.1002/smll.201501330

9. Zhang, L., Sun, H., Xie, L., Lu, J., Zhang, L., Wu, S., ... & Liu, J. M. (2015). Inorganic solar cells based on electrospun ZnO nanofibrous networks and electrodeposited Cu_2O. *Nanoscale research letters*, *10*(1), 1–13. https://doi.org/10.1186/s11671-015-1169-8

10. Koo, H. S., Wang, D. T., Yu, Y. K., Ho, S. H., Jhang, J. Y., Chen, M., & Tai, M. F. (2012). Effect of Cu_2O Doping in TiO_2 Films on Device Performance of Dye-Sensitized Solar Cells. *Japanese Journal of Applied Physics*, *51*(10S), 10NE18.

11. Miao, X., Wang, S., Sun, W., Zhu, Y., Du, C., Ma, R., & Wang, C. (2019). Effect of Cu_2O Content in Electrodeposited CuOx Film on Perovskite Solar Cells. *Nano*, *14*(10), 1950126. https://doi.org/10.1142/S1793292019501261

12. Polat, Ö., Aytug, T., Lupini, A. R., Paranthaman, P. M., Ertugrul, M., Bogorin, D. F., ... & Christen, D. K. (2013). Nanostructured columnar heterostructures of TiO_2 and Cu2O enabled by a thin-film self-assembly approach: Potential for photovoltaics. *Materials Research Bulletin*, *48*(2), 352–356. https://doi.org/10.1016/j.materresbull.2012.10.044

13. Shang, Y., & Guo, L. (2015). Facet□Controlled Synthetic Strategy of Cu_2O□Based Crystals for Catalysis and Sensing. *Advanced Science*, *2*(10), 1500140. https://doi.org/10.1002/advs.201500140

14. Zeng, Z., Yan, Y., Chen, J., Zan, P., Tian, Q., & Chen, P. (2019). Boosting the photocatalytic ability of Cu_2O nanowires for CO_2 conversion by MXene quantum dots. *Advanced Functional Materials*, *29*(2), 1806500. https://doi.org/10.1002/adfm.201806500

15. Robatjazi, H., Zhao, H., Swearer, D. F., Hogan, N. J., Zhou, L., Alabastri, A., ... & Halas, N. J. (2017). Plasmon-induced selective carbon dioxide conversion on earth-abundant aluminum-cuprous oxide antenna-reactor nanoparticles. *Nature communications*, *8*(1), 1-10. https://doi.org/10.1038/s41467-017-00055-z

16. Wu, Y. A., McNulty, I., Liu, C., Lau, K. C., Liu, Q., Paulikas, A. P., ... & Rajh, T. (2019). Facet-dependent active sites of a single Cu_2O particle photocatalyst for CO_2 reduction to methanol. *Nature Energy*, *4*(11), 957–968. https://doi.org/10.1038/s41560-019-0490-3

17. Blackburn, B., Hassan, I., Zhang, C., Blackman, C., Holt, K., & Carmalt, C. (2016). Aerosol assisted chemical vapour deposition synthesis of copper (I) oxide thin films for CO_2 reduction photocatalysis. *Journal of Nanoscience and Nanotechnology*, *16*(9), 10112–10116. https://doi.org/10.1166/jnn.2016.12843

18. Miller, E. B., Zahran, E. M., Knecht, M. R., & Bachas, L. G. (2017). Metal oxide semiconductor nanomaterial for reductive debromination: Visible light degradation of polybrominated diphenyl ethers by Cu2O@ Pd nanostructures. *Applied Catalysis B: Environmental*, *213*, 147–154. https://doi.org/10.1016/j.apcatb.2017.05.020

19. Kumar, A., Kumar, A., Sharma, G., Ala'a, H., Naushad, M., Ghfar, A. A., & Stadler, F. J. (2018). Quaternary magnetic BiOCl/g-C3N4/Cu2O/Fe3O4 nano-junction for visible light and solar powered degradation of sulfamethoxazole from aqueous environment. *Chemical Engineering Journal*, *334*, 462–478. https://doi.org/10.1016/j.cej.2017.10.049

20. Cui, W., An, W., Liu, L., Hu, J., & Liang, Y. (2014). Novel Cu2O quantum dots coupled flower-like BiOBr for enhanced photocatalytic degradation of organic contaminant. *Journal of hazardous materials*, *280*, 417–427. https://doi.org/10.1016/j.jhazmat.2014.08.032

21. Yu, X., Zhang, J., Zhang, J., Niu, J., Zhao, J., Wei, Y., & Yao, B. (2019). Photocatalytic degradation of ciprofloxacin using Zn-doped Cu2O particles: analysis of degradation pathways and intermediates. *Chemical Engineering Journal*, *374*, 316–327. https://doi.org/10.1016/j.cej.2019.05.177

22. Cui, Y., Wang, C., Liu, G., Yang, H., Wu, S., & Wang, T. (2011). Fabrication and photocatalytic property of ZnO nanorod arrays on Cu2O thin film. *Materials Letters*, *65*(14), 2284–2286. https://doi.org/10.1016/j.matlet.2011.04.041

23. Chen, R., Lu, J., Wang, Z., Zhou, Q., & Zheng, M. (2018). Microwave synthesis of Cu/Cu2O/SnO2 composite with improved photocatalytic ability using SnCl4 as a protector. *Journal of Materials Science*, *53*(13), 9557–9566. https://doi.org/10.1007/s10853-018-2261-0

24. Grondahl, L. O. (1933). The copper-cuprous-oxide rectifier and photoelectric cell. *Reviews of Modern Physics*, *5*(2), 141. https://doi.org/10.1103/RevModPhys.5.141

25. Omelchenko, S. T., Tolstova, Y., Atwater, H. A., & Lewis, N. S. (2017). Excitonic effects in emerging photovoltaic materials: A case study in Cu2O. *ACS Energy Letters*, *2*(2), 431–437.

26. Hu, P., Du, W., Wang, M., Wei, H., Ouyang, J., Qian, Z., & Tian, Y. (2020). Reduced bandgap and enhanced p-type electrical conduction in Ag-alloyed Cu2O thin films. *Journal of Applied Physics*, *128*(12), 125302. https://doi.org/10.1063/5.0019408

27. Izaki, M., Fukazawa, K., Sato, K., Khoo, P. L., Kobayashi, M., Takeuchi, A., & Uesugi, K. (2019). Defect structure and photovoltaic characteristics of internally stacked CuO/Cu2O photoactive layer prepared by electrodeposition and heating. *ACS Applied Energy Materials*, *2*(7), 4833–4840. https://doi.org/10.1021/acsaem.9b00514

28. Zang, Z. (2018). Efficiency enhancement of ZnO/Cu2O solar cells with well oriented and micrometer grain sized Cu2O films. *Applied Physics Letters*, *112*(4), 042106. https://doi.org/10.1063/1.5017002

29. Hossain, M. I., Alharbi, F. H., & Tabet, N. (2015). Copper oxide as inorganic hole transport material for lead halide perovskite based solar cells. *Solar Energy*, *120*, 370-380. https://doi.org/10.1016/j.solener.2015.07.040

30. Nejand, B. A., Ahmadi, V., Gharibzadeh, S., & Shahverdi, H. R. (2016). Cuprous oxide as a potential low□cost hole□transport material for stable perovskite solar cells. *ChemSusChem*, *9*(3), 302–313. https://doi.org/10.1002/cssc.201501273

31. Guo, Y., Lei, H., Xiong, L., Li, B., Chen, Z., Wen, J., ... & Fang, G. (2017). Single phase, high hole mobility Cu 2 O films as an efficient and robust hole transporting layer for organic solar cells. *Journal of Materials Chemistry A*, *5*(22), 11055–11062. https://doi.org/10.1039/C7TA01628J

32. Elseman, A. M., Selim, M. S., Luo, L., Xu, C. Y., Wang, G., Jiang, Y., ... & Song, Q. L. (2019). Efficient and Stable Planar np Perovskite Solar Cells with Negligible Hysteresis through Solution Processed Cu2O Nanocubes as a Low□Cost Hole□Transport Material. *ChemSusChem*, *12*(16), 3808–3816. https://doi.org/10.1002/cssc.201901430

33. Jeong, S. S., Mittiga, A., Salza, E., Masci, A., & Passerini, S. (2008). Electrodeposited ZnO/Cu2O heterojunction solar cells. *Electrochimica Acta*, *53*(5), 2226–2231. https://doi.org/10.1016/j.electacta.2007.09.030

34. Soundaram, N., Chandramohan, R., Valanarasu, S., Thomas, R., & Kathalingam, A. (2015). Studies on SILAR deposited Cu2O and ZnO films for s https://doi.org/10.1007/s10854-015-3020-5olar cell applications. *Journal of Materials Science: Materials in Electronics*, *26*(7), 5030–5036. https://doi.org/10.1007/s10854-015-3020-5

35. Gershon, T., Musselman, K. P., Marin, A., Friend, R. H., & MacManus-Driscoll, J. L. (2012). Thin-film ZnO/Cu2O solar cells incorporating an organic buffer layer. *Solar Energy Materials and Solar Cells*, *96*, 148–154. https://doi.org/10.1016/j.solmat.2011.09.043

36. Yu, L., Xiong, L., & Yu, Y. (2015). Cu2O homojunction solar cells: F-doped N-type thin film and highly improved efficiency. *The Journal of Physical Chemistry C*, *119*(40), 22803–22811. https://doi.org/10.1021/acs.jpcc.5b06736

37. Naz, G., Shamsuddin, M., Butt, F. K., Bajwa, S. Z., Khan, W. S., Irfan, M., & Irfan, M. (2019). Au/Cu2O core/shell nanostructures with efficient photoresponses. *Chinese Journal of Physics*, *59*, 307–316. https://doi.org/10.1016/j.cjph.2019.03.008

38. Chang, X., Wang, T., Zhang, P., Wei, Y., Zhao, J., & Gong, J. (2016). Stable aqueous photoelectrochemical CO2 reduction by a Cu2O dark cathode with improved selectivity for carbonaceous products. *Angewandte Chemie International Edition*, *55*(31), 8840–8845. https://doi.org/10.1002/anie.201602973

39. Yuan, Q., Chen, L., Xiong, M., He, J., Luo, S. L., Au, C. T., & Yin, S. F. (2014). Cu2O/BiVO4 heterostructures: synthesis and application in simultaneous photocatalytic oxidation of organic dyes and reduction of Cr (VI) under visible light. *Chemical Engineering Journal*, *255*, 394–402. https://doi.org/10.1016/j.cej.2014.06.031

40. Omrani, N., & Nezamzadeh-Ejhieh, A. (2020). A comprehensive study on the enhanced photocatalytic activity of Cu2O/BiVO4/WO3 nanoparticles. *Journal of Photochemistry and Photobiology A: Chemistry*, *389*, 112223. https://doi.org/10.1016/j.jphotochem.2019.112223

41. Liu, A., Zhu, Y., Li, K., Chu, D., Huang, J., Li, X., ... & Du, Y. (2018). A high performance p-type nickel oxide/cuprous oxide nanocomposite with heterojunction as the photocathodic catalyst for water splitting to produce hydrogen. *Chemical Physics Letters*, *703*, 56–62. https://doi.org/10.1016/j.cplett.2018.05.020

42. Li, H., Lei, Y., Huang, Y., Fang, Y., Xu, Y., Zhu, L., & Li, X. (2011). Photocatalytic reduction of carbon dioxide to methanol by Cu2O/SiC nanocrystallite under visible light irradiation. *Journal of Natural Gas Chemistry*, *20*(2), 145–150. https://doi.org/10.1016/S1003-9953(10)60166-1

43. Li, Y., Wang, W. N., Zhan, Z., Woo, M. H., Wu, C. Y., & Biswas, P. (2010). Photocatalytic reduction of CO2 with H2O on mesoporous silica supported Cu/TiO2 catalysts. *Applied Catalysis B: Environmental*, *100*(1-2), 386-392. https://doi.org/10.1016/j.apcatb.2010.08.015

44. Guo, L., Cao, J., Zhang, J., Hao, Y., & Bi, K. (2019). Photoelectrochemical CO2 reduction by Cu2O/Cu2S hybrid catalyst immobilized in TiO_2 nanocavity arrays. *Journal of Materials Science*, *54*(14), 10379-10388. https://doi.org/10.1007/s10853-019-03615-4

45. Zhou, C., Wang, S., Zhao, Z., Shi, Z., Yan, S., & Zou, Z. (2018). A Facet□Dependent Schottky□Junction Electron Shuttle in a BiVO4 {010}–Au–Cu2O Z□Scheme Photocatalyst for Efficient Charge Separation. *Advanced Functional Materials*, *28*(31), 1801214. https://doi.org/10.1002/adfm.201801214

46. Zhang, W., Shi, L., Tang, K., & Dou, S. (2010). Controllable synthesis of Cu2O microcrystals via a complexant□assisted synthetic route. https://doi.org/10.1002/ejic.200900866

47. Chang, P. Y., & Tseng, I. H. (2018). Photocatalytic conversion of gas phase carbon dioxide by graphitic carbon nitride decorated with cuprous oxide with various morphologies. *Journal of CO2 Utilization*, *26*, 511–521. https://doi.org/10.1016/j.jcou.2018.06.009

48. Ojha, N., Bajpai, A., & Kumar, S. (2021). Enriched oxygen vacancies of Cu2O/SnS2/SnO2 heterostructure for enhanced photocatalytic reduction of CO2 by water and nitrogen fixation. *Journal of Colloid and Interface Science*, *585*, 764–777. https://doi.org/10.1016/j.jcis.2020.10.056

49. Li, P., Jing, H., Xu, J., Wu, C., Peng, H., Lu, J., & Lu, F. (2014). High-efficiency synergistic conversion of CO 2 to methanol using Fe 2 O 3 nanotubes modified with double-layer Cu 2 O spheres. *Nanoscale*, *6*(19), 11380–11386. https://doi.org/10.1039/C4NR02902J

50. Lu, Y., Zhang, X., Chu, Y., Yu, H., Huo, M., Qu, J., ... & Yuan, X. (2018). Cu2O nanocrystals/TiO2 microspheres film on a rotating disk containing long-afterglow phosphor for enhanced round-the-clock photocatalysis. *Applied Catalysis B: Environmental*, *224*, 239–248. https://doi.org/10.1016/j.apcatb.2017.10.054

51. Li, B., Niu, W., Cheng, Y., Gu, J., Ning, P., & Guan, Q. (2018). Preparation of Cu2O modified TiO2 nanopowder and its application to the visible light photoelectrocatalytic reduction of CO2 to CH3OH. *Chemical Physics Letters*, *700*, 57–63. https://doi.org/10.1016/j.cplett.2018.03.049

52. Kulandaivalu, T., Rashid, S. A., Sabli, N., & Tan, T. L. (2019). Visible light assisted photocatalytic reduction of CO2 to ethane using CQDs/Cu2O nanocomposite photocatalyst. *Diamond and Related Materials*, *91*, 64–73. https://doi.org/10.1016/j.diamond.2018.11.002

53. Masegi, H., Goto, H., Sadale, S. B., & Noda, K. (2020). Real-time monitoring of photocatalytic methanol decomposition over Cu2O-loaded TiO2 nanotube arrays in high vacuum. *Journal of Vacuum Science & Technology B, Nanotechnology and Microelectronics: Materials, Processing, Measurement, and Phenomena*, *38*(5), 052401. https://doi.org/10.1116/6.0000194

54. Fujita, S. I., Kawamori, H., Honda, D., Yoshida, H., & Arai, M. (2016). Photocatalytic hydrogen production from aqueous glycerol solution using NiO/TiO2 catalysts: Effects of preparation and reaction conditions. *Applied Catalysis B: Environmental*, *181*, 818–824. https://doi.org/10.1016/j.apcatb.2015.08.048

55. Tawfik, W. Z., Hassan, M. A., Johar, M. A., Ryu, S. W., & Lee, J. K. (2019). Highly conversion efficiency of solar water splitting over p-Cu2O/ZnO photocatalyst grown on a metallic substrate. *Journal of Catalysis*, *374*, 276–283. https://doi.org/10.1016/j.jcat.2019.04.045

56. Carrier, M., Perol, N., Herrmann, J. M., Bordes, C., Horikoshi, S., Paisse, J. O., ... & Guillard, C. (2006). Kinetics and reactional pathway of Imazapyr photocatalytic degradation Influence of pH and metallic ions. *Applied Catalysis B: Environmental*, *65*(1–2), 11–20. https://doi.org/10.1016/j.apcatb.2005.11.014

57. Wang, M., Sun, L., Lin, Z., Cai, J., Xie, K., & Lin, C. (2013). p–n Heterojunction photoelectrodes composed of Cu 2 O-loaded TiO 2 nanotube arrays with enhanced photoelectrochemical and photoelectrocatalytic activities. *Energy & Environmental Science*, *6*(4), 1211–1220. https://doi.org/10.1039/C3EE24162A

58. Wang, Y., Shang, X., Shen, J., Zhang, Z., Wang, D., Lin, J., ... & Li, C. (2020). Direct and indirect Z-scheme heterostructure-coupled photosystem enabling cooperation of CO2 reduction and H2O oxidation. *Nature communications*, *11*(1), 1–11. https://doi.org/10.1038/s41467-020-16742-3

59. Deng, X., Zhang, Q., Zhou, E., Ji, C., Huang, J., Shao, M., ... & Xu, X. (2015). Morphology transformation of Cu2O sub-microstructures by Sn doping for enhanced photocatalytic properties. *Journal of Alloys and Compounds*, *649*, 1124–1129. https://doi.org/10.1016/j.jallcom.2015.07.124

60. Ping, T., Mihua, S., Chengwen, S., Shuaihua, W., & Murong, C. (2016). Enhanced photocatalytic activity of Cu2O/Cu heterogeneous nanoparticles synthesized in aqueous colloidal solutions on degradation of methyl orange. *Rare Metal Materials and Engineering*, *45*(9), 2214–2218. https://doi.org/10.1016/S1875-5372(17)30005-X

61. Shi, Y., Yang, Z., Wang, B., An, H., Chen, Z., & Cui, H. (2016). Adsorption and photocatalytic degradation of tetracycline hydrochloride using a palygorskite-supported Cu2O–TiO2 composite. *Applied Clay Science*, *119*, 311–320. https://doi.org/10.1016/j.clay.2015.10.033

62. Tang, Q., Wu, W., Zhang, B., Luo, J., Zhang, H., Guo, X., ... & Cao, J. (2019). A novel in situ synthesis of Cu/Cu2O/CuO/sulfonated polystyrene heterojunction photocatalyst with enhanced photodegradation activity. *Journal of Inorganic and Organometallic Polymers and Materials*, *29*(2), 340–345. https://doi.org/10.1007/s10904-018-1004-7

63. An, J., & Zhou, Q. (2012). Degradation of some typical pharmaceuticals and personal care products with copper-plating iron doped Cu2O under visible light irradiation. *Journal of Environmental Sciences*, *24*(5), 827–833. https://doi.org/10.1016/S1001-0742(11)60847-4

64. Zhu, Q., Zhang, Y., Lv, F., Chu, P. K., Ye, Z., & Zhou, F. (2012). Cuprous oxide created on sepiolite: preparation, characterization, and photocatalytic activity in treatment of red water from 2, 4, 6-trinitrotoluene manufacturing. *Journal of Hazardous Materials*, *217*, 11–18. https://doi.org/10.1016/j.jhazmat.2011.12.053

65. Zhang, A. Y., He, Y. Y., Lin, T., Huang, N. H., Xu, Q., & Feng, J. W. (2017). A simple strategy to refine Cu2O photocatalytic capacity for refractory pollutants removal: Roles of oxygen reduction and Fe (II) chemistry. *Journal of hazardous materials*, *330*, 9–17. https://doi.org/10.1016/j.jhazmat.2017.01.051

66. Huang, Z., Dai, X., Huang, Z., Wang, T., Cui, L., Ye, J., & Wu, P. (2019). Simultaneous and efficient photocatalytic reduction of Cr (VI) and oxidation of trace sulfamethoxazole under LED light by rGO@ Cu2O/BiVO4 pn heterojunction composite. *Chemosphere*, *221*, 824–833. https://doi.org/10.1016/j.chemosphere.2019.01.087

67. Falah, M., & MacKenzie, K. J. (2015). Synthesis and properties of novel photoactive composites of P25 titanium dioxide and copper (I) oxide with inorganic polymers. *Ceramics International*, *41*(10), 13702–13708. https://doi.org/10.1016/j.ceramint.2015.07.198

68. Zhang, Z., Zhai, S., Wang, M., Ji, H., He, L., Ye, C., ... & Zhang, H. (2016). Photocatalytic degradation of rhodamine B by using a nanocomposite of cuprous oxide, three-dimensional reduced graphene oxide, and nanochitosan prepared via one-pot synthesis. *Journal of Alloys and Compounds*, *659*, 101–111. https://doi.org/10.1016/j.jallcom.2015.11.027

69. Anku, W. W., Shukla, S. K., & Govender, P. P. (2018). Graft Gum Ghatti Caped Cu2O nanocomposite for photocatalytic degradation of naphthol blue black dye. *Journal of Inorganic and Organometallic Polymers and Materials*, *28*(4), 1540–1551. https://doi.org/10.1007/s10904-018-0875-y

70. Razmara, Z., & Poorsargol, M. (2019). Ultrasonic□assisted synthesis of supramolecular copper (II) complex a precursor for the preparation of octahedron Cu2O nanoparticles applicable in the adsorption and photodegradation of Rhodamine B. *Applied Organometallic Chemistry*, *33*(9), e5084. https://doi.org/10.1002/aoc.5084

71. Xu, Q., Huang, Z., Ji, S., Zhou, J., Shi, R., & Shi, W. (2020). Cu2O nanoparticles grafting onto PLA fibers via electron beam irradiation: bifunctional composite fibers with enhanced photocatalytic of organic pollutants in aqueous and soil systems. *Journal of Radioanalytical and Nuclear Chemistry*, *323*(1), 253–261. https://doi.org/10.1007/s10967-019-06842-w

Список литературы:

1. Yu W., Li F., Wang H., Alarousu E., Chen Y., Lin B., Wu T. Ultrathin Cu_2O as an efficient inorganic hole transporting material for perovskite solar cells // Nanoscale. 2016. V. 8. №11. P. 6173-6179. https://doi.org/10.1039/C5NR07758C

2. Gusain R., Kumar P., Sharma O. P., Jain S. L., Khatri O. P. Reduced graphene oxide–CuO nanocomposites for photocatalytic conversion of CO_2 into methanol under visible light irradiation // Applied Catalysis B: Environmental. 2016. V. 181. P. 352-362. https://doi.org/10.1016/j.apcatb.2015.08.012

3. Omrani N., Nezamzadeh-Ejhieh A. Focus on scavengers' effects and GC-MASS analysis of photodegradation intermediates of sulfasalazine by Cu2O/CdS nanocomposite // Separation and Purification Technology. 2020. V. 235. P. 116228. https://doi.org/10.1016/j.seppur.2019.116228

4. Izaki M., Shinagawa T., Mizuno K. T., Ida Y., Inaba M., Tasaka, A. Electrochemically constructed p-Cu_2O/n-ZnO heterojunction diode for photovoltaic device // Journal of Physics D: Applied Physics. 2007. V. 40. №11. P. 3326.

5. Ali S., Lee J., Kim H., Hwang Y., Razzaq A., Jung J. W., In S. I. Sustained, photocatalytic CO2 reduction to CH4 in a continuous flow reactor by earth-abundant materials: Reduced titania-Cu2O Z-scheme heterostructures // Applied Catalysis B: Environmental. 2020. V. 279. P. 119344. https://doi.org/10.1016/j.apcatb.2020.119344

6. Chen J., Liu X., Zhang H., Liu P., Li G., An T., Zhao H. Soft-template assisted synthesis of mesoporous CuO/Cu_2O composite hollow microspheres as efficient visible-light photocatalyst // Materials Letters. 2016. V. 182. P. 47-51. https://doi.org/10.1016/j.matlet.2016.06.077

7. Chen S., Lin L., Liu J., Lv P., Wu X., Zheng W., Lai F. An electrochemical constructed p-Cu2O/n-ZnO heterojunction for solar cell // Journal of Alloys and Compounds. 2015. V. 644. P. 378-382. https://doi.org/10.1016/j.jallcom.2015.02.230

8. Zuo C, Ding L. Solution-Processed Cu2O and CuO as Hole Transport Materials for Efficient Perovskite Solar Cells. Small 2015; 11:5528-5532. https://doi.org/10.1002/smll.201501330

9. Zhang L., Sun H., Xie L., Lu J., Zhang L., Wu S., Liu J. M. Inorganic solar cells based on electrospun ZnO nanofibrous networks and electrodeposited Cu2O // Nanoscale research letters. – 2015. V. 10. №1. P. 1-13. https://doi.org/10.1186/s11671-015-1169-8

10. Koo H. S., Wang D. T., Yu Y. K., Ho S. H., Jhang J. Y., Chen M., Tai M. F. Effect of Cu2O Doping in TiO2 Films on Device Performance of Dye-Sensitized Solar Cells // Japanese Journal of Applied Physics. 2012. V. 51. №10S. P. 10NE18.

11. Miao, X., Wang, S., Sun, W., Zhu, Y., Du, C., Ma, R., & Wang, C. Effect of Cu2O Content in Electrodeposited CuOx Film on Perovskite Solar Cells //Nano. – 2019. – Т. 14. – №. 10. – С. 1950126. https://doi.org/10.1142/S1793292019501261

12. Polat Ö., Aytug T., Lupini A. R., Paranthaman P. M., Ertugrul M., Bogorin D. F., Christen D. K. Nanostructured columnar heterostructures of TiO2 and Cu2O enabled by a thin-film self-assembly approach: Potential for photovoltaics // Materials Research Bulletin. 2013. V. 48. №2. P. 352-356. https://doi.org/10.1016/j.materresbull.2012.10.044

13. Shang Y., Guo L. Facet□Controlled Synthetic Strategy of Cu2O□Based Crystals for Catalysis and Sensing // Advanced Science. 2015. V. 2. №10. P. 1500140. https://doi.org/10.1002/advs.201500140

14. Zeng Z., Yan Y., Chen J., Zan P., Tian Q., Chen P. Boosting the photocatalytic ability of Cu2O nanowires for CO2 conversion by MXene quantum dots // Advanced Functional Materials. 2019. V. 29. №2. P. 1806500. https://doi.org/10.1002/adfm.201806500

15. Robatjazi H., Zhao H., Swearer D. F., Hogan N. J., Zhou L., Alabastri A., Halas N. J. Plasmon-induced selective carbon dioxide conversion on earth-abundant aluminum-cuprous oxide antenna-reactor nanoparticles // Nature communications. 2017. V. 8. №1. P. 1-10. https://doi.org/10.1038/s41467-017-00055-z

16. Wu Y. A., McNulty I., Liu C., Lau K. C., Liu Q., Paulikas A. P., Rajh T. Facet-dependent active sites of a single Cu_2O particle photocatalyst for CO_2 reduction to methanol // Nature Energy. 2019. V. 4. №11. P. 957-968. https://doi.org/10.1038/s41560-019-0490-3

17. Blackburn B., Hassan I., Zhang C., Blackman C., Holt K., Carmalt C. Aerosol assisted chemical vapour deposition synthesis of copper (I) oxide thin films for CO2 reduction photocatalysis // Journal of Nanoscience and Nanotechnology. 2016. V. 16. №9. P. 10112-10116. https://doi.org/10.1166/jnn.2016.12843

18. Miller E. B., Zahran E. M., Knecht M. R., Bachas L. G. Metal oxide semiconductor nanomaterial for reductive debromination: Visible light degradation of polybrominated diphenyl ethers by Cu2O@ Pd nanostructures // Applied Catalysis B: Environmental. 2017. V. 213. P. 147-154. https://doi.org/10.1016/j.apcatb.2017.05.020

19. Kumar A., Kumar A., Sharma G., Ala'a H., Naushad M., Ghfar A. A., Stadler F. J. Quaternary magnetic BiOCl/g-C3N4/Cu2O/Fe3O4 nano-junction for visible light and solar powered degradation of sulfamethoxazole from aqueous environment // Chemical Engineering Journal. 2018. V. 334. P. 462-478. https://doi.org/10.1016/j.cej.2017.10.049

20. Cui W., An W., Liu L., Hu J., Liang Y. Novel Cu2O quantum dots coupled flower-like BiOBr for enhanced photocatalytic degradation of organic contaminant // Journal of hazardous materials. 2014. V. 280. P. 417-427. https://doi.org/10.1016/j.jhazmat.2014.08.032

21. Yu X., Zhang J., Zhang J., Niu J., Zhao J., Wei Y., Yao B. Photocatalytic degradation of ciprofloxacin using Zn-doped Cu2O particles: analysis of degradation pathways and intermediates // Chemical Engineering Journal. 2019. V. 374. P. 316-327. https://doi.org/10.1016/j.cej.2019.05.177

22. Cui Y., Wang C., Liu G., Yang H., Wu S., Wang T. Fabrication and photocatalytic property of ZnO nanorod arrays on Cu2O thin film // Materials Letters. 2011. V. 65. №14. P. 2284-2286. https://doi.org/10.1016/j.matlet.2011.04.041

23. Chen R., Lu J., Wang Z., Zhou Q., Zheng M. Microwave synthesis of Cu/Cu2O/SnO2 composite with improved photocatalytic ability using SnCl4 as a protector // Journal of Materials Science. 2018. V. 53. №13. P. 9557-9566. https://doi.org/10.1007/s10853-018-2261-0

24. Grondahl L. O. The copper-cuprous-oxide rectifier and photoelectric cell // Reviews of Modern Physics. 1933. V. 5. №2. P. 141. https://doi.org/10.1103/RevModPhys.5.141

25. Omelchenko S. T., Tolstova Y., Atwater H. A., Lewis N. S. Excitonic effects in emerging photovoltaic materials: A case study in Cu2O // ACS Energy Letters. 2017. V. 2. №2. P. 431-437.

26. Hu, P., Du W., Wang M., Wei H., Ouyang J., Qian Z., Tian Y. Reduced bandgap and enhanced p-type electrical conduction in Ag-alloyed Cu2O thin films //Journal of Applied Physics. 2020. V. 128. №12. P. 125302. https://doi.org/10.1063/5.0019408

27. Izaki M., Fukazawa K., Sato K., Khoo P. L., Kobayashi M., Takeuchi A., Uesugi K. Defect structure and photovoltaic characteristics of internally stacked CuO/Cu2O photoactive layer

prepared by electrodeposition and heating // ACS Applied Energy Materials. 2019. V. 2. №7. P. 4833-4840. https://doi.org/10.1021/acsaem.9b00514

28. Zang Z. Efficiency enhancement of ZnO/Cu2O solar cells with well oriented and micrometer grain sized Cu2O films // Applied Physics Letters. 2018. V. 112. №4. P. 042106. https://doi.org/10.1063/1.5017002

29. Hossain M. I., Alharbi F. H., Tabet N. Copper oxide as inorganic hole transport material for lead halide perovskite based solar cells // Solar Energy. 2015. V. 120. P. 370-380. https://doi.org/10.1016/j.solener.2015.07.040

30. Nejand B. A., Ahmadi V., Gharibzadeh S., Shahverdi H. R. Cuprous oxide as a potential lowcost hole□transport material for stable perovskite solar cells // ChemSusChem. 2016. V. 9. №. 3. P. 302-313. https://doi.org/10.1002/cssc.201501273

31. Guo Y., Lei H., Xiong L., Li B., Chen Z., Wen J., Fang G. Single phase, high hole mobility Cu 2 O films as an efficient and robust hole transporting layer for organic solar cells // Journal of Materials Chemistry A. 2017. V. 5. №22. P. 11055-11062. https://doi.org/10.1039/C7TA01628J

32. Elseman A. M., Selim M. S., Luo L., Xu C. Y., Wang G., Jiang Y., Song Q. L. Efficient and Stable Planar n□i□p Perovskite Solar Cells with Negligible Hysteresis through Solution□ Processed Cu2O Nanocubes as a Low□Cost Hole□Transport Material // ChemSusChem. 2019. V. 12. №16. P. 3808-3816. https://doi.org/10.1002/cssc.201901430

33. Jeong S. S., Mittiga A., Salza E., Masci A., Passerini S. Electrodeposited ZnO/Cu2O heterojunction solar cells // Electrochimica Acta. 2008. V. 53. №5. P. 2226-2231. https://doi.org/10.1016/j.electacta.2007.09.030

34. Soundaram N., Chandramohan R., Valanarasu S., Thomas R., Kathalingam A. Studies on SILAR deposited Cu2O and ZnO films for solar cell applications //Journal of Materials Science: Materials in Electronics. 2015. V. 26. №7. P. 5030-5036. https://doi.org/10.1007/s10854-015-3020-5

35. Gershon T., Musselman K. P., Marin A., Friend R. H., MacManus-Driscoll J. L. Thin-film ZnO/Cu2O solar cells incorporating an organic buffer layer // Solar Energy Materials and Solar Cells. 2012. V. 96. P. 148-154. https://doi.org/10.1016/j.solmat.2011.09.043

36. Yu L., Xiong L., Yu Y. Cu2O homojunction solar cells: F-doped N-type thin film and highly improved efficiency // The Journal of Physical Chemistry C. 2015. V. 119. №40. P. 22803-22811. https://doi.org/10.1021/acs.jpcc.5b06736

37. Naz G., Shamsuddin M., Butt F. K., Bajwa S. Z., Khan W. S., Irfan M., Irfan M. Au/Cu2O core/shell nanostructures with efficient photoresponses // Chinese Journal of Physics. 2019. V. 59. P. 307-316. https://doi.org/10.1016/j.cjph.2019.03.008

38. Chang X., Wang T., Zhang P., Wei Y., Zhao J., Gong J. Stable aqueous photoelectrochemical CO2 reduction by a Cu2O dark cathode with improved selectivity for carbonaceous products // Angewandte Chemie International Edition. 2016. V. 55. №31. P. 8840-8845. https://doi.org/10.1002/anie.201602973

39. Yuan Q., Chen L., Xiong M., He J., Luo S. L., Au C. T., Yin S. F.Cu2O/BiVO4 heterostructures: synthesis and application in simultaneous photocatalytic oxidation of organic dyes and reduction of Cr (VI) under visible light // Chemical Engineering Journal. 2014. V. 255. P. 394-402. https://doi.org/10.1016/j.cej.2014.06.031

40. Omrani N., Nezamzadeh-Ejhieh A. A comprehensive study on the enhanced photocatalytic activity of Cu2O/BiVO4/WO3 nanoparticles // Journal of Photochemistry and Photobiology A: Chemistry. 2020. V. 389. P. 112223. https://doi.org/10.1016/j.jphotochem.2019.112223

41. Liu A., Zhu Y., Li K., Chu D., Huang J., Li X., Du Y. A high performance p-type nickel oxide/cuprous oxide nanocomposite with heterojunction as the photocathodic catalyst for water splitting to produce hydrogen // Chemical Physics Letters. 2018. V. 703. P. 56-62. https://doi.org/10.1016/j.cplett.2018.05.020

42. Li H., Lei Y., Huang Y., Fang Y., Xu Y., Zhu L., Li X. Photocatalytic reduction of carbon dioxide to methanol by Cu2O/SiC nanocrystallite under visible light irradiation // Journal of Natural Gas Chemistry. 2011. V. 20. №2. P. 145-150. https://doi.org/10.1016/S1003-9953(10)60166-1

43. Li Y., Wang W. N., Zhan Z., Woo M. H., Wu C. Y., Biswas P. Photocatalytic reduction of CO2 with H2O on mesoporous silica supported Cu/TiO2 catalysts // Applied Catalysis B: Environmental. 2010. V. 100. №1-2. P. 386-392. https://doi.org/10.1016/j.apcatb.2010.08.015

44. Guo L., Cao J., Zhang J., Hao Y., Bi K. Photoelectrochemical CO2 reduction by Cu2O/Cu2S hybrid catalyst immobilized in TiO2 nanocavity arrays // Journal of Materials Science. 2019. V. 54. №14. P. 10379-10388. https://doi.org/10.1007/s10853-019-03615-4

45. Zhou C., Wang S., Zhao Z., Shi Z., Yan S., Zou Z. A Facet□Dependent Schottky□ Junction Electron Shuttle in a BiVO4 {010}–Au–Cu2O Z□Scheme Photocatalyst for Efficient Charge Separation // Advanced Functional Materials. 2018. V. 28. №31. P. 1801214. https://doi.org/10.1002/adfm.201801214

46. Zhang W., Shi L., Tang K., Dou S. Controllable synthesis of Cu2O microcrystals via a complexant‐assisted synthetic route. 2010. https://doi.org/10.1002/ejic.200900866

47. Chang P. Y., Tseng I. H. Photocatalytic conversion of gas phase carbon dioxide by graphitic carbon nitride decorated with cuprous oxide with various morphologies // Journal of CO2 Utilization. 2018. V. 26. P. 511-521. https://doi.org/10.1016/j.jcou.2018.06.009

48. Ojha N., Bajpai A., Kumar S. Enriched oxygen vacancies of Cu2O/SnS2/SnO2 heterostructure for enhanced photocatalytic reduction of CO2 by water and nitrogen fixation // Journal of Colloid and Interface Science. 2021. V. 585. P. 764-777. https://doi.org/10.1016/j.jcis.2020.10.056

49. Li P., Jing H., Xu J., Wu C., Peng H., Lu J., Lu F. High-efficiency synergistic conversion of CO 2 to methanol using Fe 2 O 3 nanotubes modified with double-layer Cu 2 O spheres // Nanoscale. 2014. V. 6. №19. P. 11380-11386. https://doi.org/10.1039/C4NR02902J

50. Lu Y., Zhang X., Chu Y., Yu H., Huo M., Qu J., Yuan X. Cu2O nanocrystals/TiO2 microspheres film on a rotating disk containing long-afterglow phosphor for enhanced round-the-clock photocatalysis // Applied Catalysis B: Environmental. 2018. V. 224. P. 239-248. https://doi.org/10.1016/j.apcatb.2017.10.054

51. Li B., Niu W., Cheng Y., Gu J., Ning P., Guan Q. Preparation of Cu2O modified TiO2 nanopowder and its application to the visible light photoelectrocatalytic reduction of CO2 to CH3OH // Chemical Physics Letters. 2018. V. 700. P. 57-63. https://doi.org/10.1016/j.cplett.2018.03.049

52. Kulandaivalu T., Rashid S. A., Sabli N., Tan T. L. Visible light assisted photocatalytic reduction of CO2 to ethane using CQDs/Cu2O nanocomposite photocatalyst // Diamond and Related Materials. 2019. V. 91. P. 64-73. https://doi.org/10.1016/j.diamond.2018.11.002

53. Masegi H., Goto H., Sadale S. B., Noda K. Real-time monitoring of photocatalytic methanol decomposition over Cu2O-loaded TiO2 nanotube arrays in high vacuum // Journal of Vacuum Science & Technology B, Nanotechnology and Microelectronics: Materials, Processing, Measurement, and Phenomena. 2020. V. 38. №5. P. 052401. https://doi.org/10.1116/6.0000194

54. Fujita S. I., Kawamori H., Honda D., Yoshida H., Arai M. Photocatalytic hydrogen production from aqueous glycerol solution using NiO/TiO2 catalysts: Effects of preparation and

reaction conditions // Applied Catalysis B: Environmental. 2016. V. 181. P. 818-824. https://doi.org/10.1016/j.apcatb.2015.08.048

55. Tawfik W. Z., Hassan M. A., Johar M. A., Ryu S. W., Lee J. K. Highly conversion efficiency of solar water splitting over p-Cu2O/ZnO photocatalyst grown on a metallic substrate // Journal of Catalysis. 2019. V. 374. P. 276-283. https://doi.org/10.1016/j.jcat.2019.04.045

56. Carrier M., Perol N., Herrmann J. M., Bordes C., Horikoshi S., Paisse J. O., Guillard C. Kinetics and reactional pathway of Imazapyr photocatalytic degradation Influence of pH and metallic ions // Applied Catalysis B: Environmental. 2006. V. 65. №1-2. P. 11-20. https://doi.org/10.1016/j.apcatb.2005.11.014

57. Wang M., Sun L., Lin Z., Cai J., Xie K., Lin C. p–n Heterojunction photoelectrodes composed of Cu 2 O-loaded TiO 2 nanotube arrays with enhanced photoelectrochemical and photoelectrocatalytic activities // Energy & Environmental Science. 2013. V. 6. №4. P. 1211-1220. https://doi.org/10.1039/C3EE24162A

58. Wang Y., Shang X., Shen J., Zhang Z., Wang D., Lin J., Li C. Direct and indirect Z-scheme heterostructure-coupled photosystem enabling cooperation of CO2 reduction and H2O oxidation // Nature communications. 2020. V. 11. №1. P. 1-11. https://doi.org/10.1038/s41467-020-16742-3

59. Deng X., Zhang Q., Zhou E., Ji C., Huang J., Shao M., Xu X. Morphology transformation of Cu2O sub-microstructures by Sn doping for enhanced photocatalytic properties // Journal of Alloys and Compounds. 2015. V. 649. P. 1124-1129. https://doi.org/10.1016/j.jallcom.2015.07.124

60. Ping T., Mihua S., Chengwen S., Shuaihua W., Murong C. Enhanced photocatalytic activity of Cu2O/Cu heterogeneous nanoparticles synthesized in aqueous colloidal solutions on degradation of methyl orange // Rare Metal Materials and Engineering. 2016. V. 45. №9. P. 2214-2218. https://doi.org/10.1016/S1875-5372(17)30005-X

61. Shi Y., Yang Z., Wang B., An H., Chen Z., Cui H. Adsorption and photocatalytic degradation of tetracycline hydrochloride using a palygorskite-supported Cu2O–TiO2 composite // Applied Clay Science. 2016. V. 119. P. 311-320. https://doi.org/10.1016/j.clay.2015.10.033

62. Tang Q., Wu W., Zhang B., Luo J., Zhang H., Guo X., Cao J. A novel in situ synthesis of Cu/Cu2O/CuO/sulfonated polystyrene heterojunction photocatalyst with enhanced photodegradation activity // Journal of Inorganic and Organometallic Polymers and Materials. 2019. V. 29. №2. P. 340-345. https://doi.org/10.1007/s10904-018-1004-7

63. An J., Zhou Q. Degradation of some typical pharmaceuticals and personal care products with copper-plating iron doped Cu2O under visible light irradiation // Journal of Environmental Sciences. 2012. V. 24. №5. P. 827-833. https://doi.org/10.1016/S1001-0742(11)60847-4

64. Zhu Q., Zhang Y., Lv F., Chu P. K., Ye Z., Zhou F. Cuprous oxide created on sepiolite: preparation, characterization, and photocatalytic activity in treatment of red water from 2, 4, 6-trinitrotoluene manufacturing // Journal of Hazardous Materials. 2012. V. 217. P. 11-18. https://doi.org/10.1016/j.jhazmat.2011.12.053

65. Zhang A. Y., He Y. Y., Lin T., Huang N. H., Xu Q., Feng J. W. A simple strategy to refine Cu2O photocatalytic capacity for refractory pollutants removal: Roles of oxygen reduction and Fe (II) chemistry // Journal of hazardous materials. 2017. V. 330. P. 9-17. https://doi.org/10.1016/j.jhazmat.2017.01.051

66. Huang Z., Dai X., Huang Z., Wang T., Cui L., Ye J., Wu P. Simultaneous and efficient photocatalytic reduction of Cr (VI) and oxidation of trace sulfamethoxazole under LED light by rGO@ Cu2O/BiVO4 pn heterojunction composite // Chemosphere. 2019. V. 221. P. 824-833. https://doi.org/10.1016/j.chemosphere.2019.01.087

67. Falah M., MacKenzie K. J. D. Synthesis and properties of novel photoactive composites of P25 titanium dioxide and copper (I) oxide with inorganic polymers // Ceramics International. 2015. V. 41. №10. P. 13702-13708. https://doi.org/10.1016/j.ceramint.2015.07.198

68. Zhang Z., Zhai S., Wang M., Ji H., He L., Ye C., Zhang H. Photocatalytic degradation of rhodamine B by using a nanocomposite of cuprous oxide, three-dimensional reduced graphene oxide, and nanochitosan prepared via one-pot synthesis // Journal of Alloys and Compounds. 2016. V. 659. P. 101-111. https://doi.org/10.1016/j.jallcom.2015.11.027

69. Anku W. W., Shukla S. K., Govender P. P. Graft Gum Ghatti Caped Cu2O nanocomposite for photocatalytic degradation of naphthol blue black dye // Journal of Inorganic and Organometallic Polymers and Materials. 2018. V. 28. №4. P. 1540-1551. https://doi.org/10.1007/s10904-018-0875-y

70. Razmara Z., Poorsargol M. Ultrasonic‐assisted synthesis of supramolecular copper (II) complex a precursor for the preparation of octahedron Cu2O nanoparticles applicable in the adsorption and photodegradation of Rhodamine B // Applied Organometallic Chemistry. 2019. V. 33. №9. P. e5084. https://doi.org/10.1002/aoc.5084

71. Xu Q., Huang Z., Ji S., Zhou J., Shi R., Shi W. Cu2O nanoparticles grafting onto PLA fibers via electron beam irradiation: bifunctional composite fibers with enhanced photocatalytic of organic pollutants in aqueous and soil systems // Journal of Radioanalytical and Nuclear Chemistry. 2020. V. 323. №1. P. 253-261. https://doi.org/10.1007/s10967-019-06842-w

Работа поступила
в редакцию 04.07.2022 г.

Принята к публикации
08.07.2022 г.

Ссылка для цитирования:

Ren Bingbing, Mindrov K. Research Progress of Type P Copper (I) Oxide in the Field of Light Energy Utilization // Бюллетень науки и практики. 2022. Т. 8. №8. С. 194-215. https://doi.org/10.33619/2414-2948/81/25

Cite as (APA):

Ren, Bingbing, & Mindrov, K., (2022). Research Progress of Type P Copper (I) Oxide in the Field of Light Energy Utilization. *Bulletin of Science and Practice, 8*(8), 194-215. https://doi.org/10.33619/2414-2948/81/25