CHEMISTRY & CHEMICAL TECHNOLOGY

Chem. Chem. Technol., 2025,
Vol. 19, No. 4, pp. 664–672

Chemistry

ENHANCED ELECTRICAL PROPERTIES OF CRYSTALLINE SILICON SOLAR CELLS USING COPPER OXIDE NANOPARTICLES

Mansour Bayati[1,✉], Ammar M. Hamza[1], Hanaa K. Egzar[1]

[1] Department of Chemistry, College of Science, University of Kufa, Najaf city, Iraq
✉ *mansourk.ali@uokufa.edu.iq*

https://doi.org/10.23939/chcht19.04.664

Abstract. The research aimed to create an electrochemical system that could effectively and affordably produce different-sized and shaped copper oxide nanoparticles. CuO NPs also enhance the efficiency of crystalline silicon solar cells by coating them with copper oxide nanoparticles. Field emission scanning microscopy (FESEM) characterized the CuO NPs, revealing the nanorod morphologies. The presence of pure-phase CuO NPs with a monoclinic structure and an average crystallite size of 9.54 nm was verified by X-ray diffraction (XRD). CuO nanoparticles were shown to exhibit a variety of shapes using transmission electron microscopy (TEM), including platelets and rods. The CuO NPs' excellent purity was validated by an examination using an energy-dispersive X-ray spectroscopy (EDX). The measurements' results show that the efficiency of solar cells coated with CuO NPs (10.43 η at 20 °C) is higher than that of solar cells without coating (9.831η at 20 °C).

Keywords: copper oxide, electrochemical, efficiency, crystalline solar cell, nanoparticles.

1. Introduction

Many people are interested in using combined semiconductor metal oxide nanocomposites to create novel optoelectronic, electrochemical, and electrical devices, like solar cells, UV sensors, and gas sensors.[1] Tenorite (CuO), a cupric oxide, and cuprite (Cu_2O), a cuprous oxide, are the two common oxides that make up copper. P-type semiconductors with narrow bandgap energies of 1.21 to 1.51 eV and 2.10 to 2.60 eV, respectively, are known as tenorites and cuprites.[2, 3]

Its conductivity increases because it is a p-type semiconductor and has holes in the valence that can be caused by doping or annealing. Over the years, CuO, a semiconducting combination found in groups I–IV of the periodic table, has attracted a lot of attention due to its electrical and optical characteristics.[4] The substance has also attracted a lot of interest from businesses due to its high optical absorption rate,[5, 6] outstanding electrical conductivity,[7] non-toxic nature,[8] production efficiency, and, above all, its low manufacturing costs. It possesses strong solar absorption and low thermal emittance.[9]

CuO nanostructures can be made in a variety of ways using a range of chemical techniques, such as electrochemical deposition, sol-gel techniques, high-temperature annealing in an oxidative environment, and micelle-assisted precipitation.[10] Many other types of nanostructures have already been documented to develop, including nanospheres, nanoflowers, leaf-shaped nanocrystals, nanorings, nanoribbons, multi-pod nanocrystals, *etc.*, and comprehensive reviews of the state-of-the-art have been published.[11]

Moreover, research on a wide range of CuO nanostructure applications, including solar cells, has been spurred by this diversity of nanostructures with high surface-to-bulk atom ratios.[12] When it comes to morphological control, the creation of high-aspect ratio nanostructures, and their doping, copper anodization may offer unforeseen advantages. Operating circumstances influence the morphological characteristics of nanostructured anodic oxides, for instance, the pore.[13, 14]

Copper oxide nanoparticles find extensive use in a wide range of commercial applications, including heat transfer nanofluids, gas sensors, photovoltaic cells, catalysts, and antibacterial agents. When added to plastics, textiles, coatings, and other materials, they have demonstrated efficacy against a variety of bacteria and can also function as anti-fungal agents.[15, 16] An important and sustainable source of renewable energy that can help the global energy crisis is a solar cell, which is a device that converts solar energy into electrical power.[17]

Solar energy with photovoltaic capabilities is a powerful instrument for building a sustainable, affluent, and environmentally conscious civilization on a global scale. The crystalline silicon solar cell, a simple optoelectronic device, is largely responsible for its recent economic viability as a power source. Although this technology has always evolved slowly, in recent years it has accelerated, bringing with it both new potential and challenges.[18]

The goal of this research is to produce nanoparticles with favorable chemical and physical characteristics and use them to increase solar cell efficiency.

2. Experimental

2.1. Materials

All chemicals utilized in this work are of analytical grade with high purity. The chemicals and reagents used, as well as the supplier companies, are listed in Table 1.

Table 2.1 The used chemicals nd their suppliers

Material	Formula	Purity, %	Company
Potassium chloride	(KCl)	98	CDH India
Poly vinyl alcohol (PVA)	(C_2H_4) n	99	CDH India
Copper foil	Cu	98	Laboratory Chemical India
Ethanol	C_2H_5OH	99	Sigma. USA
Acetone	C_3H_6O	99	CDH India
Iodine	I2	98	CDH India

2.2. Preparation of Electrolytes and Stabilizing Solutions

KCl (100 g L-1): 10 grams of pure KCl were dissolved in 100 mL of deionized water. PVA (100 g. L-1) : 10 grams of pure PVA was dissolved in 100 mL of deionized water, and a magnetic stirrer was used to dissolve PVA.

2.3. Electrochemical Preparation

2.3.1. Electrochemical Preparation of CuO NPs

The electrochemical deposition technique for nanomaterial fabrication comprises a power source, graphite as the cathode, copper foil as the anode, and a cell solution (185 mL of deionized water, 5 mL of potassium chloride, and 10 mL of PVA). To prepare CuO NPs, 2×5 cm of copper foil (the anode electrode) was submerged in the cell's solution face-to-face with graphite (the cathode electrode). All electrodes were connected to the power supply at 15 V and 0.15 A. As the reaction started, a pale greenish (bluish green) precipitate representing copper hydroxide was noted, and over time, the color's density increased. Following a 45-minute reaction period, the electrodes were disconnected from the power source, and the precipitate was centrifuged to separate the copper hydroxide from the cell solution. The precipitate was then cleaned three times with ethanol and four times with deionized water before being heated to 100 °C to create copper oxide nanoparticles (NPs).

2.3.2. Preparation of Crystalline Silicon Solar Cell

The solar cell utilized is a crystalline silicon solar cell, measuring 2 cm by 5 cm. As seen in Fig. 1, this type of solar cell has two faces: a positive (blue face) and a negative (grey face). The positive and negative connections with the wire facilitate a simpler measuring procedure when utilizing the PV analysis device.

2.3.3. Coating Crystalline Silicon Solar Cell with CuO NPs

The coating method uses an ultrasonic device to eliminate the CuO NP accumulation. A few drops are then applied to the solar cell using a dropper, and the mixture is allowed to cure in a dark area.[19]

2.4. Measurement Efficiency of Crystalline Solar Cell

One way to determine a solar cell's efficiency is to use a PV analyzer instrument. The components of the analyzer are a laptop, a halogen lamp, a data recorder, a solar cell module analyzer, and a pyrometer solar power. The coated solar cell is placed under a halogen lamp, and the efficiency is measured every five minutes using a pyrometer to track the solar cell's temperature. Following the measurements, the efficiency and other parameters are displayed on the laptop screen. This procedure is also used to measure the efficiency of the uncoated solar cell.

3. Results and Discussion

This chapter discusses experimental results and identification methods such as XRD, FESEM, TEM, and EDX. The nanomaterial was used to enhance the efficiency of the solar cell.

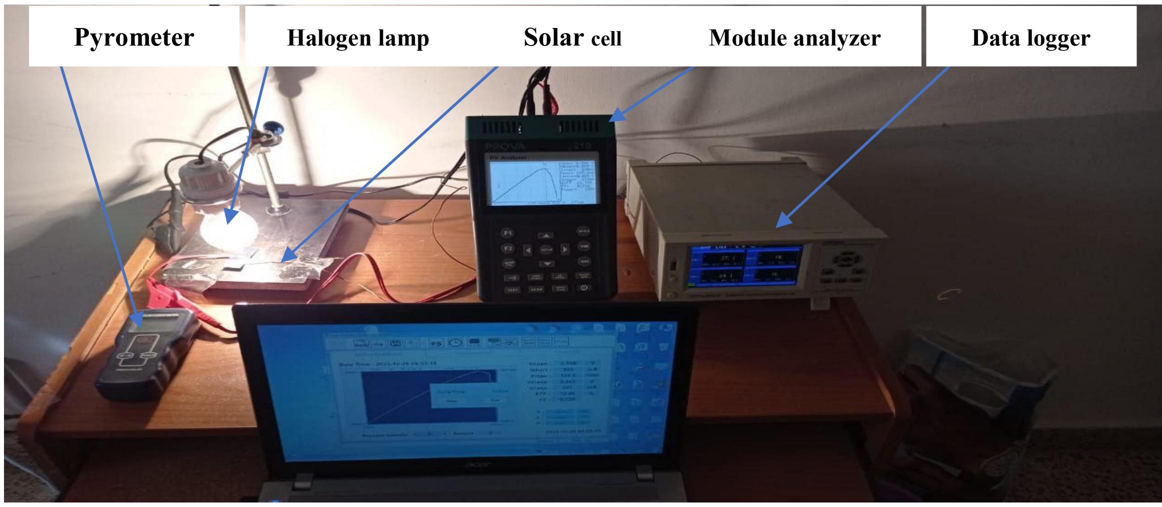

Fig. 1. PV Analyzer Device

3.1. Identification of Copper Oxide Nanoparticles (CuO NPs)

Copper oxide nanoparticles were prepared by the electrochemical method and identified by using a plethora of techniques such as XRD, FESEM, TEM, and EDX.

3.1.1. X-Ray Diffraction Analysis for CuO NPs

Using a diffraction setup with Cu-Kα1 of (= 1.54060 A) under 40 kV and 30 mA in the range of 2 θ from 10 to 80, CuO NPs were studied. The XRD pattern CuO NPs has shown in Fig. 2. several diffraction peaks at 2θ values of (32.79190, 35.65950, 38.89610, 48.82660, 53.68420, 58.39340, 61.68210, 66.19050, 68.20690, and 75.13600), which correspond to Miller indices (110), (002), (111), (–202), (020), (202), (–113), (022), (220), and (–222) that characterized the CuO NPs 20, the diffraction peaks correlated to the planes refer to the Monoclinic structure of CuO NPs which agrees with the JCPDS card No. (00-041-0254) as shown in Fig. 3.

3.1.2. Transmission Electron Microscopy (TEM) Analysis for CuO NPs

Copper oxide nanoparticles were analyzed using transmission electron microscopy. The form of the CuO nanoparticles is depicted in the microscope photos, with some appearing as a lamellar structure,[21] as seen in Fig. 4.

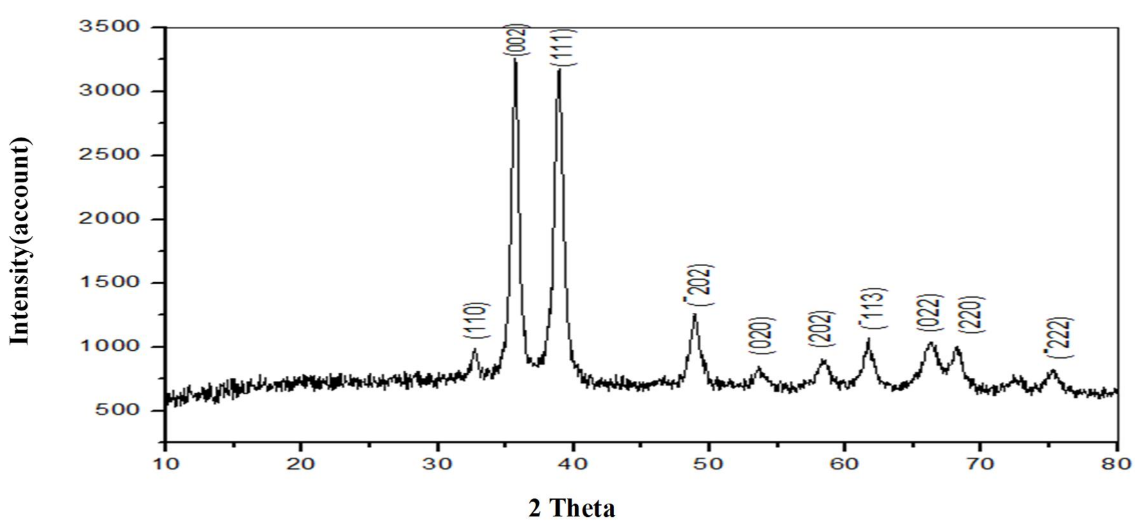

Fig. 2. X-Ray Diffraction pattern of CuO NPs

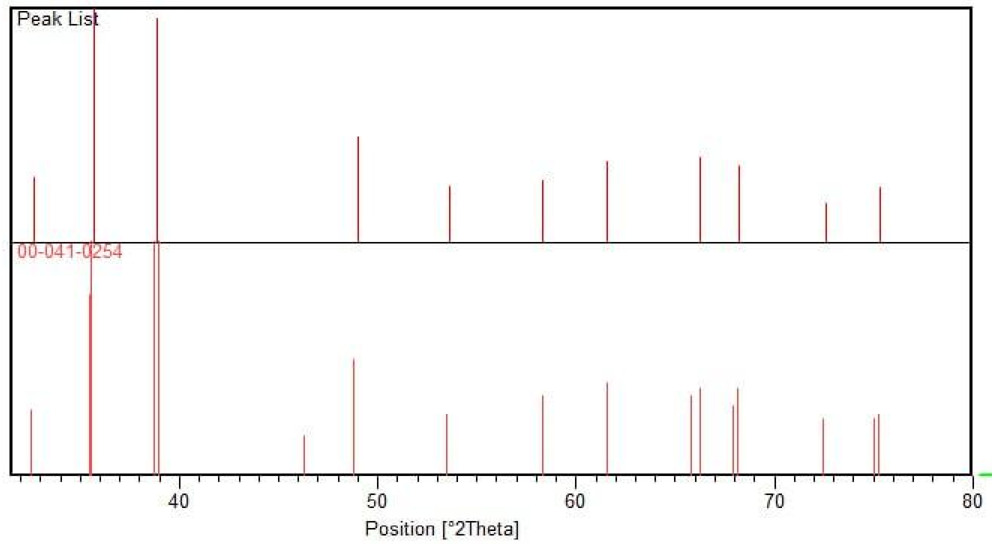

Fig. 3. JCPDS Card of CuO NPs (a); pattern of CuO NPs prepared by electrochemical deposition (b)

Table 2. X-Ray Diffraction data of CuO NPs

Pos., 2Th.	Height, cts	FWHM, 2Th.	d-spacing	Rel. Int., %	Tip width, 2Th.	Crystal size xs, nm
32.7919	94.00	0.8856	2.73117	6.62	0.9000	9.347134
35.6595	1361.31	0.9840	2.51784	95.84	1.0000	8.477489
38.8961	1420.42	0.9840	2.31546	100.00	1.0000	8.558644
48.8266	357.03	0.6888	1.86525	25.14	0.7000	12.66108
53.6842	83.00	0.8856	1.70738	5.84	0.9000	10.04985
58.3934	138.63	0.9840	1.58041	9.76	1.0000	9.244881
61.6821	219.14	0.9840	1.50380	15.43	1.0000	9.399473
66.1905	276.00	0.9840	1.41189	19.43	1.0000	9.633167
68.2069	208.00	0.8856	1.37498	14.64	0.9000	10.82939
75.1360	102.00	1.2000	1.26340	7.18	1.0000	8.34899

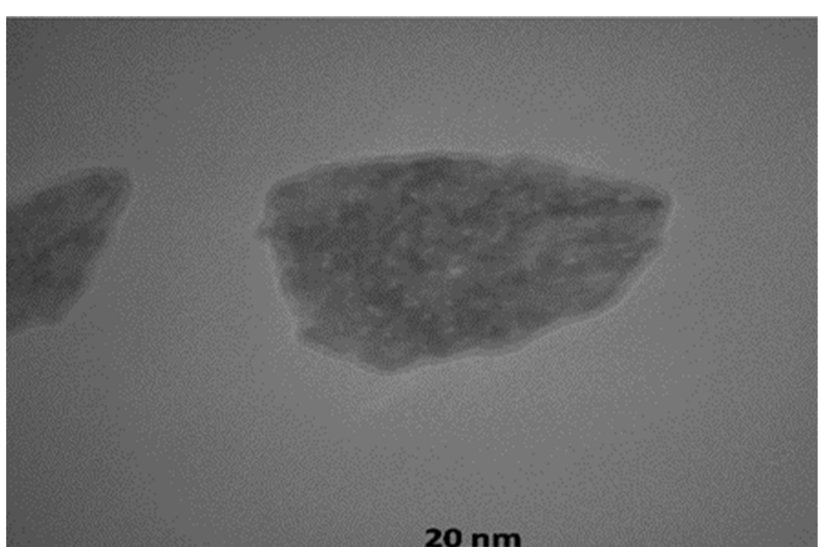

Fig. 4. TEM Image of CuO NPs

3.1.3. The Field Emission Scanning Electron Microscope (FESEM) Analysis for CuO NPs

A scanning electron microscope (SEM) was used to record the morphologies of CuO. The CuO nanoparticles' SEM picture is displayed in Fig. 5. The majority of these CuO nanoparticles had the outline of nanosheets.[22] The shape of copper oxide nanoparticles and their lamellar structure are shown below.[23]

3.1.4. Energy Dispersive X-Ray Spectroscopy (EDX) for CuO NPs

Energy Dispersive X-Ray Spectroscopy analysis of copper oxide nanoparticles indicated that CuO NPs have a high purity, as shown in Fig. 6.

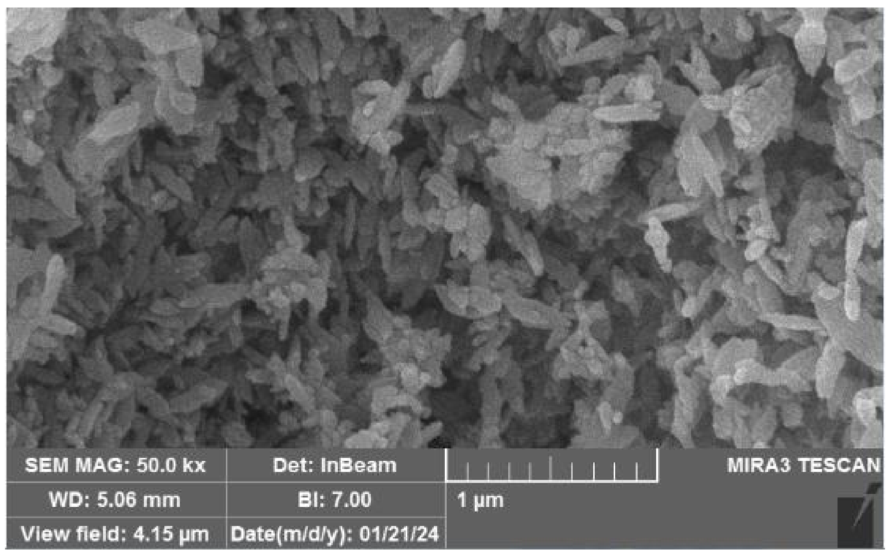

Fig. 5. FESEM Image of CuO NPs

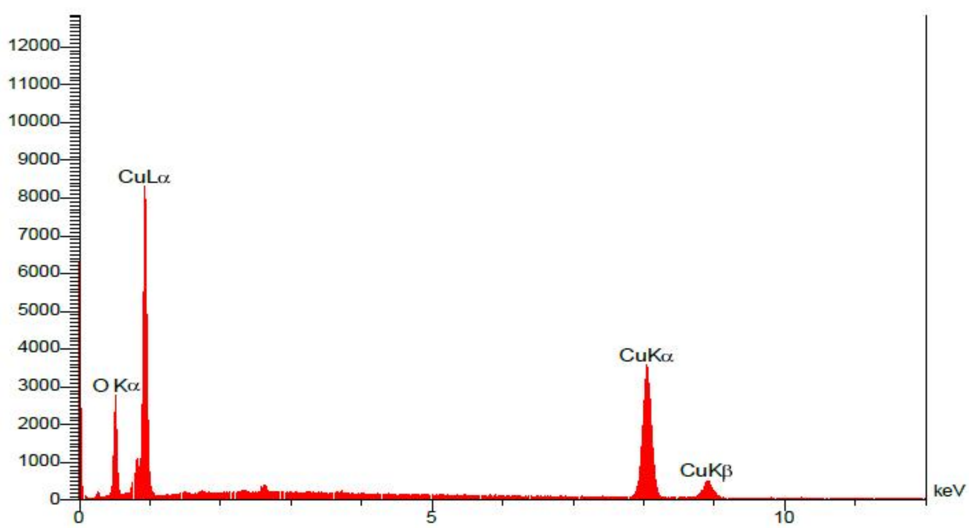

Fig. 6. EDX-Ray of CuO NPs

3.2. Solar Cell Efficiency

Crystalline silicon solar cells, measuring 2 cm by 5 cm, were used. The efficiency of the cells was measured using a PV analyzer device type (PRAVO-200) for both solar cells (coated with CuO NPs and uncoated) at different times and fixed radiant flux (1000 w/m^2) with normal light flowing through the cells. Different parameters, such as efficiency percentage, I_{max}, V_{max}, and P_{max}, were calculated for each cell, as indicated in Tables 3 and 4.

Table 3. Parameters of crystalline silicon solar cell coating without coating with CuO NPs coating

Time	Room temperature	Cell temperature	P_{max}	V_{max}	I_{max}	Efficiency
10.22	20.7	47.5	98.31	0.379	259	9.831
10.27	20.6	49	98.66	0.356	281	9.866
10.32	20.5	48	99.14	0.360	277	9.614
10.37	20.5	56	94.32	0.350	271	9.232
10.42	20.5	57	93.1	0.350	272	9.21
10.47	20.4	60	86.86	0.325	270	9.186
10.52	20.7	66.8	86.44	0.312	277	9.044
10.57	20.6	71.1	85.71	0.309	277	9.071
11.02	20.5	71.5	85.89	0.311	276	8.589
11.07	20.7	73.2	85.59	0.310	276	8.559
11.12	20.6	74.7	84.91	0.306	278	8.491
11.17	20.7	75.5	84.34	0.316	267	8.434
11.22	20.8	75.8	82.89	0.302	275	8.289

Table 4. Parameters of crystalline silicon solar cell coating with CuO NPs

Time	Room temperature	Cell temperature	P_{max}	V_{max}	I_{max}	Efficiency, %
9.10	19.5	44.7	104.3	0.386	270	10.43
9.15	19.6	46.6	100.01	0.366	275	10.01
9.20	19.7	54.9	99.06	0.357	277	9.706
9.25	19.8	59.7	96.98	0.345	275	9.398
9.30	20.0	61.9	95.41	0.350	274	9.241
9.35	20.0	65.6	90.59	0.330	276	9.059
9.40	20.1	67.4	91.35	0.331	276	9.135
9.45	20.2	68.9	90.66	0.325	280	9.066
9.50	20.2	71.3	88.75	0.322	278	8.875
9.55	20.3	72.9	88.59	0.323	274	8.859
10.00	20.3	73.2	88.70	0.312	284	8.870
10.05	20.4	73.3	88.95	0.315	282	8.895
10.10	20.3	74.0	86.71	0.326	268	8.671
10.15	20.5	75.0	86.99	0.318	275	8.69

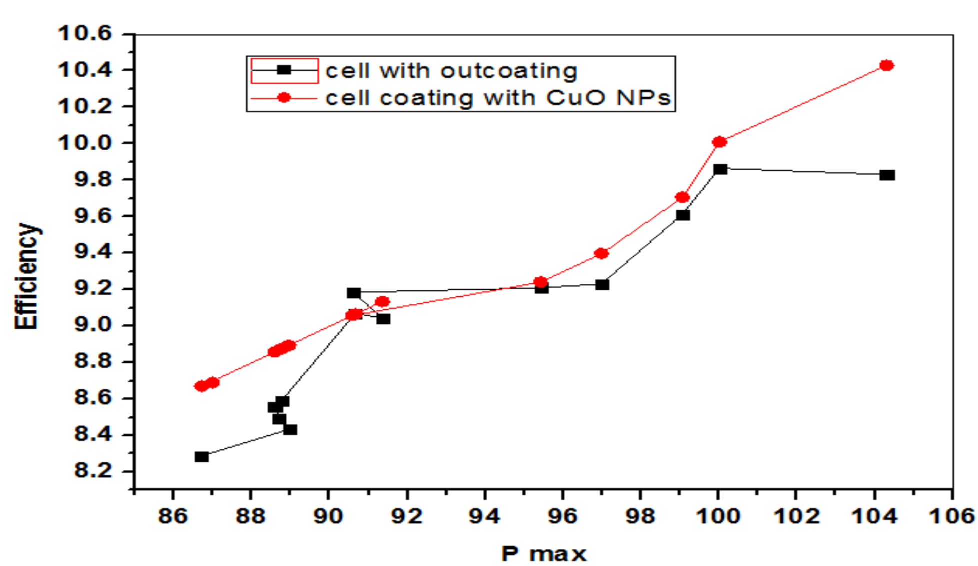

Fig. 7. Efficiency of solar cell coating with CuO NPs and solar cell without coating

The measurement results show that the efficiency of solar cells coated with copper oxide nanoparticles is higher than that of uncoated solar cells because copper oxide particles have a high surface area and play a major role in reducing light reflection. In addition, copper oxide nanoparticles provide a surface that increases electrical conductivity because copper oxide has a small energy band gap of (1.21 to 1.51 eV).

The temperature of both cells measured by the pyrometer was increasing with time due to the impact of incident power; as a result, the efficiency decreased with increasing temperature for both cells,[24, 25] as shown in Fig. 8.

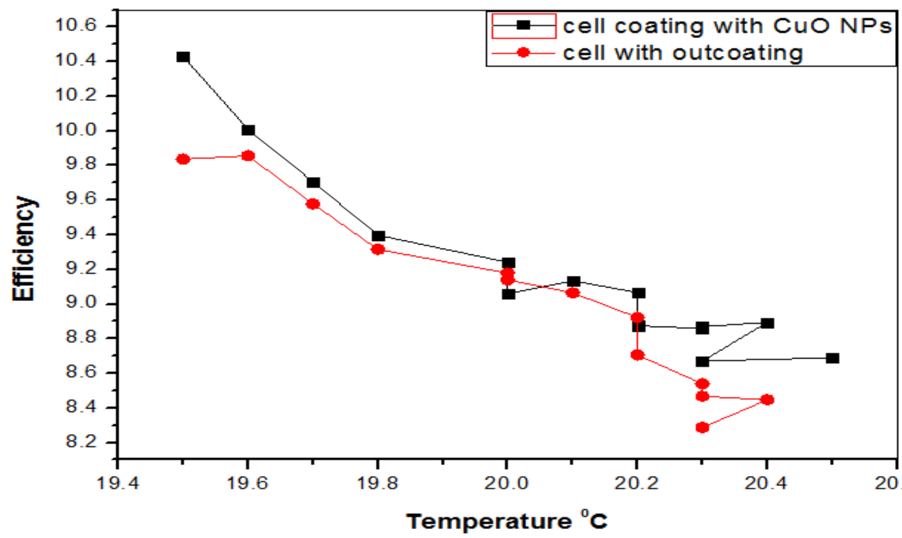

Fig. 8. Change in Efficiency of solar cell coating with CuO NPs coating and the cell without coating

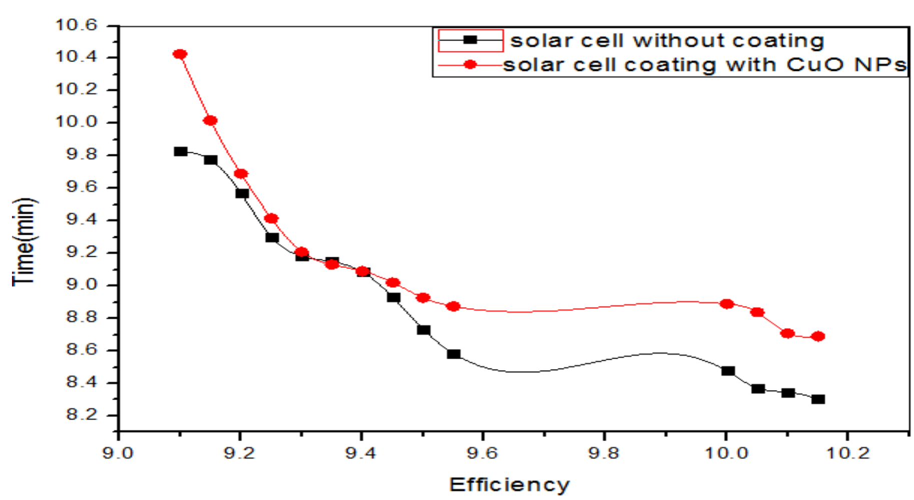

Fig. 9. Decrease in efficiency of both solar cells with time

4. Conclusions

In conclusion, this research provides compelling evidence that copper oxide (CuO) nanoparticles synthesized via electrochemical deposition serve as an effective coating to enhance the performance of crystalline silicon solar cells. Comprehensive characterization by XRD, TEM, FESEM, and EDX confirmed the successful fabrication of high-purity, monoclinic-structured CuO nanorods with a uniform morphology. The CuO nanoparticle coating significantly improved the solar cells' electrical parameters, achieving a maximum power conversion efficiency of 10.43 % at 20 °C, surpassing the 9.83 % efficiency of uncoated cells. This enhancement is attributed to the CuO layer' superior light absorption and electrical conductivity properties, which facilitate more efficient charge carrier generation and transport. The observed decrease in efficiency with increasing temperature highlights the critical role of thermal effects on device performance and underscores the necessity for effective thermal management strategies. Overall, the findings demonstrate the potential of CuO nanoparticles as a cost-effective, scalable approach to optimizing silicon-based photovoltaic devices. Future work should focus on stability assessments under operational conditions, exploring alternative nanoparticle compositions, and refining deposition parameters to further maximize device efficiency and durability.

Acknowledgements

This work is dedicated to the College of Science, University of Kufa, to the Director of the Central Laboratory, and the professors involved in the work.

Abbreviations

°C	Centigrade degree
T	Temperature
α	optical absorption coefficient
λ	Wavelength, nm
Isc	Short circuit current, mA
Voc	Open-Circuit Voltage, Volt
V_{max}	Maximum voltage, Volts
I_{max}	Maximum current, mA
η	Efficiency
FWHM	full width at half maximum
TEM	Transmission Electron Microscopy
CE	Current efficiency
NPs	Nanoparticle
DIW	Deionized Water
EDX	Energy Dispersive Spectroscopy
FE-SEM	Field Emission-Scanning Electron Microscopy

References

[1] Sah, D.; Chitra, N.; Kumar, S. Investigation and Recovery of Copper from Waste Silicon Solar Module. *Mater. Chem. Phys*. **2022**, *296*, 127205. https://doi.org/10.1016/j.matchemphys.2022.127205

[2] Chakraborty, N.; Banerjee, J.; Chakraborty, P.; Banerjee, A.; Chanda, S.; Ray, K.; Acharya, K.; Sarkar, J. Green Synthesis of Copper/Copper Oxide Nanoparticles and Their Applications: A Review. *Green Chem. Lett. Rev*. **2022**, *15*, 187–215. https://doi.org/10.1080/17518253.2022.2025916

[3] Asadi, M.; Rozati, S. M. Optical and Structural Properties of Nanostructured Copper Oxide Thin Films as Solar Selective Coating Prepared by Spray Pyrolysis Method. *Mater. Sci.-Pol*. **2017**, *35*, 355–361. https://doi.org/10.1515/msp-2017-0054

[4] Dhaouadi, M. Physical Properties of Copper Oxide Thin Films Prepared by Sol-Gel Spin-Coating Method. *Am. J. Phys*. **2018**, *6*, 43. https://doi.org/10.11648/j.ajpa.20180602.13

[5] Prabu, R. D.; Valanarasu, S.; Ganesh, V.; Shkir, M.; AlFaify, S.; Kathalingam, A.; Srikumar, S. R.; Chandramohan, R. An Effect of Temperature on Structural, Optical, Photoluminescence and Electrical Properties of Copper Oxide Thin Films Deposited by Nebulizer Spray Pyrolysis Technique. *Mater. Sci. Semicond. Process*. **2017**, *74*, 129–135. https://doi.org/10.1016/j.mssp.2017.10.023

[6] Aghayan, M.; Hussainova, I.; Kirakosyan, K.; Rodríguez, M. A. The Template-Assisted Wet-Combustion Synthesis of Copper Oxide Nanoparticles on Mesoporous Network of Alumina Nanofibers. *Mater. Chem. Phys*. **2017**, *192*, 138–146. https://doi.org/10.1016/j.matchemphys.2017.01.068

[7] Akgul, U.; Yildiz, K.; Atici, Y. Effect of Annealing Temperature on Morphological, Structural and Optical Properties of Nanostructured CuO Thin Film. *Eur. Phys. J. Plus*. **2016**, *131*, 89. https://doi.org/10.1140/epjp/i2016-16089-3

[8] Mikami, K.; Kido, Y.; Akaishi, Y.; Quitain, A.; Kida, T. Synthesis of CU_2O/CuO Nanocrystals and their Application to H_2S Sensing. *Sensors* **2019**, *19*, 211. https://doi.org/10.3390/s19010211

[9] Wisz, G.; Sawicka-Chudy, P.; Sibiński, M.; Płoch, D.; Bester, M.; Cholewa, M.; Woźny, J.; Yavorskyi, R.; Nykyruy, L.; Ruszała, M. TIO_2/CuO/Cu_2O Photovoltaic Nanostructures Prepared by DC Reactive Magnetron Sputtering. *Nanomaterials* **2022**, *12*, 1328. https://doi.org/10.3390/nano12081328

[10] Immanuel, S.; Aparna, T. K.; Sivasubramanian, R. Graphene-Metal Oxide Nanocomposite Modified Electrochemical Sensors. In *Graphene-Based Electrochemical Sensors for Biomolecules*; Pandikumar, A.; Rameshkumar, P., Eds.; Elsevier, 2019; pp 113–138. https://doi.org/10.1016/b978-0-12-815394-9.00005-4

[11] Zhang, Q.; Zhang, K.; Xu, D.; Yang, G.; Huang, H.; Nie, F.; Liu, C.; Yang, S. CuO Nanostructures: Synthesis, Characterization, Growth Mechanisms, Fundamental Properties, and Applications. *Prog. Mater. Sci*. **2013**, *60*, 208–337. https://doi.org/10.1016/j.pmatsci.2013.09.003

[12] Sun, S.; Zhang, X.; Yang, Q.; Liang, S.; Zhang, X.; Yang, Z. Cuprous Oxide (Cu_2O) Crystals with Tailored Architectures: A Comprehensive review on Synthesis, Fundamental Properties, Functional Modifications and Applications. *Prog. Mater. Sci*. **2018**, *96*, 111–173. https://doi.org/10.1016/j.pmatsci.2018.03.006

[13] Stepniowski, W. J.; Stojadinović, S.; Vasilić, R.; Tadić, N.; Karczewski, K.; Abrahami, S. T.; Buijnsters, J. G.; Mol, J. M. C. Morphology and Photoluminescence of Nanostructured Oxides Grown by Copper Passivation in Aqueous Potassium Hydroxide Solution. *Mater. Lett*. **2017**, *198*, 89–92. https://doi.org/10.1016/j.matlet.2017.03.155

[14] Macdonald, T. J.; Clancy, A. J.; Shutt, R. R. C.; Howard, C. A. Phosphorene Nanoribbons for Next-Generation Energy Devices. *Joule*. **2022**, *6*, 2441–2446. https://doi.org/10.1016/j.joule.2022.09.010

[15] Rheima, A. M.; Anber, A. A.; Abdullah, H. I.; Ismail, A. H. Synthesis of Alpha-Gamma Aluminum Oxide Nanocomposite *via* Electrochemical Method for Antibacterial Activity. *Nano Biomed. Eng*. **2020**, *13*, 1–5. https://doi.org/10.5101/nbe.v13i1.p1-5

[16] Soleymani, F. Analysis of Microstructural Changes, Morphology and Optical Properties of the Surface of Copper Oxide Thin Layers due to Annealing for Use in Optoelectronic Devices. *J. Adv. Mater. Eng.* **2024**, *43*, 17–28. https://doi.org/10.47176/jame.43.2.1062

[17] Stępniowski, W. J.; Norek, M.; Budner, B.; Michalska-Domańska, M.; Nowak-Stępniowska, A.; Bombalska, A.;

Kaliszewski, M.; Mostek, A.; Thorat, S.; Salerno, M.; *et al*. *In-situ* Electrochemical Doping of Nanoporous Anodic Aluminum Oxide with Indigo Carmine Organic Dye. *Thin Solid Films.* **2015**, *598*, 60–64. https://doi.org/10.1016/j.tsf.2015.11.084

[18] Patwary, M. A. M.; Hossain, M. A.; Ghos, B. C.; Chakrabarty, J.; Haque, S. R.; Rupa, S. A.; Uddin, J.; Tanaka, T. Copper Oxide Nanostructured Thin Films Processed by SILAR for Optoelectronic Applications. *RSC Adv*. **2022**, *12*, 32853–32884. https://doi.org/10.1039/d2ra06303d

[19] Yun, J.-W.; Ullah, F.; Jang, S.-J.; Kim, D. H.; Nguyen, T. K.; Ryu, K. Y.; Cho, S.; Jang, J. I.; Lee, D.; Park, S.; *et al*. Ultrasonic-Assisted Spin-Coating: Improved Junction by Enhanced Permeation of a Coating Material within Nanostructures. *ACS Appl. Mater. Interfaces.* **2018**, *10*, 20025–20031. https://doi.org/10.1021/acsami.8b04516

[20] Zimbovskii, D. S.; Churagulov, B. R. Cu_2O and CuO Films Produced by Chemical and Anodic Oxidation on the Surface of Copper Foil. *Inorg. Mater*. **2018**, *54*, 660–666. https://doi.org/10.1134/s0020168518070208

[21] Vieillard, J.; Bouazizi, N.; Morshed, M. N.; Clamens, T.; Desriac, F.; Bargougui, R.; Thebault, P.; Lesouhaitier, O.; Derf, F. L.; Azzouz, A. CuO Nanosheets Modified with Amine and Thiol Grafting for High Catalytic and Antibacterial Activities. *Ind. Eng. Chem. Res*. **2019**, *58*, 10179–10189. https://doi.org/10.1021/acs.iecr.9b00609

[22] Tavakoli, S.; Kharaziha, M.; Ahmadi, S. Green Synthesis and Morphology Dependent Antibacterial Activity of Copper Oxide Nanoparticles. *J. Nanostruct*. **2019**, *9*, 163–171. https://doi.org/10.22052/jns.2019.01.018

[23] Moëzzi, F.; Hedayati, S. A.; Ghadermazi, A. Ecotoxicological Impacts of Exposure to Copper Oxide Nanoparticles on the Gill of the Swan Mussel, *Anodonta cygnea* (Linnaeus, 1758). *Molluscan Res.* **2018**, *38*, 187–197. https://doi.org/10.1080/13235818.2018.1441591

[24] Chopra, N. R.; Kashyap, N. N.; Kumar, N. A.; Banerjee, N. D. Chemical Synthesis of Copper Oxide Nanoparticles Study of its Optical and Electrical Properties. *Int. J. Eng. Res.* **2020**, 9, IJERTV9IS010160. https://doi.org/10.17577/ijertv9is010160

[25] Wanninayake, A. P.; Gunashekar, S.; Li, S.; Church, B. C.; Abu-Zahra, N. Performance Enhancement of Polymer Solar Cells Using Copper Oxide Nanoparticles. *Semicond. Sci. Technol*. **2015**, *30*, 064004. https://doi.org/10.1088/0268-1242/30/6/064004

Received: August 09, 2024 / Revised: June 08, 2025 / Accepted: June 11, 2025

ПОКРАЩЕНІ ЕЛЕКТРИЧНІ ВЛАСТИВОСТІ КРИСТАЛІЧНИХ КРЕМНІЄВИХ СОНЯЧНИХ ЕЛЕМЕНТІВ ІЗ ВИКОРИСТАННЯМ НАНОЧАСТИНОК ОКСИДУ МІДІ

Анотація. *Мета дослідження – створити електрохімічну систему, яка б могла ефективно та економічно виробляти наночастинки оксиду міді різних розмірів та форми. Наночастинки CuO також підвищують ефективність кристалічних кремнієвих сонячних елементів, покриваючи їх наночастинками оксиду міді. Наночастинки CuO досліджено за допомогою FESEM. Виявлено морфологію наностержнів. Наявність наночастинок CuO чистої фази з моноклінною структурою та середнім розміром кристалітів 9,54 нм підтверджено рентгенівською дифракцією (XRD). За допомогою трансмісійної електронної мікроскопії (TEM) виявлено, що наночастинки CuO мають різноманітні форми, серед яких платівки та стержні. Відмінну чистоту наночастинок CuO підтверджено дослідженням за допомогою енергодисперсійної рентгенівської спектроскопії (EDX). Результати вимірювань показують, що ефективність сонячних елементів, покритих наночастинками CuO (10,43 η за 20 °C), вища, ніж у сонячних елементів без покриття (9,831 η за 20 °C).*

Ключові слова: *оксид міді, електрохімічний, ефективність, кристалічний сонячний елемент, наночастинки.*