MIKAILALSYS
Journal of Multidisciplinary Sciences

e-ISSN : 2987-2286
p-ISSN : 2987-3924

Index : Dimensions, Scilit, Crossref, Garuda, Semantic, Lens,Google Scholar,Base, etc

https://doi.org/10.58578/mikailalsys.v4i1.9537

Synthesis and Characterization of ZnO-Doped CuO with the Addition of Monoethanolamine Using the Sol-Gel Method

Nazellia Asnur, Hary Sanjaya, Indang Dewata, Fajri Ikhsan
Padang State University, Indonesia
nazelliaasnur30@gmail.com; hary.s@fmipa.unp.ac.id

Article Info:

Submitted:	Revised:	Accepted:	Published:
Mar 15, 2026	Apr 12, 2026	Apr 24, 2026	Apr 29, 2026

Abstract

Semiconductors are materials capable of conducting electricity within specific limits, a property that is essential for applications in photocatalysts and solar cells. Copper oxide (CuO), a transition metal oxide, exhibits favorable properties as a p-type semiconductor and is characterized by a narrow bandgap ranging from 1.2 to 1.8 eV. However, CuO has a limitation in the form of a high electron–hole recombination rate, which requires modification through doping and additive incorporation. This study aims to analyze the effects of zinc oxide (ZnO) doping and the addition of monoethanolamine (MEA) on the characteristics of CuO nanoparticles synthesized using the sol–gel method. This method was selected because it can produce materials with a large surface area and good stability. Characterization was conducted using ultraviolet–diffuse reflectance spectroscopy (UV–DRS) to determine bandgap energy. The findings show that the optimal bandgap value was obtained at 20% ZnO concentration, with a bandgap energy of 1.33 eV, while the addition of 2 mL MEA produced a bandgap energy of 1.42 eV. The decrease in bandgap value indicates that ZnO doping affects the optical properties of CuO. A smaller bandgap narrows the distance between the valence band and the conduction band, thereby facilitating electron excitation and requiring lower photon energy. This study contributes to the development of modified CuO-based semiconductor materials by demonstrating the potential role of ZnO doping and MEA addition in improving optical characteristics relevant to photocatalytic and solar cell applications.

Keywords: Copper Oxide; Zinc Oxide Doping; Monoethanolamine; Sol–Gel Method; Bandgap Energy

INTRODUCTION

The development of nanotechnology materials, particularly semiconductor nanoparticles, is accelerating because they have great potential in various applications such as photocatalysis, sensors, and energy. Semiconductors are materials that have the ability to conduct electricity within certain limits, and this significantly affects the function of photocatalysts as well as solar cells (Wang et al. 2021). Semiconductors have characteristics such as smooth surfaces or grains, allowing the formation of layers that facilitate research processes and reduce costs, making them very suitable for applications such as solar panels, providing flexibility in material structures (Liza et al. 2018). One material that has been extensively studied in various research is copper (II) oxide (CuO).

CuO, being a p-type semiconductor, has a narrow bandgap, enabling it to absorb light in the visible spectrum (Singh, 2020). This material has advantages such as good chemical stability, low production costs, and being environmentally friendly (Chopade, 2024). Nevertheless, CuO has a drawback in the form of high electron-hole recombination, which can reduce its performance (Sanjaya 2024). To improve this performance, modification is carried out through the addition of doping.

Doping is the addition of other elements into the material structure to improve its electrical and optical properties (Kasuma et al. 2017). Doping is a technique of adding other atoms into the semiconductor structure to enhance its electrical and optical properties (Kasuma et al. 2017). ZnO is one of the potential dopant candidates because it is an n-type semiconductor, has a wide bandgap, and is stable and non-toxic (Supu, 2022). The combination of CuO and ZnO can form a p–n heterojunction structure that is capable of enhancing charge separation and suppressing electron-hole recombination (Parashar, 2020).

Zinc Oxide (ZnO) is an n-type semiconductor with a wide bandgap, stable, and non-toxic, making it potentially useful as a dopant for CuO (Supu, 2022). The combination of CuO and ZnO can form a p–n type heterojunction that enhances charge separation, reduces electron–hole recombination, and improves material performance (Zhao et al. 2020). Aside from dopants, the use of additives also affects the synthesis process. MEA is often used in the sol-gel method because it can control the hydrolysis and condensation processes, as well as help produce particles with more uniform size and morphology. Therefore, the combination of ZnO doping and MEA addition is expected to improve the quality of CuO nanoparticles (Ningsih et al. 2021). The role of MEA is not only as a stabilizer but also can influence particle size, morphology, homogeneity, and the optical properties of the resulting nanoparticles (Anjelina, 2024). Thus, the combination of ZnO doping and MEA addition is expected to produce CuO nanoparticles with more optimal characteristics.

The sol-gel, hydrothermal, and co-precipitation methods are some of the commonly used techniques in the synthesis of CuO (Arini et al., 2022). These methods work by converting a colloidal system (sol) into a continuous gel phase, allowing for control over particle size and structure (Supu et al., 2022). Among these methods, sol-gel is often preferred because it has advantages in producing high-purity materials, requires relatively lower synthesis temperatures, and provides good control over particle size and morphology (Saleem et al., 2025).

According to research (Saleem et al. 2025), it was shown that CuO has a band gap of 1.47 eV. The research conducted by (Saleem et al. 2025) involved the synthesis of CuO added with ZnO, resulting in a band gap value of 1.47 - 1.62 eV. This increase is caused by excess ZnO addition, which can lead to disruption of the crystal structure or domination of the ZnO phase in the system, making the heterojunction effect less optimal. Excessive ZnO concentration can increase the likelihood of electron-hole pair recombination, thereby reducing charge separation efficiency. As doping increases, the conduction band becomes filled, so the energy required for electronic transitions increases, which ultimately enlarges the band gap and reduces crystal homogeneity (Peng et al., 2020).

Based on the literature review, previous studies have primarily focused on single modification approaches, either through ZnO doping or the use of additives in CuO synthesis. However, studies that systematically investigate the combined effect of ZnO doping and monoethanolamine (MEA) addition on the optical properties of CuO, particularly bandgap energy, are still limited.

Therefore, this study aims to explore the simultaneous influence of ZnO concentration and MEA volume on the bandgap characteristics of CuO nanoparticles synthesized via the sol–gel method. The novelty of this work lies in the combined modification strategy and the systematic evaluation of its effect on bandgap energy as a fundamental optical parameter.

Based on the description above, this study aims to analyze the effect of adding Zinc Oxide (ZnO) and MEA doping on the band gap of CuO nanoparticles using the sol-gel method. The band gap values of ZnO-doped synthesized CuO will be analyzed using UV - Diffuse Reflectance Spectroscopy methods.

METHODS

1. Tools

The tools used in this study include beakers, measuring pipettes, evaporating dishes, watch glasses, magnetic stirrers, stirring rods, ovens, and UV-Diffuse Reflectance (UV-DRS) spectrophotometers.

2. Materials

In this study, the materials used include copper (II) nitrate $Cu(NO_3)_2.3H_2O$, zinc nitrate $Zn(NO_3)_2.6H_2O$, methanol (CH_3OH) (p.a), distilled water, and Monoethanolamine (MEA) (p.a).

3. Procedure

a. Synthesis of CuO material

4.7 grams $Cu(NO_3)_2.3H_2O$ with a concentration of 0.5M is dissolved in 50 mL of methanol solvent and covered with plastic wrap. Then, it is homogenized using a magnetic stirrer for 1 hour. After that, the solution is sonicated for 30 minutes at 50 W to produce a homogeneous solution (sol). To stabilize the sol, the solution is left for 24 hours. After that, the sample is dried in an oven for ± 1 hour at 85°C. The resulting gel is calcined in a furnace at 500°C for ± 3 hours to obtain CuO nanoparticles so that the sample can be characterized.

b. Synthesis of CuO/ZnO material

4.7 grams $Cu(NO_3)_2.3H_2O$ with a concentration of 0.5M and $Zn(NO_3)_2.6H_2O$ with concentrations of 5%, 10%, 15%, 20%, and 25%. Both were dissolved in 50 mL of methanol solvent, covered with plastic wrap, and homogenized using a magnetic stirrer for 1 hour. Then, the solution was sonicated for 30 minutes at 50 W so that the solution (sol) became homogeneous and was left for 24 hours to stabilize the sol. Next, the sample was dried in an oven at 85 °C for approximately 1 hour. The resulting gel was then calcined in a furnace at 500 °C for approximately 3 hours to produce CuO nanoparticles so that the sample could be characterized.

c. Synthesis of CuO/ZnO material with MEA additive variations\

For MEA variation, the optimal ZnO concentration (20%) was used as the baseline condition obtained were dissolved in 50 mL of methanol solvent, then covered with plastic wrap and homogenized using a magnetic stirrer for 1 hour, then MEA was added with variations of 1 mL, 2 mL, and 3 mL, then covered with plastic wrap and homogenized using a magnetic stirrer for 1 hour. Next, the solution was sonicated for 30 minutes at 50 W to produce a homogeneous solution (sol), and left for 24 hours to stabilize the sol. Furthermore, the sample was dried in an oven at 85°C for ± 1 hour. The resulting gel was calcined in a furnace at 500°C for ± 3 hours to produce CuO nanoparticles, allowing the sample to be characterized.

RESULTS

The optical properties of the samples were analyzed using UV–DRS Spectroscopy with a wavelength range of 185–1100 nm. This test was conducted to determine the effect of variations in ZnO doping concentration and the addition of Monoethanolamine (MEA) on the bandgap value of the synthesized CuO nanoparticles. The variations in ZnO concentration used included 5%, 10%, 15%, 20%, and 25%, while the MEA volume was varied at 1 mL, 2 mL, and 3 mL. The bandgap value was determined by applying the Kubelka–Munk equation approach (Sanjaya, 2024). The optical bandgap energy was determined using the Kubelka–Munk function:

$$F(R) = (1 - R)^2 / (2R)$$

where R is the reflectance.

The Tauc relation was applied:

$$(\alpha h\nu)^n = A(h\nu - Eg)$$

where:

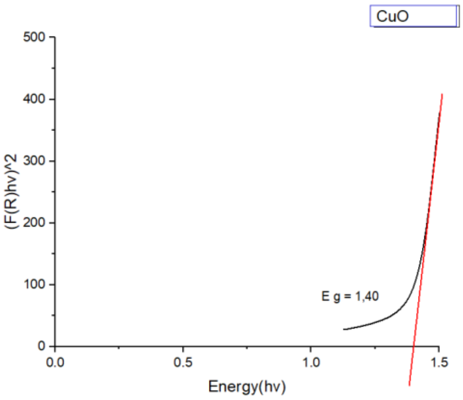
$h\nu$ = photon energy

Eg = bandgap energy

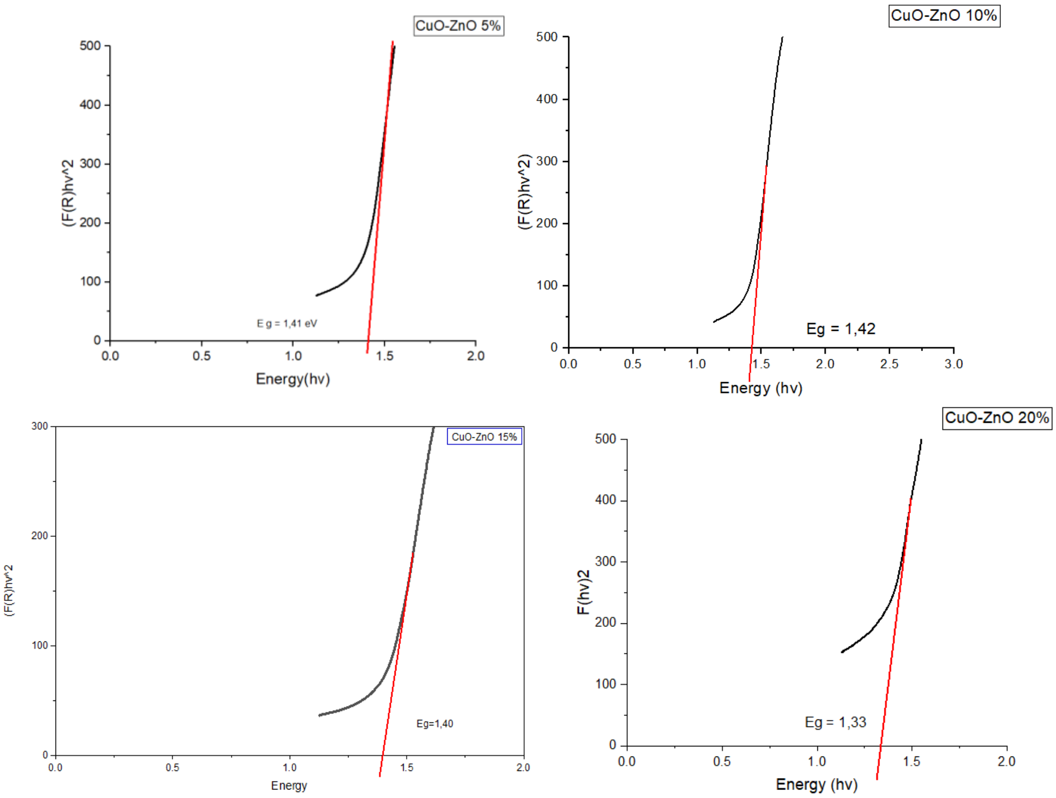
$n = 2$ (direct allowed transition assumed)

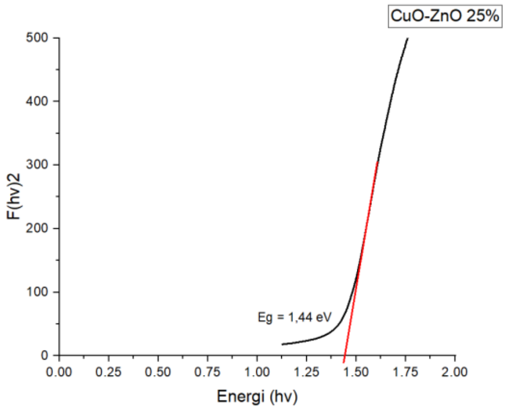
The bandgap was obtained by extrapolating the linear region of the Tauc plot to the photon energy axis.

The following is data of CuO-ZnO processed using OriginPro and displayed in the form of a graph in Figure 1.

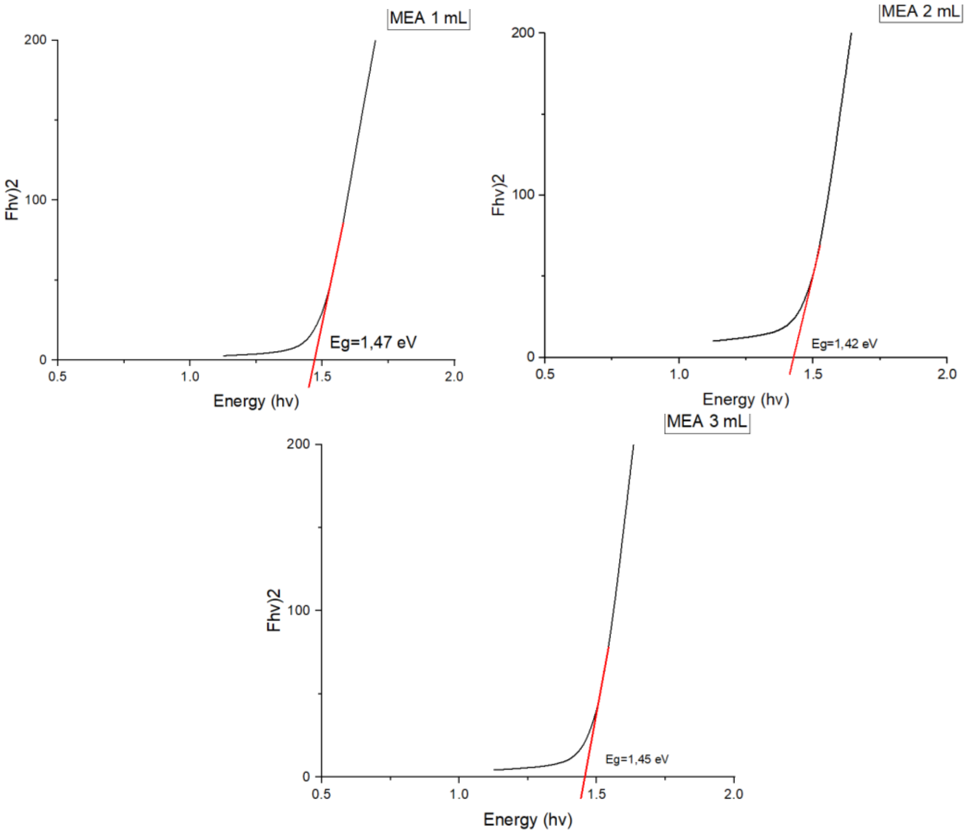


(a) Tauc plot of pure CuO





(b) Effect of ZnO doping concentration on bandgap energy



(c) Effect of MEA addition on bandgap energy

Figure 1. (a) Tauc plot of pure CuO, (b) Effect of ZnO doping concentration on bandgap energi, (c) Effect of MEA addition on bandgap energi.

The graphic images above show the absorption curves from UV-DRS used to determine the bandgap values of CuO doped with ZnO in various concentration variations. Graph (a) shows that CuO without dopant addition has a bandgap value of 1.40 eV. After ZnO doping, there is a change in the bandgap value depending on the concentration of dopant added. In image (b), at ZnO concentrations of 5% and 10%, the bandgap values increase to 1.41 eV and 1.42 eV, respectively. However, at a concentration of 15%, the bandgap decreases back to 1.40 eV, and the most significant decrease occurs at a ZnO concentration of 20% with a bandgap value of 1.33 eV, while at a concentration of 25%, it increases again to 1.44 eV. In image (c), the effect of adding MEA on the bandgap value of CuO-ZnO is also observed. Measurement results show that adding 1 mL of MEA produces a bandgap value of 1.47 eV. Furthermore, increasing the MEA volume to 2 mL causes the bandgap value to decrease to 1.42 eV. However, when the MEA volume is increased to 3 mL, the bandgap value rises again to 1.45 eV. These results indicate that variations in ZnO doping concentration and MEA volume have a significant effect on the bandgap values of the resulting CuO nanoparticles.

Table 1. Bandgap energy Against the Effect of Zinc Oxide Doping Concentration

Doping Concentration	Bandgap Value (Eg)
CuO tanpa ZnO	1.40 eV
5% ZnO	1.41 eV
10% ZnO	1.42 eV
15% ZnO	1.40 eV
20% ZnO	1.33 eV
25% ZnO	1.44 eV

The table above shows the band gap results of CuO doped with ZnO with different concentration variations. It can be seen that the addition of ZnO at a 20% concentration results in a decrease compared to pure CuO, and the addition of ZnO doping can reduce the CuO bandgap (Ben Soltan et al., 2016).

Table 2. The Effect of Concentration on the Bandgap Energy of CuO-ZnO + MEA

CuO-ZnO + MEA Concentration	Bandgap Value (Eg)
MEA 1 mL	1.47 eV
MEA 2 mL	1.42 eV
MEA 3 mL	1.45 eV

From the table above, the bandgap values of CuO-ZnO + MEA are obtained at various concentration variations. It is seen that the addition of MEA at a concentration of 2 mL causes a decrease in the bandgap value.

DISCUSSION

The results demonstrate that ZnO doping and MEA addition significantly influence the bandgap energy of CuO nanoparticles. These variations are closely related to changes in crystal structure, defect formation, and the interaction between electronic energy levels.

The decrease in bandgap energy observed at 20% ZnO concentration (1.33 eV) indicates the formation of an optimal p–n heterojunction between CuO (p-type) and ZnO (n-type). This heterojunction facilitates more effective charge separation and reduces electron–hole recombination. As a result, additional intermediate energy levels may form within the band structure, leading to bandgap narrowing. This finding is consistent with previous studies reporting that appropriate doping concentrations can enhance electronic interaction and modify optical properties (Saleem et al., 2025).

At lower ZnO concentrations (5% and 10%), the increase in bandgap energy suggests that the dopant has not been optimally incorporated into the CuO lattice. In this condition, ZnO tends to act as an impurity phase rather than forming a well-defined heterojunction, resulting in limited electronic interaction between the two materials. Consequently, the energy required for electron excitation increases slightly.

In contrast, at higher ZnO concentration (25%), the bandgap increases again to 1.44 eV. This phenomenon may be attributed to excessive doping, which can disrupt the crystal structure and reduce material homogeneity. High dopant concentration can also lead to phase segregation or dominance of ZnO, which has a wider bandgap, thereby increasing the overall bandgap of the composite material. Similar behavior has been reported by Peng et al. (2020), where excessive doping reduces the effectiveness of heterojunction formation.

The decrease in bandgap at optimal doping levels can also be associated with the presence of crystal defects such as oxygen vacancies. These defects introduce localized energy states within the bandgap, which facilitate electron transition at lower energy levels. This mechanism contributes to the narrowing of the bandgap and enhances the optical absorption in the visible region.

Furthermore, the addition of monoethanolamine (MEA) plays an important role in controlling particle growth and morphology during the sol–gel process. The reduction in bandgap observed at 2 mL MEA (1.42 eV) suggests that this concentration provides optimal conditions for particle uniformity and structural stability. MEA acts as a stabilizing and complexing agent, which helps regulate hydrolysis and condensation reactions, leading to more homogeneous nanoparticles.

However, at higher MEA volume (3 mL), the bandgap increases again. This may be caused by excessive organic content that interferes with crystal formation, resulting in reduced crystallinity and less efficient electronic interaction. Therefore, the amount of MEA must be carefully controlled to achieve optimal material properties.

Overall, the results indicate that both ZnO doping and MEA addition must be optimized to achieve desirable optical properties. The combination of 20% ZnO and 2 mL MEA provides the most effective modification, resulting in the lowest bandgap energy. This condition is favorable for applications such as photocatalysis, as lower bandgap materials require less energy for electron excitation and can utilize visible light more efficiently.

CONCLUSION

This study demonstrates that ZnO doping and MEA addition influence the optical bandgap of CuO nanoparticles synthesized via the sol–gel method. The lowest bandgap (1.33 eV) was obtained at 20% ZnO, while the addition of 2 mL MEA resulted in a bandgap of 1.42 eV. These results indicate that both parameters affect bandgap modulation. This study provides insight into the tuning of optical properties of CuO through combined modification strategies.

REFERENCES

Anjelina, V., Sanjaya, H., & Budiman, S. (2024). Pengaruh Penambahan Monoethanolamine (MEA) Sebagai Aditif dalam Sintesis dan Karakterisasi Lapisan Tipis Tembaga (II) Oksida (CuO). *Jurnal Pendidikan Tambusai, 8*(1), 9233–9238. https://doi.org/10.31004/jptam.v8i1.13787

Arini, T., Lalasari, L. H., Setiawan, I., Andriyah, L., Natasha, N. C., Yunita, F. E., & Suharyanto, A. (2022). Struktur Kristal dan Morfologi Permukaan: Sintesis SnO_2 Menggunakan Metode Sol-Gel. *Jurnal Rekayasa Mesin, 13*(2), 427–433. https://doi.org/10.21776/jrm.v13i2.1048

Chopade, A. S., Walekar, L. S., Kolhe, N. D., Kadam, A. N., Parbat, H. A., Patil, V., Misra, M., Mhamane, D. S., & Mali, M. G. (2024). Hard acid soft base (HSAB)-guided morphology engineered copper oxides for efficient photocatalytic degradation of textile effluent under visible light. *Inorganic Chemistry Communications, 159*, Article 111696. https://doi.org/10.1016/j.inoche.2023.111696

Julita, M., Shiddiq, M., & Khair, M. (2023). Penentuan Energi Celah Pita (Band Gap) Nanopartikel ZnO/Au Hasil Ablasi Laser dalam Cairan. *Periodic, 12*(2), 71. https://doi.org/10.24036/periodic.v12i2.118243

Liza, Y. M., Yasin, R. C., Maidani, S. S., & Zainul, R. (2018). *Gelation process in sol-gel method: Densification, ageing, and drying.*

Ningsih, S. K. W., Nizar, U. K., & Novitria, U. (2017). Sintesis dan Karakterisasi Nanopartikel ZnO Doped Cu^{2+} melalui Metoda Sol-Gel. *EKSAKTA: Berkala Ilmiah Bidang MIPA, 18*(2), 39–51. https://doi.org/10.24036/eksakta/vol18-iss02/51

Ningsih, S. K. W., Nizar, U. K., Bahrizal, Nasra, E., & Mutiara, R. S. F. (2021). Sintesis Mg^{2+} Doped ZnO dengan Penambahan Albumen Ayam Ras Menggunakan Gabungan Metode Sol-Gel dan Sonokimia. *Jurnal Riset Kimia, 12*(1), 27–35. https://doi.org/10.25077/jrk.v12i1.374

Parashar, M., Shukla, V. K., & Singh, R. (2020). Metal oxides nanoparticles via sol–gel method: A review on synthesis, characterization and applications. *Journal of Materials Science: Materials in Electronics, 31*(5), 3729–3749. https://doi.org/10.1007/s10854-020-02994-8

Saleem, S., Khalid, A., Aldhafeeri, Z. M., Alomayri, T., Ali, A., Jabbar, A., Begum, M. Y., & Kandasamy, G. (2025). A comparative analysis of optical and electrical properties of pure CuO and Zn doped CuO nanoparticles for optoelectronic device applications. *Journal of Sol-Gel Science and Technology, 113*(1), 213–224. https://doi.org/10.1007/s10971-024-06591-7

Singh, S. J., & Chinnamuthu, P. (2021). Highly efficient natural-sunlight-driven photodegradation of organic dyes with combustion derived Ce-doped CuO nanoparticles. *Colloids and Surfaces A: Physicochemical and Engineering Aspects, 625*, Article 126864. https://doi.org/10.1016/j.colsurfa.2021.126864

Supu, I., Odde, N., & Hala, A. (2022). Sintesis Semikonduktor ZnO Undoped dan Cu^{2+} Doped ZnO dengan Variasi Temperatur Kalsinasi Menggunakan Metode Sol-Gel. *Cokroaminoto Journal of Chemical Science, 4*(2), 9–14.

Wang, M., Guo, Y., Zhu, Z., Liu, Q., Sun, T., Cui, H., & Tang, Y. (2021). Diethanolamine-assisted and morphology controllable synthesis of ZnO with enhanced photocatalytic activities. *Materials Letters, 299*, Article 130114. https://doi.org/10.1016/j.matlet.2021.130114

Zhao, B., Li, Y., & Wang, R. (2022). Solar thermal systems: Components and applications. In *Comprehensive renewable energy* (2nd ed.). Elsevier. https://doi.org/10.1016/B978-0-12-819727-1.00020-0