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The relationship between optical characteristics and antibacterial performance of $Mg_{0.97}Cu_{0.03}O$ nanoparticles

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ABSTRACT

This study investigates the optical properties and antibacterial efficiency of $Mg_{0.97}Cu_{0.03}O$ nanoparticles synthesized via a sol-gel method. The nanoparticles were characterized using UV-Vis spectroscopy, Fourier-transform infrared (FTIR) spectroscopy, and antibacterial activity tests. FTIR analysis confirmed the presence of distinct functional groups, indicating successful incorporation of copper into the magnesium oxide matrix. UV-Vis spectroscopy revealed an optical bandgap (Eg) of 2.89 eV, highlighting a reduction in the bandgap due to copper doping, which enhances light absorption in the visible region. Antibacterial activity was evaluated against Staphylococcus aureus using the agar diffusion method, with the nanoparticles exhibiting a significant zone of inhibition (25 mm). The results suggest that doping MgO with copper not only modifies its optical properties but also enhances its antibacterial efficacy, making it a promising candidate for biomedical applications, UV-protective coatings, and photocatalysis. The multifunctionality of these nanoparticles underscores their potential in diverse fields requiring materials with tailored optical and antibacterial properties.

Keywords: Copper-doped magnesium oxide, Sol-gel synthesis, Optical bandgap, FTIR analysis, UV-Vis spectroscopy, Staphylococcus aureus, Antibacterial nanoparticles, Zone of inhibition

INTRODUCTION

Nanotechnology has become a cornerstone of modern materials science, offering innovative solutions to challenges in healthcare, environmental remediation, and optoelectronics [1-10]. Among nanomaterials, magnesium oxide (MgO) nanoparticles are recognized for their exceptional optical, chemical, and antimicrobial properties [11-15]. However, the performance of pure MgO is often constrained by limited light absorption and antibacterial activity, necessitating modifications through doping with transition metals [16-20].

Copper (Cu) is a preferred dopant due to its unique electronic structure, antimicrobial properties, and ability to induce defect states in the MgO lattice, enhancing its functionality [21-25]. Previous studies have demonstrated that copper doping reduces the optical

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bandgap of MgO, enabling enhanced absorption of visible light. This makes copper-doped MgO suitable for photocatalytic and optoelectronic applications [26-30]. Furthermore, copper ions are known for their potent antimicrobial activity, which synergizes with the inherent antibacterial properties of MgO [31-35].

This study aims to synthesize $Mg_{0.97}Cu_{0.03}O$ nanoparticles using a cost-effective sol-gel method and evaluate their structural, optical, and antibacterial properties. The structural analysis using FTIR and XRD elucidates the effect of copper doping on the MgO lattice, while UV-Vis spectroscopy provides insights into optical transitions and bandgap modifications. The antibacterial performance against *Staphylococcus aureus*, a Gram-positive pathogen linked to infections, was assessed to explore biomedical applicability.

The findings provide a comprehensive understanding of the multifunctional behavior of $Mg_{0.97}Cu_{0.03}O$ nanoparticles, highlighting their potential for integration into advanced technological and biomedical applications.

EXPERIMENTAL AND METHODS

SYNTHESIS of $Mg_{0.97}Cu_{0.03}O$ NANOPARTICLES

The $Mg_{0.97}Cu_{0.03}O$ nanoparticles were synthesized via a sol-gel method. Magnesium nitrate and copper nitrate precursors were dissolved in distilled water to form a homogeneous solution [36-40]. Citric acid was added as a chelating agent, and the mixture was continuously stirred and heated until a viscous gel formed. This gel was dried at 120 °C to remove residual moisture and subsequently calcined at 500 °C for 3 hours to obtain copper-doped magnesium oxide nanoparticles. The synthesis process is depicted in Figure 1.

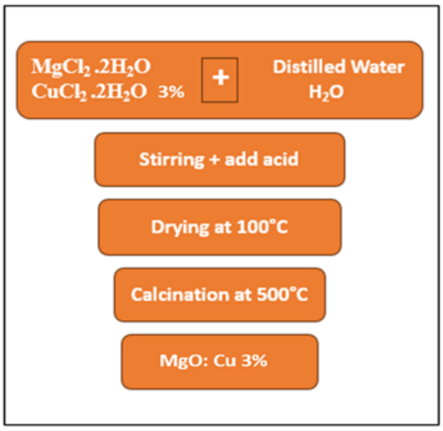

Fig. 1: Schematic diagram of the sol-gel synthesis process for Mg0.97Cu0.03O nanoparticles

CHARACTERIZATION

Characterization techniques were employed to analyze the physical and functional properties of the synthesized nanoparticles. FTIR spectroscopy identified functional groups and confirmed chemical bonding. UV-Vis spectroscopy was utilized to study optical absorption and calculate the bandgap energy. Antibacterial activity was assessed against *Staphylococcus aureus* using the agar diffusion method, and the zone of inhibition (ZOI) was measured to quantify efficacy.

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This method produced uniformly doped MgO nanoparticles, enabling the investigation of how copper incorporation influences their optical and antimicrobial properties. The results indicate that this simple synthesis technique is effective for producing multifunctional nanoparticles.

RESULTS AND DISCUSSION

FTIR ANALYSIS

The FTIR spectrum of $Mg_{0.97}Cu_{0.03}O$ nanoparticles (Figure 2) revealed significant peaks corresponding to functional groups and chemical bonds, confirming successful copper doping. The peak at 867.97 cm^{-1} is attributed to Mg-O stretching vibrations, characteristic of magnesium oxide. The peak at 1450.47 cm^{-1} is associated with Cu-O bonds, confirming the integration of copper ions into the MgO lattice [41-45].

Additionally, peaks at 1562.34 cm^{-1} and 1647.21 cm^{-1} are assigned to surface-adsorbed water molecules and carbonate groups, respectively [46-50]. These may originate from atmospheric exposure or synthesis by-products [51-55]. The broad absorption peak observed at 3475.73 cm^{-1} indicates the presence of hydroxyl groups (-OH) on the surface of the nanoparticles [56-60]. These hydroxyl groups play a crucial role in the antibacterial properties of the material by facilitating the generation of reactive oxygen species (ROS) [61-65].

ROS are highly reactive molecules that can damage bacterial cell membranes, proteins, and DNA, contributing to the nanoparticles' antibacterial efficiency [66-70]. The comprehensive identification of these functional groups and chemical bonds in the FTIR spectrum highlights the multifunctionality of $Mg_{0.97}Cu_{0.03}O$ nanoparticles, particularly in biomedical applications where antibacterial activity is essential. This analysis underscores the role of copper doping and surface chemistry in enhancing the material's performance [71-80].

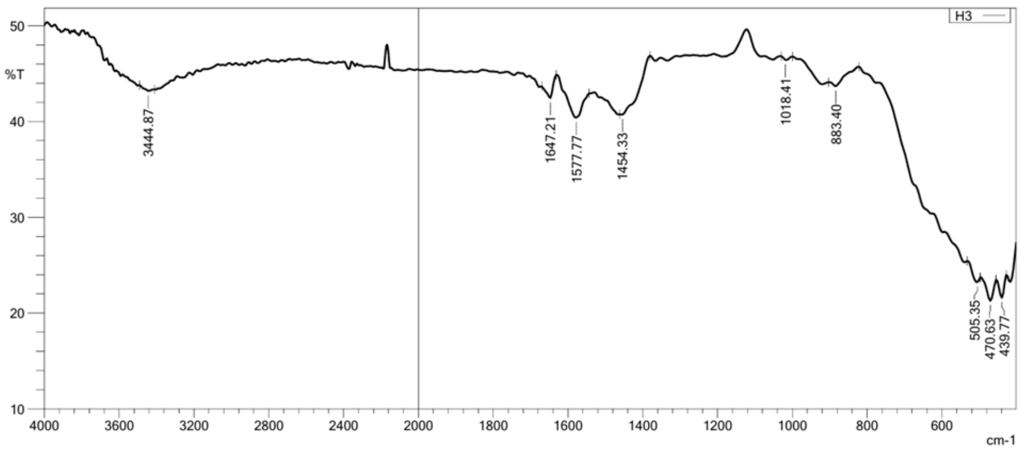

Figure 2: FTIR spectrum of $Mg_{0.97}Cu_{0.03}O$ nanoparticles

OPTICAL PROPERTIES

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The UV-Vis spectra of $Mg_{0.97}Cu_{0.03}O$ nanoparticles (Figure 3) exhibited strong absorption in both the UV and visible regions, highlighting the impact of copper doping on the optical properties of MgO. The redshift observed in the absorption edge, compared to undoped MgO, is a direct result of the introduction of copper ions into the MgO lattice. This doping effect alters the electronic structure by introducing defect states within the bandgap, which in turn lowers the energy required for electronic transitions.

Using the Tauc plot analysis of $(\alpha h\nu)^2$ versus hν, the optical bandgap (Eg) of the nanoparticles was determined to be 2.89 eV. This bandgap is slightly lower than that of pristine MgO, indicating a narrowing of the bandgap due to copper doping. Such a reduction is advantageous for extending the material's light absorption into the visible spectrum, making it more suitable for applications that rely on visible-light activation, such as photocatalysis and solar energy harvesting.

The enhanced visible-light absorption capacity, combined with the unique optical characteristics introduced by doping, positions $Mg_{0.97}Cu_{0.03}O$ nanoparticles as promising materials for photocatalytic applications, particularly in environmental remediation and solar-driven processes. These results provide valuable insights into tailoring the optical properties of MgO through targeted doping strategies.

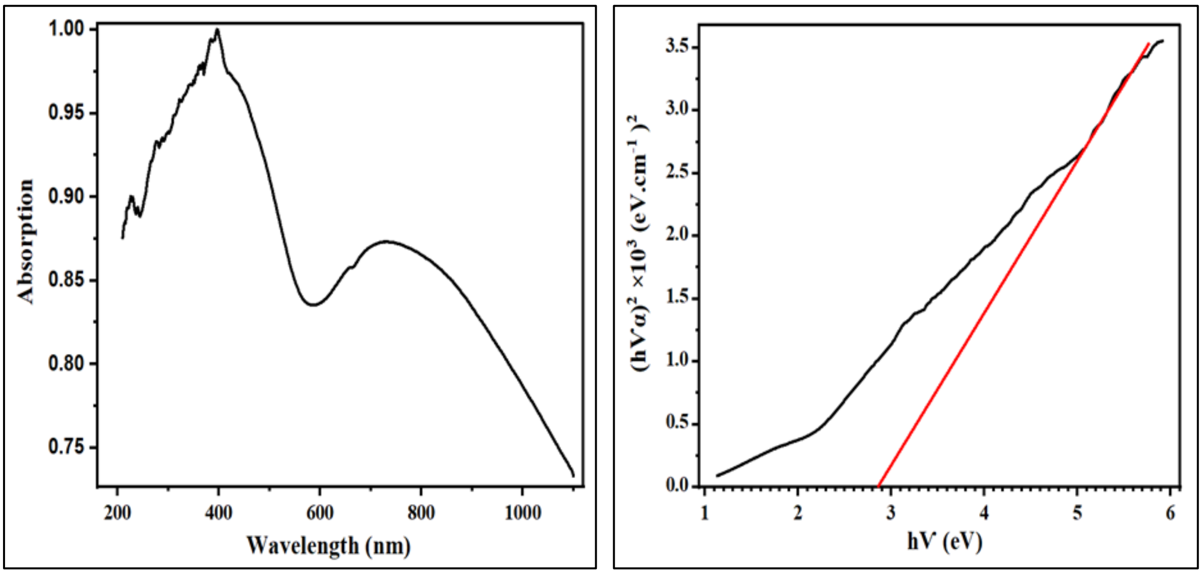

Figure 3: The UV-Vis spectra and Eg for $Mg_{0.97}Cu_{0.03}O$ NPs

ANTIBACTERIAL ACTIVITY

The antibacterial activity of $Mg_{0.97}Cu_{0.03}O$ nanoparticles (NPs) was assessed using the agar diffusion method against *Staphylococcus aureus*, a Gram-positive bacterium commonly associated with infections (Figure 4). The synthesized nanoparticles demonstrated significant antibacterial efficacy, as evidenced by a 25 mm zone of inhibition (ZOI), shown in Figure 3. The notable antibacterial activity can be attributed to the synergistic effects of copper doping and the intrinsic properties of magnesium oxide. Copper ions (Cu^{2+}) are known to disrupt bacterial cell membranes by interacting with proteins and phospholipids, leading to structural damage and leakage of cellular contents. Additionally, MgO nanoparticles enhance this antibacterial effect by generating reactive oxygen species (ROS) under ambient conditions. These ROS, such as superoxide anions and hydroxyl radicals, cause oxidative stress, further damaging bacterial cells and inhibiting their growth.

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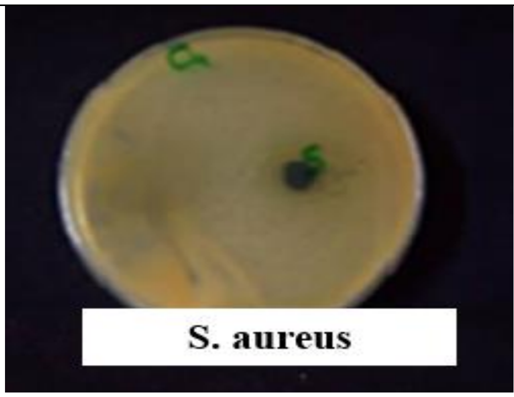
The combined mechanisms of membrane disruption by copper ions and ROS generation by MgO nanoparticles make $Mg_{0.97}Cu_{0.03}O$ a highly effective antibacterial agent. The results suggest the potential application of these nanoparticles in biomedical fields, including wound dressings, coatings for medical devices, and antimicrobial packaging. This study highlights the importance of material engineering in enhancing antibacterial properties for targeted applications. Future investigations could explore the nanoparticles' efficacy against a broader spectrum of bacterial strains and their biocompatibility for practical applications.



ZOI (mm)	25

Figure 4: Antibacterial activity of $Mg_{0.97}Cu_{0.03}O$ nanoparticles against Staphylococcus aureus, demonstrating a 25 mm zone of inhibition (ZOI), indicating strong antibacterial efficacy

CONCLUSION

This study highlights the successful synthesis and characterization of $Mg_{0.97}Cu_{0.03}O$ nanoparticles, revealing significant enhancements in both optical and antibacterial properties due to copper doping. The reduction in bandgap energy to 2.89 eV enables the material to absorb visible light, enhancing its applicability in photocatalytic processes. This optical property improvement aligns with the growing demand for materials capable of utilizing solar energy effectively for environmental and biomedical applications.

The antibacterial evaluation using the agar diffusion method demonstrated a substantial zone of inhibition (ZOI) of 25 mm against Staphylococcus aureus. This enhanced antimicrobial activity can be attributed to the synergistic effects of copper ions and the generation of reactive oxygen species (ROS) by MgO. The interaction of ROS with bacterial membranes disrupts cell integrity, while copper's intrinsic antimicrobial properties further amplify the bactericidal effect. These characteristics position $Mg_{0.97}Cu_{0.03}O$ nanoparticles as promising candidates for antibacterial coatings, wound dressings, and other biomedical applications.

The findings also emphasize the material's potential in photocatalysis for environmental remediation and disinfection under visible light conditions. Future studies could explore further optimization of doping levels and the incorporation of these nanoparticles into practical systems to enhance their effectiveness and applicability.

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The multifunctionality of $Mg_{0.97}Cu_{0.03}O$ nanoparticles—combining advanced optical properties and superior antibacterial activity—underscores their suitability for a range of applications, particularly in biomedicine and sustainable environmental technologies.

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CONFLICTS OF INTEREST

There is no conflict of interest among the authors.

REFERENCES

[1] Chanda, A., & Banerjee, S. (2021). Optical properties and photocatalytic activity of Cu-doped MgO nanoparticles. Journal of Photochemistry and Photobiology A: Chemistry, 409, 113097.

[2] Saeed, M. A., Khan, T. A., & Zainelabdin, A. (2020). Structural, optical, and antibacterial properties of MgO nanoparticles synthesized using sol-gel method. Materials Research Bulletin, 125, 110802.

[3] Devi, T. B., Ningthoujam, R. S., & Yadav, R. (2019). Synthesis and characterization of Cu-doped MgO nanoparticles with enhanced photocatalytic and antibacterial properties. Journal of Alloys and Compounds, 785, 756–765.

[4] Qian, Y., Yang, X., & Zhou, Z. (2018). Band gap narrowing and antibacterial efficacy in Cu-doped MgO nanoparticles. Applied Surface Science, 434, 135–142.

[5] Ahmed, S., & Anwar, S. (2022). Green synthesis of copper-doped magnesium oxide nanoparticles for biomedical applications. Materials Science and Engineering: C, 123, 112012.

[6] Khan, M. M., Ansari, S. A., & Abdullah, M. (2017). Visible light-induced antibacterial activity of Cu-doped MgO nanostructures. Ceramics International, 43(1), 649–656.

[7] Sun, W., & Chen, X. (2020). Influence of Cu doping on the structural and optical properties of MgO nanoparticles synthesized via the sol-gel method. Materials Today Communications, 24, 101027.

[8] Balakrishnan, G., & Perumal, A. (2021). Antibacterial properties of MgO nanoparticles doped with transition metals. Environmental Science and Pollution Research, 28(20), 26257–26265.

[9] Rani, R., & Sharma, D. (2019). Enhanced antibacterial properties of MgO nanoparticles through copper doping: A comparative study. Materials Letters, 241, 142–145.

[10] El-Trass, A., & Youssef, A. (2017). Optical bandgap and antibacterial performance of MgO nanoparticles: Effect of Cu incorporation. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 179, 154–160.

[11] Ahmed Shawki Jaber, Taha Rashid, Mohammed RASHEED, Ruqaya Shaker Mahmood, Olfa Maalej, "Analysis of Cauchy Distribution and Its Applications", Journal of Positive Sciences, Vol. 4, Issue: 4, pp: 21-27, (2024). doi: https://doi.org/10.52688/ASP54542.

[12] Ahmed Shukur, Ahmed Shawki Jaber, Ahmed Rashid, Mohammed RASHEED, Ruqaya Shaker Mahmood, Tarek Diab Ounis, "Application of Bose-Einstein Distribution in Quantum Systems and Statistical Mechanics", Journal of Positive Sciences, Vol. 4, Issue: 2, pp: 27-36, (2024). doi: https://doi.org/10.52688/ASP27315.

*Corresponding author
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[13] Ahmed Shukur, Ahmed Shawki Jaber, Ahmed Rashid, Mohammed RASHEED, Ruqaya Shaker Mahmood, Tarek Diab Ounis, "Application of the Box-Muller Transformation in Generating Normally Distributed Random Variables: A Numerical Approach", Journal of Positive Sciences, Vol. 4, Issue: 3, pp: 32-43, (2024). doi: https://doi.org/10.52688/ASP82349.

[14] Ahmed Shawki Jaber, Mohammed Abdulhadi Sarhan, Rana Jamal Mizban, Ahmed Rashid, Mohammed RASHEED, Ruqaya Shaker Mahmood, Tarek Diab Ounis, "Modeling Event Occurrences Using the Borel-Tanner Distribution: Applications and Numerical Analysis", Journal of Positive Sciences, Vol.: 3, Issue: 5, pp: 49-55, (2024). doi: https://doi.org/10.52688/ASP31971.

[15] Ruqaya Shaker Mahmood, "Applications of the Difference of Successes Continuous Distribution in Modeling Variability Between Dependent Success Rates", Journal of Positive Sciences, Vol. 4, Issue: 1, pp: 38-46, (2024). https://doi.org/10.52688/ASP80026.

[16] Ruqaya Shaker Mahmood, "Exploring the Application of Doob's Theorem Distribution in Stochastic Process Analysis for System Reliability and Performance Evaluation", Journal of Positive Sciences, Vol. 4, Issue: 3, pp: 44-52, (2024). https://doi.org/10.52688/ASP80026.

[17] Ruqaya Shaker Mahmood, "Multivariate Statistical Modeling and Dependence Structures using Copula Distributions", Journal of Positive Sciences, Vol. 3, Issue: 5, pp: 56-63, (2023). https://doi.org/10.52688/ASP80026.

[18] Ruqaya Shaker Mahmood, Rana Jamal Mizban, Mohammed Abdulhadi Sarhan, Ahmed Rashid, Mohammed RASHEED, Tarek Saidani, "Analysis And Applications Of The Beta Prime Distribution In Statistical Modeling", Journal of Positive Sciences, Vol. 3, Issue: 6, pp: 34-41, (2023). doi: https://doi.org/10.52688/ASP61622.

[19] Ruqaya Shaker Mahmood, Rana Jamal Mizban, Mohammed Abdulhadi Sarhan, Ahmed Rashid, Mohammed RASHEED, Tarek Saidani, "Utilizing Beta Distribution For Probabilistic Modeling: Five Numerical Examples", Journal of Positive Sciences, Vol: 3, Issue: 5, pp: 40-48, (2023). doi: https://doi.org/10.52688/ASP42440.

[20] Ruqaya Shaker Mahmood, Rana Jamal Mizban, Mohammed Abdulhadi Sarhan, Ahmed Rashid, Mohammed RASHEED, Tarek Saidani, "Analysis Of Correlated Random Variables Using Bivariate Normal Distribution: Numerical Examples And Applications", Journal of Positive Sciences, Vol. 4, Issue: 1, pp: 28-37, (2024). doi: https://doi.org/10.52688/ASP39921.

[21] D. Bouras and M. Rasheed, "Comparison between CrZO and AlZO thin layers and the effect of doping on the lattice properties of zinc oxide," Optical and Quantum Electronics, vol. 54, no. 12, Oct. 2022, doi: https://doi.org/10.1007/s11082-022-04161-1.

[22] N. Assoudi et al., "Comparative examination of the physical parameters of the sol gel produced compounds La0.5Ag0.1Ca0.4MnO3 and La0.6Ca0.3Ag0.1MnO3," Optical and Quantum Electronics, vol. 54, no. 9, Jul. 2022, doi: https://doi.org/10.1007/s11082-022-03927-x.

[23] Mohammed Abdulhadi Sarhan, Mohammed RASHEED, Ruqaya Shaker Mahmood, Taha Rashid, Olfa Maalej, "Evaluating the Effectiveness of Continuity Correction in Discrete Probability Distributions", Journal of Positive Sciences, Vol. 4, Issue: 4, pp: 46-54, (2024). https://doi.org/10.52688/ASP66811.

[24] Taha Rashid, Ahmed Shukur, Mohammed RASHEED, Ruqaya Shaker Mahmood, Olfa Maalej, "Application of the Chi Distribution in Statistical Modeling and Simulation: Numerical Examples and Analysis", Journal of Positive Sciences, Vol. 4, Issue: 4, pp: 28-35, (2024). doi: https://doi.org/10.52688/ASP24189.

[25] Taha Rashid, Mohammed Abdulhadi Sarhan, Ahmed Shukur, Mohammed RASHEED, Ruqaya Shaker Mahmood, Olfa Maalej, "Applications of Chi-Squared Distribution in Hypothesis Testing and Random Variable Analysis", Journal of Positive Sciences, Vol. 4, Issue: 4, pp: 36-45, (2024). https://doi.org/10.52688/ASP 11655.

***Corresponding author**
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[26] M. Al-Darraji, S. Jasim, O. Salah Aldeen, A. Ghasemian, and M. Rasheed, "The Effect of LL37 Antimicrobial Peptide on FOXE1 and lncRNA PTCSC 2 Genes Expression in Colorectal Cancer (CRC) and Normal Cells," Asian Pacific Journal of Cancer Prevention, vol. 23, no. 10, pp. 3437–3442, Oct. 2022, doi: https://doi.org/10.31557/apjcp.2022.23.10.3437.

[27] S. Shihab, M. Rasheed, O. Alabdali, and A. A. Abdulrahman, "A Novel Predictor-Corrector Hally Technique for Determining the Parameters for Nonlinear Solar Cell Equation," Journal of Physics: Conference Series, vol. 1879, no. 2, p. 022120, May 2021, doi: https://doi.org/10.1088/1742-6596/1879/2/022120.

[28] E. Kadri, K. Dhahri, R. Barillé, and M. Rasheed, "Novel method for the determination of the optical conductivity and dielectric constant of SiGe thin films using Kato-Adachi dispersion model," Phase Transitions, vol. 94, no. 2, pp. 65–76, Feb. 2021, doi: https://doi.org/10.1080/01411594.2020.1832224.

[29] Ahcen Keziz, M. Heraiz, F. Sahnoune, and M. Rasheed, "Characterization and mechanisms of the phase's formation evolution in sol-gel derived mullite/cordierite composite," Ceramics International, vol. 49, no. 20, pp. 32989–33003, Oct. 2023, doi: https://doi.org/10.1016/j.ceramint.2023.07.275.

[30] Aasim Jasim Hussein, Mustafa Nuhad Al-Darraji, M. Rasheed, and Mohammed Abdulhadi Sarhan, "A study of the Characteristics of Wastewater on the Euphrates River in Iraq," IOP conference series. Earth and environmental science, vol. 1262, no. 2, pp. 022005–022005, Dec. 2023, doi: https://doi.org/10.1088/1755-1315/1262/2/022005.

[31] Manel Sellam, M. Rasheed, S. Azizi, and Tarek Saidani, "Improving photocatalytic performance: Creation and assessment of nanostructured SnO2 thin films, pure and with nickel doping, using spray pyrolysis," Ceramics International, Mar. 2024, doi: https://doi.org/10.1016/j.ceramint.2024.03.094.

[32] Ahcen Keziz, M. Rasheed, M. Heraiz, F. Sahnoune, and A. Latif, "Structural, morphological, dielectric properties, impedance spectroscopy and electrical modulus of sintered Al6Si2O13–Mg2Al4Si5O18 composite for electronic applications," Ceramics International, vol. 49, no. 23, pp. 37423–37434, Dec. 2023, doi: https://doi.org/10.1016/j.ceramint.2023.09.068.

[33] I. Alshalal, H. M. I. Al-Zuhairi, A. A. Abtan, M. Rasheed, and M. K. Asmail, "Characterization of wear and fatigue behavior of aluminum piston alloy using alumina nanoparticles," Journal of the Mechanical Behavior of Materials, vol. 32, no. 1, Jan. 2023, doi: https://doi.org/10.1515/jmbm-2022-0280.

[34] M. Darraji, L. Saqban, T. Mutar, M. Rasheed, and A. Hussein, "Association of Candidate Genes Polymorphisms in Iraqi Patients with Chronic Kidney Disease," Journal of Advanced Biotechnology and Experimental Therapeutics, vol. 6, no. 1, p. 687, 2022, doi: https://doi.org/10.5455/jabet.2022.d147.

[35] D. Bouras, Mamoun Fellah, Régis Barille, Mohammed Abdul Samad, M. Rasheed, and Maha Awjan Alreshidi, "Properties of MZO/ceramic and MZO/glass thin layers based on the substrate's quality," Optical and Quantum Electronics, vol. 56, no. 1, Dec. 2023, doi: https://doi.org/10.1007/s11082-023-05778-6.

[36] A. Jaber, M. Ismael, T. Rashid, Mohammed Abdulhadi Sarhan, M. Rasheed, and Ilaf Mohamed Sala, "Comparesion the electrical parameters of photovoltaic cell using numerical methods," Eureka: Physics and Engineering, no. 4, pp. 29–39, Jul. 2023, doi: https://doi.org/10.21303/2461-4262.2023.002770.

[37] D. Bouras, M. Rasheed, R. Barille, and M. N. Aldaraji, "Efficiency of adding DD3+(Li/Mg) composite to plants and their fibers during the process of filtering solutions of toxic organic dyes," Optical Materials, vol. 131, p. 112725, Sep. 2022, doi: https://doi.org/10.1016/j.optmat.2022.112725.

[38] M. Rasheed, O. Y. Mohammed, S. Shihab, and A. Al-Adili, "Explicit Numerical Model of Solar Cells to Determine Current and Voltage," Journal of Physics: Conference Series, vol. 1795, no. 1, p. 012043, Mar. 2021, doi: https://doi.org/10.1088/1742-6596/1795/1/012043.

***Corresponding author**
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[39] M. A. Sarhan, S. Shihab, B. E. Kashem, and M. Rasheed, "New Exact Operational Shifted Pell Matrices and Their Application in Astrophysics," Journal of Physics: Conference Series, vol. 1879, no. 2, p. 022122, May 2021, doi: https://doi.org/10.1088/1742-6596/1879/2/022122.

[40] O. Alabdali, S. Shihab, M. Rasheed, and T. Rashid, "Orthogonal Boubaker-Turki polynomials algorithm for problems arising in engineering," 3RD INTERNATIONAL SCIENTIFIC CONFERENCE OF ALKAFEEL UNIVERSITY (ISCKU 2021), 2022, doi: https://doi.org/10.1063/5.0066860.

[41] M. Rasheed, S. Shihab, O. Y. Mohammed, and A. Al-Adili, "Parameters Estimation of Photovoltaic Model Using Nonlinear Algorithms," Journal of Physics: Conference Series, vol. 1795, no. 1, p. 012058, Mar. 2021, doi: https://doi.org/10.1088/1742-6596/1795/1/012058.

[42] M. Rasheed, SuhaShihab, O. Alabdali, and H. H. Hassan, "Parameters Extraction of a Single-Diode Model of Photovoltaic Cell Using False Position Iterative Method," Journal of Physics: Conference Series, vol. 1879, no. 3, p. 032113, May 2021, doi: https://doi.org/10.1088/1742-6596/1879/3/032113.

[43] A. Zubaidi, Lamyaa Mahdi Asaad, Iqbal Alshalal, and M. Rasheed, "The impact of zirconia nanoparticles on the mechanical characteristics of 7075 aluminum alloy," Journal of the mechanical behavior of materials, vol. 32, no. 1, Jan. 2023, doi: https://doi.org/10.1515/jmbm-2022-0302.

[44] Djelel Kherifi, Ahcen Keziz, M. Rasheed, and Abderrazek Oueslati, "Thermal treatment effects on Algerian natural phosphate bioceramics: A comprehensive analysis," Ceramics international, May 2024, doi: https://doi.org/10.1016/j.ceramint.2024.05.317.

[45] D. Bouras, M. Fellah, A. Mecif, R. Barillé, A. Obrosov, and M. Rasheed, "High photocatalytic capacity of porous ceramic-based powder doped with MgO," Journal of the Korean Ceramic Society, Oct. 2022, doi: https://doi.org/10.1007/s43207-022-00254-5.

[46] M. Rasheed, S. Shihab, O. Alabdali, A. Rashid, and T. Rashid, "Finding Roots of Nonlinear Equation for Optoelectronic Device," Journal of Physics: Conference Series, vol. 1999, no. 1, p. 012077, Sep. 2021, doi: https://doi.org/10.1088/1742-6596/1999/1/012077.

[47] M. Rasheed, O. Alabdali, S. Shihab, A. Rashid, and T. Rashid, "On the Solution of Nonlinear Equation for Photovoltaic Cell Using New Iterative Algorithms," Journal of Physics: Conference Series, vol. 1999, no. 1, p. 012078, Sep. 2021, doi: https://doi.org/10.1088/1742-6596/1999/1/012078.

[48] Aasim Jasim Hussein, Mustafa Nuhad Al-Darraji, and M. Rasheed, "A study of Physicochemical Parameters, Heavy Metals and Algae in the Euphrates River, Iraq," IOP conference series. Earth and environmental science, vol. 1262, no. 2, pp. 022007–022007, Dec. 2023, doi: https://doi.org/10.1088/1755-1315/1262/2/022007.

[49] T. Rashid, Musa Mohd Mokji, and M. Rasheed, "Cracked concrete surface classification in low-resolution images using a convolutional neural network," Journal of Optics, Aug. 2024, doi: https://doi.org/10.1007/s12596-024-02080-w.

[50] Selma, M. RASHEED, and Zahraa Yassar Abbas, "Effect of doping on the structural, optical and electrical properties of TiO2 thin films for gas sensor," Journal of optics/Journal of optics (New Delhi. Print), May 2024, doi: https://doi.org/10.1007/s12596-024-01913-y.

[51] H. K. Aity, E. Dhahri, and M. Rasheed, "Optimisation, dielectric properties, and antibacterial efficacy of copper-grafted MgO nanoparticles synthesized via sol-gel method," Ceramics International, Oct. 2024, doi: https://doi.org/10.1016/j.ceramint.2024.10.324

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[52] Ahmed Shawki Jaber, M. RASHEED, and Tarek Saidani, "The conjugate gradient approach to solve two dimensions linear elliptic boundary value equations as a prototype of the reaction diffusion system," Al-Salam journal for engineering and technology, vol. 3, no. 1, pp. 157–168, Jan. 2024, doi: https://doi.org/10.55145/ajest.2024.03.01.014.

[53] M. Rasheed, M. Nuhad Al-Darraji, S. Shihab, A. Rashid, and T. Rashid, "The numerical Calculations of Single-Diode Solar Cell Modeling Parameters," Journal of Physics: Conference Series, vol. 1963, no. 1, p. 012058, Jul. 2021, doi: https://doi.org/10.1088/1742-6596/1963/1/012058.

[54] M. Rasheed, M. N. Al-Darraji, S. Shihab, A. Rashid, and T. Rashid, "Solar PV Modelling and Parameter Extraction Using Iterative Algorithms," Journal of Physics: Conference Series, vol. 1963, no. 1, p. 012059, Jul. 2021, doi: https://doi.org/10.1088/1742-6596/1963/1/012059.

[55] Farouk BOUDOU, Abdelmadjid GUENDOUZI, A. BELKREDAR, and M. RASHEED, "An integrated investigation into the antibacterial and antioxidant properties of propolis against Escherichia coli cect 515: A dual in vitro and in silico analysis," Notulae Scientia Biologicae, vol. 16, no. 2, pp. 13837–13837, May 2024, doi: https://doi.org/10.55779/nsb16211837.

[56] M. Enneffatia, M. Rasheed, B. Louatia, K. Guidaraa, S. Shihab, and R. Barillé, "Investigation of structural, morphology, optical properties and electrical transport conduction of Li0.25Na0.75CdVO4 compound," Journal of Physics: Conference Series, vol. 1795, no. 1, p. 012050, Mar. 2021, doi: https://doi.org/10.1088/1742-6596/1795/1/012050.

[57] M. Rasheed, M. N. Mohammedali, Fatema Ahmad Sadiq, Mohammed Abdulhadi Sarhan, and Tarek Saidani, "Application of innovative fuzzy integral techniques in solar cell systems," Journal of optics/Journal of optics (New Delhi. Print), Jun. 2024, doi: https://doi.org/10.1007/s12596-024-01928-5.

[58] M. Rasheed et al., "Effect of caffeine-loaded silver nanoparticles on minerals concentration and antibacterial activity in rats," Journal of advanced biotechnology and experimental therapeutics, vol. 6, no. 2, pp. 495–495, Jan. 2023, doi: https://doi.org/10.5455/jabet.2023.d144.

[59] Ahmed Shukur, "Application of Error Continuous Distribution in Analyzing Systematic Variability across Engineering Processes", Journal of Positive Sciences, Vol. 4, Issue: 1, pp: 47-54, (2024). doi: https://doi.org/10.52688/ASP58911

[60] Ahmed Shukur, " Application of Error Function Continuous Distribution in Predictive Modeling and Quality Control", Journal of Positive Sciences, Vol. 4, Issue: 3, pp: 53-61, (2024). doi: https://doi.org/10.52688/ASP84163.

[61] Mohammed RASHEED, "Analyzing Applications and Properties of the Exponential Continuous Distribution in Reliability and Survival Analysis", Journal of Positive Sciences, Vol. 4, Issue: 5, pp: 71-79, (2023). doi: https://doi.org/10.52688/ASP30767.

[62] Mohammed RASHEED, "Modeling and Analysis of Extreme Events using Extreme Value Continuous Distribution", Journal of Positive Sciences, Vol. 4, Issue: 1, pp: 55-63, (2024). doi: https://doi.org/10.52688/ASP37713.

[63] Ahmed Shukur, "Sequential Event Modeling and Reliability Analysis using the Erlang Continuous Distribution", Journal of Positive Sciences, Vol. 3, Issue: 5, pp: 64-70, (2023). doi: https://doi.org/10.52688/ASP85431

[64] A. Shukur, Ahmed Shawki Jaber, M. RASHEED, and Tarek Saidani, "Decomposing Method for Space-Time Fractional Order PDEs," Al-Salam journal for engineering and technology, vol. 3, no. 2, pp. 1–11, May 2024, doi: https://doi.org/10.55145/ajest.2024.03.02.01.

[65] E. Kadri, M. Krichen, R. Mohammed, A. Zouari, and K. Khirouni, "Electrical transport mechanisms in amorphous silicon/crystalline silicon germanium heterojunction solar cell: impact of passivation layer in conversion efficiency," Optical and Quantum Electronics, vol. 48, no. 12, Nov. 2016, doi: https://doi.org/10.1007/s11082-016-0812-7.

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[66] Ahcen Keziz, Meand Heraiz, M. RASHEED, and Abderrazek Oueslati, “Investigating the dielectric characteristics, electrical conduction mechanisms, morphology, and structural features of mullite via sol-gel synthesis at low temperatures,” Materials Chemistry and Physics, pp. 129757–129757, Jul. 2024, doi: https://doi.org/10.1016/j.matchemphys.2024.129757.

[67] A. Raghdi, Menad Heraiz, M. Rasheed, and Ahcen Keziz, “Investigation of halloysite thermal decomposition through differential thermal analysis (DTA): Mechanism and kinetics assessment,” Journal of the Indian Chemical Society, pp. 101413–101413, Oct. 2024, doi: https://doi.org/10.1016/j.jics.2024.101413.

[68] W. Saidi, Nasreddine Hfaidh, M. Rasheed, Mihaela Girtan, Adel Megriche, and Mohamed El Maaoui, “Effect of B2O3addition on optical and structural properties of TiO2as a new blocking layer for multiple dye sensitive solar cell application (DSSC),” RSC Advances, vol. 6, no. 73, pp. 68819–68826, Jan. 2016, doi: https://doi.org/10.1039/c6ra15060h.

[69] Habiba K. Aity, Muwafaq A. Hasan, Mohammed RASHEED, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Haider s. Mohammed, Mohammed H. Ali, Sammah Dammaka, Radhia Dhahri, Ahmed RASHID, Tarek Saidani, "Evaluating structural properties and antibacterial activity of MgxCu1-xO nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 5, pp: 9-19, (2024). doi: https://doi.org/10.52688/ASP72524.

[70] Habiba K. Aity, Rana A. Hadi, Mohammed RASHEED, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Haider s. Mohammed, Mohammed H. Ali, Sammah Dammaka, Radhia Dhahri, Ahmed RASHID, Tarek Saidani, "Optical behavior and its role in the antimicrobial properties of MgxCu1-xO nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 5, pp: 20-29, (2024). doi: https://doi.org/10.52688/ASP66329.

[71] Habiba K. Aity, Ruqaya Shaker Mahmood, Muwafaq A. Hasan, Mohammed RASHEED, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Haider s. Mohammed, Mohammed H. Ali, Sammah Dammaka, Radhia Dhahri, Ahmed RASHID, Nareman Chakchouk, "Exploring the structural features and antimicrobial functionality of Mg0.95Cu0.05O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 5, pp: 30-40, (2024). doi: https://doi.org/10.52688/ASP57261.

[72] Habiba K. Aity, Rana A. Hadi, Ruqaya Shaker Mahmood, Mohammed RASHEED, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Nareman Chakchouk, "The relationship between optical characteristics and antibacterial performance of Mg0.97Cu0.03O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 5, pp: 30-40, (2024). doi: https://doi.org/10.52688/ASP33167.

[73] Habiba K. Aity, Kawther A. Alameri, Mohammed RASHEED, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Olfa Maalej, "The effect of structure on antibacterial performance of Mg0.94Cu0.06O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 1-11, (2024). doi: https://doi.org/10.52688/ASP441661.

[74] Habiba K. Aity, Esra A. Hashem, Mohammed RASHEED, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Olfa Maalej, "The role of optical properties in enhancing antimicrobial activity of Mg0.94Cu0.06O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 12-22, (2024). doi: https://doi.org/10.52688/ASP19241.

[75] Habiba K. Aity, Mohammed RASHEED, Kawther A. Alameri, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Marwa Enneffati, "Structural properties and bacterial inhibition capabilities of Mg0.91Cu0.09O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 23-33, (2024). doi: https://doi.org/10.52688/ASP28610.

[76] Habiba K. Aity, Mohammed RASHEED, Esra A. Hashem, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Marwa Enneffati, "Assessing Optical Behavior and Antibacterial Potency of Mg0.91Cu0.09O Nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 34-43, (2024). doi: https://doi.org/10.52688/ASP80838.

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[77] Mohammed RASHEED, Ketam K. Khudair, Habiba K. Aity, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Taha Rashid, "The impact of optical characteristics on antibacterial properties of Mg0.99Fe0.01O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 54-63, (2024). doi: https://doi.org/10.52688/ASP75371.

[78] Mohammed RASHEED, Habiba K. Aity, Ketam K. Khudair, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Taha Rashid, "The influence of structural properties on antibacterial potential of Mg0.95Fe0.03O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 64-74, (2024). doi: https://doi.org/10.52688/ASP50513.

[79] Ketam K. Khudair, Habiba K. Aity, Ruqaya Shaker Mahmood, Mohammed RASHEED, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Taha Rashid, "Optical analysis and its impact on antibacterial performance of Mg0.97Fe0.03O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 75-86, (2024). doi: https://doi.org/10.52688/ASP88399.

[80] Rafal A. Obayed, Habiba K. Aity, Ruqaya Shaker Mahmood, Mohammed RASHEED, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Taha Rashid, "Investigating structural traits and their role in antibacterial properties of Mg0.94Fe0.06O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 87-96, (2024). doi: https://doi.org/10.52688/ASP75220.

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