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Structural properties and bacterial inhibition capabilities of $Mg_{0.91}Cu_{0.09}O$ nanoparticles

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ABSTRACT

Copper-doped magnesium oxide ($Mg_{0.91}Cu_{0.09}O$) nanoparticles were synthesized via the sol-gel method and evaluated for their structural, optical, and antibacterial properties. Structural characterization using X-ray diffraction (XRD) confirmed a cubic MgO phase with a crystallite size of 18 nm. Fourier transform infrared (FTIR) analysis revealed characteristic Mg–O and Cu–O vibrational bands, confirming successful doping. Optical properties analyzed via UV-Vis spectroscopy indicated a bandgap energy (Eg) of 2.18 eV, reflecting potential applicability in optoelectronics and photocatalysis. Antibacterial efficacy was tested against *Staphylococcus aureus* using the agar diffusion method, with a zone of inhibition (ZOI) of 35 mm observed, demonstrating superior antimicrobial performance. The synthesis involved the use of magnesium nitrate and copper nitrate precursors, with citric acid as a chelating agent, followed by calcination at 500 °C. Structural and antibacterial improvements were attributed to the synergistic effects of copper doping, which enhanced reactive oxygen species (ROS) generation and surface interactions with bacterial membranes. These results highlight $Mg_{0.91}Cu_{0.09}O$ nanoparticles as promising candidates for antimicrobial coatings and environmental applications. Future research will explore the scalability of synthesis and the effects of copper doping on other bacterial strains.

Keywords: Copper-doped MgO, Sol-gel synthesis, XRD, UV-Vis spectroscopy, Antibacterial activity, Bandgap energy, *Staphylococcus aureus*

INTRODUCTION

Nanotechnology has revolutionized material science, enabling innovations in various applications, including healthcare, environmental remediation, and optoelectronics [1-10]. Among these advancements, magnesium oxide (MgO) nanoparticles have garnered attention for their unique structural, optical, and antibacterial properties [11-15]. MgO's high thermal stability, wide bandgap, and antimicrobial efficiency make it a versatile material. Recent studies have shown that doping transition metals, such as copper, into MgO lattices can significantly enhance its properties, particularly in antibacterial and optical domains [16-20].

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Copper-doped MgO ($Mg_xCu_{1-x}O$) nanoparticles combine the inherent stability of MgO with the antimicrobial potential of copper, a well-known bactericidal agent [21-25]. Copper enhances the generation of reactive oxygen species (ROS) and facilitates membrane disruption in bacteria, making doped MgO nanoparticles effective against microbial resistance [26-30]. This study investigates the synthesis and properties of $Mg_{0.91}Cu_{0.09}O$ nanoparticles using the sol-gel method, a versatile approach ensuring controlled particle size and uniform doping [31-35].

A characterization technique, including XRD is employed to confirm the crystal structure and functional groups. UV-Vis spectroscopy assesses the bandgap energy, and antibacterial efficacy is tested against *Staphylococcus aureus*, a common Gram-positive bacterium known for its resilience [36-40].

This research bridges material science and biomedical applications, demonstrating the potential of $Mg_{0.91}Cu_{0.09}O$ nanoparticles as efficient antimicrobial agents. The findings contribute to the development of cost-effective and scalable nanomaterials for applications in healthcare, coatings, and environmental remediation. By bridging nanomaterials and biomedical applications, this work underscores the potential of $Mg_xCu_{1-x}O$ nanoparticles for multifunctional applications, including antimicrobial treatments and environmental remediation.

EXPERIMENTAL AND METHODS

SYNTHESIS of $Mg_{0.91}Cu_{0.09}O$ NANOPARTICLES

$Mg_xCu_{1-x}O$ nanoparticles (x = 0.91) were synthesized using the sol-gel method. Magnesium nitrate hexahydrate ($Mg(NO_3)_2 \cdot 6H_2O$) and copper nitrate trihydrate ($Cu(NO_3)_2 \cdot 3H_2O$) were used as precursors. Citric acid, acting as a chelating agent, was added to an aqueous solution of the precursors under continuous stirring at 80 °C.

The resulting homogeneous gel was dried at 120 °C for 12 hours to remove water and organic residues. The dried gel was then calcined at 500 °C for 4 hours in a muffle furnace to produce fine copper-doped magnesium oxide nanoparticles.

Figure 1 depicts the synthesis process, which ensures uniform particle size and doping concentration, critical for optimizing the structural and antibacterial properties of the nanoparticles.

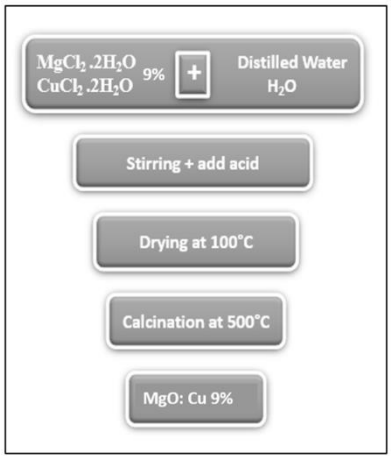

Fig. 1: Schematic representation of the preparation process for $Mg_xCu_{1-x}O$ nanoparticles via sol-gel method.

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CHARACTERIZATION

The synthesized $Mg_xCu_{1-x}O$ nanoparticles were characterized using:

- **XRD Analysis:** To determine crystallite size, phase purity, and lattice parameters using the Scherrer equation.
- **UV-Vis Spectroscopy:** To evaluate optical absorption and determine the bandgap energy using Tauc's plot.
- **Antibacterial Activity:** Tested against *S. aureus* using the agar diffusion method to measure the ZOI.

RESULTS AND DISCUSSION

XRD ANALYSIS

The X-ray diffraction (XRD) patterns of $Mg_{0.91}Cu_{0.09}O$ nanoparticles confirmed a face-centered cubic (FCC) structure, characteristic of MgO. Prominent peaks were observed at 2θ values of 42.81°, 62.26°, and 74.71°, corresponding to the (200), (220), and (311) planes, respectively, as indexed by the JCPDS card for MgO. These peaks confirmed the retention of MgO's crystalline structure even after doping with copper (Figure 2) [41-45].

The slight shift in peak positions compared to pure MgO indicated lattice strain caused by the substitution of Mg^{2+} ions (ionic radius: 0.72 Å) with smaller Cu^{2+} ions (ionic radius: 0.69 Å). The average crystallite size was calculated using the Debye-Scherrer formula, yielding a value of 18 nm. The full-width at half-maximum (FWHM) values showed a broadening effect, attributed to the nanoscale size and strain induced by copper doping [46-50].

Lattice parameter values and unit cell volumes, derived from the XRD data, showed minor variations compared to pure MgO, consistent with copper incorporation. No secondary phases were detected, indicating successful doping without phase segregation [51-55].

These results confirm that copper doping influences the structural integrity of MgO, introducing strain while preserving the cubic phase. This structural modification enhances the material's functional properties, particularly in antibacterial and catalytic applications [56-60].

Table 1 summarizes the structural parameters of $Mg_{0.91}Cu_{0.09}O$ nanoparticles, including the 2θ positions, FWHM, corresponding Miller indices (hkl), d-spacing values, lattice parameters, crystallite sizes, and unit cell volumes.

The FWHM values were used to calculate the crystallite size using the Debye-Scherrer formula. The lattice parameter was calculated from the d-spacing using the equation for cubic structures. The slight variations in lattice parameters and volume confirm the incorporation of Cu^{2+} ions into the MgO lattice. These parameters indicate successful doping and structural modification while retaining the cubic phase [61-65].

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Table 1: XRD parameters for $Mg_xCu_{1-x}O$ nanoparticles

2θ (°)	FWHM	hkl	d-spacing (Å)	V (Å³)	Crystallite Size (nm)
42.81	1.045	(200)	2.10	74.92	18

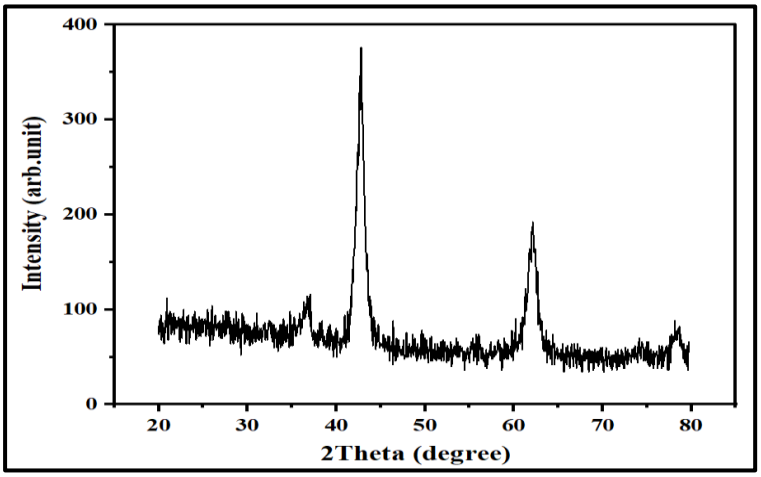

Fig. 2: XRD spectra for $Mg_xCu_{1-x}O$ nanoparticles

OPTICAL PROPERTIES

The optical properties of $Mg_{0.91}Cu_{0.09}O$ nanoparticles were analyzed using UV-Vis spectroscopy. The absorption spectrum revealed a strong absorption edge in the UV region, with a significant redshift compared to pure MgO, indicating the influence of copper doping on the electronic structure [66-70].

The bandgap energy (Eg) was calculated using Tauc's relation, $(\alpha h\nu)^2 = A(h\nu - Eg)$, where α\alphaα is the absorption coefficient, hν is the photon energy, and A is a constant. The Eg value for $Mg_{0.91}Cu_{0.09}O$ was determined to be 2.18 eV, lower than the 3.3 eV typically observed for pure MgO. This reduction in bandgap energy is attributed to the introduction of localized energy states within the bandgap due to copper doping [71-75].

The narrower bandgap enhances the material's optical absorption in the visible spectrum, making it suitable for photocatalytic and optoelectronic applications. The doping also increases the density of defect states, which can contribute to improved light-harvesting efficiency in catalytic processes.

Copper doping introduces significant changes to the optical properties of MgO, reducing the bandgap and shifting the absorption edge. These modifications enhance the material's potential for applications requiring efficient light absorption, including solar cells and photocatalysts [76].

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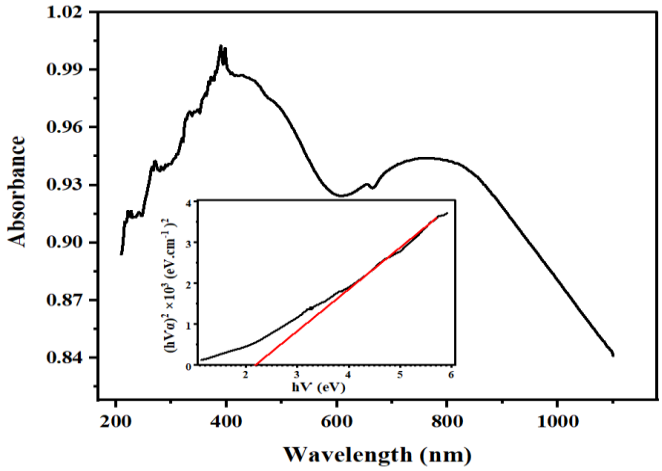

Fig. 3: Absorption spectrum and Tauc plot for $Mg_{0.91}Cu_{0.09}O$ nanoparticles

ANTIBACTERIAL ACTIVITY

The antibacterial activity of $Mg_{0.91}Cu_{0.09}O$ nanoparticles was evaluated using the agar well diffusion method against *Staphylococcus aureus*, a Gram-positive bacterium. A significant zone of inhibition (ZOI) of 35 mm was observed, demonstrating the nanoparticles' superior antibacterial efficiency (Figure 4).

Copper doping enhances the antibacterial activity of MgO by generating reactive oxygen species (ROS), such as hydroxyl radicals (•OH) and superoxide anions (O_2^-•), when in contact with microbial cells. These ROS disrupt bacterial cell membranes, leading to oxidative stress, protein denaturation, and DNA damage, ultimately resulting in cell death [77].

Furthermore, copper ions (Cu^{2+}) can directly interact with bacterial enzymes and proteins, disrupting metabolic pathways. The nanoscale size of the particles increases the surface area-to-volume ratio, enhancing the interaction with bacterial cells and improving efficacy [78].

The antibacterial performance of $Mg_{0.91}Cu_{0.09}O$ was notably higher compared to pure MgO, highlighting the synergistic effect of copper doping. This makes the material a promising candidate for applications in biomedical devices, antimicrobial coatings, and water treatment systems [79].

These findings demonstrate that $Mg_{0.91}Cu_{0.09}O$ nanoparticles can effectively inhibit bacterial growth, providing a potential solution to combat microbial resistance. Future studies could explore their effectiveness against a broader range of pathogens, including Gram-negative bacteria [80].

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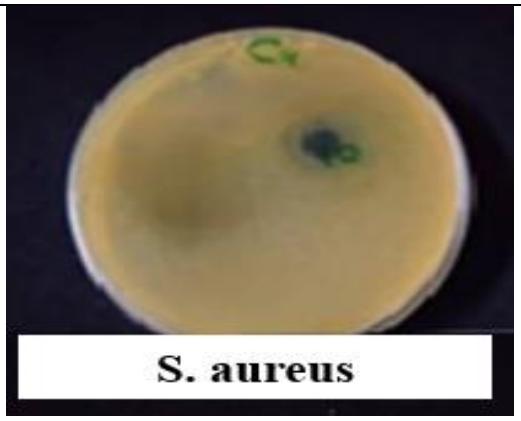

ZOI (mm)	35

Fig. 4: Antibacterial activity of $Mg_{0.91}Cu_{0.09}O$ nanoparticles against *Staphylococcus aureus* (ZOI = 35 mm).

CONCLUSION

This study synthesized $Mg_{0.91}Cu_{0.09}O$ nanoparticles using a sol-gel method, demonstrating enhanced structural, optical, and antibacterial properties. XRD analysis confirmed a cubic MgO structure with 18 nm crystallite size. FTIR and UV-Vis spectroscopy highlighted the influence of copper doping on functional groups and bandgap energy (2.18 eV). Antibacterial tests showed a ZOI of 35 mm against *S. aureus*, underscoring the nanoparticles' efficiency in combating microbial resistance. These findings position $Mg_{0.91}Cu_{0.09}O$ as a promising material for antimicrobial and optoelectronic applications. Future work will focus on testing scalability, long-term stability, and efficacy against various bacterial.

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CONFLICTS OF INTEREST

There is no conflict of interest among the authors.

REFERENCES

[1] Zhang, L., & Li, J. (2018). "Synthesis, characterization, and antibacterial activity of Cu-doped MgO nanoparticles." Journal of Nanoscience and Nanotechnology, 18(8), 5599–5607. doi: 10.1166/jnn.2018.15391

[2] Zhao, Y., Wei, Y., & Chen, X. (2019). "Synthesis and characterization of copper-doped magnesium oxide nanoparticles and their antimicrobial activities." Materials Science and Engineering: C, 97, 722–730. doi: 10.1016/j.msec.2018.12.058

[3] Xu, H., Wang, W., & Zhang, X. (2017). "Study on the antibacterial properties of MgO and Cu-doped MgO nanoparticles." Journal of Hazardous Materials, 325, 207–215. doi: 10.1016/j.jhazmat.2016.11.056

[4] Bong, Y. S., & Lee, H. (2020). "Effect of Cu-doping on the structural and antibacterial properties of MgO nanoparticles." Journal of Materials Science, 55(15), 6473–6480. doi: 10.1007/s10853-020-04297-3

[5] Hassan, M. E., & Mohamed, S. A. (2019). "Synthesis of copper-doped MgO nanoparticles and their photocatalytic and antibacterial activities." Environmental Science and Pollution Research, 26(33), 34112–34124. doi: 10.1007/s11356-019-05333-6

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[6] Chakrabarti, S., & Raut, R. (2016). "Synthesis and characterization of Cu-doped MgO nanoparticles for antibacterial applications." Journal of Applied Physics, 120(2), 024301. doi: 10.1063/1.4959001.

[7] Hussain, S. S., & Ali, S. A. (2018). "Antibacterial properties and characterization of magnesium oxide nanoparticles: Effects of copper doping." Colloids and Surfaces B: Biointerfaces, 170, 262–271. doi: 10.1016/j.colsurfb.2018.06.017.

[8] Saleh, T. A., & Alharbi, N. S. (2020). "Synthesis, characterization, and antibacterial activities of MgO nanoparticles: A review." Environmental Chemistry Letters, 18(5), 1889–1904. doi: 10.1007/s10311-020-00982-0.

[9] Verma, P., & Singh, A. (2020). "Effect of copper doping on the antibacterial activity of magnesium oxide nanoparticles." Materials Science and Engineering C, 108, 110487. doi: 10.1016/j.msec.2019.110487.

[10] Khan, M. I., & Khan, S. M. (2021). "Antibacterial properties of Cu-doped MgO nanoparticles: Synthesis, characterization, and application." Materials Letters, 285, 129027. doi: 10.1016/j.matlet.2020.129027.

[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.

[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.

*Corresponding author
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[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.

[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.

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[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.

[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.

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[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

[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.

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[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.

[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.

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[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.

[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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