Soft Nanoscience Letters, 2023, 13, 1-12
https://www.scirp.org/journal/snl
ISSN Online: 2160-0740
ISSN Print: 2160-0600

Effect on Optical and Antibacterial Activity of SnO_2 and CuO Blended SnO_2 Nanoparticles

Suresh Gopal[1], Baskaran Iruson[1*], Sathyaseelan Balaraman[2*], Senthilnathan Krishnmoorthy[3], Manikandan Elayaperumal[4]

[1]Department of Physics, Arignar Anna Govt. Arts College, Cheyyar, India
[2]Department of Physics, University College of Engineering Arni (A Constituent College of Anna University Chennai), Arni, India
[3]Department of Physics, VIT University, Vellore, India
[4]Department of Physics, Thiruvalluvar University, TVUCAS Campus, Thennangur, India
Email: *bsseelan03@gmail.com, *ibk1978@gmail.com

How to cite this paper: Gopal, S., Iruson, B., Balaraman, S., Krishnmoorthy, S. and Elayaperumal, M. (2023) Effect on Optical and Antibacterial Activity of SnO_2 and CuO Blended SnO_2 Nanoparticles. *Soft Nanoscience Letters*, **13**, 1-12.
https://doi.org/10.4236/snl.2023.132001

Received: September 19, 2022
Accepted: January 28, 2023
Published: January 31, 2023

Abstract

Nanocrystalline SnO_2 and CuO doped with SnO_2 were prepared by the co-precipitation method and characterized for different physiochemical properties and microbiological activity. The composition and morphological formation were characterized by XRD, HRTEM, Raman, FTIR, and UV-vis spectroscopy. The Powder X-ray analysis reveals that Sn4+ ions have substituted the Cu^{2+} ions without changing the monoclinic structure of SnO_2 but the average particle size of the SnO_2 and CuO doped SnO_2 samples from 11 and 5 nm respectively. However, it exhibits an inhibiting strong bacterial growth against tested bacterial strains.

Keywords

SnO_2, CuO Doped SnO_2, Physiochemical Properties, Microbiological Activity

1. Introduction

Recently, metal oxide nanoparticles received great interest and attention from dynamic researchers in the application of biomedical field technology [1]. Among the Cu doped SnO_2 nanoparticles are considered very interesting materials in chemical and physical studies. As highly efficient catalysis, sensors and biosensors, and photodegradation owing to their potential features and unique properties include semiconductivity and less toxicity [2] [3] [4] [5]. Stannic Oxide is a colorless, odorless, diamagnetic, and amphoteric solid. SnO_2 is an important wide bandgap semiconducting metal oxide (Eg = 3.6 eV, 330 K) that has a wide

range of applications, such as in transparent conducting electrodes, gas sensors, Li batteries, and optoelectronic devices [6] [7] [8] [9]. The p-type transition metal oxide with a narrow bandgap CuO nanoparticles, Eg = 1.2 eV shows unique properties, such as super paramagnetism and high magnetic susceptibility at low temperatures [10] [11] [12] [13]. Copper oxide nanomaterials may have the advantage of a lower surface potential barrier than that of the metals, which affects electron field emission properties. Copper-oxide is considered a potential field emitter, an efficient catalytic agent, and a good gas sensing material. An improved understanding of nanoparticles and biological cell interactions can lead to the development of new sensing, diagnostic, and treatment capabilities, such as improved targeted drug delivery, gene therapy, magnetic resonance imaging (MRI) contrast agents, and biological warfare agent detection [14] [15]. Nano-sized metallic copper and its oxides possess the good potential for photo-catalytic, sensing applications [16] [17] [18].

In recent years, different methods were used to synthesize various metal oxide nanoparticles, such as the mechano chemical method [19], solvothermal [14] sol-gel method, chemical co-precipitation method [16] [17]. In addition, various attempts were made to enhance the biological activities of metal oxides [20] [21]. The antibacterial/biological activities of pure and doped SnO_2 nanoparticles were recently studied by researchers [22] [23]. Numerous types of doped nanoparticles showed outstanding antibacterial properties against different bacteria such as *Escherichia coli*, *K. neumo*, and *S. aureus*, etc. These nanoparticles can induce membrane stress by direct contact with walls of bacterial cells, damaging and disrupting cell membranes and leading to cell death [24] [25] [26] [27] [28]. Compared to the pure SnO_2 nanoparticles, the Cu doped SnO_2 nanoparticles inhibit more of those bacterial. Therefore, in this study, an attempt was made to synthesize both pure and Cu dope SnO_2 nanoparticles in the absence of reducing agents and their antibacterial activity against three bacterial.

2. Experimental Section

2.1. Co-Precipitation Method

Analytical grade Tin tetrachloride Dehydrate ($SnCl_4{\cdot}2H_2O$), Copper(II) nitrate hydrate($Cu(NO_3)_2\ xH_2O$), and Ammonia solution (NH_4OH) were used as starting materials for Sn, O & Cu, respectively to prepare nanoparticles of SnO_2 compound in the precipitation method. Then the mixture was stirred for 30 min. After mixing, the precipitation of the dissolved chemicals was achieved by the addition of a 4 M NH_4OH solution drop by drop with continuous stirring for about 30 min. In this method, the process of precipitate formation was controlled by pH and temperature change. Precipitates were then filtered, washed away properly with de-ionized water to eliminate any chloride or other impurity. Then these particles were dried at 120˚C for 12 h in an oven. Finally, the synthesized particles are fully dried form were ground to a fine powder in **Figure 1**.

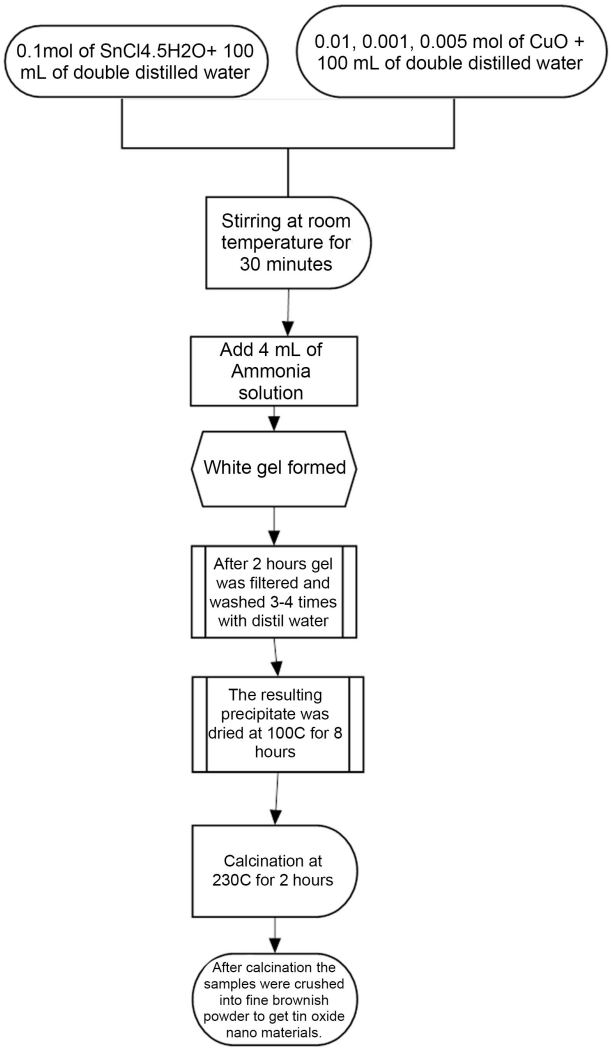

Figure 1. Preparation flowchart of CuO doped SnO_2 nanoparticles.

2.2. Characterization

The prepared CuO-doped SnO_2 nanoparticles underwent analysis to identify their structure, surface morphology, composition, and also to know about optical properties. The structural properties of CuO-doped SnO_2 nanoparticles were studied using an X-ray diffractometer (Philips PW1700) with Cu Kα (λ = 1.5406 Å) radiation in Bragg angle range of "20 - 80". The Fourier transform infrared (FTIR) spectra of the samples were collected using an AVATAR 360 spectrometer with KBr as compressed slices, in the range of 4000 - 400 cm^{-1}. Absorption spectra and Optical band gap was measured using OPTIMA SP-3000 UV-Vis Spectrometer in the range of 300 - 800 nm. High-resolution transmission electron microscope (HRTEM) was taken with a JEOL-3010 operating at 200 kV and EDX spectra of prepared CuO-doped SnO_2 nanoparticles.

2.3. Antibacterial Activity

Microbiological activities of the SnO_2 nanoparticles are examined against clini-

cally isolated; gram-negative *E. coli* bacteria by Agar well diffusion method. The SnO_2 nanoparticles are diffused out into the medium and interacted in a plate freshly seeded with the test organisms. The resulting zones of inhibition will be uniformly circular as there will be a confluent lawn of growth. The diameter of the zone of inhibition is measured in centimeters. The medium is prepared by dissolving 28 g of the commercially available Nutrient Agar Medium (Hi-Media) in 1000 mL of distilled water. The dissolved medium is autoclaved at 15 lb pressure at 121˚C for 15 min. The autoclaved medium is mixed well and poured onto 100 mm Petri plates (25 - 30 mL/plate) while still molten. 1 L of nutrient broth is prepared by dissolving 13 g of commercially available nutrient medium (Hi-Media) in 1000 mL distilled water and boiled to dissolve the medium completely. The medium is dispensed as desired and sterilized by autoclaving at 15 lb pressure (121˚C) for 15 min. Gentamycin with a concentration of 20 mg/mL is used as the positive control.

3. Results and Discussion

3.1. X-Ray Diffraction Analysis

The XRD pattern of SnO_2 and CuO doped SnO_2 are illustrated in **Figure 1** The growth of nanoparticles reveals along (110), (101), (200), (211), (220), (310), (301) plane at an angle 26.6490, 33.9450, 51.6110, 54.6480, 61.8460, 64.9060, 78.4270 respectively, which is indexed to the tetragonal rutile structure of SnO_2 (JCPDS file no. 71-0652) [29] [30]. Crystallites sizes of nanoparticles were obtained using Debye Scherer's formula and were found to be in the range 10 - 15 nm. The significant effect of Cu doping on structural parameters of the nanoparticle can be seen in **Figure 2** clearly. Diffraction maxima intensity along (110) is reduced while noticeable improvement is observed in diffraction maxima intensity within Cu doping concentration. This confirms the Cu atom successfully replaced the Cu atom from the SnO_2 lattice and developed Cu doping SnO_2 material (**Figure 3**).

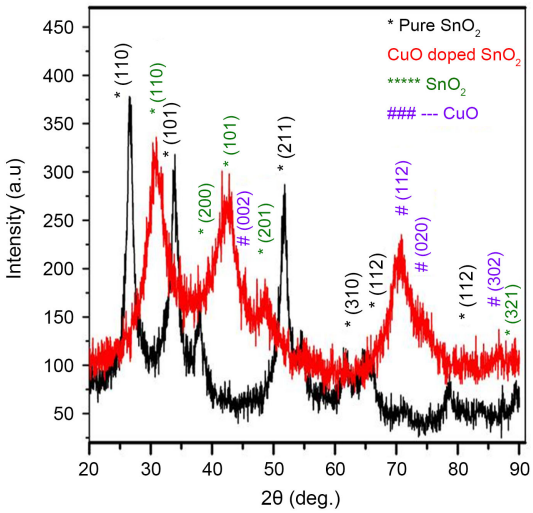

Figure 2. Power XRD pattern of the SnO_2 and CuO-doped SnO_2 nanoparticles.

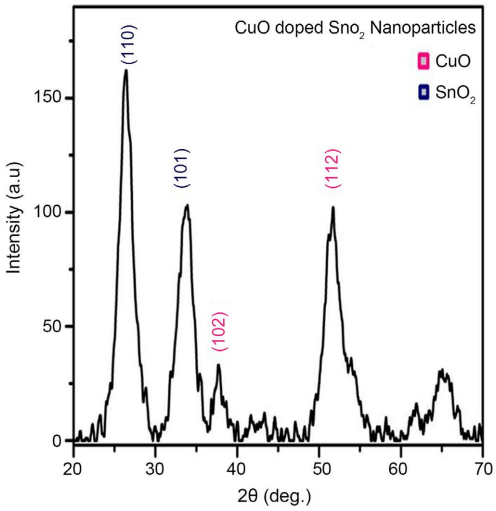

Figure 3. The XRD pattern of the CuO doped SnO_2 nanoparticles.

3.2. Optical Analysis

Understanding the photosensitive behavior of nanoparticles of SnO_2 and CuO doped SnO_2 to explore electronic structure information of nanoparticles is essential **Figure 4**, illustrated absorbance spectra of nanoparticles in the UV-vis region. Pure and Cu doped nanoparticles reveal strong absorbance (band edge) at 446 and 566 nm which arises due to the interband transition in SnO_2 material [31] [32]. This confirms the reduction in defects vacancy and photoresponse improved. Tauc's plots of nanoparticles are illustrated in **Figure 5**. From **Figure 5** to extrapolate linear portion of plots to zero absorption coefficient on the x-axis, these intercept values are the optical band gap of materials.

3.3. FT-IR Analysis

Figure 6 shows the FTIR spectra showing absorption regions and their functional groups of SnO_2 and CuO doped SnO_2 nanoparticles. The broadband around the 3392 cm^{-1} and band at 1626 cm^{-1} can be attributed to the O-H vibration of absorbed water on the sample surface. Intense broadband around 661 cm^{-1} was observed the samples are assigned to the O-Sn-O bridge functional groups of SnO_2 which confirms the presence of SnO_2 as a crystalline phase [33] [34].

3.4. HRTEM Analysis

The morphology of SnO_2 and CuO doped SnO_2 composite was investigated by TEM techniques (**Figure 7** and **Figure 8**). **Figure 7** and **Figure 8** display the HRTEM images of SnO_2 and CuO doped SnO_2 nanoparticles and reveal the aggregated. Hence, HRTEM analyses also indicate the successful formation of spherical shapes. The selected area diffraction (SAED) pattern of SnO_2 and CuO doped SnO_2 shows the ring patterns, which is a characteristic feature of polycrystalline. As is evident, an interplanar distance of 0.333 nm is close to the d-spacing of the (110) planes of the tetragonal rutile SnO_2. On the other hand, an interplanar dis-

tance of 0.252 nm is in good agreement with the d-spacing of the (002) planes of the monoclinic structure CuO [35]. From these results, CuO-SnO_2 nanocomposite structure has been possibly facilitating the creation of the p-n junctions compared with large-grained CuO-SnO_2 normal composite materials.

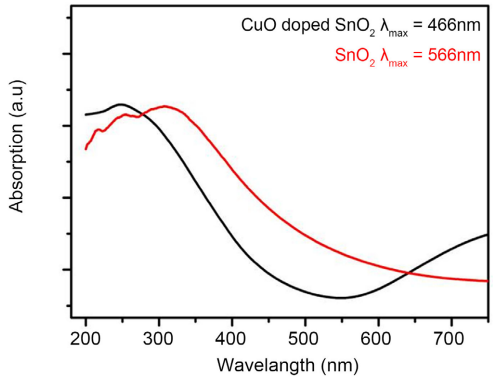

Figure 4. The UV pattern of the SnO_2 and CuO doped SnO_2 nanoparticles.

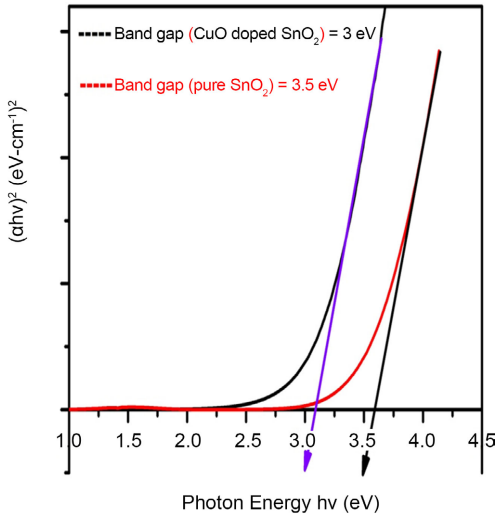

Figure 5. The Band gap energy of the SnO_2 and CuO doped SnO_2 nanoparticles.

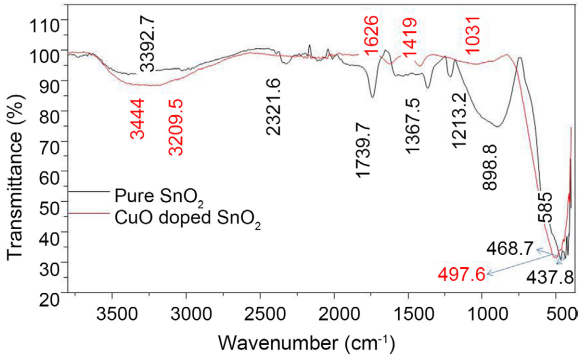

Figure 6. FTIR spectrum of the SnO_2 and CuO doped SnO_2 nanoparticles.

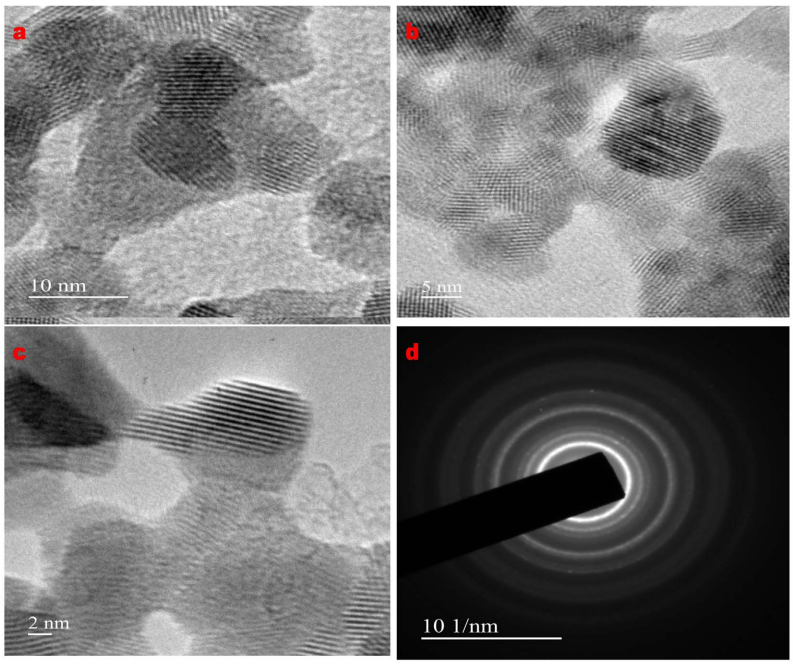

Figure 7. The HRTEM of the SnO_2 nanoparticles.

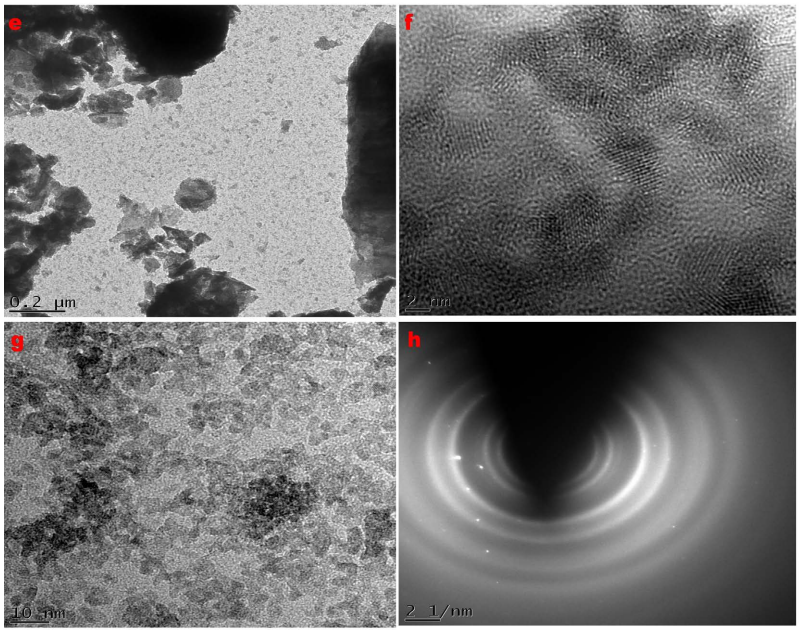

Figure 8. The HRTEM of the CuO doped SnO_2 nanoparticles.

3.5. EDX Analysis

The surface electronic state and composition of SnO_2 and CuO doped SnO_2 were assessed by EDX analysis (**Figure 9**). The survey EDX spectrum shows the clear signals of Copper (Cu), oxygen, (O) and tin (Sn), Nickel (Ni), Calcium (Ca), and Chlorine (Cl) elements, which are consistent with the EDX reports. It is clear from **Figure 9** that Cu ions are successfully incorporated in the host SnO_2 material. The consistent and sharp peaks with tin oxide and cupric-tin oxide dem-

onstrated that both synthesized nanoparticles were crystalline. Hence, synthesized nanoparticles were obtained in their pure forms.

3.6. Antibacterial Activity Analysis

CuO doped SnO_2 a nanoparticle were investigated to evaluate antibacterial activity against bacterial strains. As *K. neumo*, *S. aureus* and *E. coli* by Agar-well diffusion method. Evaluation of the antibacterials activity of these varieties recorded in Table 1 and illustrated in Figure 10. The results revealed that higher inhibition zone was recorded in *E. coli* 10 mm in 0.005 moles of CuO doped SnO_2, a gram +ve bacterial strain whereas gram +ve *K. neumo* showed inhibition of 9 mm in 0.01 mole CuO doped SnO_2 (Figure 10). Both the bacterial strains were tested against 1 mg SnO_2 nanoparticles. *S. aureus* is a major hospital-acquired pathogen thus the prevention of microbial surfaces is of utmost concern in the health care system similar results were reported [36] [37] [38] [39] [40]. Metal oxide nanoparticles possess a high surface area which is responsible for their increased chemical and biological activity. It is assumed that nanoparticles interact with the cell wall of the bacteria and disturbs the membrane permeability and respiration system of the bacteria and consequently, leading to their death. That created by nanoparticles depends on their bacterial potential.

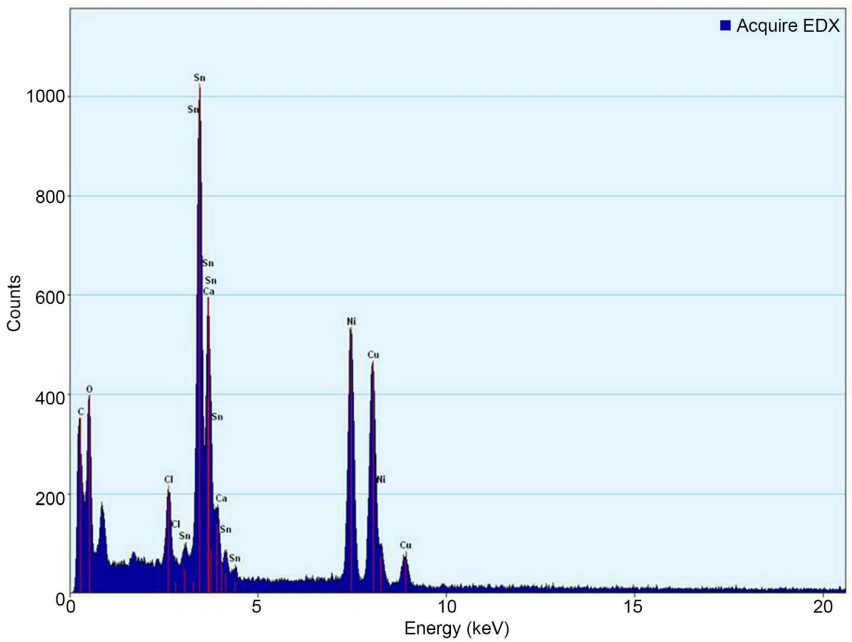

Figure 9. EDX of the CuO doped SnO_2 nanoparticles.

Table 1. Antibacterial Activity of the CuO doped SnO_2 nanoparticles.

Microbes	Zone of inhibition (mm)			
	0.01	0.001	0.005	Strep
K. neumo	9	8	7	7
S. aureus	7	9	8	8
E. coli	8	9	10	7

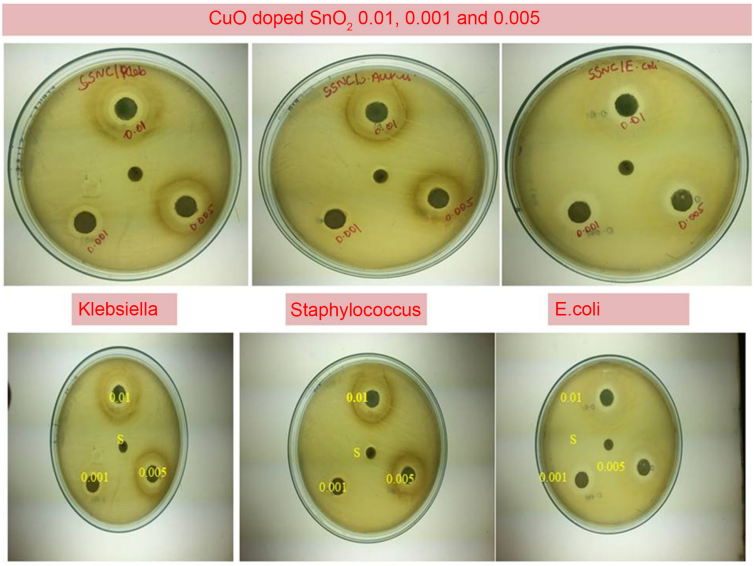

Figure 10. Antibacterial Activity of the CuO doped SnO_2 nanoparticles.

4. Conclusion

In summary, SnO_2 and CuO doped with SnO_2 were prepared by the co-precipitation method. As grown nanoparticle structural and optical properties were studied in detail in correlation with the Cu doping concentration. Structural studies of nanoparticles found that the crystallinity of the particles becomes improved on Cu doping in the SnO_2 matrix. The current study showed a significant level of antibacterial activity in all tested bacterial strains. Further, re-engineering offers interesting and immense future impact with unexplored biological activities.

Acknowledgements

This research has been funded by Tamilnadu State Council for Science and Technology under grant number, C. No. TNSCST/STP-PRG/AR/2018-2019/9333.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Bargougui, R., Omri, K., Mhemdi, A. and Ammar, S. (2015) Synthesis and Characterization of SnO_2 Nanoparticles: Effect of Hydrolysis Rate on the Optical Properties. *Advanced Materials Letters*, **6**, 816-819. https://doi.org/10.5185/amlett.2015.5844

[2] Agrahari, V., Mathpal, M.C., Kumar, M. and Agarwal, A. (2015) Investigations of Optoelectronic Properties in DMS SnO_2 Nanoparticles. *Journal of Alloys and Compounds*, **622**, 48-53. https://doi.org/10.1016/j.jallcom.2014.10.009

[3] Song, H., Lee, K.H., Jeong, H., *et al.* (2013) A Simple Self-Assembly Route to Single Crystalline SnO_2 Nanorod Growth by Oriented Attachment for Dye Sensitized Solar Cells. *Nanoscale*, **5**, 1188-1194. https://doi.org/10.1039/c2nr33114d

[4] Naje, A.N., Norry, A.S. and Suhail, A.M. (2013) Preparation and Characterization of SnO_2 Nanoparticles. *International Journal of Innovative Research in Science, Engineering and Technology*, **2**, 7068-7072.

[5] Anandan, K. and Rajendran, V. (2010) Size Controlled Synthesis of SnO_2 Nanoparticles: Facile Solvothermal Process. *Journal of Non-Oxide Glasses*, **2**, 83-89.

[6] Khanom, R., Khan, M.A., Gafur, A., *et al.* (2017) Synthesis of SnO_2 Nanopowders for Advanced Ceramics and Electronic Sensor Transducer Devices and Characterization and Band Gap. *Nanoscience and Nanometrology*, **3**, 12. https://doi.org/10.11648/j.nsnm.20170301.13

[7] Fan, B., Hu, A., Chen, X., *et al.* (2016) Hierarchical Porous $ZnMn_2O_4$ Microspheres as a High-Performance Anode for Lithium-Ion Batteries. *Electrochimica Acta*, **213**, 37-45. https://doi.org/10.1016/j.electacta.2016.07.030

[8] Ravichandran, K., Thirumurugan, K., Begum, N.J. and Snega, S. (2013) Investigation of p-Type SnO_2: Zn Films Deposited Using a Simplified Spray Pyrolysis Technique. *Superlattices and Microstructures*, **60**, 327-335. https://doi.org/10.1016/j.spmi.2013.05.006

[9] Yu, X.Y., Xu, R.X., Gao, C., *et al.* (2012) Novel 3D Hierarchical Cotton-Candy-Like CuO: Surfactant-Free Solvothermal Synthesis and Application in As(III) Removal. *ACS Applied Materials & Interfaces*, **4**, 1954-1962. https://doi.org/10.1021/am201663d

[10] Wei, Y., Gao, C., Meng, F.L., *et al.* (2012) SnO_2/Reduced Graphene Oxide Nanocomposite for the Simultaneous Electrochemical Detection of Cadmium(II), Lead(II), Copper(II), and Mercury(II): An Interesting Favorable Mutual Interference. *The Journal of Physical Chemistry C*, **116**, 1034-1041. https://doi.org/10.1021/jp209805c

[11] Gao, S., Yang, S., Shu, J., *et al.* (2008) Green Fabrication of Hierarchical CuO Hollow Micro/Nanostructures and Enhanced Performance as Electrode Materials for Lithium-Ion Batteries. *The Journal of Physical Chemistry C*, **112**, 19324-19328. https://doi.org/10.1021/jp808545r

[12] Patil, G.E., Kajale, D.D., Chavan, D.N., Pawar, N.K., *et al.* (2011) Synthesis, Characterization and Gas Sensing Performance of SnO_2 Thin Films Prepared by Spray Pyrolysis. *Bulletin of Materials Science*, **34**, 1-9. https://doi.org/10.1007/s12034-011-0045-0

[13] Okitsu, K., Mizukoshi, Y., Yamamoto, T.A., *et al.* (2007) Sonochemical Synthesis of Gold Nanoparticles on Chitosan. *Materials Letters*, **61**, 3429-3431. https://doi.org/10.1016/j.matlet.2006.11.090

[14] Narsinga Rao, G., Yao, Y.D. and Chen, J.W. (2009) Evolution of Size, Morphology, and Magnetic Properties of CuO Nanoparticles by Thermal Annealing. *Journal of Applied Physics*, **105**, Article ID: 093901. https://doi.org/10.1063/1.3120785

[15] Guo, S., Huang, Y., Jiang, Q., *et al.* (2010) Enhanced Gene Delivery and siRNA Silencing by Gold Nanoparticles Coated with Charge-Reversal Polyelectrolyte. *ACS nano*, **4**, 5505-5511. https://doi.org/10.1021/nn101638u

[16] Hillaireau, H. and Couvreur, P. (2006) Polymeric Nanoparticles as Drug Carriers. CRC Press, Boca Raton. https://doi.org/10.1201/9781420021677-8

[17] Zhang, J., Liu, J., Peng, Q., Wang, X. and Li, Y. (2006) Nearly Monodisperse Cu_2O and CuO Nanospheres: Preparation and Applications for Sensitive Gas Sensors. *Chemistry of Materials*, **18**, 867-871. https://doi.org/10.1021/cm052256f

[18] Dodd, A., McKinley, A., Saunders, M. and Tsuzuki, T. (2006) Mechanochemical Synthesis of Nanocrystalline SnO_2-ZnO Photocatalysts. *Nanotechnology*, **17**, 692.

https://doi.org/10.1088/0957-4484/17/3/013

[19] Qamar, M.A., Shahid, S., Khan, S.A., Zaman, S. and Sarwar, M.N. (2017) Synthesis Characterization, Optical and Antibacterial Studies of Co-Doped SnO_2 Nanoparticles. *Digest Journal of Nanomaterials and Biostructures*, **12**, 1127-1135.

[20] Khan, S.A., Noreen, F., Kanwal, S., Iqbal, A. and Hussain, G. (2018) Green Synthesis of ZnO and Cu-Doped ZnO Nanoparticles from Leaf Extracts of *Abutilon indicum*, *Clerodendrum infortunatum*, *Clerodendrum inerme* and Investigation of Their Biological and Photocatalytic Activities. *Materials Science and Engineering*: *C*, **82**, 46-59. https://doi.org/10.1016/j.msec.2017.08.071

[21] Khan, S.A., Noreen, F., Kanwal, S. and Hussain, G. (2017) Comparative Synthesis, Characterization of Cu-Doped ZnO Nanoparticles and Their Antioxidant, Antibacterial, Antifungal and Photocatalytic Dye Degradation Activities. *Digest Journal of Nanomaterials and Biostructures*, **12**, 877-879.

[22] Reddy, K.M., Feris, K., Bell, J., Wingett, D.G., Hanley, C. and Punnoose, A. (2007) Selective Toxicity of Zinc Oxide Nanoparticles to Prokaryotic and Eukaryotic Systems. *Applied Physics Letters*, **90**, Article ID: 213902. https://doi.org/10.1063/1.2742324

[23] Dutta, D.P., Sudarsan, V., Srinivasu, P., Vinu, A. and Tyagi, A.K. (2008) Indium Oxide and Europium/Dysprosium Doped Indium Oxide Nanoparticles: Sonochemical Synthesis, Characterization, and Photoluminescence Studies. *The Journal of Physical Chemistry C*, **112**, 6781-6785. https://doi.org/10.1021/jp800576y

[24] Mastai, Y. and Gedanken, A. (2004) The Chemistry of Nanomaterials: Synthesis, Properties and Applications. In: *Sonochemistry and Other Novel Methods Developed for the Synthesis of Nanoparticles*, Wiley, Hoboken, 113-169. https://doi.org/10.1002/352760247X.ch6

[25] Gedanken, A. (2004) Using Sonochemistry for the Fabrication of Nanomaterials. *Ultrasonics Sonochemistry*, **11**, 47-55. https://doi.org/10.1016/j.ultsonch.2004.01.037

[26] Kim, Y.J., Kim, Y.S., Chai, S.Y., *et al.* (2007) Syntheses of Monodispersed SnO_2 and CeO_2 Nanoparticles through the Self-Capping Role of 2-Ethylhexanoate Ligands. *New Journal of Chemistry*, **31**, 260-264. https://doi.org/10.1039/B609577A

[27] Li, Q., Mahendra, S., Lyon, D.Y., *et al.* (2008) Antimicrobial Nanomaterials for Water Disinfection and Microbial Control: Potential Applications and Implications. *Water Research*, **42**, 4591-4602. https://doi.org/10.1016/j.watres.2008.08.015

[28] You, C., Han, C., Wang, X., *et al.* (2012) The Progress of Silver Nanoparticles in the Antibacterial Mechanism, Clinical Application and Cytotoxicity. *Molecular Biology Reports*, **39**, 9193-9201. https://doi.org/10.1007/s11033-012-1792-8

[29] Pani, S., Singh, S.K. and Mohapatra, B.K. (2019) Synthesis and Characterization of MnO Nano-Particles Using Thermal Plasma Technique. *Transactions of the Indian Institute of Metals*, **72**, 65-71. https://doi.org/10.1007/s12666-018-1461-2

[30] Ren, W., Ai, Z., Jia, F., *et al.* (2007) Low Temperature Preparation and Visible Light Photocatalytic Activity of Mesoporous Carbon-Doped Crystalline TiO_2. *Applied Catalysis B*: *Environmental*, **69**, 138-144. https://doi.org/10.1016/j.apcatb.2006.06.015

[31] Velmurugan, K., Venkatachalapathy, V.S. and Sendhilnathan, S. (2010) Synthesis of Nickel Zinc Iron Nanoparticles by Coprecipitation Technique. *Materials Research*, **13**, 299-303. https://doi.org/10.1590/S1516-14392010000300005

[32] Yao, N.Q., Liu, Z.C., Gu, G.R. and Wu, B.J. (2017) Structural, Optical, and Electrical Properties of Cu-Doped ZrO_2 Films Prepared by Magnetron Co-Sputtering. *Chi-*

nese Physics B, **26**, Article ID: 106801.
https://doi.org/10.1088/1674-1056/26/10/106801

[33] Elango, G. and Roopan, S.M. (2016) Efficacy of SnO_2 Nanoparticles toward Photocatalytic Degradation of Methylene Blue Dye. *Journal of Photochemistry and Photobiology B: Biology*, **155**, 34-38. https://doi.org/10.1016/j.jphotobiol.2015.12.010

[34] Tazikeh, S., Akbari, A., Talebi, A. and Talebi, E. (2014) Synthesis and Characterization of Tin Oxide Nanoparticles via the Co-Precipitation Method. *Materials Science-Poland*, **32**, 98-101. https://doi.org/10.2478/s13536-013-0164-y

[35] Yang, Y., Di, X., Qingyong, W. and Peng, D. (2016) Cu_2O/CuO Bilayered Composite as a High-Efficiency Photocathode for Photoelectrochemical Hydrogen Evolution Reaction. *Scientific Reports*, **6**, Article No. 35158.
https://doi.org/10.1038/srep35158

[36] Zhou, Q., Tang, C., Zhu, S.P., Chen, W.G. and Li, J. (2016) Synthesis, Characterisation and Sensing Properties of Sm_2O_3 Doped SnO_2 Nanorods to C_2H_2 Gas Extracted from Power Transformer Oil. *Materials Technology*, **31**, 364-370.
https://doi.org/10.1179/1753555715Y.0000000069

[37] Chen, W.G., Gao, T.Y., Li, Q.Z. and Gan, H.L. (2014) Study on Enhanced H_2 Gas Sensing Characteristics of CuO-SnO_2 Nanostructures. 2014 *ICHVE International Conference on High Voltage Engineering and Application*, Poznan, 8-11 September 2014, 1-4.

[38] Kumar, V., Sen, S., Muthe, K.P., Gaur, N.K., Gupta, S.K. and Yakhmi, J.V. (2009) Copper Doped SnO_2 Nanowires as Highly Sensitive H_2S Gas Sensor. *Sensors and Actuators B: Chemical*, **138**, 587-590. https://doi.org/10.1016/j.snb.2009.02.053

[39] Ashkarran, A.A., Ghavami, M., Aghaverdi, H., *et al.* (2012) Bacterial Effects and Protein Corona Evaluations: Crucial Ignored Factors in the Prediction of Bio-Efficacy of Various Forms of Silver Nanoparticles. *Chemical Research in Toxicology*, **25**, 1231-1242. https://doi.org/10.1021/tx300083s

[40] Masadeh, M.M., Karasneh, G.A., Al-Akhras, M.A., *et al.* (2015) Cerium Oxide and Iron Oxide Nanoparticles Abolish the Antibacterial Activity of Ciprofloxacin against Gram Positive and Gram Negative Biofilm Bacteria. *Cytotechnology*, **67**, 427-435.
https://doi.org/10.1007/s10616-014-9701-8