Biomedicine and Chemical Sciences 2(1) (2023) 53-57

10-BCS-1532-348

Content lists available at:
https://journals.irapa.org/index.php/BCS/issue/view/18

Biomedicine and Chemical Sciences

Journal homepage: https://journals.irapa.org/index.php/BCS

Synthesis and Characterization of Zinc Oxide Nanoparticles by Electrochemical Method for Environmentally Friendly Dye-Sensitized Solar Cell Applications (DSSCs)

Mansour Kareem Abd Ali Al-Byati*, Aqeel Mahdi Jreo Al-Duhaidahawi

Department of Chemistry, College of Science, University of Kufa – Iraq

ARTICLE INFO

Article history:

Received on: November 25, 2022
Revised on: December 23, 2022
Accepted on: December 23, 2022
Published on: January 01, 2023

Keywords:

Efficiency
Electrochemical
Fill factor
Methyl orange dye
Nanoparticles
Solar cell
Zinc oxide

ABSTRACT

In this research, zinc oxide nanoparticles (ZnO NPs) were made utilizing an electrochemical method. Which has the advantages of being quick, simple, producing no side products, and being inexpensive. Advanced techniques such as x-ray diffraction (XRD), field emission scanning electron microscopy (FESEM), transmission electron microscopy (TEM), ultraviolet-visible (UV-Vis), energy dispersive x-ray (EDX), and atomic force microscopy (AFM) were used to characterize the generated zinc oxide. Using methyl orange dye, the analysis showed that the shape of zinc oxide nanoparticles was rice-like and the band gap value was 3.62. ZnO NPs is used in dye-sensitized solar cells (DSSCs) it has many advantages including its ease of use and low cost, its ability to be integrated into buildings, and its fantastic performance under diffuse and indoor lighting. DSSCs have attracted more attention and have been deemed viable alternatives to conventional photovoltaic devices. The solar cell's efficiency (η %) and fill factor with methyl orange as a dye were 2.3, and 74.1, respectively.

1. Introduction

Nanoscience refers to investigating and improving connected materials with dimensions between 1-100 nm and frameworks with critical processes that happen over similar dimensions (Algar, et al., 2022). As a result of the rapid development of nanoscience and nanotechnology, including progressed strategies for the manufacture and portrayal of nanostructured materials, fantastic progress has been made in many areas of science, not least in environmental catalysis, energy production, and sustainability (Yentekakis, 2022). The historical background of nanomaterials is very lengthy; nevertheless, major developments in nanoscience have occurred during the past twenty years. The possibility of nanotechnology was first presented by Nobel laureate Richard Feynman, in his famous lecture at the California Institute of Technology, on 29th December 1959. Richard Feynman in one of his articles published in 1960 titled **(**Shabeeb, Al-Ani, & Rabee, 2021**)**. Nanoparticles are made up of a variety of "nanoscale" materials, which are typically less than 100 nm in size. These NPs have varying shapes or designs, for example, nanotubes, nanorods, nanoribbons, and hierarchical nanostructures (Ishtiaq, et al., 2020).

Nanomaterials are gaining much importance day by day in different fields attributable to their one-of-a-kind utilitarian properties that can be customized and specifically tailored to meet the needs of specific requirements and applications (Paranjpe, 2017). Although the fact that nanoparticles are generally considered a discovery of modern science has a long history. Nanoparticles were utilized by artisans as far back as 9 hundred years in Mesopotamia for creating a glittering effect on the surface of pots. Spectacular impacts were obtained with metal nanoparticles in a variety of shades of brilliance and glass

---

***Corresponding author:** Mansour Kareem Abd Ali Al-Byati, Department of Chemistry, College of Science, University of Kufa – Iraq
E-mail: **mansourk.ali@uokufa.edu.iq**

How to cite:

Al-Byati, M. K. A. A. ., & Al-Duhaidahawi, A. M. J. (2023). Synthesis and Characterization of Zinc Oxide Nanoparticles by Electrochemical Method for Environmentally Friendly Dye-Sensitized Solar Cell Applications (DSSCs). Biomedicine and Chemical Sciences, 2(1), 53–57.

DOI: **https://doi.org/10.48112/bcs.v2i1.348**

innovation (Ware & Patankar-Jain, 2020). Global electricity consumption has rapidly increased over the last few years, and power demand around the globe is expected to follow the same path. However, as of now, power is generally created from non-renewable energy sources, including coal, flammable gas, and oil, which are considered the reason for fossil fuel byproducts and environmental changes (Guo, et al., 2022). Along these lines, environmentally friendly power innovation is the most effective technique to moderate environmental change, as energy can be created without causing carbon dioxide emissions (Basumatary & Agarwal, 2022). Zinc oxide is an inorganic substance compound widely used in everyday life. Perceptible in later years, the very rapid advancement of nanotechnology has prompted the improvement of ZnO NPs with enhanced properties (Alim-Al-Razy, et al., 2020). Nanoparticles with diameters under 100 nm have a high surface area corresponding to their size. They have excellent catalytic properties because of their large surface area-to-volume ratio (Micó-Vicent, et al., 2021). The main advantage credited to designing ZnO NPs is the possibility of using them as sunscreens.

We need to adequately address the question of how humanity will be able to meet its energy needs in the near future. This is because the world population is currently on track to reach eight billion people and it may even reach ten billion by the middle of this century. Fossil fuels, which are also non-renewable, are currently responsible for the majority of the world's electricity production. These fuels also produce large amounts of carbon dioxide, a greenhouse gas that now poses a serious threat to our planet's ecosystem. According to the Intergovernmental Panel on Climate Change (IPCC), the largest source of greenhouse gas emissions worldwide is the energy supply sector (Mariotti, et al., 2020). In the framework of climate change, decarbonizing electricity generation is a key feature of cost-effective mitigation strategies in achieving low-stabilization levels of carbon dioxide (430-530 ppm). Hence, scientists opted to use dye solar cells as a source of electrical energy, in order to reduce the emission of toxic gases that lead to global warming (Cao & Su, 2021). The purpose of the research is to prepare environmentally friendly and highly efficient solar cells using prepared nanomaterials with favorable properties such as zinc oxide.

2. Materials and Methods

Zinc foil (97%) and polyvinyl alcohol (Fluka, Germany). Iodine (99%) (Thomas Baker, India). Ethanol (99%), acetone (98%), potassium chloride (95%), graphite, polyethylene glycol (97%), potassium iodide (97%), and indium tin oxide glass (ITO) (CDH, India).

2.2. Preparation of ZnO NPs

A 250 mL glass container, pure metal foil zinc for preparation of ZnO NPs as anode (positive) electrode, graphite plate as cathode (negative) electrode, and D.C-regulated power supply were utilized for measuring and estimating stirrer plate, and magnetic stirrer bar. Both cathode and anode were washed with acetone and ethanol and then deionized water. The electrochemical cell is filled up with a 200 mL solution which contains (5 mL of 10 g/100 mL electrolyte (KCl) as the electrolyte, 10 mL of 10 g/100 mL of the stabilizer (Polyvinyl alcohol (PVA), and deionized water). A pure metal zinc foil dimensions (1 cm x 4 cm x 0.25 mm) and inert graphite electrode (2 cm x 5 cm x 1 cm). The electrolysis reaction was performed in an undivided electrolytic cell for 60 minutes stirring at a temperature of (less than 30C°). The voltage ranges from 9 to 15 volts. The resulting white precipitate of ZnO NPs, shown in Figure 1, were centrifuged and washed with deionized water and ethanol a few times. It was poured into a drying vessel and dried at 60 C° for 60 minutes. It was then calcinated at 700C° for 60 minutes (Saffar, et al., 2021).

Fig. 1. The electrochemical system for preparation of ZnO NPs

2.2. Fabrication of DSSCs

The anode electrode, which consisted of zinc oxide, was paste to conductive indium tin oxide glass (ITO) and heated to 400C° for 1 hour (Mahdavi & Talesh, 2021). The effective area of the oxide was 1 cm^2. After heating, they are placed in the dye solution containing the methyl orange dye for 10 hours until the adsorption process occurs. The cathode is a graphite powder, to which polyethylene glycol (PEG) has been added, which is also pasted with conductive glass (ITO) and heated to a temperature of 300C°. During cell construction, an electrolyte solution comprising iodine (I_2) and potassium iodide (KI) was added between the electrodes at a concentration of 0.1 M. After the cell was completed, the Keithley device was used to calculate the efficiency.

3. Results and Discussions

3.1. XRD Analysis of ZnO NPs

Using a diffraction setup with Cu-K1 of (=1.54060 A) under 40 kV and 30 mA in the range of 2 thetas from 10 to 80, ZnO NPs were studied. Several diffraction peaks at 2θ values of (31.873°, 34.552°, 36.374°, 47.645°, 56.683°, 62.983°, 66.52°, 68.051°, 69.191°, 72,58°, and 77.044°), which correspond to Miller indices (100), (002), (101), (102), (110), (103), (200), (112), (201), (004) and (202) that characterize the ZnO NPs as shown in figure 2 (Al-Fouadi & Hussain, 2020). The size of ZnO NPs calculated by using Scherrer equation 1.

$$\mathbf{L} = \frac{\mathbf{K.ʎ}}{\mathbf{B.COS\theta}} \text{ .... } \mathbf{(1)}$$

where the: -

L= size of crystalline (nm)

K= constant dependent on crystallite shape (0.94-0.89)

ʎ = x-ray wavelength (mostly for Cu)

B= FWHM (full width at half max) or integral breadth

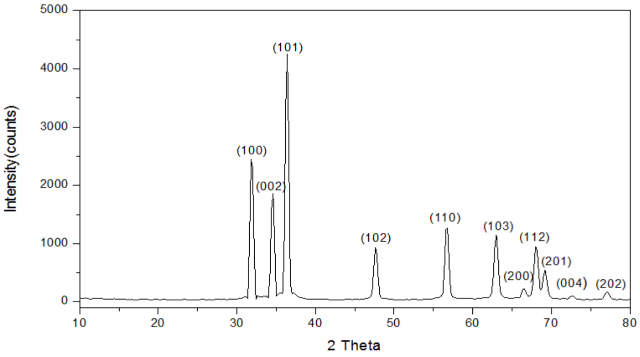

Fig. 2. X-Ray Diffraction pattern of ZnO nanostructures

3.2. TEM Analysis of ZnO NPs

The TEM image in Figure 3 shows ZnO NPs that were produced using the method described. The TEM image displays both isolated and aggregated particles. At the nanoscale, spherical and cubic forms are apparent (Nduni, Osano, & Chaka, 2021).

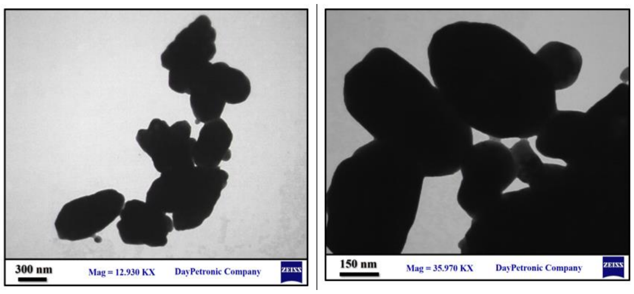

Fig. 3. TEM images of ZnO NPs

3-3FESEM Analysis of ZnO NPs

FESEM uses it to determine the morphology of the films that were formed. The FESEM can produce high-resolution pictures of a sample surface in secondary electron mode at a magnification of 100,000x and a working voltage of 10 kV. The arrangement of flakes was seen in the FESEM image. Figure 4 depicts FESEM images of ZnO NPs at various magnifications. As shown in these images, ZnO NPs are formed like rice particles.

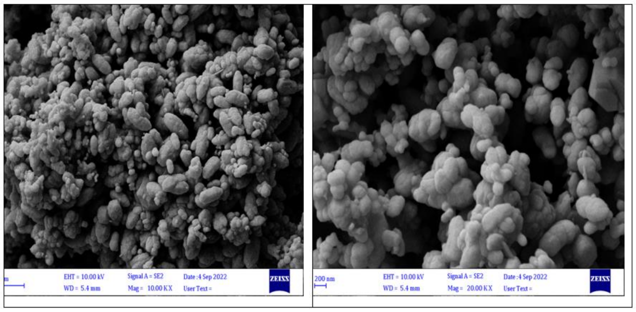

Fig. 4. FESEM images of ZnO NPs

3.4. AFM Analysis of ZnO NPs

Topography imaging using an atomic force microscope (AFM) is an effective method for learning in-depth details about the surface morphology, topography, and material of various surfaces. Due to the several directions that grain particles might go in AFM pictures, opaque colors represent feeble structures in contrast to bright colors representing soaring structures (Sutradhar & Saha, 2016). This thorough information was collected using AFM measurements that included several significant characteristics, including Surface skewness, Roughness Average, and Root Mean Square. However, AFM measurements provide excellent data on the size distribution, average nanoparticle diameter, and surface uniformity of nanoparticles. Figure 5 (a, b) shows the development of homogenous images in two and three dimensions (2D and 3D).

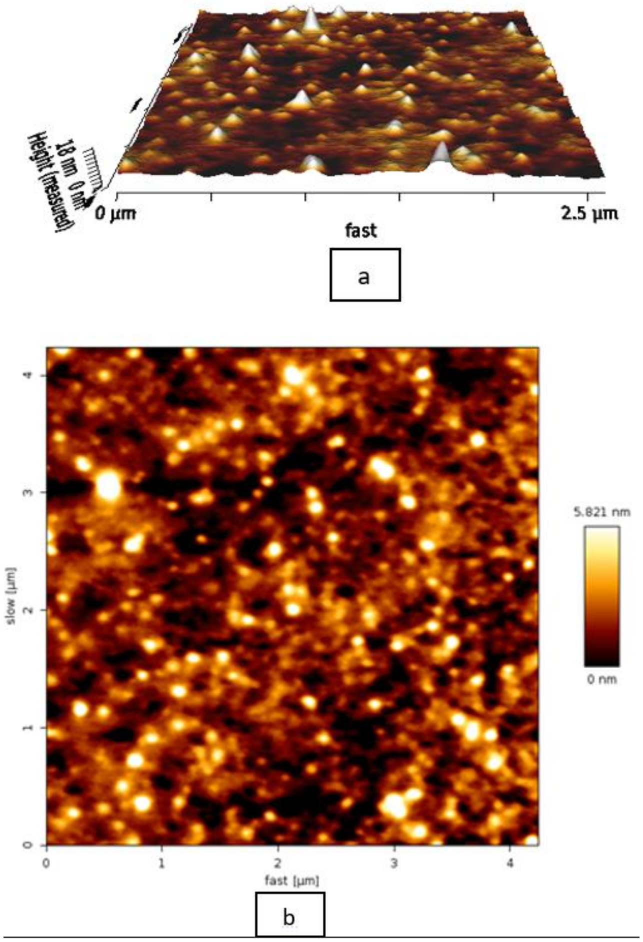

Fig. 5. (a) AFM 3D image of ZnO NPs. (b) AFM 2D image of ZnO NPs

3.5. EDX Analysis of ZnO NPs

Energy-dispersive X-ray spectroscopy (EDX) measurements of the purity and stoichiometry of ZnO NPs produced by the electrochemical technique are shown in Figure 6, which indicates the presence of distinct signals for zinc and oxygen only, which confirms the sample's high purity (Kusuma, et al., 2020). The weight percentages of ZnO appear to be Zn =88.4% and O=16.6%, and we show the presence of gold in the chart because of the coverage of the sample by gold through.

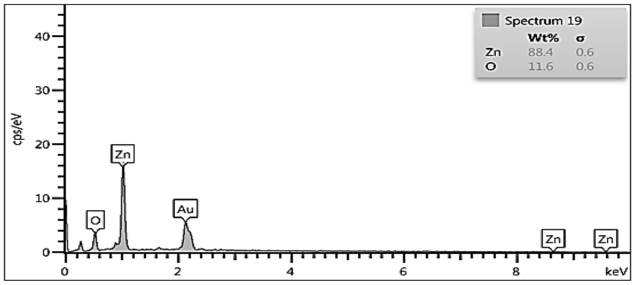

Fig. 6. EDX-ray of ZnO NPS

3.6. UV-Vis Analysis of ZnO NPs

Optical absorption is an important technique for determining the optical energy band gap of crystalline and amorphous materials as shown in Figure 7. The type and value of the optical band gap can be determined using the principle of absorption, which corresponds to the electron excitation from the valence band to the conduction band. Spectrophotometers in the 150-500 nm range were used to measure the UV-Vis spectroscopy of all the films used for this study. By calculating energy along the (hv) and $(\alpha hv)^2$ lines on the Tauc plot, the optical band gap of the synthesized films was also determined (AL-Asady, et al., 2020). The shifting of the ZnO films in the optical energy gap at 25 C° was investigated using the UV region absorption peak.

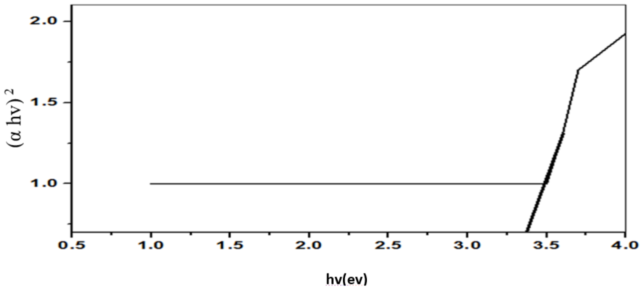

Fig. 7. The optical band gap of ZnO NPs

3.7. Calculate the Efficiency

The efficiency of the dye-sensitized solar cell and fill factor can be calculated using equations 2 and 3 (Villanueva-Cab, et al., 2018).

$$FF = \frac{Jm*vm}{Jsc*Voc} \text{......... (2)}$$

$$\eta = \frac{Jsc*Voc*FF}{pin} \text{......... (3)}$$

where Jsc, Voc, and Pin are short circuit current density, open circuit voltage, and incident light from the simulator (45.2 mW/cm^2), respectively. The I-V values of synthetic cells based on methyl orange dye are shown in Table 1 (Shanshool, et al., 2016).

Table 1

Photo-electrochemical parameter of the DSSCs, (A=**1**cm) and the intensity light (45.2Mw/cm^2)

Catalyst/ dye	Isc(mA)	Voc(V)	I_{max}	V_{max}	P_{max}	F%	η%
ZnO /methyl orange dye	2.6	0.56	2.4	0.45	0.816	56	2.3

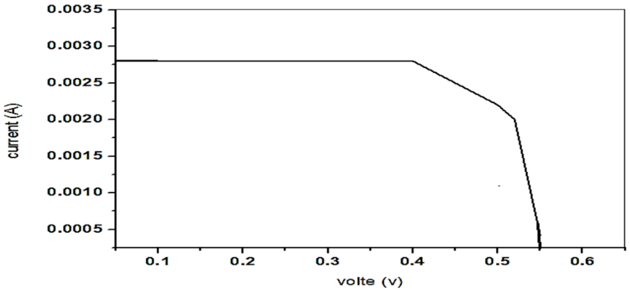

Fig. 8. I-V characteristics of prepared DSSCs ZnO with methyl orange dye

4. Conclusion

Zinc oxide has a small energy gap, and therefore its conductivity is high. It also has a high surface area. This naturally increases the adsorption capacity of the chemical dye on it, which increases the efficiency of the solar cell. In addition, the type of dye used has a simple chemical composition, which increases its adsorption on the surface of the oxide. It has a high electron density.

Competing Interests

The authors have declared that no competing interests exist.

References

AL-Asady, Z. M., AL-Hamdani, A. H., and Hussein, M. A. (2020, March). Study the optical and morphology properties of zinc oxide nanoparticles. In AIP Conference Proceedings, 2213(1), 020061). AIP Publishing LLC. **https://doi.org/10.1063/5.0000259**

Al-Fouadi, A. H. A., and Hussain, R. K. (2020). Synthesis and characterize of porous aluminum oxide nanoparticles. NeuroQuantology, 18(1), 109. **https://doi.org/10.14704/nq.2020.18.1. NQ20115**

Algar, W. R., Albrecht, T., Faulds, K., & Zhu, J. J. (2022). Analytical nanoscience. Analyst, 147(5), 765-766. **https://doi.org/10.1039/D1AN90110A**

Alim-Al-Razy, M., Bayazid, G. A., Rahman, R. U., Bosu, R., and Shamma, S. S. (2020, December). Silver nanoparticle synthesis, UV-Vis spectroscopy to find particle size and measure resistance of colloidal solution. In Journal of Physics: Conference Series (Vol. 1706, No. 1, 012020). IOP Publishing. **https://doi.org/10.1088/1742-6596/1706/1/012020**

Basumatary, P., and Agarwal, P. (2022). A short review on progress in perovskite solar cells.Materials Research Bulletin, 149, 111700. **https://doi.org/10.1016/j.materresbull.2021.111700**

Cao, J., and Su, E. (2021). Hydrophobic deep eutectic solvents: The new generation of green solvents for diversified and colorful applications in green chemistry. Journal of Cleaner Production, 314, 127965. **https://doi.org/10.1016/j.jclepro.2021.127965**

Guo, Z., Jena, A. K., Kim, G. M., and Miyasaka, T. (2022). The high open-circuit voltage of perovskite solar cells: a review. Energy and Environmental Science. **https://doi.org/10.1039/D2EE00663D**

Ishtiaq, M., al-Rashida, M., Alharthy, R. D., and Hameed, A. (2020). Ionic liquid–based colloidal nanoparticles: applications in organic synthesis. In Metal Nanoparticles for Drug Delivery and Diagnostic Applications (pp. 279-299). Elsevier. **https://doi.org/10.1016/B978-0-12-816960-5.00015-X**

Kusuma, K. B., Manju, M., Ravikumar, C. R., Nagaswarupa, H. P., Amulya, M. S., Anilkumar, M. R., ... and Ravikantha, N. (2020). Photocatalytic and electrochemical sensor for direct detection of paracetamol comprising γ-aluminium oxide nanoparticles synthesized via sonochemical route. Sensors International, 1, 100039. **https://doi.org/10.1016/j.sintl.2020.100039**

Mahdavi, R., and Talesh, S. S. A. (2021). Selective degradation of mixed dye pollutant in aqueous phase in the presence of ZnO/Al2O3 as sonophotocatalysis based on central composite design. Korean Journal of Chemical Engineering, 38(6), 1260-1271. **https://doi.org/10.1007/s11814-021-0816-2**

Mariotti, N., Bonomo, M., Fagiolari, L., Barbero, N., Gerbaldi, C., Bella, F., and Barolo, C. (2020). Recent advances in eco-friendly and cost-effective materials towards sustainable dye-sensitized solar cells. Green chemistry, 22(21), 7168-7218. **https://doi.org/10.1039/D0GC01148G**

Micó-Vicent, B., Perales Romero, E., Jordán-Núñez, J., and Viqueira, V. (2021). Halloysite and Laponite Hybrid Pigments Synthesis with Copper Chlorophyll. Applied Sciences, 11(12), 5568. **https://doi.org/10.3390/app11125568**

Nduni, M. N., Osano, A. M., and Chaka, B. (2021). Synthesis and characterization of aluminum oxide nanoparticles from waste aluminum foil and potential application in aluminum-ion cell. Cleaner Engineering and Technology, 3, 100108. **https://doi.org/10.1016/j.clet.2021.100108**

Paranjpe, K. Y. (2017). Alpha, Beta and Gamma alumina as catalyst. Pharma Innov, J, 6(11), 236-238. **https://doi.org/10.1109/ISCAS.2013.856319**

Saffar, A., Abbastabar Ahangar, H., and Barati, S. (2021). The use of high concentration of zinc acetate solution for synthesis of Al2O3-ZnO nanocomposite and it, s application for dye removal. Journal of Nano Chemistry and Electrochemistry, 1(1), 37-48. **https://doi.org/10.1533/9780857097521.1.198**

Shabeeb, I. A., Al-Ani, M. Q., and Rabee, A. M. (2021). Study of effects of silver nanoparticles on oxidative stress level and antioxidant in Cyprinus carpio fish under some ecological factors, 27, 217-225. **https://doi.org/10.1021/acs.analchem.5b01423**

Shanshool, H. M., Yahaya, M., Yunus, W. M. M., and Abdullah, I. Y. (2016). Investigation of energy band gap in polymer/ZnO nanocomposites. Journal of Materials Science: Materials in Electronics, 27(9), 9804-9811. **https://doi.org/10.1007/s10854-016-5046-8**

Sutradhar, P., and Saha, M. (2016). Green synthesis of zinc oxide nanoparticles using tomato (Lycopersicon esculentum) extract and its photovoltaic application. Journal of Experimental Nanoscience, 11(5), 314-327. **https://doi.org/10.1080/17458080.2015.105950**

Villanueva-Cab, J., Olalde-Velasco, P., Romero-Contreras, A., Zhuo, Z., Pan, F., Rodil, S. E., and Pal, U. (2018). Photocharging and band gap narrowing effects on the performance of plasmonic photoelectrodes in dye-sensitized solar cells. ACS applied materials and interfaces, 10(37), 31374-31383. **https://doi.org/10.1021/acsami.8b10063**

Ware, P. S., and Patankar-Jain, K. N. (2020) Biosynthesis and Characterization of Zno Nanoparticals by Annona Reticulata Seeds. **https://doi.org/10.1109/LEOSST.2000.869324**

Yentekakis, I. V. (2022). The 10th Anniversary of Nanomaterials-Recent Advances in Environmental Nanoscience and Nanotechnology. Nanomaterials, 12(6), 915. **https://doi.org/10.3390/nano12060915**