AU-DOPED ZNO–SM NITRATE SOLAR CELLS BASED ON DYE SYNTHESIZED SOLAR CELLS (DSSC)

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ABSTRACT: The utilization of solar energy holds immense promise as a clean and renewable power source for the future. Excitonic Solar Cells (SCs), including organic and Dye-Sensitized Solar Cells (DSSC), have emerged as highly promising, cost-effective alternatives to conventional inorganic Photovoltaic (PV) systems. Nanostructures have garnered considerable attention in the field of solar cells, as they offer significant potential for enhancing efficiency and performance. Zinc Oxide (ZnO) nanoparticles (NPs) is considered a promising material for solar cell applications due to its favorable characteristics such as high conductivity, electron mobility, resistance to photo-corrosion, and cost-effectiveness. This study focuses on the development of Dye-Sensitized Solar Cells (DSSCs) based on Gold (Au)-Doped ZnO-Samarium nitrate (Sm (NO3)3). ZnO-Sm(NO3)3 doped with Au nanoparticles is synthesized and utilized as photoelectrodes in DSSCs to enhance their photovoltaic efficiency. The aim of this research is to explore the potential of these modified solar cells for improved performance in harnessing solar energy to enhance the efficiency and performance of solar cells, a seed layer of Au-doped ZnO-Sm (NO3)3 nanoparticles and ZnO nanorods were fabricated using the Sol-gel method. The purpose of this study was to investigate the impact of utilizing films composed of Au-doped ZnO- Sm (NO3)3 nanoparticles on the performance of Dye-Sensitized Solar Cell(DSSCs). The findings of this investigation indicate that the use of such films has the potential to improve the overall performance of DSSCs.

KEYWORDS: Solar Cells (SCs), Dye-Sensitized Solar Cells (DSSC), Zinc Oxide (ZnO), NanoParticles (NPs).

I. INTRODUCTION

Nanoparticles are relatively vital due to their higher optical, physical and chemical properties. Their optical properties are narrated to be suspended on the size, which transmits exclusive shade due to absorption in visible vicinity [1]. Furthermore, the fluorescence, dimension tune capacity and excessive extinction coefficient make them fairly traumatic in many fields, such as digital devices, nanomedicine and dye-sensitized solar cells Dye-sensitized solar cells (DSSCs) are fabricated by nanoparticles of ZnO, TiO_2, CdSe and PbSe as electrode materials because of a large internal surface area for dye adsorption.
In the presence of light, the organic photosensitizer transfers electrons to the conduction band of a nano-crystalline oxide, resulting in a higher energy state. Among the oxides commonly employed in this system, TiO2 and PCBM polymer (phenyl-C61-Butyric acid Methyl ester) are frequently used. However, the high cost associated with these materials drives the exploration of novel organic and inorganic alternatives [2]. As a result of their inexpensive cost of manufacturing and exceptional redox, electrical and optical capabilities are utilized as supermolecular compounds, ZnO and thiophene derivates polymers are intriguing materials for application in SC [3]. Thermodynamic stability, excellent photochemical characteristics, remarkable crystallinity, and the production of clear

films under infrared light are only a few of the benefits of zinc oxide.

The properties of ZnO NPs are influenced by elements doping, including variations in the band gap value, shape, crystalline size, and the enhancement of ZnO's catalytic characteristics. Investigators are working hard to modify ZnO nanoparticles, like adding of doping elements such as gold, silver, cerium, fluorine, gallium, manganese, ruthenium, magnesium, cobalt [4]. Monoethanolamine, ethanol, and urea solution are components used in the synthesis of ZnO nanoparticles used non Eco-friendly components. Because consistent localized plasmonic influences are growing and promoting optical absorption as well as photoluminescence, covering of ZnO nanostructures with noble metals is one of the solutions that has been suggested [5]. It was discovered that adding AU to ZnO reduced its visible emission while enhancing its band gap emission. According to reports, the creation of surface plasmon resonance as well as the electron transfer from defective sites on ZnO surfaces to Au nanoparticles are the causes of this enhancement [6]. Owing to their intriguing photocatalytic and sensing characteristics, nano-powders and thin films of ZnO doped with Au have been investigated. By using the solgel process to create Au doped ZnO-sm Nanoparticles, this work seeks to enhance the functionality and effectiveness of solar cells by applying them to DSSC.

II.LITERATURE SURVEY

Ahmadi et al.[7] employed the V-TiO_2 nanoparticles for preparing the electron transport layer of the organic photovoltaic cells. The solar cell based on the photoanode film having a thickness of 30 nm endorsed the enhanced conversion efficiency. This enhanced performance can be attributed to the increased light absorption with the rise in external quantum efficiency in the longer wavelength region Yu et al. [8] synthesized the Zn-TiO_2 nanoparticles based on different Zn-doping concentrations and sintering temperatures. The role of sintering temperature and the dopant concentration demonstrated the phase transformation of TiO_2 from anatase to rutile. J. Duan, Q. Xiong, H. Wang, J. Zhang and J. Hu, J. Mater al. [9] demonstrated how the addition of in situ thermal breakdown on spin-coated ZnO was capable to modify the ZnO from nanoparticles morphologies in order to connect the net-like structure, leading to a boost in power conversion efficiency to 13.1%. Utilizing ZnO NanoRods (NR) would result in a greater PCE. Technically, NR's one-dimensional structure can create a direct electron channel, leading to higher PCE. Zhao, X. Zheng, Y. Deng, T. Li, Y. Shao, A. Gruverman, J. Shield and J. Huang et al. [10] Ruthenium dye (N719) and indoline dye (D205) were utilized as sensitizers in dye- sensitized solar cells with iodine-doped ZnO as the photo anode. The outcome showedthat iodine doping increases efficiency in comparison to cells lacking iodine. This experiment showed that the band gap is drastically lowered when Ag is doped, and the produced AgZnO photoelectrode could effectively absorb the visible light spectrum.

J. Dong, Y. Zhao, J. Shi, H. Wei, J. Xiao, X. Xu, J. Luo, J. Xu, D. Li and Y. Luo et al. [11] additionally, efforts were made to create AZO by (Aluminum) Al-doping ZnO NR in order to improve it. According to reports, the resulting Al-doped ZnO has a larger conduction band, more electron mobility, and greater electron density than ZnO.C. Cheng, A. Amini, C. Zhu, Z. Xu, H. Song, and N. Wang et al. [12] investigation was done on the photocatalytic characteristics of titanium dioxide (TiO2)-zinc oxide (ZnO) hybrid nanostructures, that were made by depositing amorphous Titanium dioxide

(TiO2) on the ends of ZnO nanorods in a site-specific manner. M. Misra, P. Kapur, and M. L. Singla et al. [13] Au core of the produced ZnO core-shell nanoparticle, which had a flower-like appearance, boosted the catalytic activity of ZnO by increasing light absorption and charge separation. TanujjalBora et al. [14] presented a research of Zinc oxide (ZnO) nanorods decorated with gold (Au) nanoparticles that had synthesized and used to fabricate dye-sensitized solar cells (DSSC). The picosecond-resolved, time- correlated single-photon-count (TCSPC) spectroscopy technique was used to explore the charge-transfer mechanism in the ZnO/Au-nanocomposite DSSC. Due to theformation of the Schottky barrier at the ZnO/Au interface and the higher optical absorptions of the ZnO/Au photoelectrodes arising from the surface plasmon absorption of the Au nanoparticles, enhanced power- conversion efficiency (PCE) of 6.49% for small-area (0.1 cm^2) ZnO/Au-nanocomposite DSSC was achieved compared to the 5.34% efficiency of the bare ZnO nanorod DSSC.

C. Wang, X. Wang, B. Q. Xua, J. Zhao, B. Mai, P. Peng, G. Sheng, and J. Fu et al. [15] comparing the photocatalytic performance of Ag nanoparticle-TiO2 nanotube complexes with that of un-doped TiO_2 structures and because of the effective electron-hole separation at the interface and the surface resonance of Ag organisms, it was shown that Ag nanoparticle-loaded TiO_2 Nano Tubes (Ag-TNTs) demonstrated greater photocatalytic activity than TNTs beneath sunlight. Consequently, the development of a new class of hybrid photocatalysts would greatly benefit from the use of simple ways to combine a noble metal with two linked semiconductors.

III. AU-DOPED ZnO–Sm NITRATE DYE SYNTHESIZED SOLAR CELLS

3.1 Preparation of Au-Doped ZnO–Sm $(NO_3)_3$ Nanoparticles

The starting materials for all regents—acetate, zinc, samarium nitrate, and silver nitrate are obtained from Sigma-Aldrich and employed exactly as they were given to them. The following is the detailed synthesis used to create Au-doped ZnO- Sm $(NO_3)_3$: Zinc acetate at 100% by weight, samarium nitrate at 1% by weight ($Sm(NO_3)_3$), and silver nitrate at 0.0, 0.5, 1.0, and 1.5 wt% by weight ($Au(NO_3)3$) by weight shown in the Table 1 respectively. The substances are vigorously stirred for 4 hours while being mixed in deionized water in 500mL beaker. The ammonia (NH_3) solution is then combined drop by drop while being constantly stirred till the solution's pH reached 8, then stirring was continued at 80°C for an additional hour. The thoroughly mixed solution became a thick gel after being agitated for one hour, and the resulting gel was left to age for one night. After being dried at 150^0C for 12 hours, the gel was calcined at 450^0C for 3 hours. Figure 1 illustrates the preparation method for Zno-sm $(NO_3)_3$ NPs.

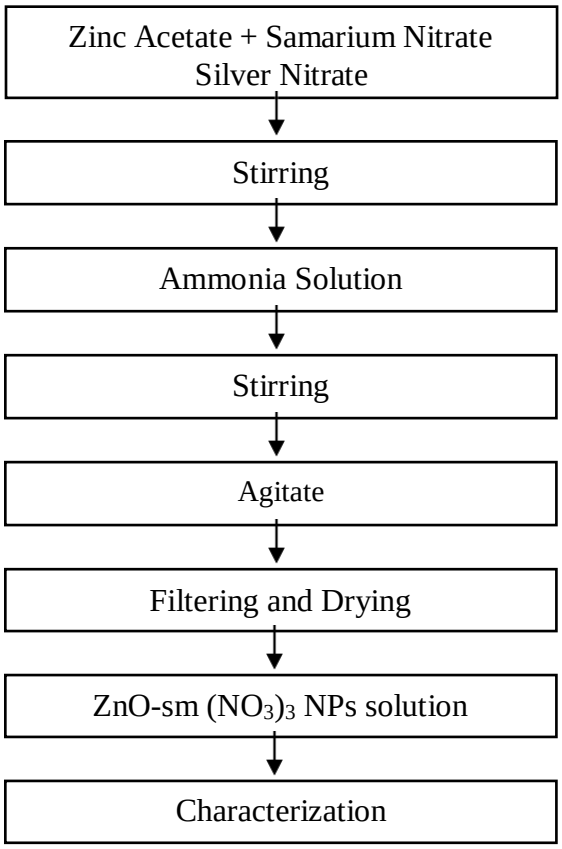

Fig. 1: Preparation f Zno-sm NPs

3.2 DSSC Solar Cells

Each and every chemical, such as distilled water, sodium hydroxide, and zinc chloride were 98 percent pure. Au doped Zinc Oxide-Sm nanoparticles were created using the Sol-gel approach, which involved dissolving 20.5 grams of $ZnCl_2$ in 500 ml of distilled water while stirring constantly. Resulting solution is then rinsed with distilled water to get rid of any remaining salt. An additional four hours of heating at 850^0C is required. The ZnO nanorods are heated again in an oven at 300 °C to remove any leftover moisture once the procedure is finished. (refer equation (2)).

$$ZnCl_2+2NaOH \rightarrow 2NaCl + Zn(OH)_2 \text{ ---(1)}$$

$$2Zn(OH)_2 \rightarrow ZnO+H_2 \text{ ----------(2)}$$

Indium Tin Oxide (ITO) conductive glass was used as the substrate for the construction of zinc oxide nanorod DSSCs. Zinc oxide nanorods were dissolved in ethanol to create a ZnO solution, which was then uniformly applied as a coating the heated (ITO) substrate's conductivity side. On the DSSC, rodhamine B dye was applied as a sensitizer. As the counter electrode, an iodine-covered heated substrate was employed. Lastly, With the purpose of measuring the I-V curve, computing the fill factor as well as efficiency, the cell was subjected to a neon lamp at 0.55mW/cm^2.

3.3 DSSC Fabrication

Before creating Au-doped ZnO-Sm $(NO_3)_3$ films, FTO (Fluorine-doped Tin Oxide) glass (3 cm x 3 cm) pieces were cleaned by sonicating in detergent, acetone, and deionized water each for 12 minutes. After that, the pieces were dried in hot air using a hairdryer. Doctor blade approach was utilized to prepare the colloidal paste into functioning electrodes. 4g of the powder, exactly as it was created, was ground in 0.8mL of ethanol utilizing a mortar and pestle to create the paste. To make the paste easier to spread over FTO substrates, triton X100 and ethanol were incorporated into the powder in drop wise. The working electrode's paste area was 1.6cm×1.6cm=2.56cm^2 and it dried in the air for 35 minutes at room temperature. In this method, a compact layer of Au-doped ZnO-Sm $(NO_3)_3$ nanoparticles are used to construct four pairs of functioning electrodes for every kind of concentration.

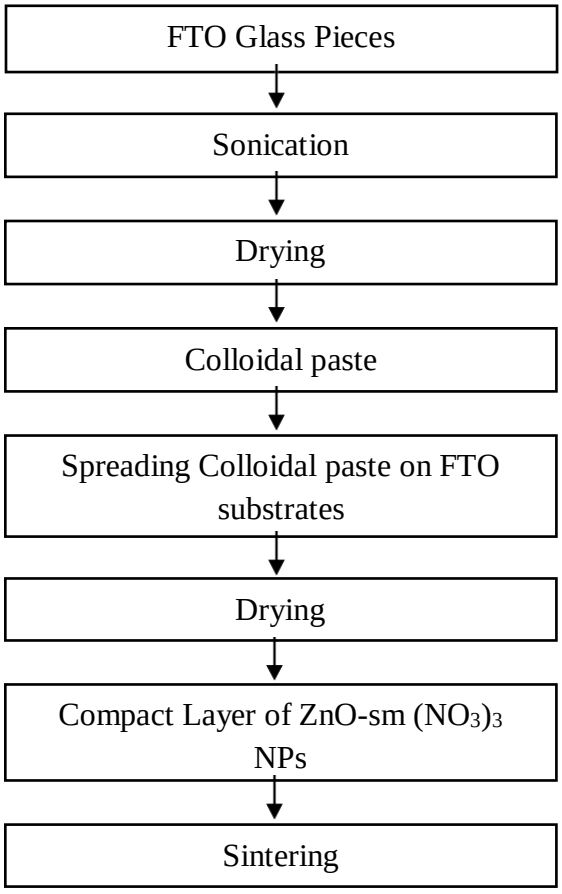

Fig. 2: DSSC Cell Fabrication Steps

The films were sintered at 400^0C for 35 minutes, after which the oven was turned off. The operating electrodes were taken out of the oven whenever the temperature reached 80^0C and sensitized for 12 hours in a 0.5 mM N719 dye solution in an acetonitrile/tert-butanol (1:1) solution. After being taken out of the dye solution, the sensitized photoelectrode films are air-dried at proper temperature. As counter electrodes, platinum-coated FTO glasses are employed. Laboratory parafilm was employed to encapsulate the cells, and a table drill machine was utilized to make a hole in electrode counter through which electrolyte (0.5M tert-butyl pyridine in acetonitrile, 0.05M iodine, 0.6M 1-methyl propylimidazolium iodide, 0.1M lithium iodide) was inserted. As illustrated in Figure 2, to block the loss of electrolyte, tiny squares of a narrow slide were then placed inside the hole.

3.4 Characterization

The structural analysis of the created nanoparticles was evaluated using X-Ray Diffraction on a Philips diffraction meter from 20 to 80 degrees. A UV-Vis spectrophotometer was used to evaluate the nanoparticles' transmittance and absorption spectra. The photocurrent-voltage (J-V) characteristics of the manufactured DSSCs were examined using a Keithley 2400 source meter (Photo Emission Tech Inc.) and the measured power was 100 mW/cm^2.

IV. RESULTS

4.1 Structural Properties

The (XRD) **X-ray diffraction** pattern of Au-doped ZnO-Sm $(NO_3)_3$ nanoparticle films confirmed that the wurtzite hexagonal single phase of ZnO, as shown in Fig. 3, is in fact a single phase of ZnO.

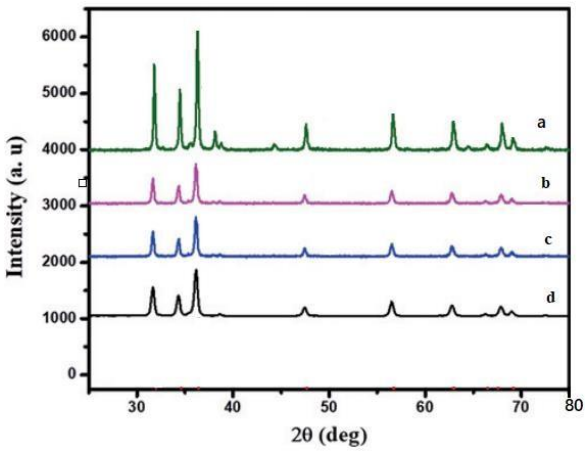

Fig. 3: XRD Patterns of Au (0.0, 0.5, 1.0 and 1.5wt %)-doped ZnO–Sm $(NO_3)_3$ nanoparticle films

Figure 3 (samples a–d) shows that no additional diffraction peak due to samarium doping and variations in the proportion of

gold up to 1.5 wt percent is found. The limited amount and the lack of characteristic peaks in the XRD pattern corresponding to Sm and Au may be due to proper integration of Sm3+/Au+ ions in the ZnO lattice.

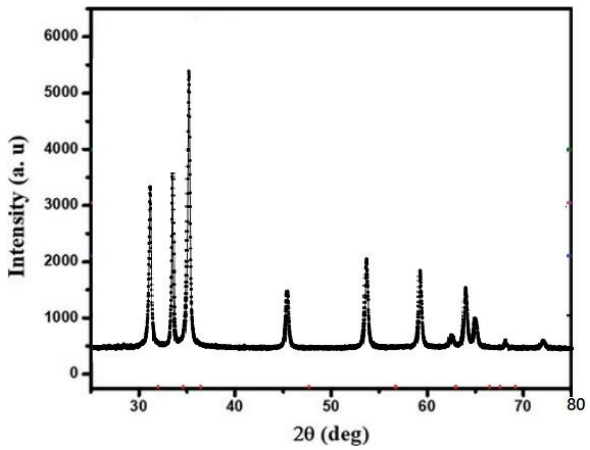

Fig. 4: XRD pattern of Au-doped ZnO–Sm $(NO_3)_3$ nanoparticle films in DSSC cells

Figure 4 depicts the XRD pattern of a DSCC cell made up of Au-doped ZnO-Sm $(NO_3)_3$ nanorods. The distinct reflection peaks showed that zinc oxide was in a cubic single phase. This is discovered that during Sol-gel procedure, the atomic as well as molecular structure of both Zno nanorods is completely conserved. Zero impurity peaks were seen in the manufactured samples, according to XRD spectra, but therewas only a small shift in the peak location, indicating that this doping is producinginternal tensions.

4.2 Optical Properties

Utilizing both the absorbance and reflectance spectrums, Zno nano particle optical band gaps can be determined using UV data. Various Au-doped ZnO-Sm nanoparticle film concentrations (0.0, 0.5, 1.0, and 1.5 wt percent) are shown in Fig. 5 along with the optical transmittance. In the 300–800 nm wavelength region, the optical transmittance ranged from 25–70%. Transmittance decreased further of 1.5 percent Au-doped ZnO-Sm nanoparticle films to 25%, as Au-doping increased from 0 to 1.5 percent.

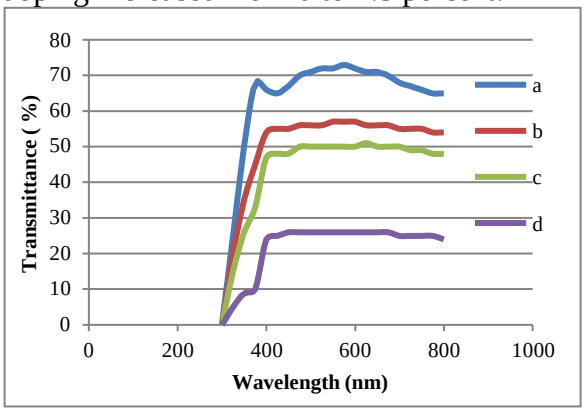

Fig. 5: Transmittance Spectra of Au-doped ZnO–Sm $(NO_3)_3$ NP

While nanoparticles of various sizes boost the absorbance of visible light, the transmission spectra revealed a declining trend owing to it's enormous roughness and porousness. The efficiency of DSSCs was increased by using these films as photoanodes by regulating the flow of electrons in the opposite direction (which will improve electron transport) and widening the range of light absorbed by up/down conversion mechanism.

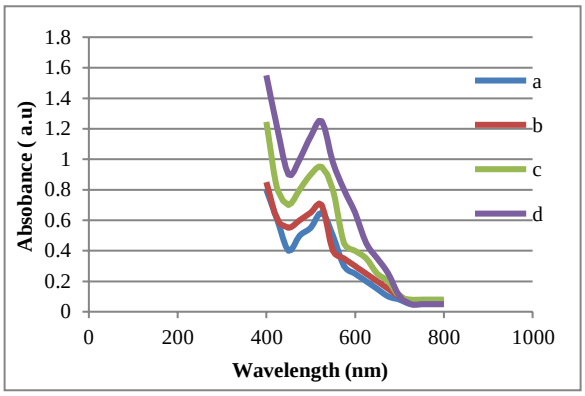

Fig. 6: Absorbance spectra of Au-doped ZnO–Sm $(NO_3)_3$ NP

Fig. 6 displays Au-doped ZnO-Sm nanoparticle films with optical absorbance spectra at numerous dilutions after loading N719 dye (0.0, 0.5, 1.0, 1.5 wt%). Figure 6 shows that the doping of Sm and Au enhanced absorption due to the visible light

range doping form of tiny and large dimension nanoparticles.

Zinc oxide nanoparticles' absorption spectrum matched the optical band gap of ZnO, which is established employing Tauc's equation and determined to be ~ 3.41 nm, which showed a peak positioned at 363 nm as depicted in Fig. 6. While utilizing the Kubelka-Munk equation and Reflectance (R) as in equation 4, the reflectance spectrum is employed to evaluate the Zno nanoparticles optical energy gap. It was discovered that the expected band gap is 3.42. The two results were determined to be nearly identical when compared using distinct spectra.

$$E(eV) = \frac{hC}{\lambda} \approx \frac{1240}{\lambda} \quad \text{---------- (3)}$$

$$R_\infty = \frac{\alpha\,(1 - R_\infty{}^2}{S} \Big/ 2R^\infty \quad \text{---------- (4)}$$

$$F(R_\infty)(hv)^2 = A\,(F(hv - E_g)) \quad \text{--- (5)}$$

Figures 7 and 8 show the I-V curves that were plotted when the neon lamp light (0.55mW/cm2), as well as the resulting voltage and current, were applied to the DSSC cell.

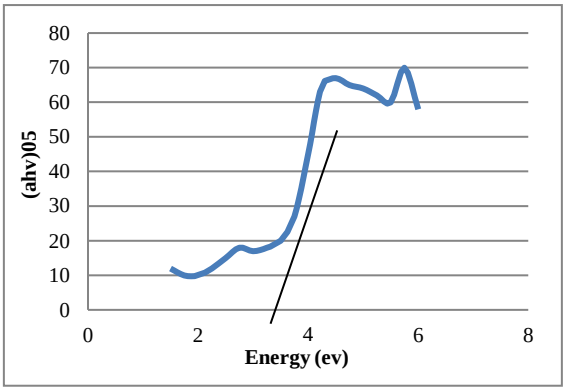

Fig. 7: Au-doped ZnO–Sm $(NO_3)_3$ NP Optical Band Gap from Reflectance Spectrum for DSSC

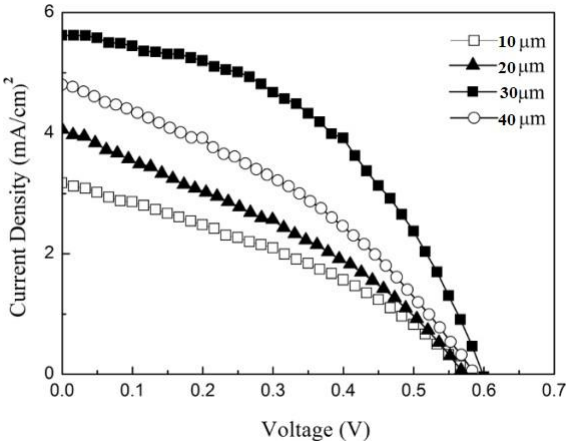

Fig. 8: J –V Curves of the Au-doped ZnO–Sm $(NO_3)_3$ NP based DSSCs from Different Lengths

V. CONCLUSION

In this study, by doping ZnO-Sm with varying amounts of Au (ranging from 0.0 wt% to 1.5 wt%) while keeping the Sm concentration constant, three nanoparticle films were successfully fabricated. The Sol-gel method was employed to create zinc oxide nanoparticle films. The structural properties were analyzed using X- ray diffraction (XRD) to determine thecrystalline structure of zinc oxide based on the X-ray diffraction pattern. The Dye-Sensitized Solar Cell (DSSC) made with a photoanode consisting of 1.5 wt% of Au- doped ZnO-Sm(NO3)3 exhibited a maximum efficiency of 4.35 percent, which was approximately 76% higher than the efficiencies observed in the other DSSC cells. The optical band gap energy for the DSSC cell was calculated using the absorbance and transmittance spectra. The calculated band gap of approximately 3.41 eV indicates the semiconductor nature of the material, which is highly advantageous for solar cell production.

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