Preparation of ZnO nanoparticles from spent zinc-carbon batteries for application in solar cell

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Abstract- **Zinc-Carbon dry cell primary batteries are frequently used batteries and such spent batteries are one of the potential secondary resources for producing Zn metal and its oxides, zinc Oxide (ZnO) having unique physical, chemical, optical and antimicrobial properties. In the present work, ZnO nanoparticles are synthesized from spent zinc-carbon batteries followed by its application in fabricating dye sensitized solar cell (DSSC). The ZnO nanoparticles was prepared by dissolving the zinc part of the dismantled spent batteries HCl to produce zinc chloride ($ZnCl_2$) followed by precipitation of Zn $(OH)_2$ by adding NaOH solution to the produced $ZnCl_2$ solution and heat treatment of Zn $(OH)_2$ to produce ZnO. The phase analysis of the produced ZnO was carried out by X-ray Diffraction (XRD) and the optical property study was carried out by UV-VIS spectrophotometry, which shows a band gap energy of 3.497 eV. The resulting ZnO was used for fabricating dye sensitized solar cell (DSSC) and the J-V plot was plotted. From the study the various parameters of DSSC were calculated such as open circuit voltage (V_{oc}), fill factor (FF) and efficiency (ή%) were calculated.**

***Key words*: Spent Zn-Carbon battery, ZnO nanoparticles, DSSC**

1. Introduction

Zinc-Carbon dry cell primary batteries are frequently used batteries in the world because of many electronic and electrical applications. In these batteries, anode material is Zinc and cathode material is Manganese dioxide and carbon rod. A very large quantity of these batteries are used in our daily lives and these batteries have a very short life [1]. So recycling of Zinc-Carbon batteries is very important to minimize the environmental pollution. Recycling with an unadorned purpose of the waste treatment is not an attractive business, particularly in developing countries where economic interests supersede environment obligations. Several types of processes are there like hydrometallurgy, pyrometallurgy and electrometallurgy adopted to recover the metal values from spent Zn-C batteries. Spent Zn-C types of batteries are one of the potential secondary resources for producing Zn metal and its oxides, zinc Oxide (ZnO) having unique physical, chemical, optical and antimicrobial properties [3]. Due to vast area of applications, various synthetic methods have been adopted to grow numbers of ZnO nanostructures, nanowires, nanotubes and other morphologies. Zinc oxide nanoparticles have significant importance due to its versatile properties and thus, ZnO have a large number of industrial applications, such as medicine, food, agriculture, gas sensors, cosmetics, electronic etc. [4]. With a view to enhance the production of ZnO in nanoscale from different sources, a lot of research work have been carried out for last three decades. [5]. In the present work, ZnO nanoparticles are synthesized from spent zinc-carbon batteries followed by its application in fabricating dye sensitized solar cell (DSSC).

2. Experimental

Spent zinc carbon dry batteries of 1.5V and same size (AA types) were collected from different sources. The preliminary process involves the manual dismantling of batteries and the anodic zinc parts of the batteries were collected very carefully separately from the other components of the batteries. All the chemical reagents used for the study are of analytical grade.

2.1 Synthesis of Zinc oxide from spent batteries

All the chemicals used in the present study are of analytical grade. For the zinc oxide synthesis, 2gm of collected zinc parts of spent batteries were dissolved with 20ml HCl in a 250ml beaker at a temperature of 80^0 C through continuous stirring with a magnetic stirrer. To the prepared zinc solution, 1M sodium hydroxide solution was added slowly to precipitate out zinc. After completion of reaction, solution was allowed to stand for few time and then filtered with Whatmann filter paper. The residue of filtration was dried and heat treated at 400^0C to produce zinc oxide nanoprticles.

In order to fabricate ZnO electrode material for solar cell application, a solution of poly vinyl alcohol (PVA) was prepared with 10 ml of distilled water. To the aqueous PVA solution required quantity of ZnO nanoparticles was added through constant stirring with a magnetic stirrer to produce a slurry of ZnO nanoparticles. The coating ZnO nanoparticles on the conducting side of the ITO plate was made through dip coating. The resulting ZnO slurry coated ITO plate was dried using a heater followed by heat treating at 400^0C for 1 hour using a furnace. The beetroot extract was used as the dye. After heat treatment the ZnO coated ITO plate was dipped in the beetroot extract for three hours and then allowed to dry. In order to prepare the counter electrode, the graphite was scratched on the conducting side of ITO.

The electrolyte in the present study is prepared through the process as described elsewhere [6]. The produced electrolyte was added drop wise on the top of the ZnO layer and then the counter electrode was placed over the ZnO coated ITO layer. Two crodile clips were used to clamp the two electrodes. A load of resistance 17A was connected to the fabricated cell. A multimeter was used to measure the potential.

2.2 Characterization

The resulting ZnO nanoparticles was characterised through phase analysis by X-ray diffraction (XRD). The optical property study of the resulting zinc oxide nanoparticles was carried out through UV-Visible study in the wave length range of 210 nm to 420 nm at room temperature.

3. Results and Discussion

3.1 XRD analysis of the produced ZnO nanoparticles

Figure 1 shows the XRD pattern of ZnO nanoparticle synthesised in the present study. The peak positions at 31.68, 34.38, 36.23, 45.41, 47.52, 56.56, 62.85 corresponds to the characteristic peaks of ZnO phase. A definite line broadening of XRD peaks indicates that the prepared material consists of particle in nanoscale range [7-9].

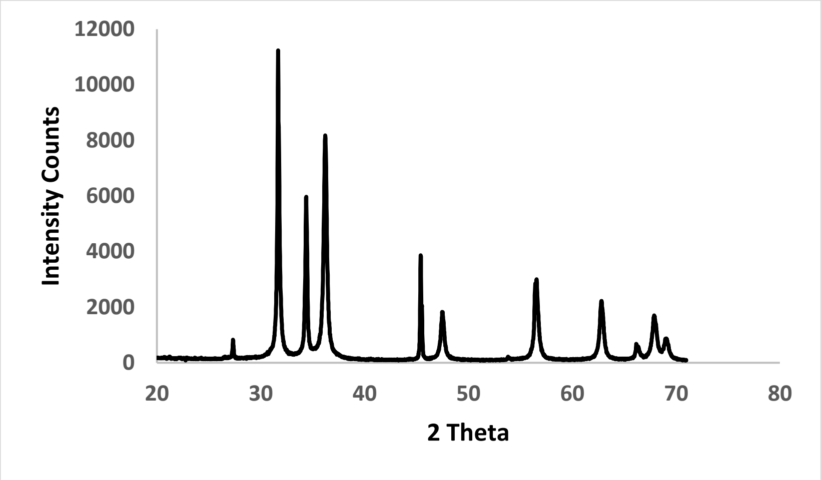

Figure 1 XRD pattern of produced ZnO

3.2. Optical characterization of the produced ZnO nanoparticles

The optical characterization of ZnO nanoparticles gives information about other physical properties, e.g. bandgap energy, band structure, and optically active defects. The prepared ZnO nanoparticles were dispersed uniformly in deionized water using ultra sonicator for 3min to get homogeneous solution. Figure 2 shows the UV-visible spectrum of synthesized ZnO nanoparticles. The spectrum absorption peak of ZnO at wavelength of 325 nm corresponds to intrinsic band-gap absorption of ZnO due to the electronic transition from the valency band to conducting band.

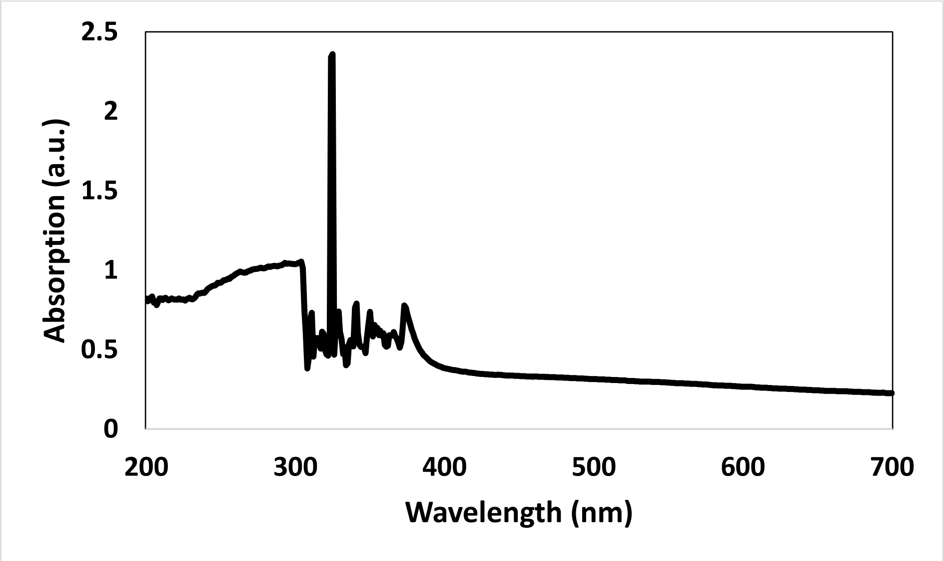

Figure 2 UV-Visible spectrum of produced ZnO nanoparticles

The bandgap energy (E) of prepared ZnO nanoparticles were calculated by using the equation given below

$E= (h \times C) /\lambda$

Where E=Bandgap energy

h=Planks constant = 6.626×10^{-34}J s

C= Speed of light = 3.0×10^{8}m/s

λ = Wavelength = 355×10^{-9}m

1eV=1.6×10^{-19} J

The calculated band gap energy value was found to be 3.82 eV and such intrinsic bandgap absorption of ZnO is due to the electron transitions from the valence band to the conduction band [10, 11].

3.3 Electrical characterization of fabricated ZnO based dye sensitized solar cell (DSSC)

The electrical characterization of a solar cell can be explained through various parameters such as Open circuit Voltage (Voc), Maximum current density or Short Circuit Current density (J_{max}), and maximum Power Output (P_{max}), fill factor (FF)

The Open circuit Voltage (Voc) is the terminal voltage of a source when no current is drawn from the source.

The maximum current density (J_{max}) is the current density when the terminals are connected with a zero ohm load i.e., a short circuit. When the current output from an ideal source is increased, the power output (Voc x I_{max}) increases linearly with current and can go up to a maximum value i.e. P_{max} i.e. the highest point on this curve is the maximum power that the cell can deliver.

Fill factor (FF), the ratio of maximum obtainable power to the product of the open-circuit voltage and short-circuit current. The fill factor (FF) in solar energy technology is a measure of how closely a solar cell acts as an ideal source. The higher the fill factor, the better is the solar cell.

The fill factor is calculated by following formula:

$$FF = (J_{max} \text{ x } V_{max}) / (J_{sc} \times V_{oc}) \qquad (2)$$

Where J_{max} = Current density corresponding to maximum power

V_{max} =Voltage corresponding to the maximum power

J_{sc} = short current density

Voc = Open-circuit voltage

The power conversion efficiency (ή%), which is the ratio between maximum power (P_{max}) and electrical input power (P_{in}).

The power conversion efficiency (ή%) is calculated by the following equation:

$$ή =(FF \text{ x } V_{oc} \text{ x } J_{sc})/ (S \text{ x } P_{in}) \qquad (3)$$

Where P_{in} = Electrical input power

S =Area of the DSSC

By using equation (2) and (3) [11,12], the fill factor (FF) and efficiency (ή%) are found to be 35.2% and 0.187% respectively. The value of FF of the fabricated DSSC is quite close to that reported one, where when the light intensity is 40 mW/cm^2 where FF value is 35.9% [11]

The current density-voltage (J-V) curve of the fabricated ZnO based DSSC is shown in Figure 3 showing a characteristics pattern as reported elsewhere [11,13]

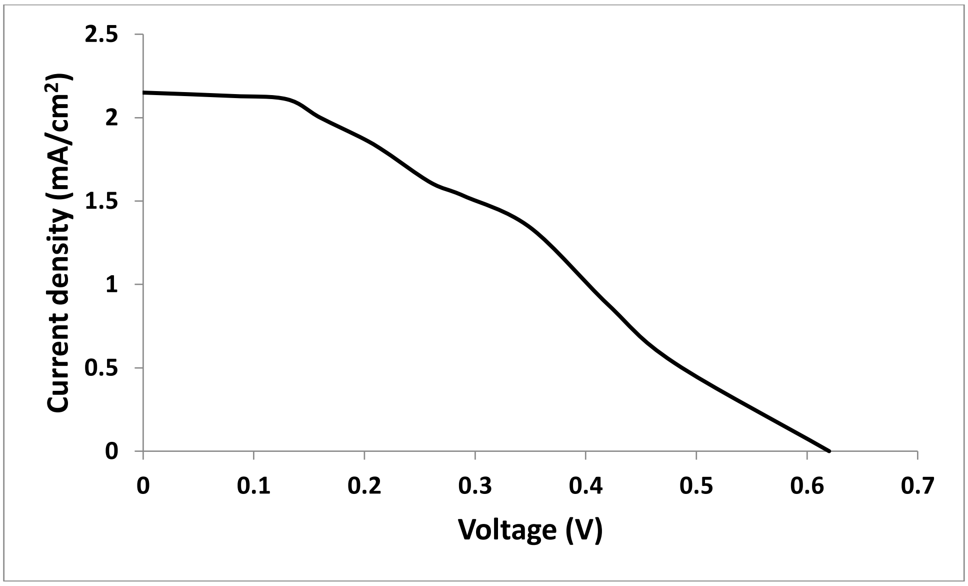

Figure 3 J-V curve of fabricated ZnO based DSSC

4. Conclusion

ZnO nanoparticles have been prepared from spent zinc-carbon batteries though the chemical method. The phase analysis of the produce ZnO corresponds to formation of nanoparticles. The optical study of the produced ZnO shows a band gap energy of 3.82 eV suggesting a semiconductor type characteristics, suitable for fabricating DSSC. The fabricated ZnO based DSSC shows a FF value 35.2% and ή value of 0.187%. Hence, the current study provides a simple method for preparation of ZnO nanoparticles from the solid waste like spent zinc-carbon batteries and its application in fabricating DSSC for electrical energy generation. However, further studies are required in terms improving the FF and ή% for creating future scope of this study.

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