# High Photo-Voltage Zinc Oxide Thin Films Deposited by DC Sputtering

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(Received August 8, 2001)

The thin films of ZnO have been deposited on conductive glass substrates by DC sputtering. The sputtering parameters have been varied to obtain ZnO films with maximum open circuit photo-voltage measured in the electrolyte $KI/I_2$. A photo-voltage as high as 40.66 V/m$^2$ could be obtained for the film synthesized at the pressure of 6 mbar for a duration of 23.75 hours. These ZnO thin films can be used to absorb the short wavelengths in the ultraviolet (UV) region of the solar spectrum.

PACS. 67.70.+n – Films.
PACS. 72.40.+w – Photoconduction and photovoltaic effects.

## I. Introduction

Mostly the sputtering technique is used to deposit the thin films of magnetic materials [1-3]. Some other techniques such as chemical vapor deposition [4], the quasi-closed space vacuum sublimation technique [5] and the screen printing techniques [6] are used to deposit the layers of material for solar energy applications. ZnO is an n-type semiconductor, which does not result in corrosion when it is brought into contact with the electrolyte. Normally most of the oxides are chemically stable and they do not react with the oxygen in air.

ZnO layers also can be used as the top layer of a solar cell with multilayers, since the top layer of a multilayer usually absorbs photons with high energies in the solar spectrum. Always the materials with higher energy gaps are useful to obtain higher photo-voltages.

## II. Experiment

Prior to the sputtering the chamber was pumped down to a base pressure of 4.2 mbar in order to avoid the contamination due to other gases in the air. Then the chamber was flushed with pure Ar gas, in order to remove the small amounts of other residual gases further. All these films were synthesized on the polished surface of well cleaned conductive glass substrates with surface area 35 mm $\times$ 26 mm in Ar by using an Edwards S150B sputter coater. A flat circular plate of pure Zn with diameter of 6 cm was used as the target for DC sputtering. The conductive surface of the conductive glass substrate was facing towards the target. The amount of oxygen in the little amount of the air left in the chamber was enough to form the phase of ZnO in this reactive sputtering process. The pressure of the chamber was varied from 5.5 to 8 mbar by controlling the Ar gas flow entering into the chamber in this dynamic process. The needle valve with a fine controlling system attached to the Edwards sputter coater was used to control the Ar gas flow.

 

Because the highest photo-voltage was obtained for the film deposited at 6 mbar, all the films described in this report have been deposited at 6 mbar. The sputtered films of ZnO appeared to be in light orange color.

All the samples were measured in an electrolyte solution with concentration of 0.01 M KI/0.0001 M $I_2$ with redox couples $I_3^{-}/I^{-}$. Sputtered ZnO film and a platinum plate immersed in electrolyte solution were used as the working electrode and the counter electrode, respectively. These two electrodes were connected to a digital multimeter to measure the open circuit voltage between electrodes before and after illumination by a fluorescent lamp of 20 W, which was placed 5 cm apart from the working electrode. The absorption spectrums of the DC sputtered films were measured by a Shimadzu UV-1601 UV visible Spectrophotometer.

## III. Results and discussion

The graph between the open circuit voltage and the time duration of sputtering is given in figure 1. The photo voltages were calculated as the difference between the measured open circuit voltages after the illumination and before the illumination. The photo voltages are given as negative values for this n-type semiconductor. The highest photo-voltage 37 mV was observed for the film synthesized for a time duration of 23.75 hours at 6 mbar and a sputtering current of 5mA. The photo-voltages measured for the ZnO films of area of 35 mm $\times$ 26 mm are given in the graph. The incident power on the ZnO film due to the fluorescent lamp was calculated to be 106 $Wm^{-2}$. But the sun delivers approximately 1000 $Wm^{-2}$ to the surface of the earth. Therefore the photo-voltage of this film under the irradiation of sunlight can be higher than our measured values of photo-voltages.

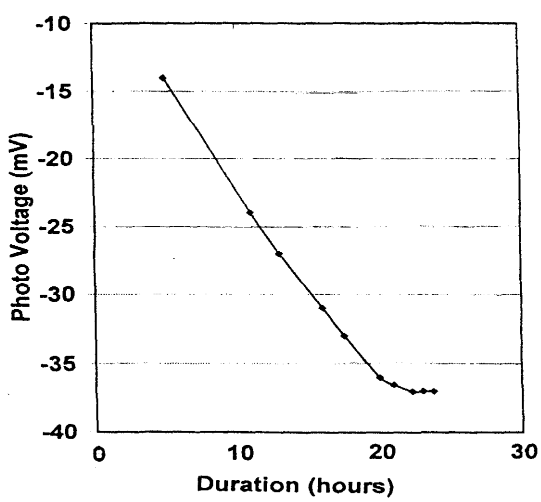


FIG. 1. The graph between the sputtering time duration and the open circuit photo-voltage for ZnO films sputtered at a pressure of 6 mbar and at a sputtering current of 5 mA.

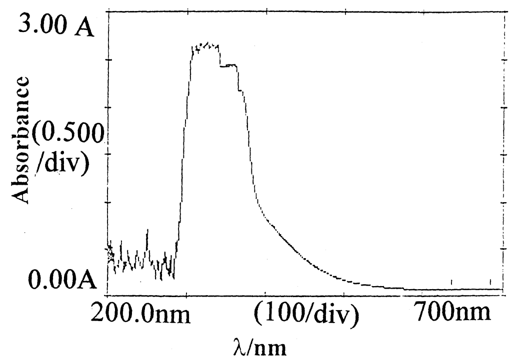


FIG. 2. The absorption spectrum of ZnO film deposited at 6 mbar for 23.75 hours.

Although the thinner ZnO films can absorb some photons with energy less than the band gap of ZnO, other photons with same energy can pass through thinner films without any absorption. But the thicker films can absorb all the photons before the photons get through the thicker film. Therefore when the film is thick enough to absorb all the photons, the photo-voltage reaches the terminal value at that value of thickness. Since the thickness of the film gradually increases with the duration of sputtering, the photo-voltage reaches the terminal value at 23.75 hours time duration.

The absorption spectrum of ZnO film sputtered at 6 mbar for 23.75 hours is given in figure 2. The peak value of absorption could not be seen on the graph since the maximum scale of absorption of this spectrometer is not high enough to measure the highest photo-absorption of our ZnO film. A sharp peak may be obtained by reducing the film thickness. The films with higher absorption provide higher photocurrent, since the higher the number of absorbed photons is the higher the photocurrent. The wavelength at maximum absorption was found to be 390 nm. The energy gap of this film material, calculated by extrapolating the part of absorption spectrum with highest slope, was found to be 3.2 eV. This energy gap is exactly the same as the accepted value of the energy gap of ZnO. This implies that the phase of ZnO has been formed on the conductive glass substrate. A higher power (P=VI) can be obtained by using a film with a higher photo-voltage and a higher photocurrent.

## IV. Conclusion

The optimum sputtering conditions required for the highest open circuit photo-voltage were studied in detail. The highest open circuit photo-voltage of 37 mV for a surface area of 35 mm £ 26 mm was measured for the film deposited for 23.75 hours at the pressure of 6 mbar. The formation of a ZnO phase has been verified using the absorption spectrum and energy gap calculations. The photons in the UV region of the solar spectrum can be absorbed by materials with higher energy gaps such as ZnO.

## References

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