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Investigate the Electrical and Structural Characteristics of the Si-ZnO Diode

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ABSTRACT: *Silicon-zinc oxide (Si-ZnO) junction has been prepared using the chemical bath technique. The zinc oxide layer was examined using different techniques, including X-ray spectroscopy and a UV-visible spectrophotometer. The ZnO film images show that the films are homogeneous with an average grain size of 70 nm, while the X-ray spectrum shows that the layers are amorphous with some crystalline phase peaks appearing between 2θ=20° and 35°, which belong to ZnO. Transmittance, absorbance and extinction coefficient were varied over the visible light wavelength range, and the energy gap of the films was about 2.6 eV. In both forward and reverse bias, the junction revealed diode characteristics. The influence of light on the current intensity was evident and reached about 240 mA compared to the current intensity in the dark state. Also, the current intensity of the diode increased at each applied voltage with the increase in the intensity of the light shining on it.*

Keywords: zinc oxide, thin films, X-ray, Si-ZnO, UV-visible spectrophotometer

1. INTRODUCTION

One of the most significant fields in solid-state physics is the study of materials in the form of thin films. In order to assess their utility in diverse applications, several physical and chemical features of thin film technology have been established. This technology has significantly contributed to the investigation of semiconductors. Thin film is an expression used to denote material atoms in one or more layers whose thickness does not exceed one micron (1 μm).[1] Many scientists have been preparing thin films since the second half of the 17th century. Thin films provided a comprehensive understanding of the chemical and physical characteristics of semiconductors, aiding in their production and study. One of the most significant semiconductors is known as Transparent Conductive Oxides (TCO), which is a semiconductor consisting of a metal and oxygen or oxidised semiconductors such as zinc oxide (ZnO), indium (III) oxide (In_2O_3) and tin (IV) oxide (SnO_2). These materials combine two of the most crucial characteristics of electronic devices: they are optically transparent and have high conductivity. We shall explain the oxygen vacancies coming from molecular mismatch (non-stoichiometry) that cause the conduction beam to be full of free electrons despite its wide energy gap.[2–4]

The significant expansion in the uses of TCO as thin films on various materials and their specifications has created an urgent need for the emergence of simple and inexpensive preparation techniques that suit the characteristics of these films and their fields of application. Consequently, preparation techniques have witnessed great developments, and many methods have been developed in the preparation of these oxides.[5,6] The most common methods in the preparation of TCO films are based on the deposition medium. Some techniques rely on the deposition of films from liquid media, as in the thermochemical spraying technique, or from gaseous media (steam), as in the evaporation method.[7,8] ZnO is one of the n-type TCO group; it exhibits good conductivity, high transmittance and absorption in the visible region and ultraviolet, respectively. Pure ZnO is a white solid powder. It can dissolve in acetic acid, mineral acids, ammonia, ammonium carbonate and alkaline hydroxides but not in water or alcohol, making it an amphoteric oxide.[9] ZnO often shows negative (n-type) conductivity, attributed to the presence of natural point defects with low energy or because of the presence of hydrogen.[10] Positive-type (p-type) ZnO is of great importance in optoelectronic applications and can be obtained by doping with elements that make up the facilitators (liable impurities), such as lithium (Li), sodium (Na), nitrogen (N), phosphorus (P), arsenic (As) and antimony (Sb).[11] Thin films prepared from ZnO compounds have a high energy gap of about 3.2 eV,[12,13] allowing their use in several fields such as solar cells, sensors and electro-optical devices.[14–16] ZnO films have recently gained importance for several reasons, including being a relatively inexpensive material compared to others. It grows along the (001) direction at relatively low temperatures and sublimes ZnO by heating without decomposing at very high temperatures.[17] The nature of the substrate material significantly affects the physical properties and composition of ZnO thin films. Using various methods, ZnO films have been deposited on several substrates, including silicon, blue sapphire, calcium arsenide, quartz, glass, acetylene, alumina strips, molybdenum and magnesium oxide.[18,19] Growing ZnO on substrates such as glass and polymer at relatively low temperatures is of specific importance in the applications of displays and solar cells.[20,21] Various methods have been employed in the preparation of ZnO films, such as the spin coating method, spray pyrolysis technique, plasma sputtering method and chemical vapor deposition (CVD).[22,23] In this study, thin films of ZnO were deposited on silicon wafers (p-type) and glass. We also investigated the optical, structural and electrical characteristics of ZnO films and the Si-ZnO junction using a UV-Spectrometer, X-ray spectrum and scanning electron microscope.

2. EXPERIMENTAL

The ZnO was prepared by combining two solutions. The first solution consisted of 0.7 g of potassium hydroxide dissolved in 25 ml of distilled water. The second solution consisted of 0.4 g of zinc chloride also dissolved in 25 ml of distilled water. These solutions were then mixed and stirred for one hour at 60°C using a magnetic stirrer:

$$ZnCl_{2\,aq} + 2KOH_{aq} \rightarrow Zn\,(OH)_2 + 2KCl \quad (1)$$

$$Zn\,(OH)_2 \rightarrow ZnO + H_2O \quad (2)$$

Silicon wafers and glass slides were used as substrates for building thin films of ZnO. Both substrates underwent a series of cleaning stages, including washing with methanol, acetone and finally with hydrofluoric acid, followed by distilled water rinse. The glass substrates were placed vertically in the latter solution for 20 min at 60°C. The films deposited on the glass and p-type silicon wafer substrates were used in the study of the optical and electrical properties of ZnO thin films, respectively. To form the Si-ZnO junction, two layers of aluminum were deposited on both ends of the silicon substrate. The device was then annealed at a constant temperature of 200°C for an hour to achieve ohmic contact between the aluminum and the semiconductor, as illustrated in Figure 1.

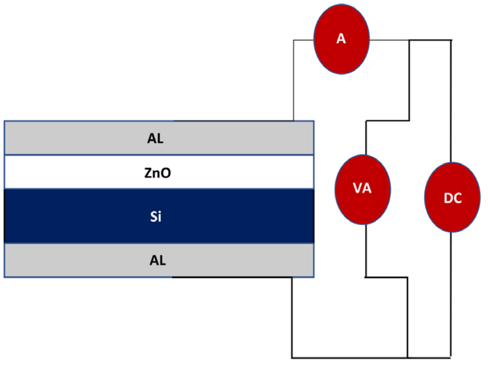

Figure 1: Block diagram and I-V characteristics measurement circuit.

3. RESULTS AND DISCUSSION

To investigate optical, structural and electrical properties, ZnO thin films were prepared on silicon wafers and glass substrates. The transmittance increased across the visible light wavelength range, becoming almost constant for wavelengths above 700 nm. This trend is mirrored in the absorbance, which decreases with wavelength and also stabilises above 700 nm as show in Figure 2. The refractive index and extinction coefficient remained nearly constant across visible light wavelengths and other low-energy rays, suggesting the homogeneity of the films. Finally, the energy gap of the prepared films was calculated to be approximately 2.6 eV.

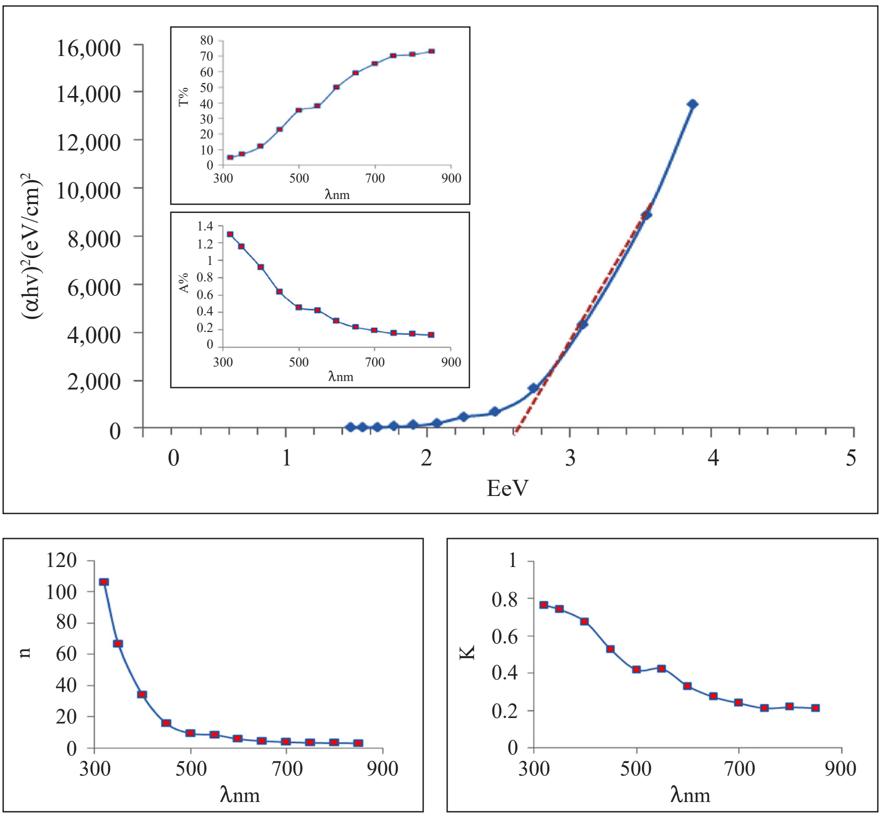

Figure 2: Optical properties and energy gap of ZnO thin film.

The scanning electron microscope (SEM) image of the ZnO film show the homogenous distribution of grains over the area of the films, the average gains size was about 70 nm Figure 3. The X-ray spectrum in Figure 4 shows that the layers are amorphous with some crystalline phase peeks appear between $2\theta = 20°$ and $35°$ which belong to ZnO.[24,25]

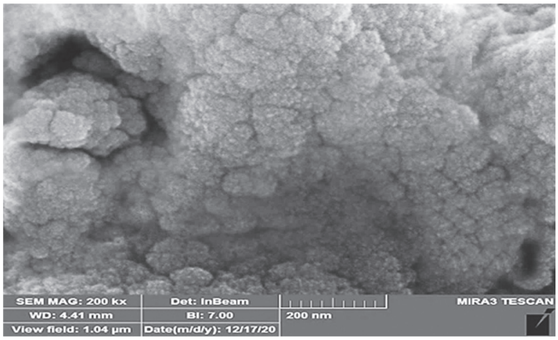

Figure 3: SEM images of ZnO thin film.

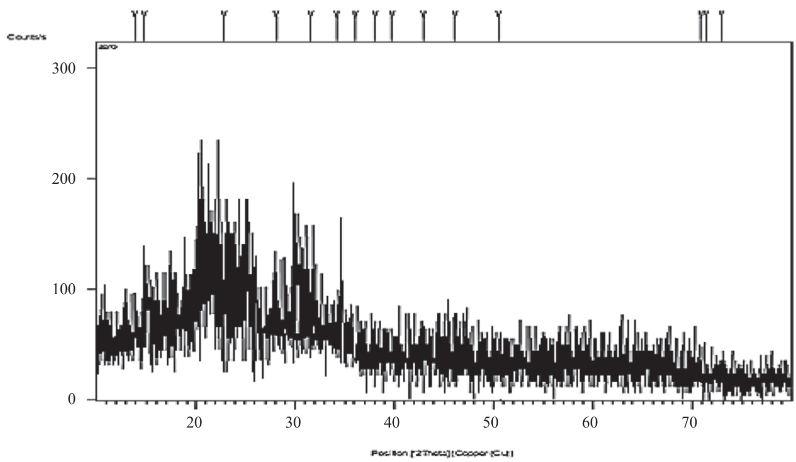

Figure 4: X-ray spectrum of ZnO thin film.

The I-V characteristics of the Si-ZnO junction resembled those of a diode. Under forward bias, the highest current in the dark state was 90 µA, increasing to about 240 µA after exposure to a 20 W light source on the junction as show in Figure 5. Furthermore, Figure 6 illustrates the sensitivity of the Si-ZnO junction to light. The current intensity rises with light power, ranging from 20 to 60 W at each applied voltage. This phenomenon is attributed to the increase in carrier energy, resulting in a higher number of carriers crossing the junction.

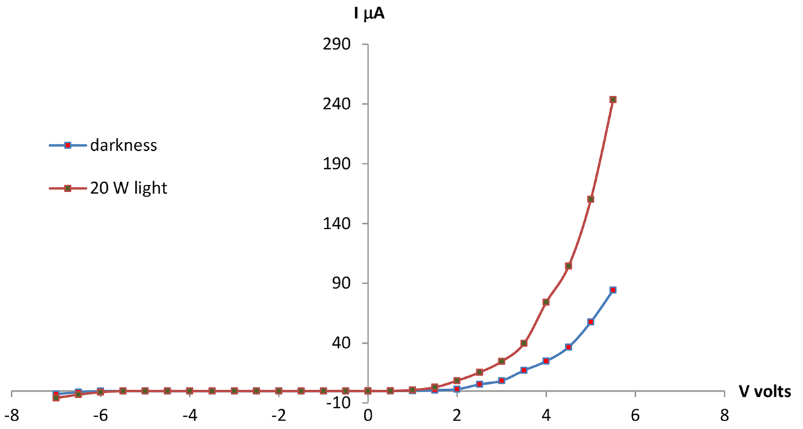

Figure 5: I-V characteristics of Si-ZnO junction at darkness and 20 W light.

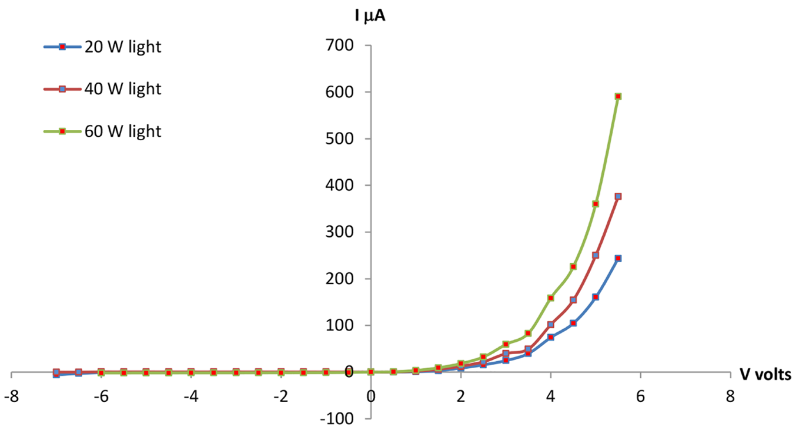

Figure 6: I-V characteristics of Si-ZnO junction at 20, 40, 60 W light.

4. CONCLUSION

The electrical and structural characteristics of the Si-ZnO diode were characterised in this study. Thin films of ZnO were deposited on silicon wafers (p-type) and glass. The results led to the following conclusions:

1. Thin films of ZnO, prepared using chemical bath deposition, exhibited an energy gap of approximately 2.6 eV.
2. The Si-ZnO junction displayed distinct current values in both dark and light conditions under the same applied voltage. Notably, the current through the junction increased with incident light power due to its high sensitivity.

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