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Characterization of ZnO by mean of I-V Measurement of respective Schottky diode by DLTS

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Abstract

Zinc Oxide (ZnO) was studied through deep level transient spectroscopy (DLTS). The current-voltage(C-V) characteristics of Schottky diode were analyzed through standard method, which is available in DLTS system. The C-V measurements of ZnO were performed at different temperatures under identical biasing circumstances. On the bases of these characteristics the behavior of the material was studied in detail and listed in the following: The ideality factor of ZnO was calculated to be 2.2183 at room temperature, observed to increase with decreasing temperature of the material. The higher value of ideality factor was attributed to high diffusion or tunneling current. The barrier height of ZnO was calculated as 0.640eV, which decreased with decrease in temperature. The change in the barrier height was related to the effective leakage current at high temperature. Reverse saturation current calculated for ZnO was found to be 7.531µA and the calculated values are found to decrease at lower temperatures.

Keywords: Semiconducting zinc oxide materials, I-V characteristics, Deep level transient spectroscopy (DLTS) of the material, schottky diode

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INTRODUCTION

Here has been a large deal of attention in zinc oxide (ZnO) semiconductor material, which is an efficient oxide material, considered over numerous decades due to its massive applications in diversity of fields. It has been used for coatings in thin film of photovoltaic cells (Budianu et al., 2002), antireflective coatings in conventional silicon solar cells (Dimova et al., 1999), light emitting diodes (Soki et al., 2000), thin film transistors (Asghar et al., 2013). owing to its exceptional conduction method based on oxygen vacancies, it is extensively used in oxygen gas sensors (Lampe et al.,1989), A single crystal aluminum nitride (AlN) wafer surface has been studied with the help of a newly unique software-based mechanism, Charged-based Deep Level Transient Spectroscopy (Q-DLTS) setup (Rothenberger et al., 2012). Current-voltage, capacitance-voltage characteristics, admittance spectra, deep level transient spectroscopy (DLTS), microcathodoluminescence (MCL) spectra of undoped n-GaN/InGaN multiquantum well (MQW) structures were studied before and after 10 MeV electron irradiation (Polyakov et al., 2007). ZnO has an exclusive arrangement of piezoelectric, conduction and photo-optical based properties (Zu et al., 1997). Currently, it has been well thought-out as an alternative to GaN because of its excellent properties, that is: (1) a large excitonic binding energy (which is almost 60 meV), (2) less power thresholds for optical pumping at normal temperature and (3) tunable band gap energy within the range 2.8 to 3.3 eV and 3.3 to 4 eV with CdO doped (Zu et al., 1997) and MgO (Heo et al., 2005) correspondingly. The large excitonic binding energy (almost 60 m eV) of ZnO makes it well matched for developing ultra violet light source and transparent electronic materials. Due to considerable large band gap and relatively saturated drift velocity, III–V compound semiconductors are rapidly becoming critical materials for a variety of novel applications (Muthukumar et al., 2004, Nakamura et al., 1996)

MATERIALS AND METHODS

Sample preparation

The sample of p-type ZnO used for research was thin film of ZnO material (with 400nm thickness) were deposited on p-type Silicon (111) maintained at 300 °C and 3 x 10^{-3} torr by thermal evaporation by means of radio frequency source with operating power of 200 W. Isochronal annealing in the temperature range 400 °C to 1000 °C for 30 minutes each under N_2 atmosphere was conceded out to get better crystalline and stoichiometric properties of the deposited film. Circular Schottky contacts having diameter of 2mm using Au and Ni separately were made by thermal evaporation.

Deep Level Transient Spectroscope (DLTS)

The deep level spectroscopy model DLS-83D is such an automatic machine which can be used to interpret the data without manual interaction. The DLTS can measure defects in semiconductors and devices. It also measures the introduced impurities in the materials. It also has versatile in measuring other associated parameters like deep traps energy level, capture cross section and concentration distribution. Impurities can be identified using this DLTS although concentration of impurity is below 10^9 atom/cm^3. This DLTS has variety of mode like: depth profiling-V characterization, capture cross section measurement, frequency scan, conductance transient measurements, temperature scan, optical injection and constant capacitance. It has digital and analog controls for C-V, I-V measurements. Moreover the data can be linked to computer by software and can be compared with available literary data base for better identification.

Current-Voltage I-V Measurements

In most device applications, the linear range of the forward I-V characteristics is important. At low semiconductor doping levels, the dominant electron transport mechanism has been reported as harmonic emission (Pearton et al., 1999). The I-V curve measurements performed both as a diagnostic tool to determine the quality of the device contacts as well as a characterization technique for the evaluation of the diode properties. Several I-V measurements were made to verify the rectifying behavior of the Schottky contacts. I-V characteristics have been performed by DLS-83D system at different temperatures. From the I-V measurement we calculated the following parameters of the assumed junction: Ideality factor, Saturation current and Barrier height.

$$n \text{ (Ideality factor)} = \frac{q}{Slope \times kT} \quad (1)$$

Where q = Charge, k = Boltzmann constant, n = Ideality factor

The value of n =1 as unity is for good diode, if n >1 then it is not a good diode and it will have reverse saturation current / leakage current.

$$\text{Intercept} = \ln(I_s). \text{ Where } I_s = e^{\text{Intercept}} \quad (2)$$

$$\Phi_B = \frac{kT}{q}\ln[A^* \; T^2 / J_s] \quad (3)$$

RESULTS AND DISCUSSION

Current-Voltage I-V Measurements of ZnO

First of all, the optical characteristics and the DLTS studied have been combined and then on the basis of this combination data has been analyzed. Now we discuss the measurement of the I-V characteristics over different ranges of -1.95V to 0.95V at different temperatures 300K to 128K. The sample of p-type ZnO used for research was thin film of ZnO material (with 400nm thickness) were deposited on p-type Silicon (111) maintained at 300 °C and 3 x 10^{-3} torr by thermal evaporation by means of radio frequency source with operating power of 200 W. The typical I-V characteristics of as grown p-type ZnO at different temperatures are shown in figure 1 to 12. The straight line in semi log I-V characteristics shows the theoretical linear fitting of the curves. Using equations (1), (2) and (3) have calculated the following values.

From table 1 we conclude that the ZnO shows better Schottky diode characteristics. The ideality factor calculated in the range of 1.9 to 3.5. At room temperature characteristics were good as required for

DLTS characterization. The reverse saturation current is measured ~ 7.5 μA and noted minute change on lowering temperature. Its value calculated as 1.85 μA at 128K. We calculate the barrier height at room temperature as 0.64 eV which decreases with the decrease in temperature up to 0.27 eV at 128K. Dhananjay et. al investigated that the ZnO/Si showed too much high rectification behavior during a turn on voltage of about 1.4V for the hetero junction (Dhananjay et al., 2007). All graphs on the right side of the figures indicate Gaussian profile (show curvature for 'ln I_s' Vs 'V') which is a reflection that there is simultaneous quantum tunneling of current with reverse biasing as indeed quantization of charge carries, with quantization of charge carriers, one would expect fractional charge quantization especially in ZnO which is compatible with Hetro-structure of GaN,GaAl.

Table: 1 Parameters calculated from IV measurements of ZnO.

Temperature (T) K	Ideality Factor (n)	saturation current (Is) A	Barrier Height (Φ_B) eV
300	2.2183	7.52×10^{-6}	0.640
240	1.9291	3.28×10^{-6}	0.520
200	2.1973	2.46×10^{-6}	0.432
180	2.4160	2.22×10^{-6}	0.387
140	3.3009	2.03×10^{-6}	0.296
128	3.5580	1.85×10^{-6}	0.270

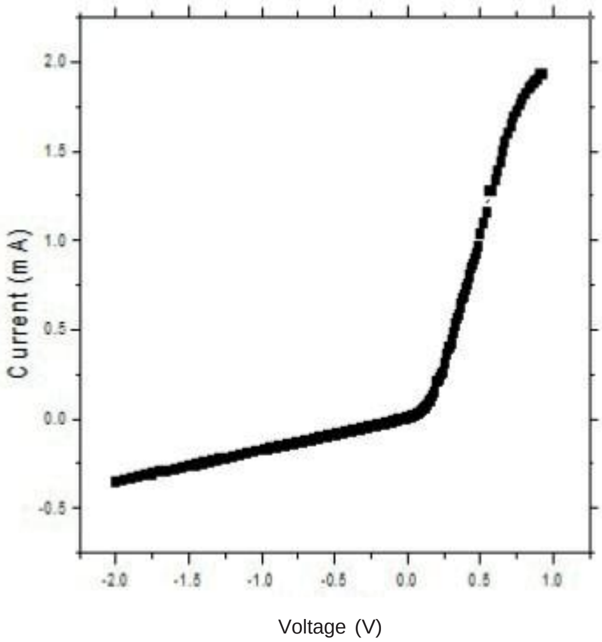

Figure 1: The graph between I-V of ZnO at T=300K.

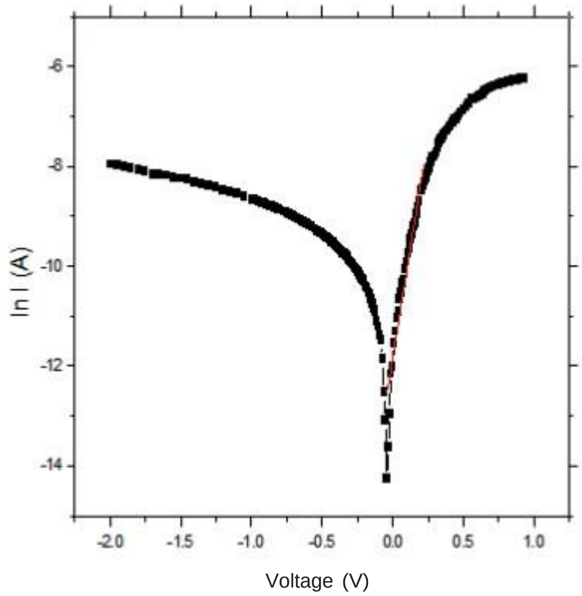

Figure 2: The graph between V and ln(I_s) of ZnO at T=300K.

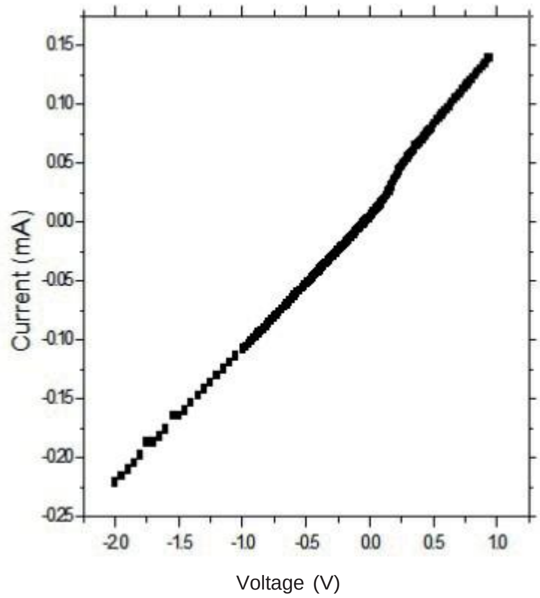

Figure 3: The graph between I-V of ZnO at T=240K.

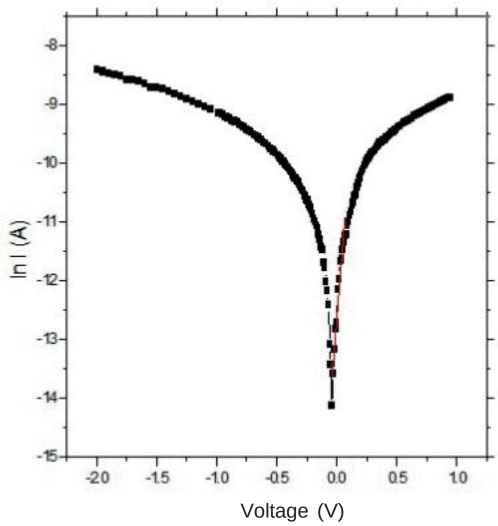

Figure 4: The graph between V and ln(I_s) of ZnO at T=240K
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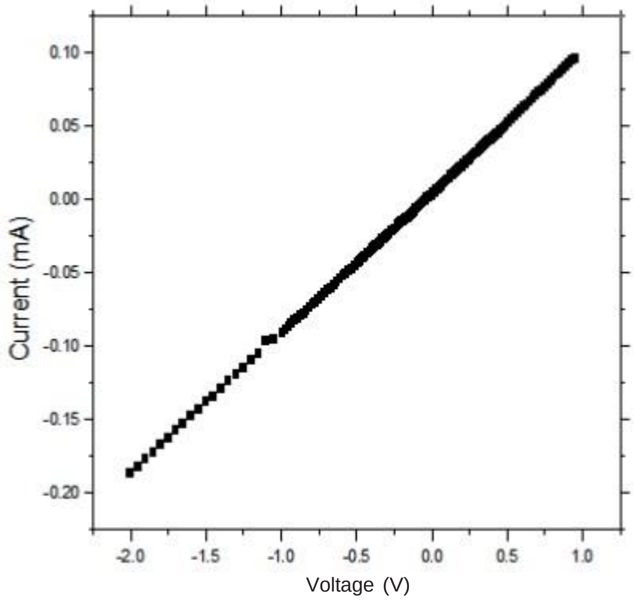

Figure 5: The graph between I-V of ZnO at T=200K

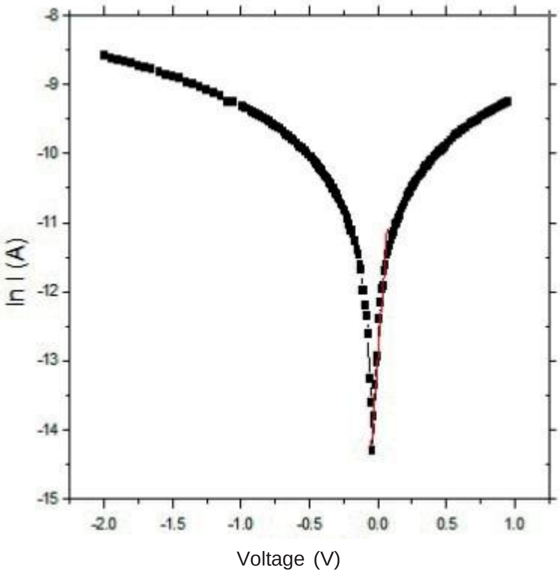

Figure 6: The graph between V and ln(I_s) of ZnO at T=200K.

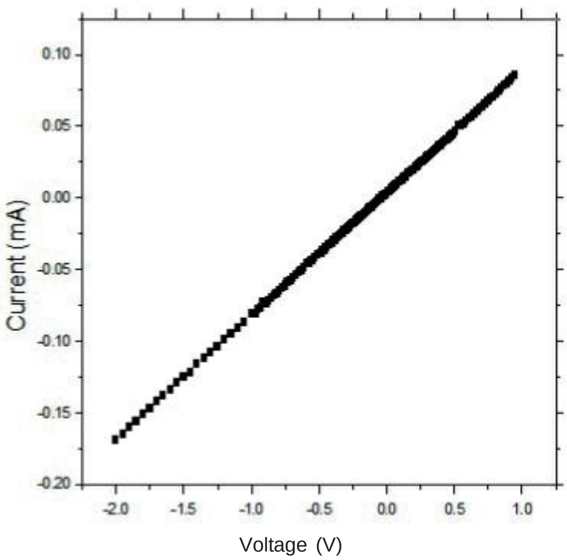

Figure 7: The graph between I-V of ZnO at T=180K.

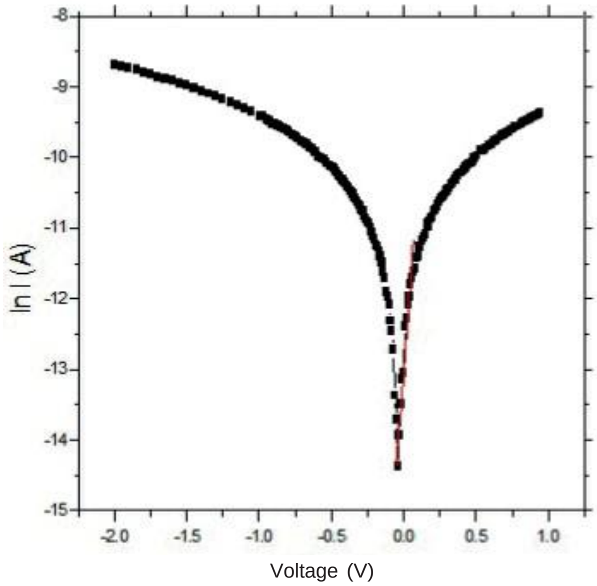

Figure 8: The graph between V and ln (I_s) of ZnO at T=180K.

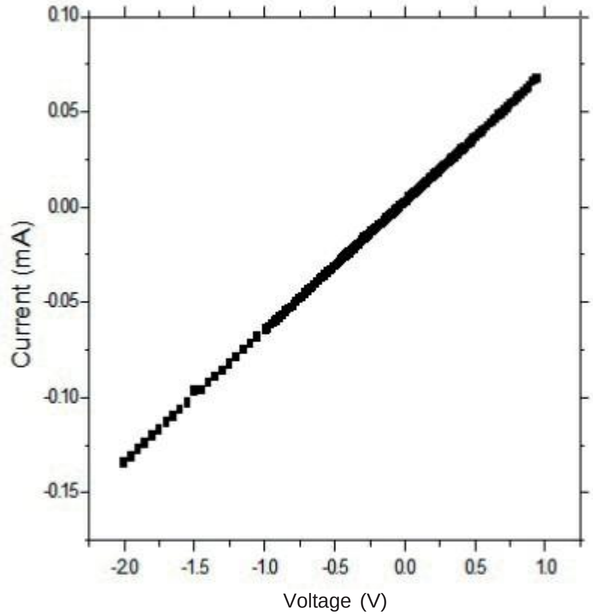

Figure 9: The graph between I-V of ZnO at T=140K.

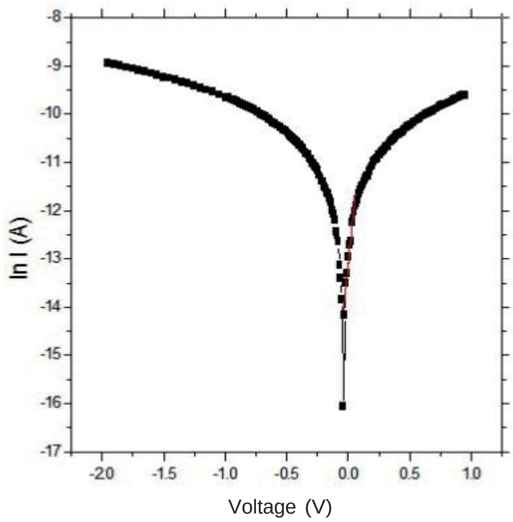

Figure 10: The graph between V and ln(I_s) of ZnO at T=140K .

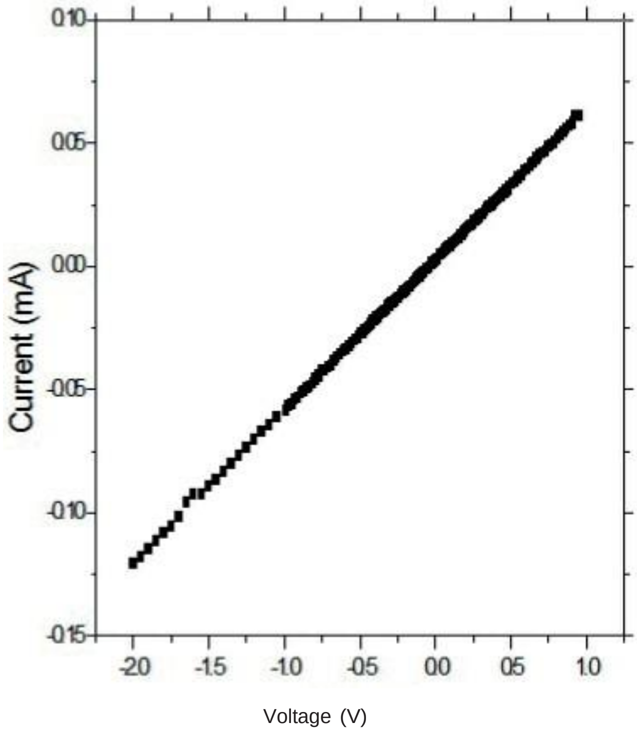

Figure 11: The graph between I-V of ZnO at T=128K.

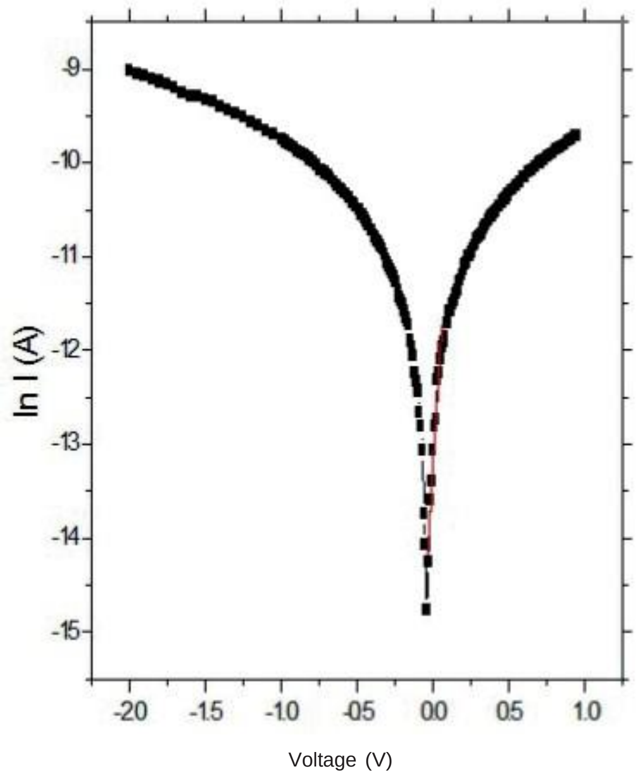

Figure 12: The graph between V and ln(I_s) of ZnO at T=128K.

CONCLUSION

From the table 1 and figures 1-12, the analysis of ZnO through DLTS. All graphs on the right side of the figures indicate Gaussian profile (show curvature for 'ln I_s' Vs 'V') which is a reflection that there is simultaneous quantum tunneling of current with reverse biasing as indeed quantization of charge carries. The I-V characteristics were performed to evaluate the rectification trend of the diode. The ideality factor (n), reverse saturation current (Is) and barrier height (ϕ_B) of the diodes at different temperatures were studied. The p-type sample of ZnO 400nm thick deposited on p-type Silicon with 111 planes by thermal evaporation. I-V measurements were taken at 300, 240, 200, 180, 140 and 128K. The calculated values of n, Is and ϕ_B at R_T were 2.2183, 7.52×10^{-6}A and 0.64eV respectively. The value of ϕ_B changed on the variation of temperature but no significant change in leakage current was observed. Also built-in potential and barrier height remained almost constant.

There is reverse tunneling it would be considered an avalanche effect of any particular barrier height. With lowering of temperatures, both barrier heights and saturation current decrease, with decreasing temperature, charge carriers are quantized. (Hidayet et al., 2005, Lin et al., 1995, Suzuki et al., 2004).

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