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| RESEARCH ARTICLE

The Study of ZnO-NRs and Ge-chips Bandgaps for the Elimination of Elemental Semiconductors and Compound Semiconductors Applications

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| ABSTRACT
In this paper, the bandgap of Germanium (Ge) and Zinc-Oxid (ZnO) materials were studied using two different techniques called the four-probe method and UV-Visible spectroscopy. A chip of Ge and a ZnO synthesized Nanorods on the FTO substrate were utilized as the samples. Scanning electron microscopy and X-ray diffraction spectroscopy were applied to understand the morphology and the crystal structure of the ZnO particles on the substrate. To get bandgap for Ge, the variation of voltage concerning temperature in $2mA$ current was recorded, and for ZnO- Nanorods (NRs), the absorption spectra in the range of (200-800) nm were taken. Based on obtained data and calculations, the band gap of Ge and ZnO-NRs were determined to be around 0.7 eV and 3.2 eV respectively. It revealed that the bandgap of compound semiconductors (ZnO- NRs) could be sufficiently large as compared to the elemental semiconductors (Ge), and through that, the modification of various devices is possible in the industry.

| KEYWORDS

Band gap, four probes, UV-Visible spectroscopy, Ge and ZnO

| ARTICLE INFORMATION

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1. Introduction

The application of semiconductors in the industry depends on their optical and electrical properties. Elemental semiconductors and compound semiconductors can exhibit different optical and electrical properties. One of their important properties of them is bandgap energy (Eg). The bandgap energy for the different materials is different; this is not constant. In industry, companies are looking for materials that have great optical and electrical properties and have high coefficients for the absorption of light for some particular purposes.

Elemental semiconductors like Ge and Si are the group Ⅳ elements and have bandgap energy around 0.7ev and 1.1 EV, respectively. Semiconductors can be obtained from the combination of elements of the III–V and II–VI groups as well, which can have a greater bandgap compared to elemental semiconductors (Hofmann 2015). These kinds of semiconductors are called compound semiconductors. The ZnO is obtained from the combination of groups VI and II and hence is a compound semiconductor. Such semiconductors are important in a wide spectrum of optoelectronic applications ranging from solar cells to smart goggles (Rajeshwar 1992). ZnO is one of a few oxides that can be grown as a polycrystalline material at relatively low or even at room temperature in a variety of substrates, such as amorphous glasses and plastics or metal foils (Fortunato et al., 2004)

The bandgap of materials can be determined by various techniques. This is mostly depending on the type and structure of the samples. The four-probe method is usually used when the sample is in the chip form, and UV-Visible spectroscopy is applied when

the sample is in the thin film form. Four probe method is a technique that is used to measure the resistivity value of a layer of electronic material, that is, a semiconductor material such as silicon (Si), Germanium (Ge), Gallium Arsenide (GaAs), as well as metallic materials in a thin film that is used in electronic devices(Waremra and Betaubun 2018). This method practically eliminates measurement errors due to contact resistances between the probes and the sample, which usually exist in the two-point probe measurement technique (Shimanovich et al., 2014).

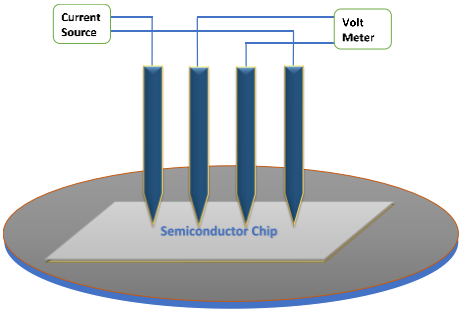

Figure 1. Four probs schematic diagram.

UV-Vis spectroscopy technique is a powerful tool that can be used for the quantitative analysis of organic compounds, particularly highly conjugated compounds (Alshehawy et al. 2021).

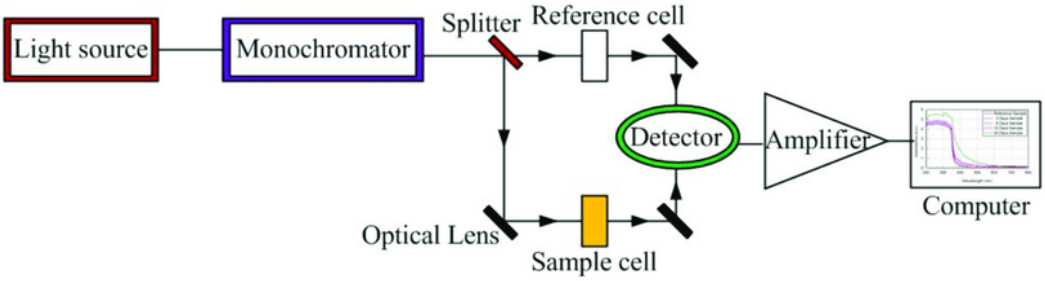

Figure 2. The schematic diagram for the experimental setup of UV-Visible spectroscopy.

In this paper, the bandgap of an elemental semiconductor (Ge) and a compound semiconductor (ZnO) are determined using two different techniques called the four-probe method and UV-Visible spectroscopy. The main goal is to indicate the procedure for measuring the bandgaps, the rules and essential equations for the calculation of bandgaps, and; the limitations of these two different techniques for the estimation of the bandgaps of materials.

2. Material and method

Four Probe method was carried out to determine the band gap of Ge. This is a major method for the determination of the conductivity of a given material (Mavrokefalos et al. 2007). A chip of Ge was used as a sample. The variation of voltage concerning temperature was recorded at a constant current. In this method, the Ge sample was placed under the four probes inside an oven. By applying a constant current of about 2 milliamperes at the two outside probes and measuring the voltage from the two inside probes, the resistivity of the sample was estimated at different temperatures, and then the $ln\rho$ vs 1/T was plotted to get the relation between the variation of resistivity concerning temperature.

The resistivity was calculated from the following relation;

$$\rho = \frac{V}{I}\frac{\pi t}{\ln 2} \quad (1)$$

Where V is voltage, I is current, and t is the thickness of the Ge chip, which was around 0.05cm (Albers and Berkowitz 1985; Waremra and Betaubun 2018).

UV-Visible spectroscopy was carried out to determine the band gap of ZnO-Nanorads. A ZnO-NRs synthesized thin film deposited on the FTO substrate was utilized as the sample. The absorption spectra were recorded in the range of (200-800) nm. X-ray diffraction spectroscopy and scanning electron microscopy were applied to know the presence of ZnO nanorods on the substrate and their morphology of them, respectively.

3. Result and Discussion

3.1 Bandgap of Ge Crystal

To determine the band gap of Ge, the variation of voltage concerning temperature was recorded at a constant current ($\sim 2\ mA$). From this data: the resistivity of Ge was calculated at any obtained voltage and corresponding temperatures (table 1). The obtained result indicates that; the resistivity of Ge decreases with increasing temperature remarkably. As seen in the table, the resistivity is around $8.882\ \Omega.cm$ at 310 K, while it varies to $1.011\ \Omega.cm$ at 420K. It means; the conductivity has increased with the increasing of temperature since the conductivity and resistivity are proportional indirectly together.

Table 1: the variation of voltage concerning temperature and corresponding calculated resistivity at (2 mA)

T (K)	**V (mv)**	$\mathbf{1/T(\times 10^{-3})}$ **(K^{-1})**	$\boldsymbol{\rho(\Omega.cm)}$	**Ln ρ**
305	195	3.279	22.084	3.095
315	192.3	3.175	21.778	3.081
325	187	3.077	21.178	3.053
335	176	2.985	19.932	2.992
345	154	2.899	17.441	2.859
355	128	2.817	14.496	2.674
365	106	2.74	12.005	2.485
375	85	2.667	9.626	2.264
385	64	2.597	7.248	1.981
395	50	2.532	5.663	1.734
405	39	2.469	4.417	1.485
415	32	2.41	3.624	1.288
420	28	2.381	3.171	1.154

The relation between resistivity ρ and the bandgap energy (E_g) of a semiconductor is given as follows;

$$\rho = \rho_0 \exp\left(\frac{E_g}{2K_B T}\right) \tag{2}$$

Where ρ_0 is the resistivity at room temperature, E_g is the bandgap, K_B is the Boltzmann constant, and T is the absolute temperature. Hence, after applying the logarithm on both sides of the equation, we get the following;

$$\ln \rho = \ln \rho_0 + \frac{E_g}{2K_B T} \tag{3}$$

To calculate the bandgap of energy (E_g); $\ln \rho$ was plotted versus T^{-1} using origin_project_software, and then the linear part; was fitted to get the slope of the curve.

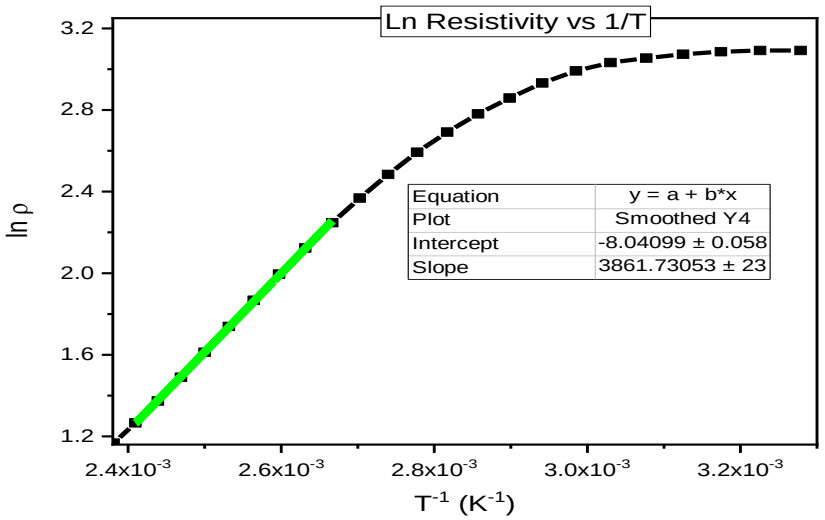

Figure 3. The plot of the resistivity logs versus the inverse of temperature for the Ge.

As it is seen, the curve is linear up to 360K since the conduction is due to electron transitions from the valence band to the conduction band (and corresponding holes) in this region.

The slope of the curve is around 3864, and hence, the energy of the bandgap for the Ge can be calculated as:

$$E_g = 2K_B T \ln \rho = 2K_B \times Slope = 0.67\ eV$$

The Boltzmann constant in the above equation is $8.617 \times 10^{-5}\ eV\ K^{-1}$. According to the other research, the band gap of Ge was reported to be $\sim 0.7 eV$, which is almost the same as this calculation.

3.2 Bandgap of ZnO-Nanorods

To reveal the surface morphology and the crystal structure of the ZnO film, SEM and XRD spectroscopy were applied (Marlinda et al. 2019). The SEM image illustrates that the morphology of the sample is nanorods, and the XRD pattern exhibits that the ZnO nanoparticles are present on the substrate (figure 2). The substrate corresponding peaks are marked with asterisks, and the ZnOs with plane symbols. The diffraction peaks at 31.78°, 34.4°, 36.3°, 47.52° (2θ)_angles corresponding to (100), (002), (101), and (102) planes express the ZnO particle's existence on the substrate (JCPDS file no 36-1451) (Sharma et al. 2016).

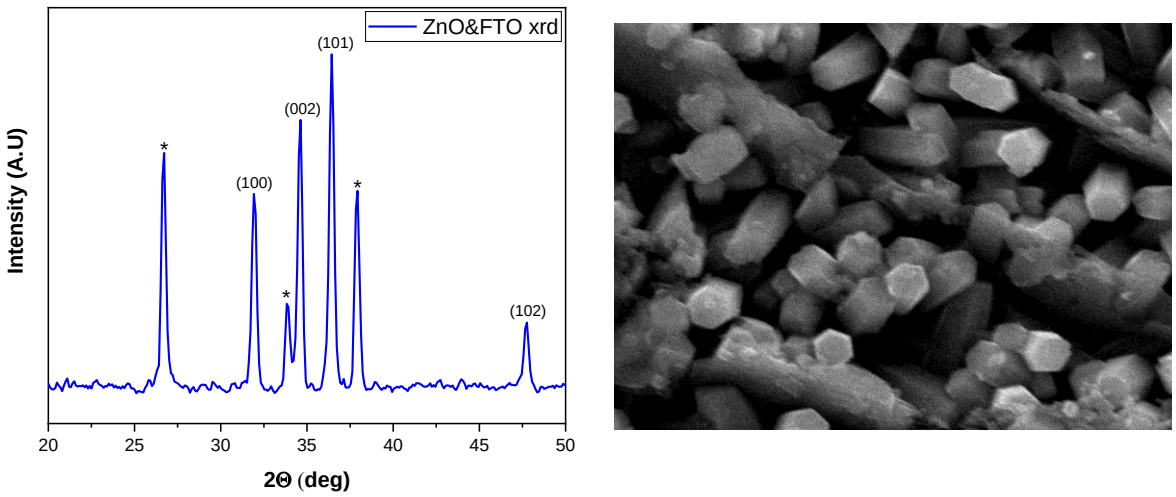

Figure 4. (a) The SEM image of the sample. (b) XRD pattern of the sample.

To determine the bandgap of ZnO-NRs, the absorption spectra of the sample were recorded (Kumari et al. 2015).

Figure 3; shows the absorption spectra of the ZnO-NRs.

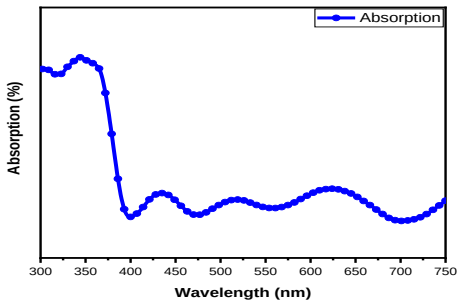

Figure 5. The absorption spectra for the ZnO thin film.

To get the bandgap of the material, the tau plot was described (Kumari et al. 2015).To convert the wavelength scale into an energy scale, the following relation was used;

$$E = \frac{hc}{\lambda} \qquad (*)$$

Where; h is the Plank constant, c is the speed of light, and λ is the wavelength of the rays. Figure (6) describes the corresponding tau plot. To define the bandgap, the tangent of the plotted graph is taken where the intersection with the energy axis gives the bandgap of the material.

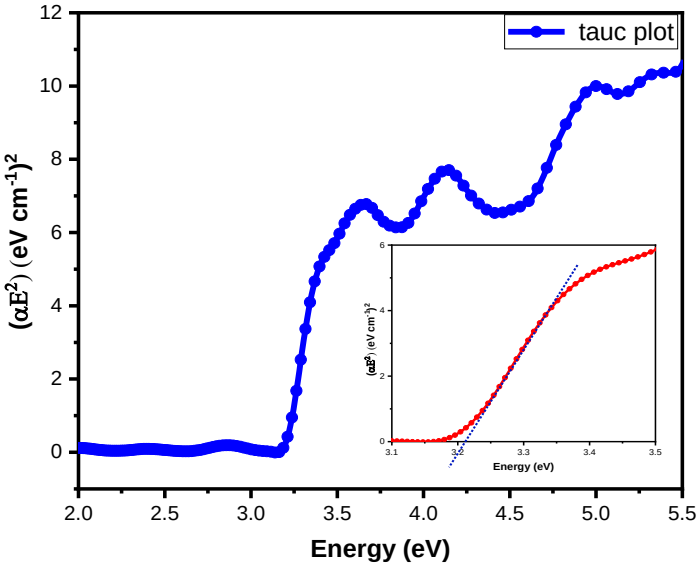

Figure 6. The taut plot for the ZnO thin film.

It is observable that the absorption has started from the point; in which the intersection is around 3.23 eV. It means; the absorption has occurred from those photons whose energies are equal to or greater than 3.23 eV, and this value determines the band gap of ZnO (Johar et al. 2015; Tsai et al. 2020).

4. Conclusion

The band gap of ZnO and Ge were compared in this study. A huge amount of absorption was observed for the wavelengths less than 380 nm for the ZnO material. Based on this absorption edge, the band gap of ZnO was determined to be around 3.23 eV. For the Ge, the logarithm of the resistivity exhibited a linear relation with the inverse of Temperature for Temperatures greater than 360K. By using the slope of this part of the curve, the bandgap of Ge was estimated to be 0.67 eV. It indicates that; compound semiconductors can have a large bandgap as compared to elemental semiconductors. Hence, it is possible to modify the different types of compound semiconductors to get better optical properties.

4.1 Highlights

1. A chip of Ge and a ZnO synthesized Nanorods on the FTO substrate were utilized as the samples.
2. The UV-Visible absorption spectra and four probe methods are two different techniques that are suitable for the determination of bandgaps of materials.
3. It revealed that the bandgap of compound semiconductors (ZnO- NRs) could be sufficiently large as compared to the elemental semiconductors (Ge), and through that, the modification of various devices is possible in the industry.

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