Behavior of A.C conductivity and Complex dielectric constant of ZnS Thin Films

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Abstract

The effect of temperature on dielectric properties of the prepared ZnS thin films by chemical bath deposition at film thickness (200) nm deposited at substrate temperature 333 K, was measured at frequency range (0.04-10 MHz) in the temperature range (298- 473) K . The temperature – dependent of electrical conductivity, the real and imaginary parts of the complex dielectric constant are calculated at the selected frequencies. The frequency exponent n, and the activation energy, Ea, are determined. The a.c. conduction mechanism of ZnS films has been explained on the basis of hopping of charge carriers

Keywords: ZnS, Thin Films, Thermal evaporation

سلوك التوصيلية الكهربائية AC وثابت العزل الكهربائي للاغشية لكبريتيد الخارصين الرقيقةZnS

الخلاصه:

تأثير درجة الحرارة على خصائص العازلة للكهربائية للأغشية الرقيقة ZnS المرسبة بطريقة الترسيب الحمام الكيميائي لغشاء ذات سماكة (200) نانومتر ومرسب على ركيزة في درجة حرارة K 333، تم القياس في مدى التردد (0،04 حتي 10 ميغاهيرتز) في نطاق درجات الحرارة (298- 473) K. تم حساب درجة الحرارة -المعتمدة على التوصيلية الكهربائية، والأجزاء حقيقية والخيالية لثابت العزل الكهربائي المعقد في ترددات محددة. كما وتم تحديد مركبة التردد، وطاقة التنشيط. تم توضيح ميكانكية التوصيل الكهربائي المتناوب للاغشية الرقيقة على أساس التنقل من حاملات الشحنة.

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INTRODUCTION

Dielectric films play an integral role in nearly every semiconductor device and integrated circuit. ZnS is one of the important II-VI compound semiconducting materials which have potential applications in a variety of solid – state devices such as solar cells, photoluminescence, photodetectors, and light emitting diodes [1]. It has a direct band gap of 3.6 eV at room temperature and has a mixture of cubic and hexagonal structure depending on preparation condition. ZnS has been investigated for its uses as visible light – emitting semiconductor laser [2,3]. It has been extensively studied for application as window layer for CdTe in CdTe/Cds and CdTe/GaAs heterojunction solar cells [4]. Semiconducting thin films have been extensively studied for a long time because of their high technical value. In recent years, owing to a number of practical applications in the field of micro-electronics and opto-electronics a great deal of interest has been shown in the study of the conduction and dielectric behavior of various semiconducting materials [5]. Most of the experimental work were carried out so far relates to a.c. measurements which give information about the nature of transport models. Studies on space charge and thermally stimulated currents in ZnS thin films have been carried out by J. Singh [6]. Also ZnS thin films have been studied by J. Borah and he applied this aspect for optoelectronic devices [7]. The aim of the present work is to study the behavior of ZnS thin films in a.c field.

Experimental Details

ZnS thin films have been deposited on glass substrate using chemical bath deposition. The used substrates for deposition are commercial glass slides of 76 mm x 25 mm used, were cleaned in propane, ethanol and methanol ultrasonically, then etched in 5 % HF solution and finally, again washed with methanol ultrasonically. The glass slides were immersed vertically in two beakers, one beaker contained 0.2 M Zn(NO3)2 aqueous solution and another contained 0.2 M Na2S.5H2O. The temperature of deposition process was 333 K and the duration of deposition varied between 15-25 minutes. All of the solutions, which were used in deposition, were clear solutions without precipitation. The bath solution was held still without stirring. Such an immersion cycle was repeated five times respectively. After the deposition, ZnS films were washed with methanol ultrasonically to remove the loosely adhered ZnS particles on the film and finally dried in air. The crystallographic structure of the films was analyzed with a (XPERT-PRO) X-ray diffractometer using Cu-Kα radiation with wavelength, 1.5418 A. The thickness of film was measured by the weight difference method at room temperature and by the Michelson interferometer (200 nm). For a.c. measurements, films were sandwiched between two electrodes and a programmable automatic LCR bridge (PM 60304 Philips) to measure the sample conductance G and the capacitance C directly . The total conductivity was calculated from the equation [8]:

$$\sigma_{tot}(\omega) = (d/A)G \qquad \ldots(1)$$

where d is the thickness of the sample, ω is the angular frequency and A is the cross sectional area . The real part of complex dielectric constant ε_1 was calculated from the equation:

$\varepsilon_1 = C/C_o$ ...(2)

where C_o is the geometrical capacitance of the sample ($Co = \varepsilon_o A/d$, where ε_o is the permittivity of free space). The dielectric loss ε_2 was calculated from the equation:

$\epsilon_2 = G/ \omega C_o$. ...
(3)

The measurements were carried out through the temperature range (298 – 473) K and frequency range (0.04–10) MHz. .

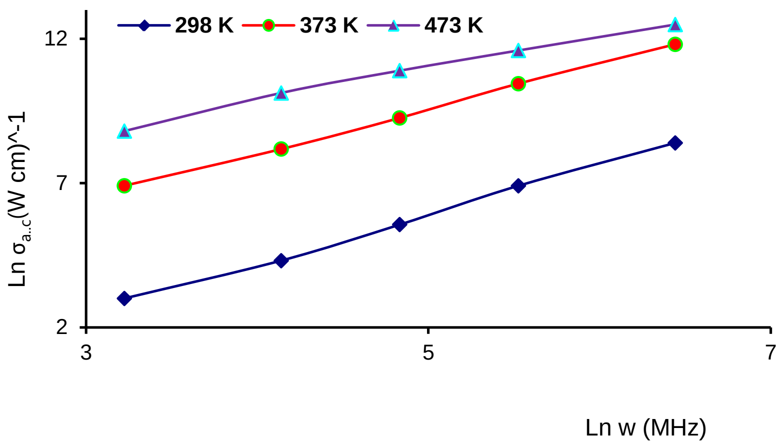
Results and Discussion

A.C conductivity

A.C. electrical conductivity $\sigma_{a.c}(\omega)$ varies with the frequency according to the equation [8] :

$\sigma_{a.c}(\omega) = \sigma_{tot.}(\omega) - \sigma_{d.c} = B\omega^s$ ....
(4)

Where
ω is the angular frequency ($\omega = 2\pi f$) , $\sigma_{tot.}(\omega)$ is the total electrical conductivity , $\sigma_{d.c}$ is the d.c electrical conductivity , (s) is the frequency exponent and B is a constant dependent on temperature .
Fig. 1shows the frequency dependent of $\ln\sigma_{a.c}(\omega)$ for ZnS thin films at thickness 200 nm at different temperatures .It is clear from the figure that $\sigma_{a.c}(\omega)$ increases linearly with the increase of frequency for all selected temperatures. Values of the frequency exponent (s) were calculated for all the investigated films from the slopes of the linear lines of $\ln\sigma_{a.c}(\omega)$. It is observed that the frequency is found to have a high effect on conductivity at relatively lower temperatures. The temperature dependence of the values of (s) for the films is shown in Fig. 2. It is seen that s decreases exponentially as the temperature increases.



Figure(1). Frequency dependence of the electrical conductivity $\sigma_{a.c}$ for ZnS thin films

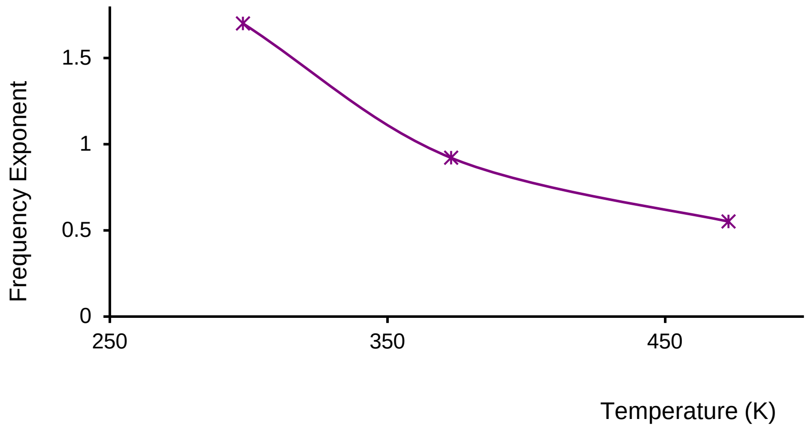
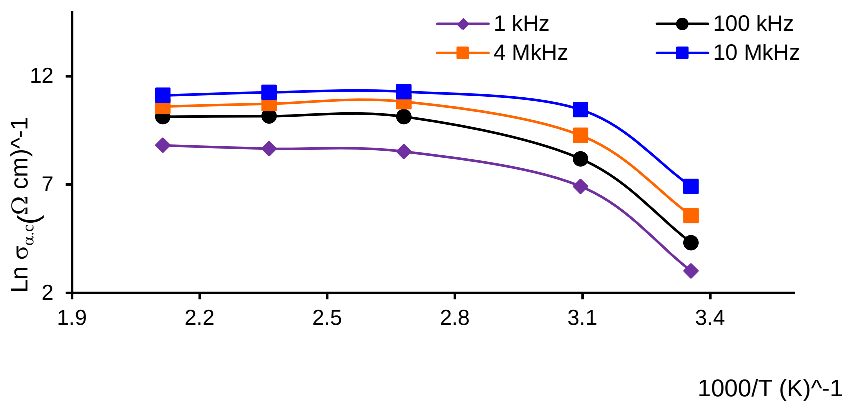


Figure (2) Temperature dependence of the frequency exponent for ZnS films

The obtained values of (s) ranged from 0.55 to 1.7 and have a tendency to decrease with the increase of temperature. This means that the obtained experimental results agree with the correlated barrier hoping model CBH. According to this model, a.c conductivity $\sigma_{a.c}(\omega)$ can be explained in terms of hoping the electrons between pairs of localized states at the Fermi level [9] .

Temperature dependence of the a.c conductivity $\sigma_{a.c}(\omega)$ at different frequencies was studied for the investigated films . Fig. 3 shows a plot of $\ln\sigma_{a.c}(\omega)$ against the reciprocal of absolute temperature 1000/T for films at thickness 200 nm .



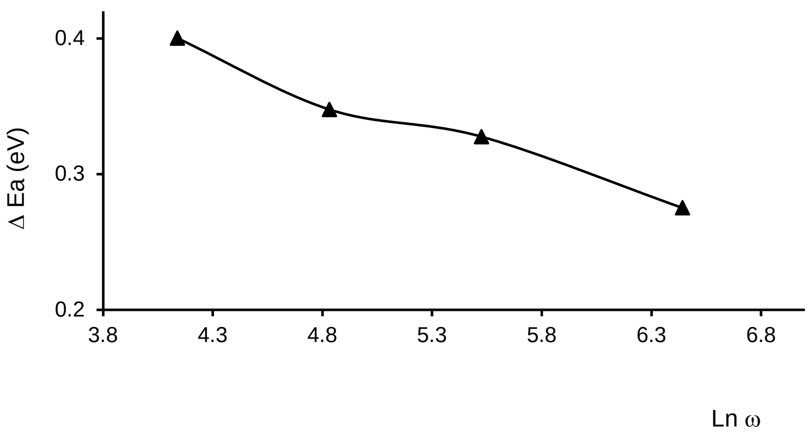
Figure(3) Temperature dependence of the a.c electrical conductivity $\sigma_{a.c}$ for ZnS films

It is clear from Fig. 3, that ln$\sigma_{a.c}(\omega)$ increases with temperature in the region from 298 K to 373 K but at high temperatures, from 373 K t0 423 K, the relation is approximately constant and this behavior is the same for all selected frequencies . This suggested that the a.c conductivity is a thermally activated process from different localized states in the gap or within extended states at lower temperatures but at high temperatures is due to traps after the carriers activate. The activation energy of conduction, $\Delta E_a(\omega)$, is calculated at different frequencies from the slopes of the straight lines of Fig. 3 at lower temperatures using the well known equation [10,11] :

$$\sigma = \sigma_o \exp(-\Delta E_a(\omega)/K_B T) \quad \ldots(5)$$

Where

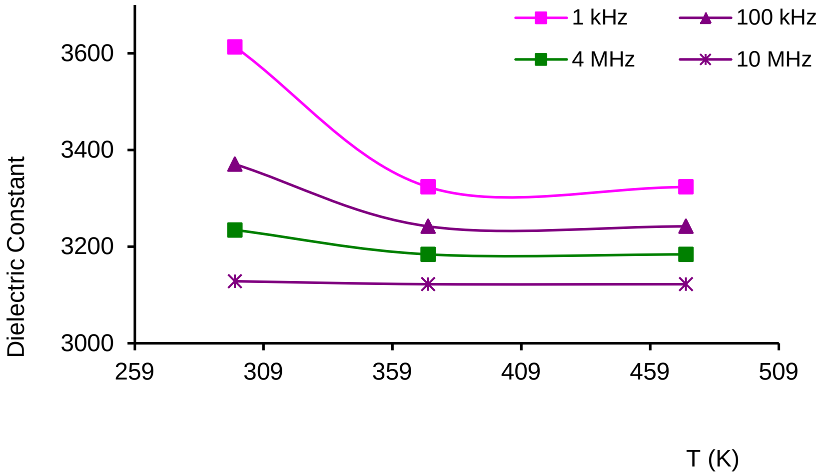
σ_o is constant, K_B is Boltzmann constant and T is the absolute temperature. The frequency dependence of the activation energy for such films is shown in Fig. 4. It is clear that $\Delta E_a(\omega)$ decreases with the increase of frequency which is due to the electronic hoping between the localized states. The smaller values of the a.c activation energy and the increase of $\sigma_{a.c}$ with the increase of frequency confirm the hopping conduction to be the dominant mechanism [12,13].



Figure(4) Frequency dependence of the a.c activation energy $\Delta E_a(\omega)$for ZnS films

Dielectric Constant and Dielectric Loss

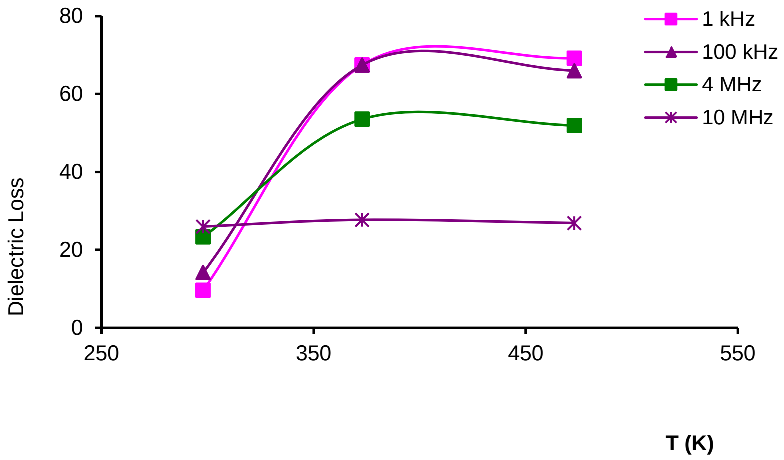
Fig. 5 shows the temperature dependence of the dielectric constant ε_1 at selected frequencies. From the figure, ε_1 decreases with the increase of temperature, (298-373) K at frequency range (0.001- 4) MHz. At 10 MHz, ε_1 is approximately constant with the increase of temperature. This decrease can be attributed to the fact that at low frequencies ε_1 for polycrystalline materials is due to the contribution of multi-component of polarization mechanisms (electronic ,ionic , orientation , and interfacial) for grains and grain boundaries[14,15] .



Figure(5) Frequency dependence of the dielectric constant ε_1 for ZnS films

When the frequency is increased the dipole can not rotate sufficiently rapidly, so that their oscillations lag behind those of the field. As the frequency is further raised the dipole will be completely unable to follow the field and the orientation polarization ceases, so ε_1 decreases approaching a constant value at high frequencies due to the interfacial polarization only [14].

Fig. 6 shows the temperature dependence of the dielectric loss ε_2 for ZnS films. At low temperature, (298-373) K, ε_2 increases with the increase of temperature. The loss is attributed to hopping of electrons over large distances or barriers between grains and boundary grains. As the electron moves, they give some of their energy to the lattice as heat and the amount of heat lost per cycle is proportional to $\sigma_{a.c}(\omega)$. However, at higher temperatures, (373-473) K, the dielectric loss ε_2 is approximately constant which is due to interfacial hoping as mentioned before [16].



Figure(6) Frequency dependence of the dielectric loss for ZnS films

Conclusion

ZnS thin films were prepared by chemical bath deposition. From the results the a.c conductivity increases within the temperature range (298 and 373) K but is approximately constant at higher temperatures (373 and 473) K. The frequency exponent decreases with the increase of temperature. The activation energy decreases exponentially with the increase of temperature. The dielectric constant decreases at low temperatures for selected frequencies but at high temperatures it is approximately constant. The dielectric loss increases with the increase of temperatures. The a.c. conduction mechanism of ZnS films has been explained on the basis of hopping of charge carriers.

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