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# The Electrical Properties Dependence on the Annealing of Flashed GaAs Films

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**Abstract:** GaAs films have prepared by flash evaporation technique on glass substrate with thickness of about 1μm and substrate temperature of about 373 K under vacuum of about $10^{-5}$ mbar. The prepared films have been annealed at different annealing temperatures 423, 473, 523, 573 K. The structures of GaAs films have been studied by X-Ray diffraction technique and show a polycrystalline structure of cubic phase with strong oriented at (111) direction, the annealing process enhance the structural improvement. The prepared films have two activation energies, which increased with increasing the annealing temperature. The electrical D.C. conductivity decreased with increasing the annealing temperature. Hall Effect showed that all prepared films are n-type, Hall mobility increased after annealing. The carriers concentrations decrease from $7.79\times10^{14}$cm$^{-3}$ to $3\times10^{14}$cm$^{-3}$. The carrier's life times increased after annealing. The correlated barrier hopping model is the most consistent mechanism to describe the σ (ω) behavior of GaAs films.

**Keywords:**GaAs films, Flash evaporation, D.C. Conductivity, Hall Effect, A.C Conductivity

## 1. INTRODUCTION

The gallium arsenide (GaAs) has found the widest use, owing to their highly developed technology. The GaAs is the material of the future and will always remain so" reflects the current status of GaAs among semiconductors [1]. III-V semiconductors are commonly used in the fabrication of optoelectronic devices, e.g. the laser and light emitting diode as used for CD and DVD drives. GaAs is also of interest for high frequency applications [2]. Its electron effective mass is only 1/16 of that of Si, consequently with higher mobility of electrons. This makes GaAs a prospective candidate for the production of future integrated circuits despite its technologically more elaborate processing [3]. One of the big attractions of III-V compounds is that, generally, they crystallize with a high degree of stoichiometry and crystals may now be grown in variety ways, an interesting feature of III-V compounds is relationship between band gap and composition which gives device designer. These compounds have direct transitions, the absorption coefficient rises steeply at the band edge to values of $10^4$ cm$^{-1}$ or more [4]. The III-V compounds have their conduction and valence band at the center of the Brillion zone, so that the lowest energy transition between the bands is vertical, this results in high optical transition probabilities, giving high absorption coefficients near the edge, All III-V compounds have high refractive indices, which generally, lying within the range of three to four [5]. In this paper, GaAs films have been prepared by flash evaporation technique. The main task of this study is a search for studying the effect of annealing temperatures on the structural properties of the prepared GaAs films and on the electrical properties of the prepared films by D.C. Conductivity, Hall Effect and A.C conductivity.

## 2. EXPERIMENTAL WORKS

Corning glass slides number 7059 were used as substrates which cleaned by deionized water into ultrasonic vessel for 15 minutes, then for the same period in pure alcohol []. Al used as ohmic contact electrode with 0.25μm thick to study the electrical characteristics of GaAs, which prepared by thermal evaporation technique the suitable configuration of electrodes for each test are illustrated in figure 1. The Edward E306A coating system was used for this purpose, under low pressure of $10^{-5}$ mbar. Flash evaporation technique is generally used for deposition of the GaAs compound, since the material is evaporated quickly; the decomposition of the compound is minimized [6]. In this method the components of the compound in spite of the difference between their vapor pressures but they do not separate through the evaporation process, GaAs alloy with 99.999% purity crushed into very small grains (powder), this powder is dropped into a heated boat from the feed passing through a guide funnel by manual vibrating handmade system. Thickness of the prepared films was measured by the weighting method which gives an approximate thickness (t) and it is determined by the following relation [6]:

$$t = m/2\pi\rho r^2 \quad (1)$$

Where m and ρ are the material mass and density respectively, r is the distance between the substrate and the Molybdenum boat (source) which was maintained at 20 cm. The thickness of the GaAs films was about 1000±50 nm with deposition rate was about 75nm/second. The substrate temperature was 373K which obtained by a tungsten heater and measured by thermometer with thermocouple type K. The prepared GaAs films annealed in vacuum of 30 mbar for 2 hours in the temperature range of 423-573 K. The structural analyses have done by Phillips PW3710 X raydiffractometer with Cu $K_\alpha$ target of 1.5405Å wavelength, 25 mA current and 40 kV voltages The d.c conductivity measures the resistance (R) of the films with sensitive digital electrometer type Keithley 616 as a function of absolute temperature (T) of the films which heated by electrical oven. The conductivity ($\sigma_{d.c}$) of the films was determined from the relation [7]

$$\sigma_{d.c} = t/\omega r\ell \quad (2)$$

Where $w$ is the width of the electrode and ℓ is the distance between the electrodes of the sample. The activation energy ($E_a$) can be calculated from the following equation [7]:

$$E_a = (1lk_B T)/(\ln(\sigma/\sigma_\circ) \quad (3)$$

Where $\sigma_0$ is the intrinsic conductivity and $K_B$ is Boltzmann constant. Then the activation energy can be calculated from the plot between $\ln\sigma/\sigma_\circ$ as a function of $10^3/T$. In order to study Hall Effect, the prepared films placed inside magnetic field $\vec{B}$ (≈ 0.257 Tesla), then Hall voltage ($V_H$) and the current (I) measured using electrometer type Keithley 616. From the plot of $V_H$ versus I, it can be calculated Hall coefficient ($R_H$) and other parameter such as carrier type, carrier concentration ($n_H$), Hall mobility ($\mu_H$) and the carriers life time ($\tau_p$) from the following equations [8]

$$R_H = tV_H/\vec{B}I \quad (4)$$

$$n_H = 1/R_H q \quad (5)$$

$$\mu_H = |R_H|\sigma_{d.c} \quad (6)$$

$$\tau_P = m_h^*/n_H e^2 \quad (7)$$

Where q is the electron charge and $m_h^*$ is the holes effective mass for p-types semiconductors. Where $m_e^*$ is the electrons effective mass for n-types semiconductors. s is a function of frequency and is determined from the following equation [9, 10].

$$s = [d\ln\sigma_{a.c}(\omega)/d\ln(\omega)] \quad (8)$$

Where $\sigma_{A.C}$ (ω) is the A.C conductivity and ω is angular frequency. s is a function of frequency and is determined from the slope of a plot $\mathrm{Ln}\sigma_{A.C}$ (ω) versus Ln (ω), because of the presence of logarithmic term then s is not constant but decreases with increasing the annealing temperature usually 0 < s <1 and approaching unity at low temperature and decreasing to 0.5 or less at high temperature [11],and the exponent s is given by:

$$s = 1 - [6k_B T/W_m] \quad (9)$$

Where $W_m$ is the energy required to take two electrons from D site into conduction band and equal to optical gap [12, 10].

## 3. RESULTS AND DISCUSSION

### *3.1 Structural Study*

X-ray diffraction spectra of as deposited and annealed GaAs films at different annealing temperature have illustrated in figure 2. It can be observed that all prepared films were polycrystalline structure.

Strong peaks appeared in the structure of films at (111), (011), (220), (311) and (222) planes reflected corresponding to Bragg's angles at 27.24°, 38.9°, 45.3°, 53.3° and 56.4° respectively which coincide exactly with that of the ASTM cards. Gallium peaks have been appeared in XRD spectra, these peaks due to Ga more active than As in interacting with $O_2$,Aguir et al [13] found that a-GaAs films contain a gallium and gallium clusters which may be due to the influence of the substrate temperature because it was not uniform [14]. (200) plane has been appeared after annealing corresponding to Bragg's angles at 31.8°. Structural improvements have been observed after annealing represented by increasing the intensities of the peaks and decreasing of full width of high maximum intensity (FHWM). Similar results have been found by Gheorghuio and Theye [14] and Al Haddad et al [15].

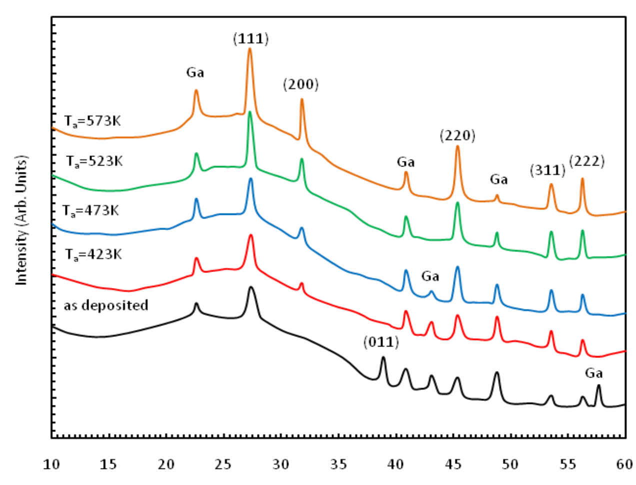


*Figure 2 XRD spectra for as deposited and annealed GaAs films at different annealing temperatures.*

### *3.2 Electrical investigation*

#### *3.2.1 D.C Conductivity*

Figure 3 illustrates the plot of lnσ versus $10^3/T$ which is study the dependence of D.C. conductivity for the as-deposited and annealed films in the range 303 to

523 K. It is almost characterized by two stages of conductivity through the whole temperature range.

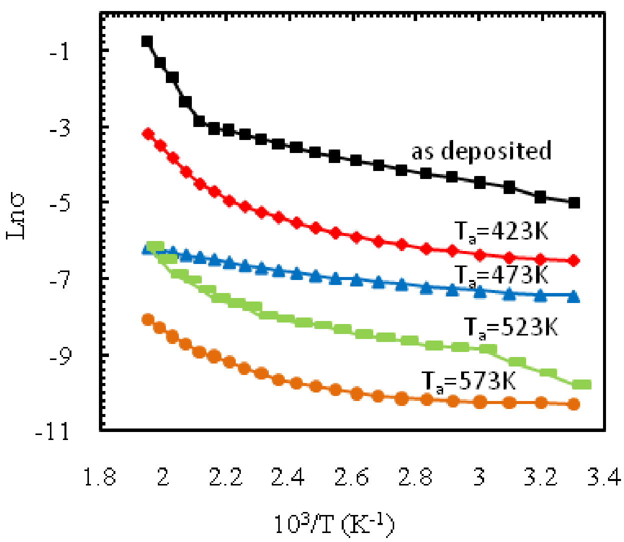


Figure 3 lnσ versus $10^3$/T for 1 μm as deposited GaAs films with substrate temperature 373 K and annealed at different annealing temperatures.

The first activation energy ($E_{a1}$) occurs at higher temperature range 513 to 473 K, the conduction mechanism of this stage is due to carrier excited into the extended states beyond the mobility edge, but the second activation energy ($E_{a2}$) occurs at lower temperature range 473 to 303 K, the conduction mechanism is due to carrier excited into localized states at the edge of the band [16]. Table 1 shows the values of the d.c conductivity and activation energies. From this table we can observe that the conductivity decrease with increasing the annealing temperatures.

Table 1 Thed.c conductivity and activation energies of 1 μm as deposited GaAs films with substrate temperature 373 K and annealed at different annealing temperatures.

| $T_a$ (K) | $\sigma_{RT}\times10^{-4}$ $(\Omega.cm)^{-1}$ | $E_{a1}$ (eV) | Temperature Range(K) | $E_{a2}$ (eV) | Temperature Range (K) |
|---|---|---|---|---|---|
| 300 | 67.67 | 0.503 | 473-513 | 0.055 | 303-463 |
| 423 | 14.85 | 0.523 | 423-513 | 0.075 | 303-413 |
| 473 | 5.87 | 0.542 | 463-513 | 0.081 | 303-453 |
| 523 | 0.568 | 0.553 | 423-513 | 0.105 | 303-413 |
| 573 | 0.34 | 0.594 | 483-513 | 0.114 | 303-473 |

This increasing of activation energy may be due to rearrangement of atoms in GaAs sites which may occur during annealing, this produce an irreversible process in the conductivity [14].
Table 1 shows the variation of conductivity measured at room temperature versus annealing temperature.
Generally the conductivity is found to decrease with increasing the annealing temperature.

### 3.2.2 *Hall Effect*

Table 2 shows the parameters of Hall effect for the as deposited and annealed GaAs films. Hall measurements showed that all prepared GaAs films are n-type, the dominate conduction is by electrons. This result is similar to Yamasheta [17], and this is obviously due to the presence of arsenide vacancies sites form shallow donor's level [17]. Table 2 shows that Hall mobility increased with increasing the annealing temperature. The carrier concentration and carrier life decreased with increasing the annealing temperature, these results coincide with that of Al-Haddad [18]. This may be due to either increasing the trapping centers of charge carriers by annealing [18].

Table 2 Hall mobility, carrier concentrations and carrier life times for 1 μm and as deposited and annealed GaAs films at different annealing temperatures.

| Annealing temperature (K) | $\mu_H$ (cm/v.s) | $n_H\times10^{14}$ $(cm)^{-1}$ | τ (ns) |
|---|---|---|---|
| As deposited | 0.012 | 7.79 | 20.7 |
| 423 | 0.068 | 6.15 | 5.75 |
| 473 | 0.222 | 4.79 | 2.92 |
| 523 | 3.431 | 3.21 | 0.42 |
| 573 | 6.123 | 3.00 | 0.27 |

### 3.3 *A.C. conductivity*

The behavior A.C. conductivity with the frequency for as deposited and annealed GaAs films has been shown in figure 2. One can observe that the A.C. conductivity increases with increasing the frequency for all films. In this case the conductivity is proportional to $\omega^s$ which means that the total conductivity ($\sigma_{tot}$) dominates at higher frequency within the range $10^4$ to $10^6$ Hz, but for lower frequency in the range (100-4000) Hz, $\sigma_{tot}(\omega)$ becomes less dependence on frequency because D.C. conductivity component dominates in this range of frequency and becomes difficult to measure A.C. conductivity component.

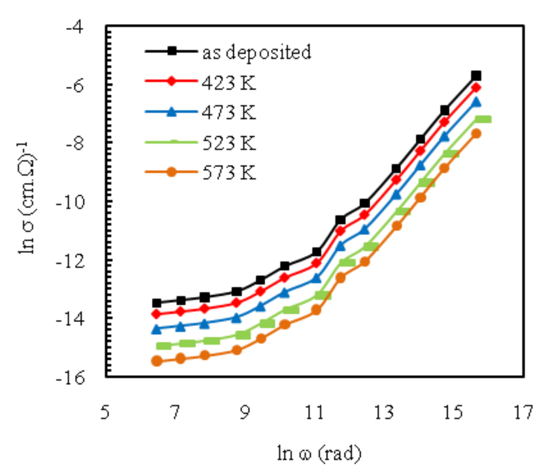


Figure 4 A.C. conductivity vs. angular frequency as deposited and annealed GaAs films.

The slope of plotting between the A.C. conductivity and the frequency determines the exponent s. We note that the value of s decrease with increasing of annealing temperature as shown in table 2, it can be found that the value of s decreases from 0.8513 to 0.6744 by increasing the annealing temperature increasing. In general, such behavior is inconsistent with the quantum mechanical tunneling (QMT) model which predicts s is independent on temperature [12], and a model involving (QMT) of large polaron can also be shown to be inconsistent with the present data. So that we suggested that the correlated barrier hopping (CBH) model given by Elliot [9] as the most consistent mechanism to describe the σ(ω) behavior of GaAs films, from which the transport mechanism of Electrons is by hopping and the conductivity occurs between two sites over the potential barrier separating between $D^+$ $D^-$ defects centers in the band gap. The variation of σ(ω) as a function of the inverse of temperature ($10^3$/T) for flash evaporated GaAs films under the frequencies $10^4$, $10^5$, $10^6$ Hz is shown in figure 4. It have seen that there is a weak temperature dependence of $\sigma_{a.c}$ at low temperature within the range 300 to 420 K which is characterized by low activation energy $E_{w2}$ due to electronic conduction, and at higher temperature within the range 440 to 540 K, we can observe that the conductivity increases more rapidly and is characterized by high activation energy $E_{w1}$ due to thermal activation (ionic conduction).

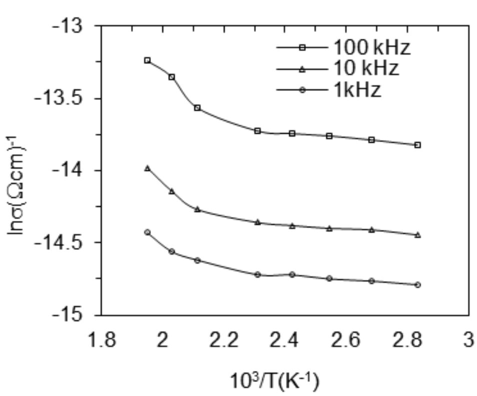


Figure 6 A.C. conductivity dependence on Temperature deposited and annealed GaAs films.

It can recognize again the only model which dominates the conduction mechanism in our data is (CBH) model. The values of activation energies tabulated in Table 1.

Table 3 The values of $E_{w1}$ and $E_{w2}$ at a given frequencies for GaAs films

| ω(Hz) | $E_{w1}$ (eV) | $E_{w2}$(eV) |
|---|---|---|
| $10^3$ | 0.3955 | 0.0155 |
| $10^4$ | 0.346 | 0.0134 |
| $10^5$ | 0.2248 | 0.0118 |

## 4 CONCLUSIONS

The prepared GaAs films are polycrystalline structure. The d.c conductivity decreased with increasing the annealing temperature. The activation energy values increase with increasing the annealing temperature. The as deposited and annealed films are n-type. Hall mobility increased with increasing the annealing temperature accompanied with decreasing the carrier concentrations.The prepared GaAs films are polycrystalline structure. The correlated barrier hopping (CBH) model is the most consistent mechanism to describe the σ (ω) behavior of GaAs films.

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