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Growth of Ga_xAs_{1-x} Alloy and Characterized the Structural and Electrical Properties of Flashed Thin Films

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Abstract: Gallium Arsenide alloy has been grown successfully by single zone computerized furnace. The grown alloy have been crushed and deposited on glass substrate by flash evaporation technique with substrate temperature of 473 K, the film thickness was about 340 nm, the films annealed at 573 K for different duration times of annealing in the range of 60, 120 and 180 minutes. The experimental percentage concentrations of Gallium and Arsine are 0.48 and 0.52 respectively. X-ray diffraction spectra show that the as deposited film was amorphous. Amorphous film has the highest value of activation energy and the electrical conductivity, which they decreased after increasing duration times of annealing. Thermoelectric power measurements show that all prepared films are n-type. Thermal energy has decreased by increasing the duration times of annealing. The smallest value achieved by amorphous film. The hopping energy increased by increasing the duration times of annealing and the highest value has achieved by amorphous film.

Keywords: Ga_xAs_{1-x} Alloy, Thin Films, Structural Properties, electrical Conductivity, Thermoelectric Power.

1. Introduction

Amorphous III-V compound semiconductors can be obtained in the form of thin films by various methods: vacuum evaporation, cathode sputtering, plasma decomposition …etc. [1]. The affected of the preparation conditions, in particular the substrate temperature, necessary for the deposition of amorphous III-V materials [2, 3]. The conductivity of the amorphous materials is rather intensive to the presence of impurities because of the valence requirements of the impurity atoms are locally satisfied in non-crystalline material [4]. Also preparation conditions play an important role in determining the electrical properties of amorphous Gallium Arsenide (GaAs) [5]. In spite of the efforts to control crystal growth, technically it's impossible to produced GaAs with an impurity concentration lower than 1014 cm-3, because there is no perfect semiconductor material, [6]. III-V semiconductors are commonly used in the fabrication of electronic and optoelectronic devices such as laser, light emitting diode, integrated circuits, light detection, solar energy conversion purposes and for high frequency devices [7, 8]. This paper described a new method to preparation of Ga_xAs_{1-x} alloy and characterized its properties. In addition to report the influence of duration times of annealing on structural properties, electrical conductivity and thermoelectric power of flashed thin Ga_xAs_{1-x} films.

2. Experimental work

A new method has been used to prepare Ga_xAs_{1-x} alloy by mixing high purity Gallium (Ga) and Arsine (As) of 99.999% manufacturer by Balzers, Switzerland according to the phase diagram of GaAs. The mass of the elements have been weighted using Metler AE200 digital micro balance. The alloy is grown from a 'seed crystal' that is a perfect crystal, so that, a seed of polycrystalline n-type GaAs mixed in addition to Gallium and Arsine and placed in the bottom of clean and dry tipped quartz tube of 20 cm length, 10 mm diameter and thick wall to solve the problem of vapor pressure of the Arsenide in the mixture and prevent the explosion of tube. Then it has joined to evacuated system (type Edward E306A) by specific design, when the vacuum reached to $2x10^{-5}$ mbar, the quartz tube was sealed by using oxy indene gas. Next the evacuated tube placed in single zone computerized furnace type Heraeui in diagonal direction to ensure molten mixing with the seed inside the tube as illustrated in figure 1. Then the quartz tube heated gradually at rate of 1℃/minute step by step up to 1238K, which it is more than the melt temperature appropriate to the chosen composition. The temperature required for synthesisation was determined from the phase diagram of GaAs, the quartz tube maintained for 200 hour at this temperature. After that the quartz tube cooling gradually at rate of 1℃/minute until it reaches to room temperature. Finally, the alloy is taken by breaking the quartz tube. Ga_xAs_{1-x} films have been prepared from the growth alloy by flash evaporation technique using Edward E306A coating system under a pressure of about 2×10-5mbar. This films deposited on 7059 corning glass slides at substrate temperature about 473K achieved by resistive heater measured by thermometer with K-type thermocouple. The prepared films have been annealed under vacuum by Memert oven at 573K for different duration times of annealing in the range of 60, 120 and180 minutes. The composition of the growth Ga_xAs_{1-x} alloy where determined by Shimadzu 601 instrument atomic absorption spectroscopy. The structural analysis was done by Phillips PW3710 X-Ray diffractometer of 1.5405Å wavelength with CuK_α source radiation, current 20 mA and Voltage 40 KV. The electrical resistance has been measured as a function of the temperature to study the electrical conductivity and thermoelectric power of the films, Aluminum was used as electrodes. Keithley 616 digital electrometer has been used to measure the resistance and voltage for studying the electrical conductivity and thermoelectric power respectively. The temperature gradient was measured by thermocouple type K monitored by digital thermometer.

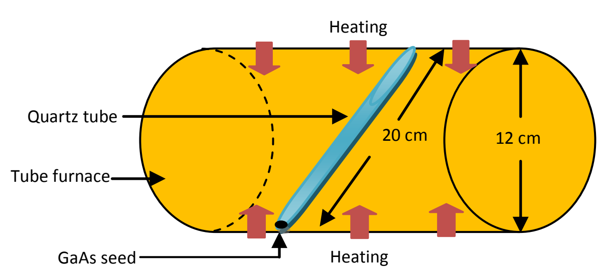

Figure 1: Schematic of the preparation Ga_xAs_{1-x} alloy in the tube furnace.

3. Results and Discussion

3.1 Composition analysis

Atomic absorption spectroscopy (AAS) analysis showed Gallium (Ga) and Arsine (As) concentrations of the Ga_xAs_{1-x} alloy by depending on the atomic absorption of the standard elements of these components. The experimental percentage concentrations of Ga and As are 0.48 and 0.52 respectively.

3.2 Composition analysis

X-ray diffraction spectrum of GaAs seed is shown in figure 2. It can be observed that strong planes of GaAs at (111), (220) and (311) direction, and coincide exactly with that of ASTM.

X-ray diffraction spectra of the deposited films at substrate temperature 473K and annealed at 573K for different duration times of annealing; 60, 120 and 180 minutes are shown in figure 2. From this figure, it can be observed that the as deposited film was amorphous structure. After annealing the films become polycrystalline and have three characteristic diffraction peaks corresponding to ASTM cards at (111), (200) and (100) planes, this attributed to the recrystallization in the lattice similar results has found by Campomanes et al [9]. The film annealed at 573 K for 120 minutes showed new characteristic diffraction peaks corresponding to ASTM cards at (220) planes. Such recrystallization was observed by Al-Haddad et al [10] and Gheorghies and Gheorghies [11].

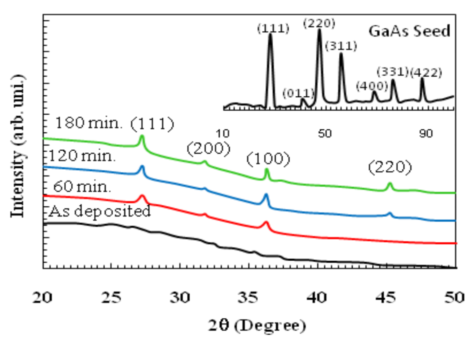

Figure 2: The X-ray diffraction spectra for GaAs seed, as deposited and annealed thin Ga_xAs_{1-x} films at 573 K for 60, 120 and 180 minutes.

3.3 Electrical conductivity

Figure 3 illustrates the conductivity behavior ($\ln\sigma$ versus $10^3/T$) for as deposited and annealed thin Ga_xAs_{1-x} films at 573 K for 60, 120 and 180 minutes. It can be observed from this figure there are two stages of conductivity through the heating temperature range. In this case, the first activation energy (E_{a1}) occurs at higher temperature range (513-373) K. This activation is due to the carrier excited into the extended states beyond the mobility edge, while the second activation energy (E_{a2}) occur at lower temperature range (373-293) K and the conduction mechanism of this stage is due to the carrier transport to the localized states near valence and conduction bands [12]. The activation energy (E_a) can be calculated from the following equation [13]:

$$E_a = \frac{1}{k_B T} \ln\left[\frac{\sigma}{\sigma_\circ}\right] \quad (1)$$

Where σ_o is the intrinsic conductivity and kB is Boltzmann's constant. Then the activation energy can be calculated from the plot between $\ln\sigma$ as a function of $10^3/T$.

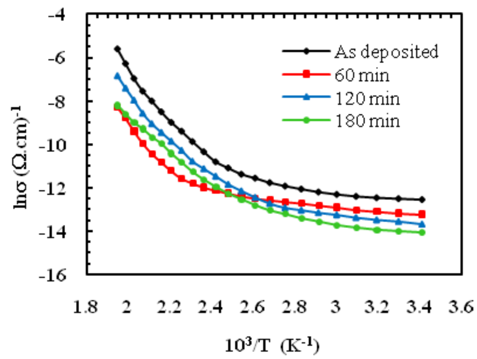

Figure 3: The conductivity behavior (lnσ versus 103/T) for as deposited and annealed thin GaxAs1-x films at 573 K for 60, 120 and 180 minutes.

The as deposited films have the highest values of activation energies. But annealed films have lower values of activation energies than the as deposited film. The value of E_{a1} for the as deposited film is 0.871 eV, and decreased after annealing for 180 minutes to be 0.685eV. E_{a2} slightly fluctuated with increasing the duration times of annealing as given in Table 1. The decreasing of E_{a1} may be attributed to the structural improvement [12]. Similar results have been found by Islam et al [14]. The conductivities of the as deposited and annealed thin Ga_xAs_{1-x} films were found to decrease with increasing duration times of annealing as given in Table 1.

The conductivity of the as deposited thin Ga_xAs1_{-x} films was 3.616×10^{-6} $(\Omega.cm)^{-1}$, which is the highest value and may be attributed to the amorphous structure. The decreasing of the conductivity with increasing the duration times of annealing may be attributed to rearrangement of atoms in Ga_xAs_{1-x} sites by increasing the duration times of annealing [15].

Table 1: The activation energies E_{a1}, E_{a2} and electrical conductivity σ, versus the duration times of annealing t, for as deposited and annealed thin Ga_xAs_{1-x} films.

t (min)	E_{a1} (eV)	E_{a2} (eV)	$\sigma\times10^{-6}$ $(\Omega.cm)^{-1}$
As deposited	0.871	0.113	3.616
60	0.851	0.099	1.795
120	0.718	0.106	1.167
180	0.685	0.133	0.779

3.4 Thermoelectric power

Thermoelectric power is defined by Seebeck coefficient (S) =ΔV/ΔT, where ΔV is Seebeck voltage which depends on the temperature gradient between hot and cold terminal of the samples. Figure 4 shows thermoelectric power as a function of annealing temperature. Negative values of Seebeck coefficient mean that all prepared films are n-type which is the same conductivity type of GaAs seed. The thermal activation energies (E_{th}) can be obtained from the slope of curvatures in figure 4, by using the following relation [16]

$$S = -\frac{k_B}{q}\left[A + \frac{E_{th}}{k_B T}\right] \quad (2)$$

Where E_{th} represents the electron thermal energy of the thermoelectric power, (A $k_B T$) is the average energy of transported electrons measured with respect to conduction band and A is constant depends on the nature of scattering [17]. The variation of thermal energy with duration times of annealing illustrated in figure 5. It can be observed that the thermal activation energy decreased by increasing the duration of annealing. The smallest value achieved by amorphous film. The hopping energy (ΔW), for hopping in band to tail localized state [18], it can be calculated from the difference between E_{a1} and E_{th}.

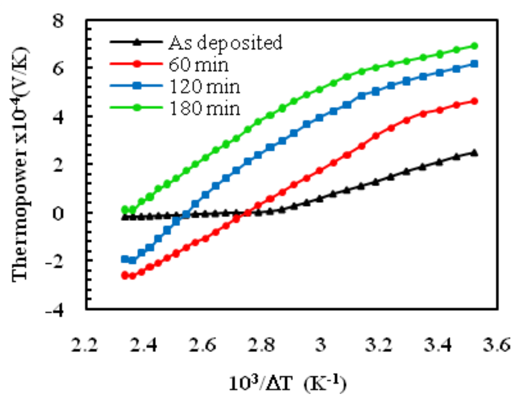

Figure 4: Thermoelectric power as a function of 10^3/T for as deposited and annealed thin Ga_xAs_{1-x} films for different duration times of annealing.

The variation of hopping energy illustrated in figure 5. It can be observed that the hopping energy increased by increasing the duration times of annealing and the highest value achieved by amorphous film.

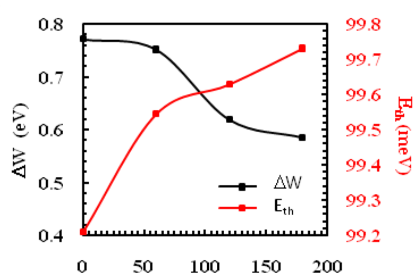

Figure 5: Thermal and hopping energies as functions of duration times of annealing for Ga_xAs_{1-x} thin films

4. Conclusions

The conclusions could be summarized as:

- Ga_xAs_{1-x} alloys have been prepared successfully with special conditions.
- As deposited thin Ga_xAs_{1-x} film is amorphous, but after annealing at 573K for 60, 120 and 180 minutes, the structure become polycrystalline.
- The most important observation in this search is that the amorphous as deposited film displayed higher values of activation energy and electrical conductivity, and then they decreased after annealing.
- Thermoelectric power shows that all prepared films are n-type, which is the same conductivity type of GaAs seed.
- Thermal energy decrease as duration times of annealing increased. Hopping energy increases as duration times of annealing increased and the highest value achieved by amorphous film.

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