

Improvement of the Electronic Properties of Gallium Antimonide Bulk Crystal

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Abstract—The improvement of the Gallium Antimonide (GaSb) single crystal surface quality is important in the performance of detectors which was made of this material, GaSb single crystal was prepared by a modified design based on Bridgman technique locally made in our laboratory. In this work we studied the influence of mechanical polishing and chemical etching on the electronic properties of the gallium antimonide single crystal. The electrical conductivity, hole concentration and Hall mobility were then investigated in a wide temperature range. Throughout these measurements; it appeared that polishing and etching enhance the electrical conductivity, hole concentration and Hall mobility by removing surface defects. On the other hand a comparison between the influence of etching and polishing was made bearing in mind to find the best for improvement the electronic properties of the grown crystals.

Keywords—Gallium Antimonide crystals, electronic properties, mechanical treatment and chemical treatment.

I. INTRODUCTION

Among the III-V binary semiconductors, gallium antimonide (GaSb) has attracted considerable attention over the last several years [1-3]. Many of its interesting properties are directly associated with its very low effective electron mass and high mobilities [4]. Consequently, it is an important candidate in high speed applications in transistors and other devices [5 - 7]. The relatively intermediate bandgap of GaSb lends itself well to mid/far range IR detectors and sources. From the device point of view, GaSb crystal with higher mobility is extremely valuable in this device manufacture [8]. GaSb is of face centered cubic (FCC) structure with a lattice parameters equals 6.095 Å [9]. GaSb can be formed in crystalline form at 710 °C (983 K) [10].

The objectives of this research are to provide the physical and structural properties of GaSb under different surface treatment conditions. We have selected gallium antimonide (GaSb) for comparison between the different surface treatments because it is a famous semiconductor compound with known properties.

II. EXPERIMENTAL

For preparing homogenized GaSb crystals, the high purity component materials are weighed to meet the specified composition. Since the atomic weights of Ga and Sb are 69.723 and 121.75 amu respectively, the ratio by weight should be 1:1.75. High purity 99.9999% Ga, and Sb (obtained from Aldrich) were used as starting materials.

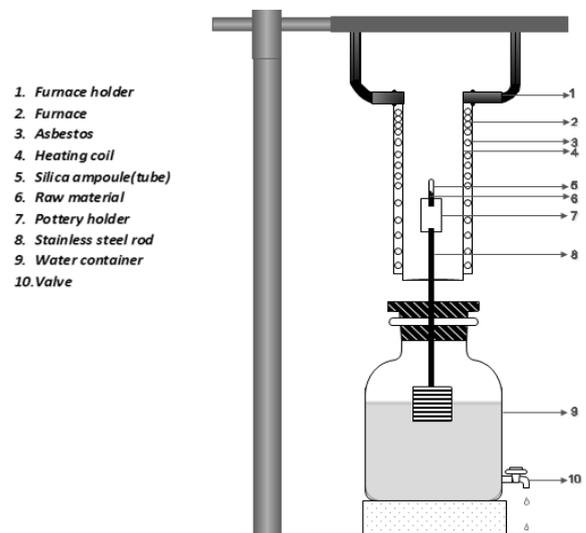


Fig. 1: Crystal growth technique

The GaSb compound was synthesized by alloying its components according to its stoichiometry in a tipped evacuated (10^{-4} Pa) and sealed quartz tube. The growth ampoule containing the charge was evacuated using a mechanical pump (Edwards MARK England). The ampoule with its charge after being sealed under vacuum was supported in its place as shown in Fig.1, where the crystal growth apparatus. According to the phase diagram of gallium antimonide, the melting point is about 710 °C [10]. The first zone temperature of the furnace was increased to about 800 °C higher than the melting point of the raw materials to ensure complete melting and then homogenized for 12 h. More details about this technique can be found elsewhere [11].

The best results for most semiconductors are obtained by polishing. Polishing is carried out by holding the specimen down in the polishing disks as or by using the instrument (Leco MARK England). It was difficult to specify how much pressure must be used:

too little pressure retards the rate of polishing and may result in some pitting of the surface; too much pressure may distort the surface. The correct polishing pressure varies with different samples and can only be learned through practice. After initial polishing with grit size (600,400,320 and 240 grit), the sample should be washed in water, rinsed in ethanol and dried in open air. In the present work we use Br-MeOH solution as an etchant for GaSb crystal for one and two minutes. The electrical measurements were done on crystals of dimensions 6mm x 2mm x 2mm. Details about the method and techniques for measuring the dc electrical conductivity and Hall coefficient have already been published [11 - 13].

III. RESULTS AND DISCUSSION

For the polished sample, the electrical conductivity (σ) measurements were done in a wide temperature range extending from 240 to 405 K as illustrated in Fig. 2. This figure is a set of three curves. The following observations should be considered for the curves:-

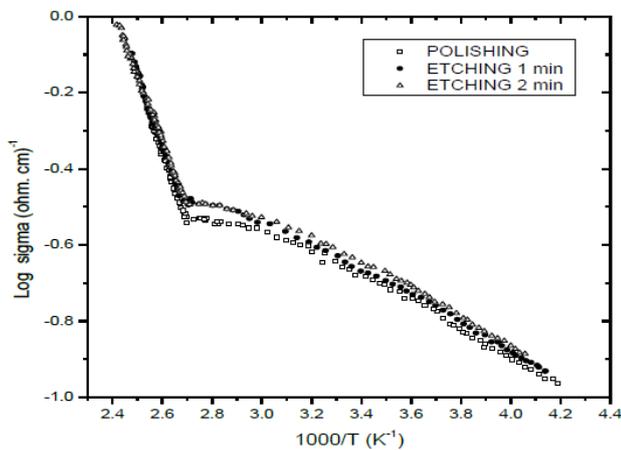


Fig. 2: Influence of the surface treatment on the resulted electrical conductivity

Each curve shows a typical semiconductor behavior as in other semiconducting compounds. In the low temperature part the following formula describes the relation between σ and T :

$$\sigma = \sigma_0 \exp(-\Delta E_a / 2K_B T) \quad 1$$

Where σ_0 is the pre-exponential factor, E_a is the ionization energy of the acceptor level and K_B is the Boltzmann constant. From the above equation we found that E_a is 0.14 eV.

Eq.2 is used to calculate the width of the energy gap in the high conductivity range after the transition region. So the value of the energy gap E_g as estimated as 0.7 eV.

$$\sigma = \sigma_0 \exp(-\Delta E_g / 2K_B T) \quad 2$$

As in the polished sample, this experiment was carried out on the etched samples. As seen in Fig.2 the effect of etching on GaSb sample for 1 and 2 minutes is depicted.

We observed the same semiconductor behavior as in the polished GaSb sample.

The same procedures were employed to estimate both E_g and E_a values and both values were found similar to that calculated from Fig.2.

It is surprising that there is no difference in σ values through the different treatments done on the crystals.

For example the value of σ at room temperature equals 0.22, 0.23 and 0.24 (ohm.cm)⁻¹ as found from Fig.2. For the cases polishing, 1 minute etching and 2 minutes etching respectively. To facilitate comparison we construct the histogram which represents σ values at the pre mentioned conditions. Also σ value for the as prepared sample is included [13]. This forced us to complete the present investigation to find out whether the charge carriers P or their mobility μ will change or not.

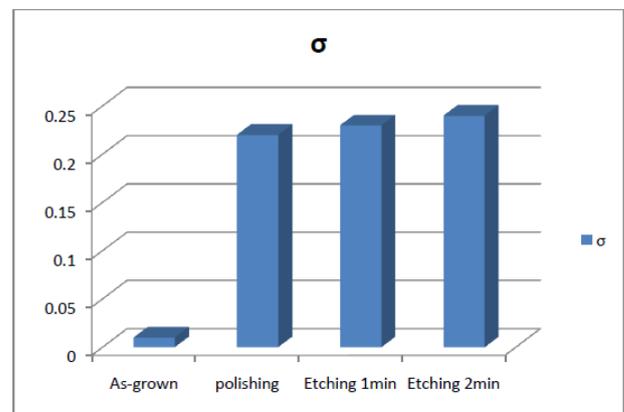


Fig. 3: Variation of electrical conductivity (at room temperature) with surface treatment

Generally Hall coefficient measurements of any semiconductors are of great importance because many physical properties could be determined. For example it is possible to determine the carrier concentration Hall mobility as well as other various properties. In the present work we studied Hall coefficient (R_H) which equal $1/Pq$. Because we are presently interested in the behavior of both P (the carriers concentration) and the mobility μ_H , so we plot here the variation of P against the ambient temperatures.

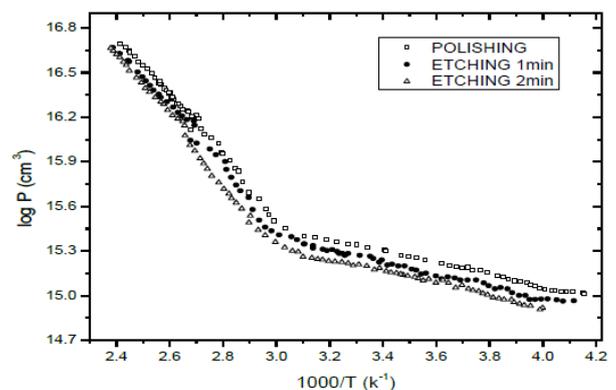


Fig.4: Influence of the surface treatment on carriers concentration

The variation of the carrier concentration as a function of temperature is typically illustrated in Fig.4. However the value of P in case of 1 min is higher than that of 2 minute. For instance the hole concentrations at room temperature equal 2.19×10^{15} , $1.9 \times 10^{15} \text{ cm}^{-3}$ and $1.6 \times 10^{15} \text{ cm}^{-3}$ for polish, 1 min and 2 min respectively. This is can be easily noticed if we considered the histogram appeared in Fig. 5.

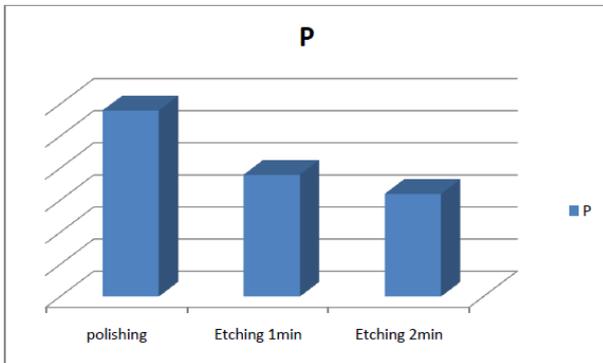


Fig. 5: Variation of carrier concentration (at room temperature) with surface treatment

The variation of the Hall mobility with temperature for the crystal treated by polishing, etching for 1 and 2 minutes are shown in Fig.6. The main striking conclusion here is that at room temperature, the Hall mobility for 1 minute and 2 minute etching treatment of the sample are $811.6 \text{ cm}^2 \text{v}^{-1} \text{ s}^{-1}$, $1006.5 \text{ cm}^2 \text{v}^{-1} \text{ s}^{-1}$ and $1104.7 \text{ cm}^2 \text{v}^{-1} \text{ s}^{-1}$ respectively. Again a simple histogram Fig. 7 is designed to compare these important variations in μ values.

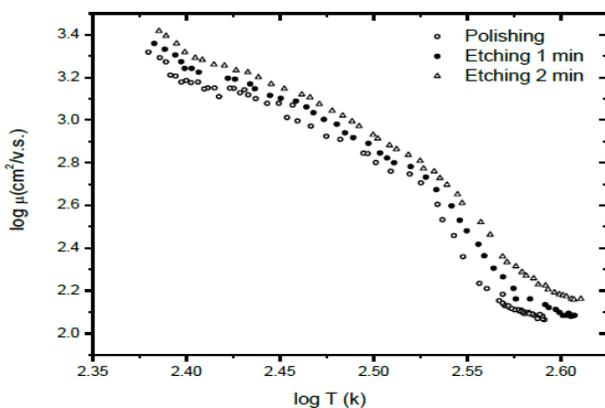


Fig. 6: Influence of the surface treatment on the charge carrier mobility

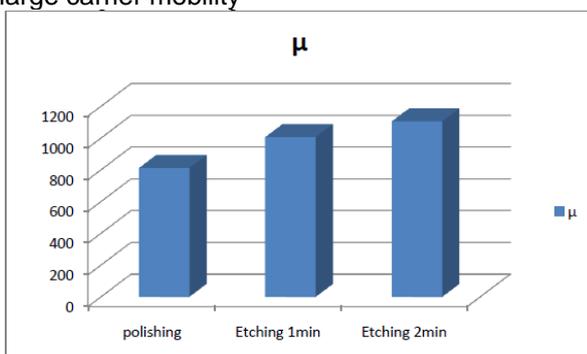


Fig. 7: Variation of charge carrier mobility (at room temperature) with surface treatment

IV. CONCLUSION

Reviewing the last results of the electrical conductivity c and the Hall effect data, one can conclude early the results are complementary. Each supports the other, we have the following concluding remarks:-

The general mode of σ variation against T reveals that GaSb is a semiconductor. This is concluded from the three regions curve appeared in Fig. 2. We estimated E_g to be 0.7 eV and E_a to be 0.14 eV from this figure.

The general mode under the different conditions listed on the graph is the same. Even temperatures of transitions are in accordance. Beside on this no noticeable effect of the surface treatment on c , except for the slight variation in the extrinsic or even in the transition regions.

We can get the highest σ (at room temperature) in case of 2 minutes etching (see Fig. 3).

Since $\sigma = eP\mu$, i.e. it is proportional to both $P(T)$ and $\mu(T)$ as indicated in figures 4, 6.

Regarding to figures 5, 7 it is easy to conclude that the relatively high σ value is due to μ affect not P affects.

Finally from point 5, we can utilize sum up this work as follows: one can improve μ by surface treatment. The highest value can be obtained if the sample is exposed to etching for 2 minutes duration time. This can be attributed to the fact that this process reduces surface defects to its minimum value. It is an established fact that μ is inversely proportional to the number of defects [15, 16].

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