

SPECIFIC CONTACT RESISTANCE MEASUREMENT ON METAL-GaTe CONTACTS AND ITS OPTIMISATION

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ABSTRACT. - A systematic study on ohmic contact formation to GaTe layered crystal grown by directional freezing method has been introduced. In this study the Ladder network (Transmission Line Method, TLM) technique was used for the measurement of specific contact resistance of ohmic contacts to GaTe. In, Au, Al, Ag metals and Au-In eutectic alloy were used as contact element. Ladder pattern formed directly on GaTe surface by evaporation of metals through a pre-patterned shadow mask. With a controllable thermal heat treatment process, the lowest ohmic contact with $2.5 \pm 1.4 \times 10^{-5}$ Ohm/cm² was formed by In after annealing at 200 °C for 2.5 min. Ohmic contacts with that process remained very stable up to six months although the other samples with higher contact resistance processed at 175-250 °C for 2.5-14 min were unstable. X-ray diffraction measurements showed that GaInTe₂ formation at In-GaTe interface even prior to annealing process. The other elements used in this study showed rectification behaviour after annealing at 175-400 °C temperature range for 5 min.

1. INTRODUCTION

GaTe compound is one of the III-VI semiconductors which is a typical layered crystal. The physical properties of GaTe are highly anisotropic because of its monoclinic layered structure. Inside layers the bonding is largely covalent whereas bonding between layers is van der Waals nature. In III-VI group the optical properties of GaSe have been extensively studied. Instead of that, even the fundamental excitonic properties of the similar GaTe have not been known well [1]. Absorption measurements done by a group researchers [2-6] was used to get the fundamental band edge. Low temperature optical properties of GaTe is also given by the studies of [7-10]. A general problem at that point is the complicated crystal structure of GaTe. In layered crystals, the main symmetry axis is perpendicular to the layer plane. However there is no such symmetry axis in GaTe and only one twofold symmetry axis exists in the direction parallel to the b-axis in the layer plane.

The transport properties of GaTe are by far less known than other layered crystals. The gathered information is the transport anisotropy [11], an acceptor level determination at 77 - 300 K range [12], Schottky barrier determination of Au, In, Ag and Al using X-ray photoelectron spectroscopy [13] and I-V, C-V measurements [14].

For the first time a systematic deep level study using DLTS is given by Shigetomi et al. [15]. They showed that after annealing at 200 °C and 400 °C, a mid gap level located at 0.82 eV trap correlated to the annealing process.

The samples used in optical measurements such as photoluminescence, absorption or Raman techniques do not require any process. Instead of that electrical measurements require

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contacts and at least one of the contacts must be in ohmic nature, in general. One way and most reliable method is to get a contact using an appropriate metal and carry out a thermal heating cycle. In literature there is no specific ohmic contact process technology for GaTe. Commonly indium is used as a metal and a heating cycle at 200-250 °C for 30 min under the nitrogen flow. Only ohmic contact forming of Au on GaTe at low voltages has been reported [12]. In any case lowest contact resistance and long term stability one of the important factor for electrical characterisation of GaTe, especially at low temperatures.

2. EXPERIMENT

GaTe has been synthesised by melting equimolar amounts of 6N gallium and 5N tellurium in a carbon coated and sealed quartz tube. A controllable heating procedure was applied to loaded tube and at 900 °C synthesising process was carried out. Directional freezing method was used to crystallise the mixture in a two zone furnace. This growth procedure took about 24 h for 30 gr. loading. The grown GaTe was p type and hole concentration was $10^{15} - 10^{16} \text{ cm}^{-3}$. The samples were prepared by cleaving an ingot parallel to the layer which was approximately perpendicular to the c-axis. The samples used in this study was about $5 \times 10 \times 0.2$ mm. To prevent any physical damage to the samples a maximum attention given from sample preparation to measurement stage.

Ladder network (TLM) technique for measuring the specific contact resistance of ohmic contacts to GaTe was used as given in Figure 1. This method was originally proposed by Shockley (1964). A constant current source connected to two large-area ohmic contact and a known current, I , driven through the sample. Two probes, connected to a high-impedance voltmeter are connected between one of the current pads and with another probe the voltage drops at B , $2B$, $3B$ are measured. That allows one to draw a potential against to position. In general zero potential appear at some distance L_t (Transfer Length). Shockley (1964) has shown that the specific contact resistance, R_c , is given by

$$R_c = I_t^2 R$$

where L_t is the intercept and R is the slope of the graph of voltage against position in Figure 1.

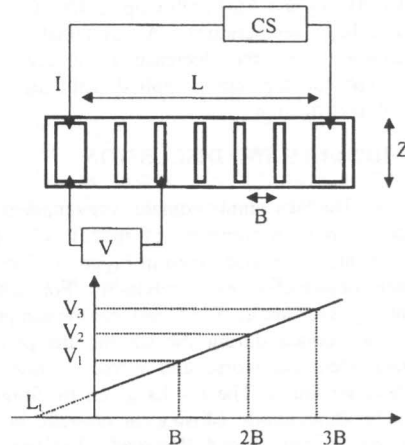


Figure 1. Ladder network pattern used for specific contact measurement. (CS - Constant current source, V-high impedance voltmeter.) [16]

Since the lack of the photoprocess technology for GaTe the only way to form a ladder pattern on GaTe sample is the use of a shadow mask. For that purposes we have developed a technology to produce shadow masks, Figure 2. Firstly, we have created a sharp positive image of pattern we intended to use. This pattern optically transferred by positive photoresist onto copper film which was obtained on optically flat glass by vacuum evaporation. After developing pattern in developer, open areas etched away in a diluted FeCl_3 solution. Positive resist cleaned from the surface by acetone and 20-30 μm copper film deposited on pattern using 75 mAcm^{-2} current density and 20 min period. These thick films easily peeled off from the glass substrate and at final stage, a short nickel electrodeposition process carried out to protect the copper film from oxidation.

In, Au, Al, Ag and Au-In (38% In, 62% Au, eutectic temperature is 550 °C) alloy were used for ohmic contact study. All metals were evaporated in 10^{-5} torr base pressure through the prepatterned shadow mask.

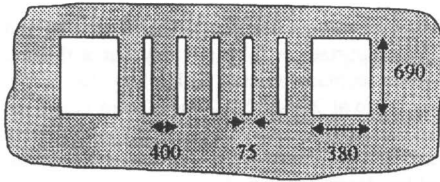


Figure 2. Prepared shadow mask for ohmic contact pattern. (all dimensions in μm)

The samples were annealed in a home made miniature alloying furnace under the N_2 gas flow. A test heating cycle is given in Figure 3. Annealing temperature was 175 - 150 $^\circ\text{C}$ for In based contacts. For other elements that increased up to 400 $^\circ\text{C}$. Any ohmic contact behaviour didn't observed from Au, Al, Ag and Au-In alloy up to 400 $^\circ\text{C}$ annealing temperature. A systematic tendency was the decrease in driven current for the same applied voltages with rectification..

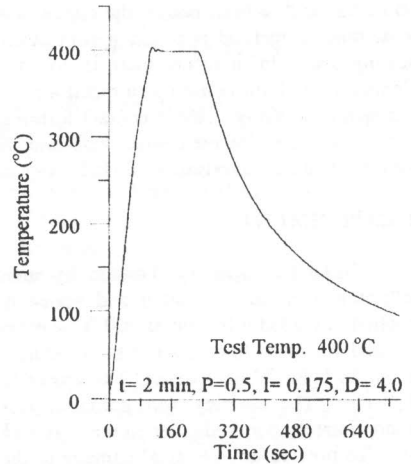


Figure 3. One heating cycle with a predetermined PID parameters. The applied power to heater was 70% of available power and heating rate was 2.7 $^\circ\text{C}/\text{sec}$.

3. RESULTS AND DISCUSSION

The best ohmic contact was obtained from In-GaTe structures after annealing at 200 $^\circ\text{C}$ for 2.5 min. A summary of specific ohmic contact values are given Table 1 and graphical presentation is also given in Figure 4. The stability of processed ohmic contacts is one of the main object of a device reliability. For that purpose a periodic measurement was carried out through six months. We found that the samples processed at 200 $^\circ\text{C}$ for 2.5 min have very stable ohmic contact during the six months period. However the contacts with different process parameters get worse and worse. Ohmic contact process is unavoidable for the electrical characterisation. The results given by Shigetomi et al. [15] shows that thermal treatment of GaTe unintentionally causing an increase in deep level concentration located at midgap. That means the optical and electrical properties of GaTe is changing during the annealing process stage. The only way to avoid that phenomenon is to use lowest temperature with shortest time.

Table 1. Calculated specific ohmic contact resistances of In-GaTe contacts with different process parameters.

Annealing Temperature ($^\circ\text{C}$)	Annealing time (min)				
	2.5	5	7.5	10	14
	R_c (ohm.cm ²)				
175	6.69±0.95E-4	3.86±0.48E-4	3.17±0.37E-4	3.30±0.6E-4	3.46±1.01E-4
200	2.46±1.38E-5	9.57±0.29E-5	1.01±0.58E-3	5.80±0.74E-4	1.15±0.39E-4
225	1.11±0.01E-2	1.12±0.05E-3	1.61±0.37E-3	3.84±1.48E-4	4.075±0.82E-4
250	2.31±0.69E-4	1.20±0.05E-3	2.76±0.34E-4	3.63±1.22E-3	6.25±4.89E-4

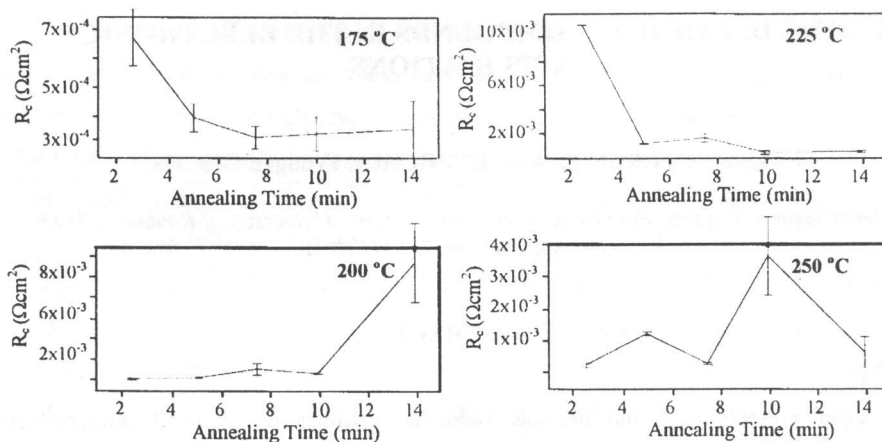


Figure 4. Specific ohmic contact values of indium to GaTe at different annealing temperatures and annealing time.

4. CONCLUSION

A suitable and most reliable ohmic contact process parameters for GaTe are found to be indium based metalisation of GaTe and annealing at 200 °C for 2.5 min. X-ray diffraction measurements showed that GaInTe_2 formation at In-GaTe interface even prior to annealing process. Stability of that structure may be the responsible for stable ohmic contacts. Only a problem is the softness of the indium films for probing on GaTe. This problem requires further research on possible use of In based alloys or multilayers.

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