Structural and Electrical Properties of Undoped GaAs Grown by MOCVD

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Abstract - The present paper describes the results from the growth of undoped epitaxial GaAs by low pressure Metal Organic Chemical Vapor Deposition (MOCVD) and its structural and electrical properties. The growth temperature and pressure were 700 °C and 100 Torr, respectively. Growth was carried out at different V/III ratios and hydrogen flow rates. Epilayers thus grown were shown to have uniform thickness, smooth surface, crystalline structure, stoichiometric and low background impurity concentration. The increasing V/III ratio resulted in the p- to n-type transformation of the epilayers. With increasing hydrogen flow rate, the background carrier concentration was decreased. Hall mobility of 90,000 $cm^2V^{-1}s^{-1}$ at 77K for a carrier concentration of $1x10^{15}$ cm^{-3} was obtained.

A. Introduction

The epitaxial version of growth by low pressure MOCVD has been of importance in view of its ability to produce epilayers of high optical and electrical properties and high throughput for the production of high speed and optoelectronic devices, such as HEMT, HBT, MESFET[1], Laser's[2], LED's etc. It is an excellent tool in producing abrupt interfaces and hetero-junctions of binary, ternary and quaternary III-V compound semiconductors. Attempts have been made to obtain epilayers with a very low background carrier concentration, uniform thickness, low autocompensation etc.

B. Experimental Details

Growth of undoped GaAs epitaxial layers was carried out in a horizontal LP-MOCVD reactor at 100 Torr using hydrogen as the carrier gas. Trimethylgallium(TMG) from Strem Chemicals and 100%Arsine(AsH_3) from Air Products Inc. were used as group III and group V sources respectively. Temperature of growth was kept at 700 °C by employing a bank of quartz halogen infrared heaters. Both Si-doped n^+ and Semi-insulating(SI) GaAs substrates of (100) orientation 2° off towards <110> direction supplied by M/s American Crystal Technology were used for the growth process. The details of the growth procedure has been discussed elsewhere[3].

The surface morpholgy and thicknesses of epilayers were determined from scanning electron microscopy (SEM) measurements. A-B etch[4] was used to delineate epi-layers from the substrate. A and B parts were mixed prior to the experiment and the sample was kept immersed inside the solution under illumination for about 10 seconds. The etched edge was then viewed under SEM. X-ray diffracion(XRD) studies were

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carried out to show the growth in (100) direction and Double Crystal XRD (DCXRD) was employed to find out any lattice mismatch between the epilayer and the substrate.

Electrical characterization included carrier concentration measurement by electrochemical C-V (ECV) profiler and Hall mobility measurements. The ECV profiler has the advantage of reducing series resistance by employing a low carier frequency for the AC-bias measurements. Also, low bias avoids the breakdown voltage as is the case with depletion mode C-V profiler. However, the disadvantage of ECV profiling is that it is destructive in nature. Thicknesses of epilayers for hall measurements were usually 7 to 9 μm.

C. Results and Discussions

For a TMG flow of 1.8×10^{-4} mole fraction, it was found that a minimum of 16.75 sccm of arsine was required to be flown through the reactor in order to achieve a good epilayer surface. It was seen that a flow of arsine below that would result in an epilayer with white patches on the surface. In the OMVPE process, increasing the arsenic partial presure effects an increase in the gallium vacancy concentration, resulting in greater silicon incorporation into gallium sites, and making the layer more n-type. Conversely, reduction of the arsenic overpressure reduces the doping level, and the material eventually becomes p-type. This process is limited by the need for having enough arsenic to avoid surface decomposition, as well as to avoid the formation of unreacted gallium. Moreover, the desorption rate of hydrocarbons from the growing surface is reduced, so that the possibility of carbon contamination increases[5]. Hence, it can be concluded that this minimum arsine is required to compensate for the out-diffusion of arsenic from the GaAs surface.

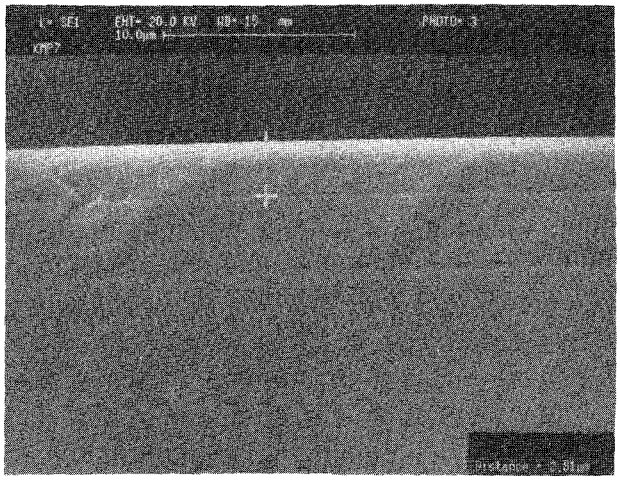

Fig.1. Cross sectional SEM of epi-/n+ GaAs

The A-B etched samples were viewed under SEM. A clear interface was visible between the epilayer and the substrate(Fig.1). Several such samples from each run were tested for uniformity of thickness and all of them produced identical results. SEM was also used to indicate the surface morphology. In all the cases of interest, where arsine flow was more than the required minimum, a shiny specular surface was obtained. Energy dispersive X-ray(EDAX) analysis confirmed that the As/Ga atomic ratio is stoichiometric and independent of V/III ratio in the range considered.

X-ray diffraction studies were carried out to confirm the crystal structure of the grown epilayers. Crystalinity of the epilayers were confirmed by an intense (004) reflection. DCXRD showed that there is no lattice mismatch between the epi-GaAs and GaAs substrate (Fig.2). The Electrochemical C-V profiler was used to measure the background carrier concerntration. The V/III ratio was varied from 21 to 67 by keeping group III flow rate constant and by varying the arsine. It was observed for the lowest Arsine flow, the epilayer is p-type of around $1x10^{16}$ cm^{-3} and highly resistive in nature. However, this carrier concentration reduces with increasing Arsine flow. At V/III ~37, the carrier type changes from p- to n-type which is in agreemnet with reported results[6,7] (Fig.3). Beyond the V/III ratio of 37, the n-type carrier concantration increases to $8E15cm^{-3}$. It was found that the unintentional carrier concentration was homogeneous throughout the epilayer and also indicated a sharp interface between the epilayer and the

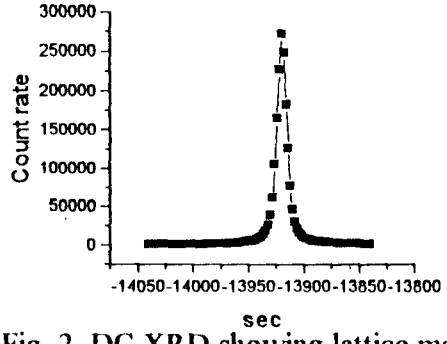

Fig .2. DC XRD showing lattice matched epi-substrate of GaAs

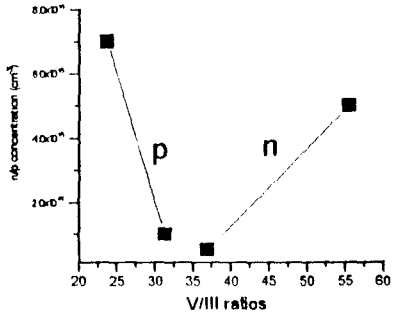

Fig .3. p-n Transition

substrate. This is indicative of low autocompensation in our samples[8,9]. At low pressure, the concentration gradient across the stagnant layer is greater for species diffusing out from the substrate, thus less of the volatile dopant is contained in the stagnant layer and impurity grading due to autodoping is reduced. This sharp interface is an important step towards achieving devices of tailormade characteristics.

Hall effect studies were carried out by employing Van der Pauw technique. Small In-contacts were made at the four corners of the sample. Thicknesses used were 7 to 9 μm. For undoped epilayers of $1x10^{15}cm^{-3}$ concentration (n-type), a Hall mobility of 6000 $cm^{-2}V^{-1}$ s^{-1} at room temperature and ~90,000 $cm^{-2}V^{-1}$ s^{-1} at 77K was achieved. It was evident that the compensation ratio in such samples were very low.

C1. Hydrogen Flow Variation

Hydrogen flow was varied from 2 standard liters per minute (slpm) to 3 slpm at a V/III ratio of 67. It was found that the background carrier concentration reduces from $2x10^{15}cm^{-3}$ to $5.65x10^{14}cm^{-3}$ (Fig.4). Another set of experiments were carried out for a V/III ratio of 39, just near the p- to n-transition region. It was found that the epilayer type changes from n- to p-type as the hydrogen flow varies from 2 slpm to 4 slpm. However, all the samples in this case were found to be resistive in nature. It was evident

However, all the samples in this case were found to be resistive in nature. It was evident that the increase in hydrogen flow rate had the same effect as that for the decrease in the arsine flow at constant group III flow rate.

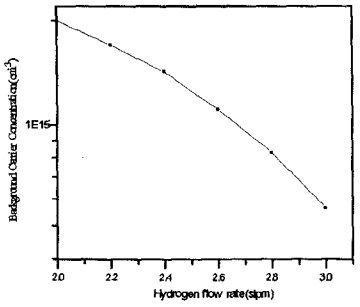

Fig. 4. Variation in Carrier Concentration with Hydrogen flow at a V/III ratio of 67.

D. Conclusion

Epitaxial growth of GaAs by MOCVD technique has been carried out. Device quality epilayers with uniform thickness, specular surface, clear demarcation between the epilayer and the substrate has been demonstrated. Variation in V/III ratio has been shown to result in a p- to n-transition of the carrier type. Hydrogen flow variation has resulted in the reduction of carrier concentration for less compensated films. High mobility values to the tune of 90,000 $cm^{-2}V^{-1}$ s^{-1} at 77K for a carrier concentration of $1x10^{15}cm^{-3}$ has been obtained. The compensation ratio was found to be low.

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