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Title Electrical properties of n- and p-type doped epitaxial GaAs layers grown by OMVPE

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Abstract LP-OMVPE growth of Silicon and Zinc doped epitaxial GaAs were carried out with a variation in growth temperature, V/III ratio and hydrogen flow rate by using silane and dimethylzinc as the nand p-type dopants respectively. Both the dopants show strong dependence on growth temperature. For silane and dimethylzinc, impurity concentration increased linearly with increase in the flow of the dopants, and in the case of silane, compensated after reaching a concentration of ~2.0*10/sup 18/ cm/sup -3/. The increase in hydrogen flow rate showed a decrease in the hole concentration. Hall measurements yielded a compensation of 0.4 for Si-doping. I-V characteristics of p-n junctions revealed good rectification. Au/p-GaAs Schottky junctions showed weak rectification below a hole concentration of 5.8*10/sup 18/ cm and above this concentration, the I-V characteristics were linear. This result is important for front grid contact applications in solar cells. Abstract no. A9901-8115H-033B9901-0520F-052.

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Electrical Properties of n- and p-type Doped Epitaxial GaAs Layers Grown By OMVPE

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LP-OMVPE growth of Silicon and Zinc doped epitaxial GaAs were carried out with a variation in growth temperature, V/III ratio and hydrogen flow rate by using silane and dimethylzinc as the n- and p-type dopants respectively. Both the dopants show strong dependence on growth temperature. For silane and dimethylzinc, impurity concentration increased linearly with increase in the flow of the dopants, and in the case of silane, compensated after reaching a concentration of $\sim 2.0*10^{18}$ cm^{-3}. The increase in hydrogen flow rate showed a decrease in the hole concentration. Hall measurements yielded a compensation of 0.4 for Si-doping. I-V characteristics of p-n junctions revealed good rectification. Au/p-GaAs Schottky junctions showed weak rectification below a hole concentration of $5.8*10^{18}$ cm^{-3} and above this concentration, the I-V characteristics were linear. This result is important for front grid contact applications in solar cells.

INTRODUCTION

Low pressure OMVPE has gained prominence in view of its ability to produce high speed and optoelectronic device structures such as MESFETs, LEDs, solar cells etc based on III-V compound semiconductors. It is an industry standard tool to achieve abrupt interfaces[1] and multilayer heterostructures including superlattices with the required conductivity type and doping concentration.

Silicon(Si) is a preferred n-type dopant for GaAs. Si has low diffusion coefficient in GaAs at typical growth and processing temperatures and does not show any memory effect [2]. There are several dopants which has been used for p-type doping of GaAs viz., Zinc(Zn)[3], Mg[4], Be[5], C[6] etc. Although Zn has high diffusion coefficient and shows memory effect, doping efficiency is high, induces low deep levels and a wide range of doping concentration can be achieved. Attempts were made to obtain epilayers with a very homogeneous impurity concentration, uniform thickness, abrupt junction, low autocompensation etc. Schottky diodes on p-GaAs and p-n junction homodiodes of epitaxial GaAs were studied in order to see the applicability of our as grown epilayers for use in specific devices. The present paper describes the results from the growth and the electrical properties of Si- and Zn- doped GaAs by low pressure OMVPE technique.

EXPERIMENTAL DETAILS

Growth of n-tye and p-type doped epitaxial GaAs layers was carried out in a horizontal LP-OMVPE reactor at 100 Torr using high purity hydrogen as the carrier gas. Trimethylgallium(TMG) and 100% Arsine(AsH_3) were used as group III and group V sources respectively, with Silane(SiH_4) diluted to 104 ppm in hydrogen and Dimethylzinc(DMZ) as the corresponding n- and p-type dopants. Both Si-doped n^+ and Cr-doped semi-insulating (SI) GaAs substrates of (100) orientation 2" off towards <110> were used for growth process. Details can be found elsewhere[7]. Doping studies were carried out with a variation in temperature from 600 to 725 °C in case of SiH_4 and 550 to 700 °C for DMZ. In both the n- and p-type doping, AsH_3 was varied between 20.1 and 33.5 sccm. For Zn doping, hydrogen flow was varied between 2.0 and 2.9 slpm.

The surface morpholgy and thickness were determined from scanning electron microscopy measurements (SEM). A-B etch[8] was used to delineate epi-layers from the substrate. The thickness thus obtained was also compared with that obtained from the Electrochemical CV (ECV) profiler. Electrical measurements on the doped layers included impurity concentration measurement by ECV profiler and Hall mobility by using Van der Pauw tehnique. Thicknesses of epilayers for Hall measurements were usually 2 to 3 μm. Schottky diodes were fabricated on epitaxial p-GaAs grown on S.I. GaAs substrates and Au was used as the Schottky metal on p-GaAs. Current voltage characteristics were obtained by applying current between any two Au dots. The p-n junction homodiodes were fabricated by mesa etching and the I-V characteristics were obtained.

RESULTS AND DISCUSSIONS

i) Silicon doping by using SiH_4

The linear dependence[9] of Si incorporation on SiH_4 mole fraction is shown in Fig.1. The deviation of the carrier concentration from the direct proportionality at carrier concentrations greater than $2*10^{18}$ cm^{-3} was due to the self compensation of Si or the formation of Si precipitates at high silicon concentrations[10]. The compensation ratio for these epilayers was measured following Walukiewicz [11] from the room temperature Hall mobility data. It was found that for SiH_4 partial pressures upto the maximum attained free carrier concentration, the compensation was around 0.4 and this increased to 0.6 for doping with higher SiH_4 partial pressures corresponding to the maximum doping attained.

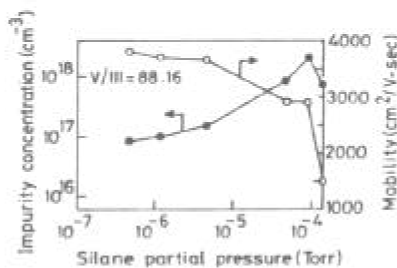

Fig.1. Free carrier concentration and mobility as a function of SiH4 partial pressure.

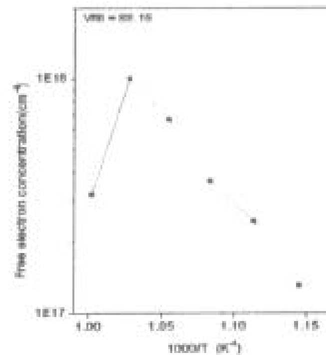

Fig.2. Si incorporation in GaAs by SiH_4 with inverse temperature. Silane mole fraction for the experiments was $5.79*10^{-7}$.

Fig.2 shows the free carrier concentration increase with growth temperature. SiH_4 decomposition follows an Arrhenius type tempereature dependence with an activation energy of 1.47 eV[12]. As the substrate temperature is increased, more Si is incorporated due to a more efficient thermal decomposition of SiH_4[13]. This implies that the Si incorporation from SiH_4 is kinetically limited.

The electron concentration reduced with increase in AsH_3 mole fraction (Fig.3). As per the vacancy control model [13], with the increase in AsH_3 flow rate, Gallium(Ga) vacancy increases, thus more Si should have been incorporated into Ga sites. This then would increase the donor impurity concentration. However, experimental results prove to the contrary. Okamoto et. al. [14] suggests that the electron concentration is mainly determined by the flux of SiH_4 but is also slightly affected by the AsH_3 partial pressure of the gas mixture just above the substrate surface. That is, under a high partial pressure of AsH_3, the incorporation of Si atoms decreases because the decomposition rate of SiH_4 is limited by the hydrogen radicals generated by the decompostion reaction of AsH_3. As methane has the same molecular structure as SiH_4, it is suggested from the above results that the increase of the AsH_3 partial pressure may alleviate carbon incorporation in the epitaxial growth by OMVPE.

ii) Zn doping by using DMZ

The hole incorporation was found to increase with DMZ partial pressure [15].

The dependence of Zn incorporation on growth temperature is shown in Fig.4. Hole concentration increased with decreasing growth temperature and a doping of $1.50*10^{20}$ cm^{-3} was obtained at a growth temperature of 550 °C. The acivation energy was found to be 3.23 eV. This data was similar to that obtained by Glew[16]. As the temperature of growth was lowered, Zn out-diffusion from the GaAs surface reduced. This reduction thus manifested itself as an inrease in hole concentration. Hall mobility data as shown in the Fig.4 compares well with published data[16].

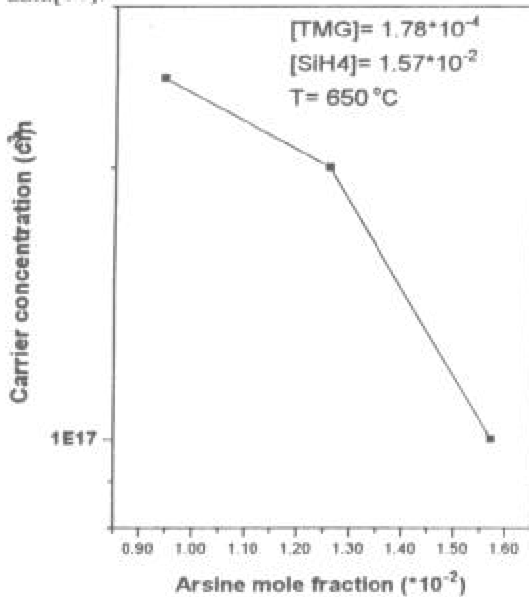

Fig.3. Si doping as a function of AsH_3 mole fraction.

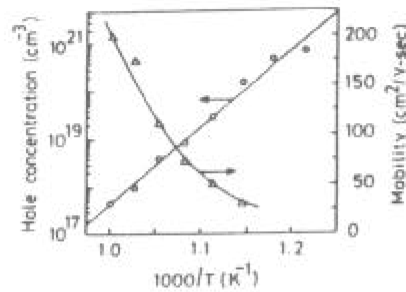

Fig.4. Effect of growth temperature on hole concentration and mobility. Growth conditions are: V/III= 88.16 $[DMZ]= 1.86*10^{-5}$.

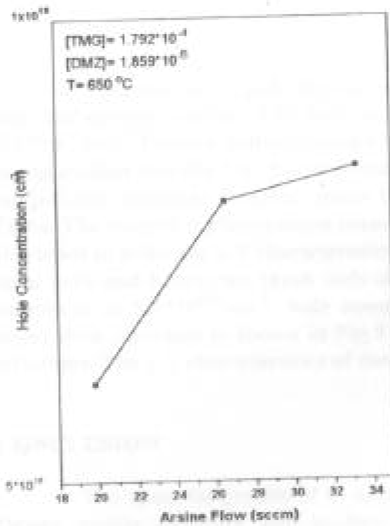

Fig.5. Relationship between AsH_3 flow rate and hole incorporation.

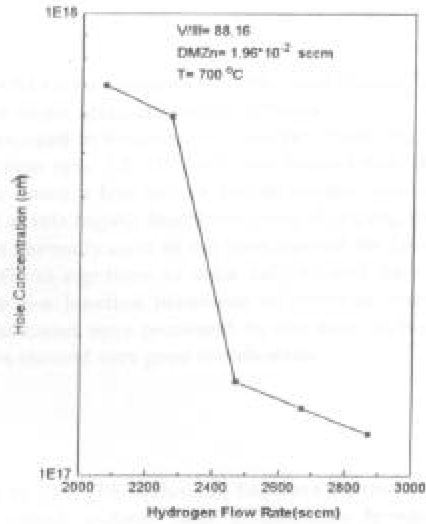

Fig.6. Hydrogen flow rate versus hole conentraton.

Fig.5 shows the relationship between AsH_3 flow rate and hole concentration. The increase in AsH_3 flow rate resulted in an increase in Zn doping[17,18]. The incease in the V/III ratio would increase the Ga vacancy concentration. Since Zn occupies Ga sites in GaAs, the increase in Ga vacancy would increase the incorporation of Zn into GaAs. The hole concentration was thus raised when the AsH_3 mole fraction was increased.

The increase in hydrogen flow from 2 standard liters per minute (slpm) to 2.9 slpm at a pressure of 100 Torr (Fig.6) resulted in the reduction of hole concentration. The increase in hydrogen flow rate at constant pressure increases gas velocity. This larger velocity causes in the reduction of the doping efficiency. In the mass transport limited region, as is the case for the incorporation of Zn from DMZ, the rate of mass transport increases with gas velocity because of the thinner boundary layer. The cause of decrease in doping efficiency remains unclear in mass transport limited regime of growth.

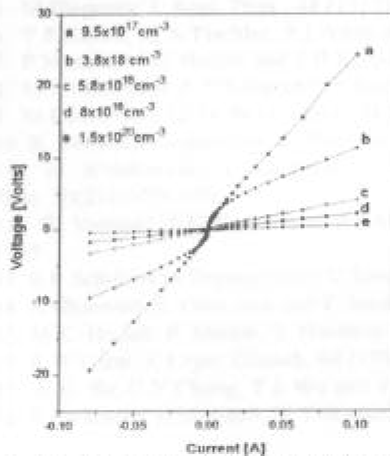

Fig.7. I-V characteristics of Au/p-GaAs Schottky diodes.

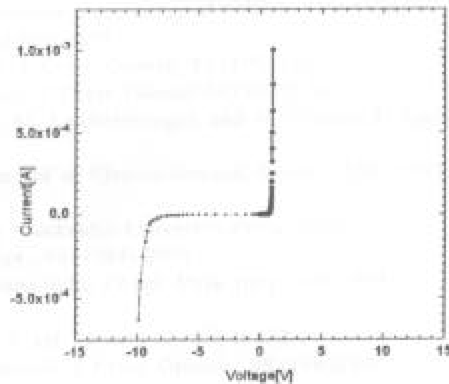

Fig.8. I-V characteristics of GaAs p-n junction homodiodes.

After the zinc doped epilayer was grown on a SI GaAs substrate, Au dots were evaporated onto the epilayer surface. The hole concentration for these epilayers varied between $9.5*10^{17}$ to $1.5*10^{20}$ cm^{-3}. Current voltage characteristics were obtained in between two Au dots. From Fig.7, it was evident that the I-V characteristics were non-linear upto $5.8*10^{18}$ cm^{-3} and beyond that, the Au/p-GaAs structures revealed ohmic behaviour. Au forms a low barrier height contact with p-GaAs. The tunneling phenomenon becomes dominant at this highly degenerate level of doping and this tends to make the I-V characteristics linear. Au is generally used as the front contact for GaAs solar cells and hence this result indicated that p++-GaAs cap layer of solar cells should have a minimum of $5.8*10^{18}$ cm^{-3} hole concentration. The p-n junction behaviour of epitaxial layers under dark condition is shown in Fig.8. The epitaxial layers were processed by the mesa etching technique. The I-V characteristics of these homodiodes showed very good rectification.

CONCLUSION

The epitaxial growth of n- and p-type GaAs by OMVPE technique has been carried out. Device quality epilayers with uniform thickness, smooth surface, clear demarcation between epilayers and the substrate has been demonstrated. For the SiH_4 doping (E_a=1.47 eV) of GaAs, a maximum carrier concentration of $2*10^{18}$ cm^{-3} has been obtained. Mobility values for silicon doping indicated a compensation of 0.4. The increase in AsH_3 mole fraction decreased the free electron concentration but the hole concentration was increased. Hydrogen flow variation resulted in the reduction of hole concentration. Hole mobilities were found to be comparable to the publised results. Current voltage characteristics of Au/p-GaAs Schottky diodes showed ohmic behaviour at and above hole concentration of $5.8*10^{18}$ cm^{-3}. I-V characteristics of p-n junction homodiodes revealed good rectification.

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