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SOME PROPERTIES OF Ga-As-$Al_xGa_{1-x}As$ HETEROJUNCTION GROWN BY LOW TEMPERATURE LIQUID PHASE EPITAXY *

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ABSTRACT

GaAs-$Al_xGa_{1-x}As$ heterojunction was grown by liquid phase epitaxy at low growth temperature 650-700°C. The series resistance of heterojunction with DH laser structure was measured. Doping properties of Mg in GaAs and $Al_xGa_{1-x}As$ were investigated. It is found that impurity concentration of Mg as high as 10^{18} cm^{-3} can be doped easily. The Shubnikov-de-Haas oscillation was observed in GaAs-N $Al_{0.35}Ga_{0.65}As$ heterointerface. It is demonstrated that in these heterointerfaces there exists 2DEG with some contribution from 3D electron of N-AlGaAs layer.

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(1) Introduction

GaAs and AlGaAs are important materials for optoelectronics and integrated circuits. Although in the last decade MBE technology has been extensively developed and high quality materials can be obtained by MBE method, liquid phase epitaxy is still a useful method for many devices fabrication, such as semiconductor heterojunction lasers, LEDs, bipolar transistors and solar cells due to its cheapness and simplicity. It was reported recently that even multi-quantum-well structure (MQW) and superlattice can also be grown successfully by LPE. For these devices the important thing is the control of layer thickness. In conventional GaAs and AlGaAs LPE technique growth temperatures are 800-850°C, at which growth rate is rather high. In order to obtain very thin and uniform layers, we have grown GaAs-$Al_xGa_{1-x}As$ heterojunction at 650-700°C and inverstigated some of their properties.

(2) Sample preparation

Epitaxy wafers were grown in horizontal liquid phase epitaxial system in conventional graphite slide boats on GaAs (100) substrates doped with Si or Cr. The growth procedure is as follows: high purity Ga (99.9999%) is baked at 900°C for 8 hours, after that the sources for epitaxy with high purity GaAs and dopants are kept at 770°C for 1 hour. The epitaxy temperatures are 650-700°C with supercooling regime.

(3) Series resistance

Samples with double-heterojunction laser structure were prepared as it is shown in Fig. 1. Real laser diodes always have some series resistance introduced by passive layers and ohmic contacts. Their effective circuits is consisting of an ideal junction and a series resistor R. (Fig.2) The I-V characteristics of ideal junction is

$$I = I_s \left(\exp\frac{qV_j}{nkT} - 1\right) \qquad (1)$$

and we have

$$\frac{dV}{dI} = R + \frac{nkT}{q} \cdot \frac{1}{I} \qquad (2)$$

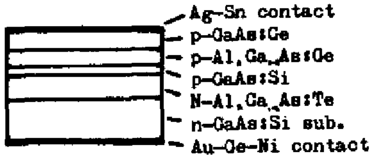

Fig.1

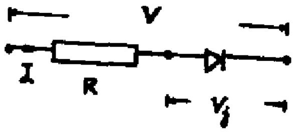

Fig.2

We used differential method to measure relationship $dV/dI \sim 1/I$ in the temperature range 77–300K. The series resistance R and ideality factor n are obtained from interception and slop of the straight line, respectively. Series resistance of lasers is a very important parameter for optical fiber communication. But R of our laser diodes were rather large for practice application of these lasers. We have measured relationships $\ln(1/R) \sim 1/T$ for heterojunction with Al composition x= 0.1—0.5. As it is well known, the activation energy ΔE_A of Ge in AlGaAs increases rapidly with the increasing of Al composition. Temperature dependence of hole concentration for $Al_xGa_{1-x}As$ in the range T<300K is given by

$$p \sim N_A \exp(-\Delta E_A/kT) \qquad (3)$$

Taking ΔE_A in $Al_xGa_{1-x}As$ with different x from [1], we calculated $\ln p \sim 1/T$. Using $R \sim 1/(p e u)$, we compare experimental and calculated results. It was concluded, that R is introduced dominantly by p-type $Al_xGa_{1-x}As$ layer. Impurity concentration of Ge in GaAs and $Al_xGa_{1-x}As$ is not large enough due to the small distribution coefficient. High hole concentration cannot be obtained at room temperature. Though the Zn dopant can easily give high concentration, it is difficult to control it during devices fabrication because its diffusion coefficient is too high.

(4) Mg doping properties

From what discussed above, we know that both Ge and Zn are not good dopants. One might propose Mg can be an appropriate candidate of p-type dopant. However, up to now there are few reports about properties of Mg in GaAs and AlGaAs [2],[3]. We have studied doping properties of Mg in GaAs and $Al_xGa_{1-x}As$ with low growth temperature. The GaAs and $Al_xGa_{1-x}As$ layers with thickness 1.5–3.9 um were grown on the semi-insulating GaAs (100) substrates. Then standard Hall bridges were formed by photolithograph. Fig.3 shows the relationship between hole concentration of epilayers at room temperature and atomic fraction of Mg in the liquid. Impurity concentration of Mg as high as 10^{18} cm^{-3} can be doped easily. Table 1 shows similar data in $Al_{0.53}Ga_{0.47}As$. It is seen that hole concentration higher than $10^{18}cm^{-3}$ can be obtained at room temperature even in high composition of Al materials. Fig. 4 shows the temperature dependence of hole concentration for two

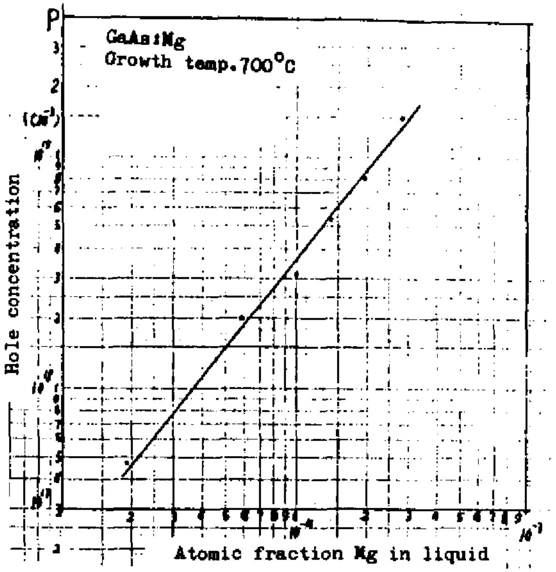

Fig. 3

Table 1

sample No.	Mg atomic fraction in liquid	hole concentration in epilayer (cm^{-3})
85-58	$5.7\ 10^{-4}$	$6.5\ 10^{17}$
85-43	$1.6\ 10^{-3}$	$9.0\ 10^{17}$
85-40	$2.0\ 10^{-3}$	$1.3\ 10^{18}$

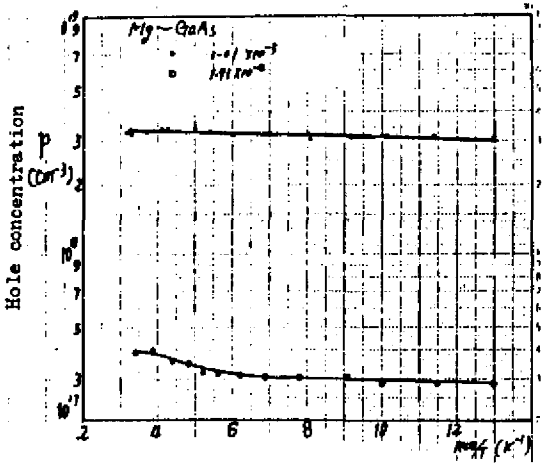

Fig.4

samples (atomic fraction of Mg in the liquid is $1.01\ 10^{-3}$ and $1.91\ 10^{-4}$) *It is clear that for highly doped epilayers,hole concentration* is Almost independent of temperature. As at room temperature all acceptors are ionized, so hole concentration is equal to the impurity concentration of Mg. Therefore, distribution coefficient of Mg in GaAs can be estimated as it is shown in Fig.5. Solid points are taken from different authors [4].

(5) Magnetoresistance oscillation

The cross section of epitaxial wafer in measurement is shown in Fig.6

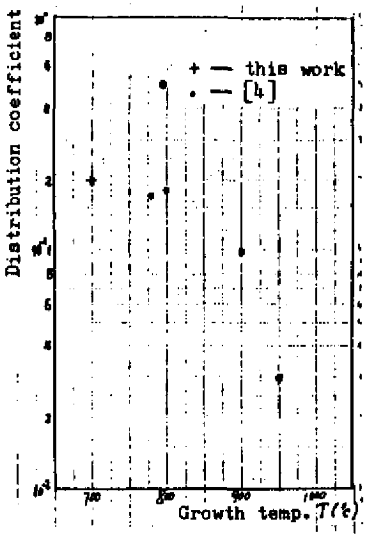

Fig.5

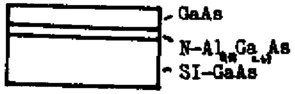

Fig.6

The N-$Al_{0.35}Ga_{0.65}As$ layer doped with Te and Sn was grown on the semi-insulating GaAs (100) substrate. Compositional grading of heterointerface is about 170 Å, which is determined by Auger measurement. Hall bridge is made from these wafers. Magnetoresistances were measured in the magnetic field range 0-7.5 T and temperature range 1.3-300K. The Shubnikov-de-Haas oscillation were observed as it is shown in Fig.7 .

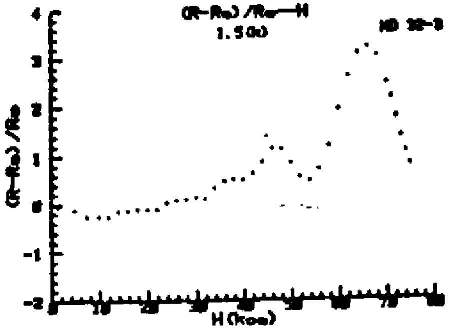

Fig.7

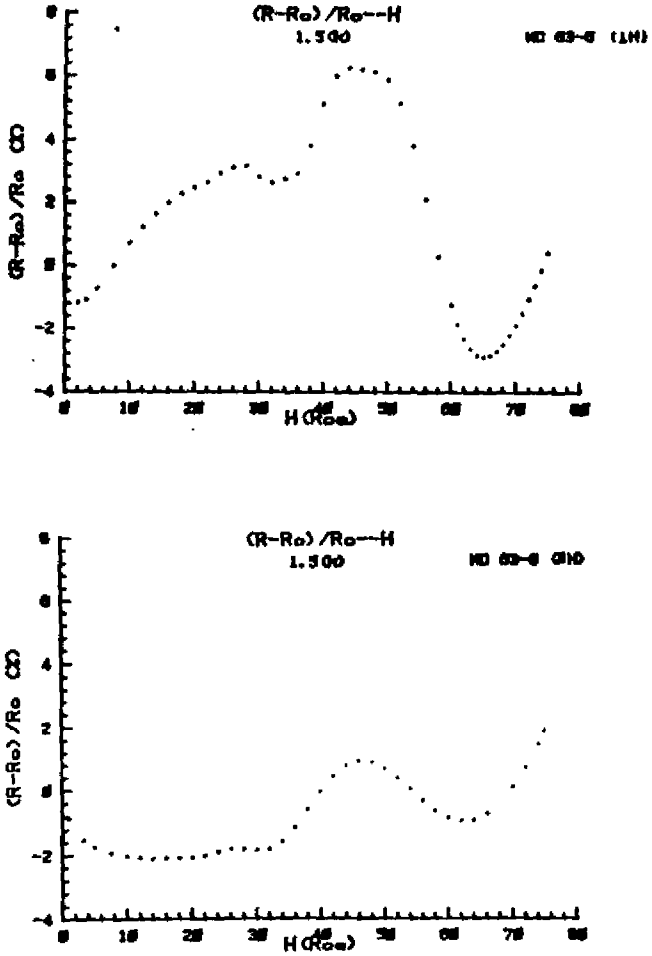

Fig. 8

Fig. 8 shows the difference in period and amplitude between oscillation with magnetic field perpendicular and parallel to the surface. It is concluded that in the heterojunction interface there exists two dimensional electron gas with some contribution from three dimensional electron in the N-$Al_xGa_{1-x}As$ layer.

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