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Schottky Barrier Heights of $In_xAl_{1-x}As(0 \leq X \leq 0.35)$Epilayers on GaAs

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The electrical characteristics of Al Schottky diodes on n-type $In_xAl_{1-x}As$ ($0 \leq x \leq 0.35$) were investigated in detail. These high quality InAlAs epilayers were grown on GaAs using step-graded buffers under proper growth conditions. The Schottky barrier height of the epilayers increases with Al content as opposed to what predicted previously. This is believed to be the first report on the Schottky barrier height of $In_xAl_{1-x}As$ epilayers in this composition range.

1. INTRODUCTION

The ternary compound semiconductor $In_xAl_{1-x}As$ is an important material for a great deal of heterostructure devices. However, most of the work has been focused on $In_xAl_{1-x}As$ epilayers with x values in the range between 0.4 and 0.6. Ohno et al.[1] reported a barrier height of 0.8 eV from capacitance-voltage (C-V) measurements for in situ deposited $Al/In_{0.52}Al_{0.48}As$ Schottky contacts. Lin et al.[2] investigated the barrier height of Au on n-type $In_xAl_{1-x}As$ as a function of In composition for x between 0.45 and 0.55. Both C-V and Internal photoemission spectroscopy (IPS) were used in their work. They predicted that the barrier height (Φ_{bn}) of $In_xAl_{1-x}As$ will reach the maximum at the direct-indirect bandgap transition and then decrease as x value approaches zero. Later, Chu et al.[3] found that the Schottky barrier height of InAlAs is dependent on the growth temperature of the epilayers. For the layers grown at high temperature, i.e. 580 °C, a composition-independent barrier height of 0.62 eV is obtained. While for the layers grown at 500 °C, barrier height increases from 0.75 eV and saturates at 1.2 eV as In composition decreases from 0.62 to 0.43. On the other hand, Sadwick et al.[4] had a systematic study on the characteristics of both n-type and p-type $In_{0.52}Al_{0.48}As$ Schottky diodes formed by various metals. The barrier heights obtained in their work range between 0.56 and 0.699 eV depending on metalization scheme.

Recently, $In_xAl_{1-x}As$ with less In content is of considerable interest for strain-compensated InGaAs/InAlAs/InP high electron mobility transistors (HEMTs) and InGaAs/InAlAs/GaAs metamorphic HEMTs.[5] It is believed that higher Al mole fraction will result in higher Schottky barrier and lead to improved gate characteristics.[6] In this work, we have systematically investigated the Schottky characteristics of n-type InAlAs for indium compositions between 0 and 0.35. We believe these to be the first reported results on InAlAs in this composition range and this work should be of practical interest for various heterostructure devices.

2. EXPERIMENTAL

The n-type InAlAs layers were grown by molecular beam epitaxy on (100)-oriented n^+-GaAs substrates at about 520 °C except for AlAs which was grown at 620 °C. The V/III beam equivalent pressure ratio was about 25. A highly Si-doped (4×10^{18} cm^{-3}) step-graded InGaAs or InAlAs buffer was first grown on GaAs substrate. This metamorphic buffer has been proven to be very effective in reducing threading dislocations.[7,8] The In composition of the active layer was varied between 0 and 0.35. The thickness and doping concentration of this layer was 0.4 μm and $2\text{-}5 \times 10^{17}$ cm^{-3}, respectively. Finally, a 10 nm InGaAs cap was grown to prevent the active layer from rapid oxidation. A schematic diagram of the layer structure is shown in Fig. 1. The indium composition of each layer was designed according to the growth calibration curves and verified by double crystal x-ray diffraction afterwards. Al Schottky diodes (100 μm in diameter) were fabricated by standard photolithography and lift-off techniques. The I-V and C-V characteristics of these diodes were measured using an HP 4145B semiconductor parameter analyzer and a Keithley C-V meter, respectively.

3. RESULTS AND DISCUSSION

Fig. 2 shows the I-V characteristics of the Al/$In_xAl_{1-x}As$/step-graded $In_yAl_{1-y}As$ Schottky diodes studied in this work. The ideality factors of these diodes are in the range of 1.2 to 1.3 as shown in Table I. Other important electrical properties of the diodes are also listed in Table I. Among the devices studied, diodes with x=0.2 exhibit the lowest ideality factor and leakage current density. Schottky barrier heights determined from I-V characteristics for these diodes are also listed in Table I. It can be seen that the barrier height decreases from 1.1 eV to 0.9 eV as the In composition of the epilayer increases from 0 to 0.35.

The C^{-2}-V plot of the Schottky diodes is shown in Fig. 3. The barrier heights determined by C-V measurements as listed in Table I exhibit the same trend as observed in the results of I-V measurements. However, the barrier heights obtained from C-V measurements, i.e. 1.4-1.8 eV, are significantly larger than those obtained by I-V measurements. This phenomenon is frequently seen in many experimental results. There are several factors may cause this discrepancy. Image-force lowering is the first possible cause of this situation.[9)] An estimation of the barrier lowered gives a $\Delta\Phi_b$ of about 0.1 eV. This value, however, is not large enough to account for the difference of the barrier heights obtained by I-V and C-V measurements. The second possibility is the contribution of the recombination current in the depletion region. It is well known that the ideality factor for this recombination current is 2 which leads to the deviation of the I-V characteristics of a Schottky diode from the ideal thermionic emission mechanism.[9)] Since the ideality factors of our devices are about 1.2 to 1.3, it is likely that the extrapolated J_o in this work was overestimated, and gives rise to a lower value of barrier height. Hoenow et al.[10)] have observed a similar behavior in their InAlAs Schottky contacts fabricated by different metalization techniques, i.e. pure e^--beam evaporation, Ar^+-ion etching before e^--beam evaporation, and a sputter deposition of the first metal layer. They attributed their experimental discrepancy to the plasma induced defects which may be recombination centers. Beside the two aforementioned reasons, the existence of a thin insulating interfacial layer may not be ruled out of the picture since high Al-content InAlAs is easily oxidized during processing. In fact, previous experimental results on GaP Schottky diodes prepared under different vacuum conditions have shown the impact of this interfacial layer.[11] The barrier heights deduced by the C-V measurements on the diodes metallized in a worse vacuum system are consistently higher than those obtained by the photoelectric method by as much as 0.5 eV. However, further work is needed to fully understand this issue quantitatively.

Fig. 4 shows the bandgap and barrier height of $In_xAl_{1-x}As$ versus In composition. Data obtained by I-V and C-V measurements are displayed respectively. We have also included previously reported results obtained under similar conditions for comparison.[1-4,12,13] It is interesting to note that the barrier height follows the bandgap so closely for such a wide range of composition. This is contrary to what Lin et al.[2] predicted. Nevertheless, the empirical equation proposed by the same authors predicts a barrier height of 1.45 eV for x=0.32 where the transition of direct to indirect bandgap occurs. This value is fairly consistent with the results obtained in this work.

4. CONCLUSION

In conclusion, the Schottky barrier height of Al on n-type $In_xAl_{1-x}As$ ($0 \leq x \leq 0.35$) have been first measured as a function of In composition. The barrier height is found to increase with Al content at a rate about the same as the bandgap varies. Possible reasons for the discrepancy between the absolute values of barrier height determined by I-V and C-V measurements are presented and discussed.

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Table I Characteristics of $In_xAl_{1-x}As$ Schottky diodes on GaAs

In composition	0	0.1	0.2	0.3	0.35
ϕ_b (eV)-IV	1.1	1.0	1.0	0.9	0.9
ϕ_b (eV)-CV	1.8	1.7	1.6	1.5	1.4
n	1.28	1.23	1.23	1.28	1.28
N_D ($10^{17}cm^{-3}$)	3.3	2.4	5.2	2.6	4.3
V_{BK} (V)	9	7	7	6.5	6
J_{leak}(-4V,$\mu A/cm^2$)	7.5	5.0	2.4	120	500

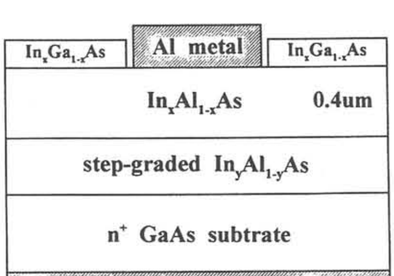

Fig.1. Schematic device structure of the $In_xAl_{1-x}As$/ step-graded $In_yAl_{1-y}As$ Schottky diodes

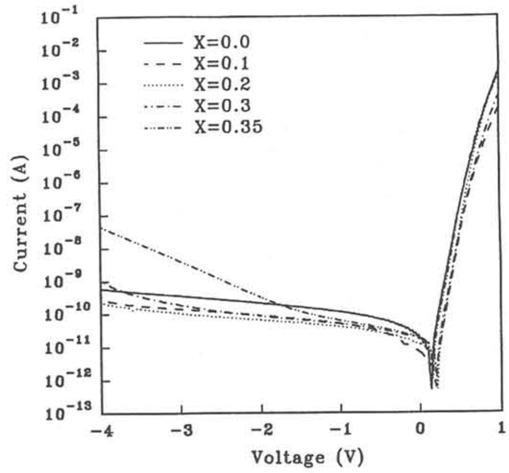

Fig.2. Current-voltage (I-V) characteristics of the $In_xAl_{1-x}As$ Schottky diodes

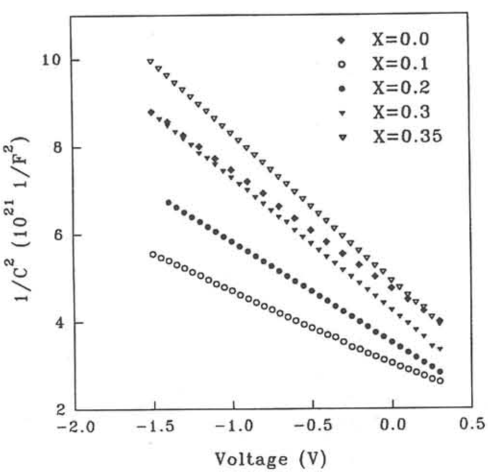

Fig.3. Capacitance-voltage (C-V) characteristics of the $In_xAl_{1-x}As$ Schottky diodes

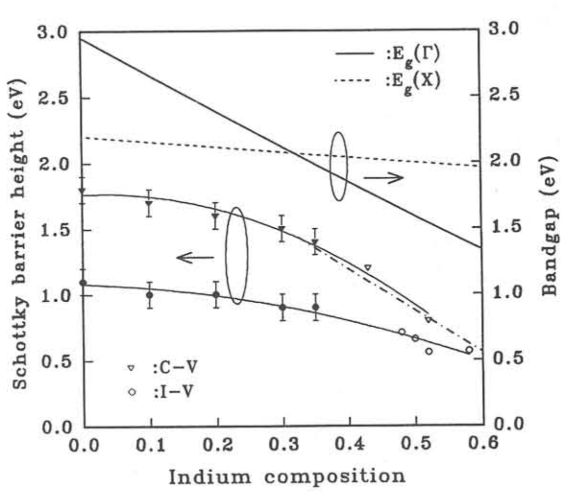

Fig.4. Bandgap and Schottky barrier height of n-type $In_xAl_{1-x}As$ epilayers as a function of In composition. (Filled symbols: this work, open symbols: previous results from Ref. 1-4, 12 and 13. Dash-dotted line: obtained from Ref. 2)