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Electrical Characterization and Analysis of Lateral p-n Interfaces Grown on (111)A GaAs Nonplanar Substrates by Molecular Beam Epitaxy

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Electrical characteristics and their dependence on growth conditions of lateral p-n junctions grown on (111)A GaAs nonplanar substrates by Molecular Beam Epitaxy have been investigated. Uniformly Si-doped and δ-doped lateral p-n junctions were grown successfully and characterized by current-voltage and capacitance-voltage measurements. The uniformly doped lateral p-n junctions showed graded interfaces and the interface became steeper as the growth temperature decreased. The δ-doped lateral p-n junctions exhibited a tunneling phenomenon in the I-V characteristics. We discuss these junction characteristics in connection with the surface migration of Ga adatoms.

1. Introduction

Studies of epitaxial growth of GaAs by MBE on non-planar and vicinal substrates has recently provided interesting and potentially useful results. These include lateral p-n junctions (plane selective doping), lateral alloy composition modulation and lateral thickness modulation [1]-[5]. Lateral p-n junction had intensively been studied for application to the current blocking layer for TJS devices [6][7]. Quantum wire lasers and resonant tunneling barrier structures have been fabricated [8], taking advantage of the lateral well thickness modulation. Conversely, these characteristics have also been used to identify the growth mechanism, microfacet formation mechanism and atomic behavior [9].

We have studied the epitaxial growth of GaAs on (111)A planar and nonplanar GaAs substrates. We have recently succeeded in growing mirror-like GaAs films on (111)A substrates [10]. Taking advantage of the three-fold symmetry of the (111)A surface and the amphoteric nature of Si dopants, we have fabricated novel lateral p-n junctions with triangular p-type regions bounded by three equivalent n-type slopes [11]. However, in order to apply this structure to low-dimensional carrier confinement systems, it is necessary to evaluate the p-n interface qualities.

In this paper, we report the electrical characteristics of lateral p-n junctions with different doping profiles and their dependence on growth conditions. On the basis of these electrical characteristics, we discuss the factors which influence the junction characteristics.

2. Experimental

Side walls of 2.5 μm depth with approximately (311)A orientation (≈30° to the substrate plane) were formed on CrO-doped GaAs (111)A substrates using conventional photolithography and selective wet chemical etching. Prior to loading into the MBE system, the wafer was carefully degreased and etched in an $NH_4OH:H_2O_2:H_2O$ solution to remove any remaining surface damage and contamination [10].

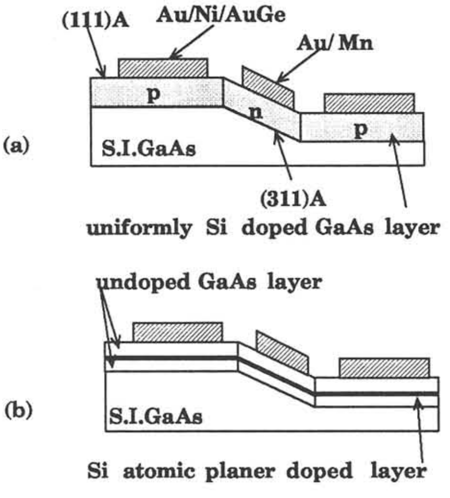

Fig.1 Schematic cross-sectional diagram of lateral p-n junction structure.
(a) A-type sample with uniformly Si doped layer
(b) B-type sample with Si δ-doped layer

We prepared two types of samples with different active layer structures in order to study Si incorporation characteristics in the vicinity of the intersection of the (111)A and

(311)A planes. A-type samples shown in Fig. 1 (a) consist of a 1.0-μm Si doped GaAs layer and a 0.1-μm undoped GaAs buffer, while B-type samples shown in Fig.1 (b) have a single 0.4μm undoped GaAs layer with a Si δ-doped plane at 0.1μm deep from the top surface. A-type samples were grown at a substrate temperature T_{sub} of 520°C, 580°C and 620°C under a high As/Ga ratio of 7. B-type samples were grown at 620°C under the same As/Ga ratio. During the Si δ-doped layer growth period, Si were supplied for 50 sec. The GaAs growth rate was 1.0 μm/h and the substrate rotation was 60rpm. A conventional Au/Ni/AuGe electrode was employed as an n-type ohmic contact to the (311)A slope facets and Au/Mn electrode fabricated as a p-type ohmic contact to the (111)A flat region. Carrier concentrations of the (311)A sidewall and the (111)A flat surface have been estimated to be $2x10^{18}$ holes cm^{-3} and $3x10^{18}$ electrons cm^{-3}, respectively, from Hall effect and cathodoluminescence measurements on Si-doped layers grown on (111)A and (311)A flat substrates. Capacitance-voltage (C-V) and current-voltage (I-V) characteristics were measured at room temperature for the junction between (311)A sidewall and (111)A upper flat surface.

3. Results and Discussion

3-1 Uniformly doped lateral p-n junctions

(a) I-V characteristics

The I-V characteristics of the A-type sample are shown in Fig. 2 for the three different substrate temperature. This figure demonstrates that the lateral p-n junctions are successfully obtained. From the I-V characteristics of all the A-type samples, we estimated the breakdown voltage V_{BD}, reverse leakage current density J_R and ideality factor, as shown in Table I. From this table, it can be seen that V_{BD} increases and J_R decreases as T_{sub} increases while the ideality factor is approximately 2.0 independent of T_{sub}.

Table I. List of parameters estimated from I-V measurement.

T_{sub}	V_{BD}	J_R	ideality factor
520°C	5V	$3x10^{-4}$ A/cm^2	~2
580°C	7.2V	$2x10^{-3}$ A/cm^2	~2
620°C	11.5V	$7x10^{-3}$ A/cm^2	~2

Because of high V_{BD}, in spite of the high carrier concentrations, the junctions of the A-type samples were all considered to be graded junctions. Therefore, we considered that the decreases in V_{BD} results from the increase in the concentration gradient at the p-n interface, that is, the p-n junctions approaches to the abrupt junctions as T_{sub} decreases. High J_R and ideality factors around 2.0 indicate that the p-n junctions contains many generation-recombination centers.

(b) C-V characteristics

Figure 3 shows the C^{-3} - V characteristics of A-type samples as a function of T_{sub}. From the linearity of the C^{-3}-V curves, it is obvious that the lateral p-n junctions of all A-type samples have graded doping profiles in the vicinity of the intersection between the side wall and the substrate plane. Employing Poisson's equation, we evaluated the carrier concentration gradient D_C from the C^{-3} - V curves. Figure 4 shows D_C as a function of T_{sub} and indicates that D_C decreases as T_{sub} increases. This is consistent with the results obtained from the I-V measurements.

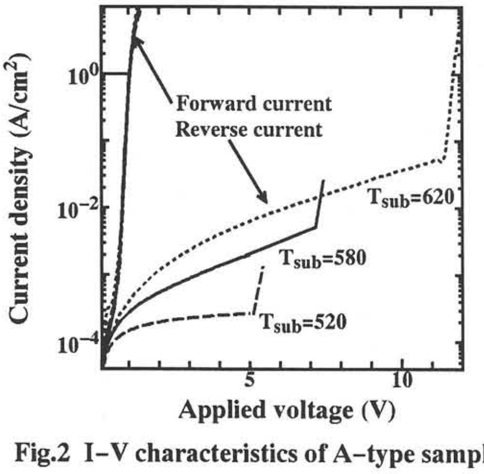

Fig.2 I-V characteristics of A-type sample

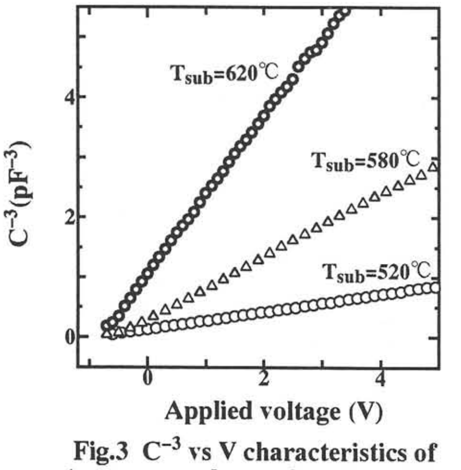

Fig.3 C^{-3} vs V characteristics of A-type sample as a function of T_{sub}

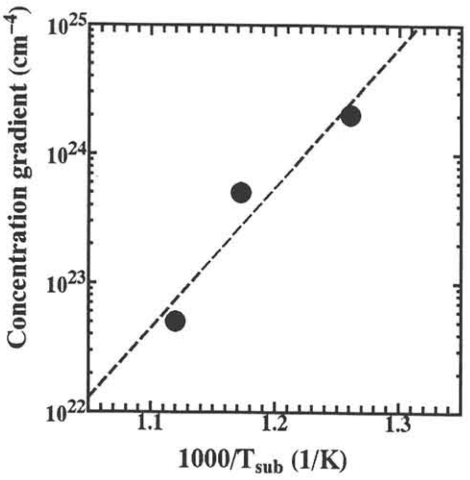

Fig.4 Concentration gradient as a function of T_{sub}

The difference in the diffusion length of Ga adatoms between (111)A and (311)A surfaces are supposed to yield an excess As region on the (111)A side and an excess Ga region on the (311)A side in the vicinity of the intersection of the two surfaces during growth. According to this hypothesis, there will be a fluctuation of the GaAs stoichiometry and a modification of Si incorporation and compensation. We consider that this is the mechanism on which the p-n interface become graded. Since the Ga adatom diffusion length decreases as T_{sub} goes down [10], the widths of two regions are accordingly reduced, hence D_C increase.

3-2 Si δ-doped lateral p-n junctions

A negative differential resistance due to a tunneling effect was observed in the I-V characteristics of B-type samples shown in Fig. 5. The peak current in the negative differential resistance regime was located around 1V and the peak to valley ratio of approximately 2.0 was obtained at room temperature.

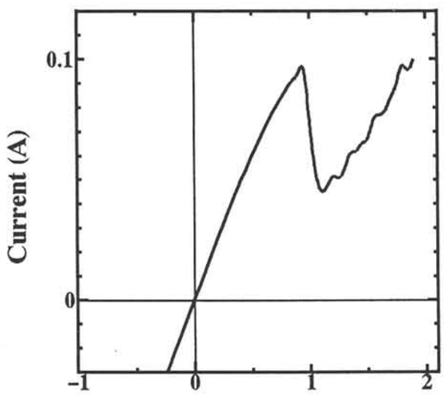

Fig.5 I-V characteristics of B-type sample

The tunneling phenomena occurs when the p-n junction is an abrupt junction in which both p and n sides are degenerate. Hence, the lateral p-n junctions of B-type samples have a steeper interface than those of A-type samples. Taking into account that Ga atoms were not supplied during Si δ-doping, Ga adatom migration between the two surfaces may be less active, hence more fixed Si incorporation sites. This qualitatively explains the difference in the junction steepness between A-type and B-type samples.

4. Conclusion

We have successfully formed uniformly Si-doped and δ-doped lateral p-n junctions as confirmed from the electrical characteristics of the junctions by I-V and C-V methods. Uniformly doped lateral p-n junctions consisted of graded p-n interfaces and the carrier concentration gradient increased as the growth temperature decreased. δ-doped lateral p-n junctions consisted of steeper p-n interfaces and exhibited a tunneling effect through the junctions. It has been suggested that Ga adatom migration between the (311)A side wall and the (111)A substrate plane influenced the Si incorporation process in the vicinity of the boundary, causing graded p-n interfaces.

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References

[1] S.Nilsson, Appl. Phys. Lett. 55(1989) 972
[2] M.C.Tamargo, J. Vac. Sci. Technol. B10(1992) 982
[3] M.E.Hoenk, Appl. Phys. Lett. 54(1989) 1347
[4] H.P.Meier, Appl. Phys. Lett. 54(1989) 433
[5] M.E.Hoenk, Appl. Phys. Lett. 55(1989) 53
[6] H.P.Meier, J. Vac. Sci. Technol. B6(1988) 692
[7] D.J.Arent, J. Vac. Sci. Technol. B8(1990) 145
[8] E.Kapon, Appl. Phys. Lett. 52(1988) 607
[9] M.Hata, J. Vac. Sci. Technol. B8(1990) 692
[10] T.Yamamoto, Inst. Phys. Conf. Ser. 120 (1991) 31
[11] M.Fujii, Surface Science 267(1992) 26