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Molecular Beam Epitaxy with Ionized Beam Doping

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In recent years, Molecular Beam Epitaxy (MBE)[1] has attracted special interest, because it is very useful to produce electron devices with ultra-thin planar structures. But, in MBE, doping elements with high vapor pressures, both n- and p- type, can not be adsorbed and incorporated into the crystal because of their low sticking coefficients. Consequently, we have proposed[2] a method to overcome the problem by ionizing the dopant molecular beam and increasing its effective sticking coefficient. Experiments with Zn in GaAs are reported that show the success of the method.

The experiments were conducted in a normal GaAs MBE system except for the dopant ionizer as shown in Fig. 1. The Zn neutral beam evaporated by usual resistive heating was bombarded and ionized by an accelerated electron beam. The ion current density (I_i) obtained by the apparatus is enough for usual deposition conditions, and the ion accelerating voltage (V_i) was set at 1-2 kV to implant the dopant ions just beneath the surface, and at 100-200 V when only the effect of ionization was examined.

Crystallographic characteristics of ion-doped GaAs films are as good as for conventional undoped MBE layers. Reflection high energy electron diffraction (RHEED) pattern shows vertically elongated clear spots, which indicate a single crystal with rather flat surface. Also, the room temperature Hall mobilities are comparable to those of LPE and VPE p-type GaAs.

The effective sticking coefficient of Zn ions was estimated from ion current density I_i, deposition rate d and carrier concentration n. Figure 2 shows the dependence of the carrier concentration on the ratio of the arrival rate of Zn ions to that of Ga atoms. The solid line drawn in the figure corresponds to a sticking coefficient of 0.03, and so the effective sticking coefficient of Zn ions was estimated to be 0.01-0.03. These results are summarized in Table 1 in comparison to conventional MBE doping with neutral beams. The sticking coefficient of Zn ions is still lower than unity but two orders larger than that of neutral Mg which is the largest one for the p-type dopants in conventional MBE GaAs, except for Ge and Si which are amphoteric. The Zn ion accelerating voltages in Fig. 2 are 1.5 kV (∘) and 200 V (□), and the fact that a 200 V point also lies near the line corresponding to a sticking coefficient of 0.03 suggests that strong ion acceleration is not essential for a large sticking coefficient.

In the future with this method not only the problem of the dopants with low sticking coefficients can be solved, but with the ion beams focused and deflected, electron devices with complicated structures can be fabricated by scanning the dopant beams and describing patterns in the doped areas. Another possible advantage of this method is that II-VI compounds may be doped either p- or n-type by implanting the accelerated ions during MBE growth.

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References

(1) A. Y. Cho and J. R. Arthur: Prog. Sol. Stat. Chem. 10 (1975) 157

(2) M. Naganuma and K. Takahashi: Appl. Phys. Lett. 27 (1975) 342

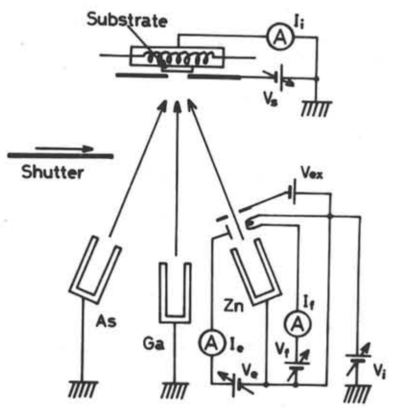

Fig. 1 Schematic of experimental arrangement. Dopant Zn is ionized by an accelerated electron (V_e) and extracted by voltage V_i. The ovens of the Ga and As neutral beams are held at the same potential as the substrate.

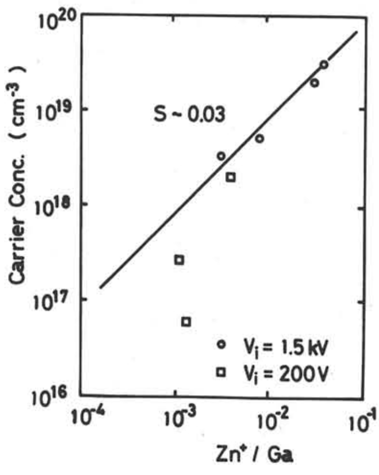

Fig. 2 Dependence of the carrier concentrations on the ratio of the arrival rates of Zn ions to that of Ga atoms. Zn ion accelerating voltages were 1.5 kV (∘), and 200 V (□). The solid line corresponds to an effective sticking coefficient of 0.03.

Table 1 Summarized results of p-type doping into GaAs by molecular beam epitaxy

Sample No.	Dopant	Ion Acc. Volt (V)	Arrival Rate ($cm^{-2}sec^{-1}$) Dopant	Ga	Carrier Conc. (cm^{-3})	Mobility (cm^2/Vsec)	Sticking Coeff.
IX - 2	Zn ion	2.0×10^2	2.5×10^{12} (0.4μA/cm^2)	1.8×10^{15} (8.3Å/sec)	2.9×10^{17}	248	0.010
IY - 9	Zn ion	1.5×10^3	6.3×10^{13} (10μA/cm^2)	2.1×10^{15} (9.5Å/sec)	2.0×10^{19}	54	0.030
G - 14	Zn atom	-	$>1.3 \times 10^{17}$	1.1×10^{15} (5 Å/sec)	1.3×10^{18}	16	$<5 \times 10^{-7}$
H - 72	Mg atom	-	2.0×10^{14}	9.2×10^{14} (4 Å/sec)	9.5×10^{17}	99	2×10^{-4}