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Schottky Barrier Height Control by Using Knock-on Effect in Ion Implantation

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Recently, it has become important to control the Schottky barrier height for formation of electrodes of the Gunn diodes, for fabrication of the decoupling and clamp diodes in such high-speed logics as complementary constant current logics (C^3L), and so on. However, in order to control the barrier height effectively by changing impurity concentration at the surface of semiconductors[1], formation of the highly-doped layer with several 10 Å thick is needed[2].

One of the methods obtaining such thin layers is considered to use the knock-on atoms in ion implantation into double-layer substrates, since they will have lower average energies than 1 keV. This paper presents a study on the method utilizing the knock-on effect to impurity doping. This method will have the following merits over other doping methods; (1) Formation of the thin layers, (2) Maximum concentration at the surface, (3) Low dose (in suitable conditions, amount of the knocked-on atoms is known about 10 times greater than that of implanted ions) and (4) Simple process (ion beams to form other doping layers can also be used for this process).

Possibility of this method was experimentally checked as follows. In order to form n^+ layers on Si surfaces, Sb films with 400-900 Å thick were evaporated on n(∿10Ωcm)-n^+ epitaxial wafers. 80-150 keV-Ar ions were implanted at doses of 1×10^{11} -$5\times10^{13}cm^{-2}$ as shown in Fig.1 and four regions were formed on the same wafer. After implantation, the Sb films were etched off and amount of the knocked-on atoms was measured for the regions C and D by using the N^+ ions backscattering technique. It was observed that about one Sb atom in a 400 Å-thick film is knocked-on into Si by an 80 keV-Ar ion. After annealing process (700°C,10min.), the Schottky barrier height for Au electrodes was measured. Fig.2 and 3 show the typical V-I characteristics of the Au-Si diodes. The barrier heights listed in Table 1 were calculated from the J_s in Fig. 3 by assuming that $A^*=110\ A/cm^2/K^2$. Decrease of the barrier height by 0.14 eV was observed in the region C where 150 keV-Ar ions were implanted through a 500 Å-thick Sb film at a dose of $5\times10^{13}\ cm^{-2}$. On the other hand, the decrease was less than 0.04 eV in the region B where Ar ions were directly implanted into a bare Si under the same conditions.

Next, distributions of donor centers in Si were measured by using the usual C-V method. The results are shown in Fig.4, in which formation of donor centers is observed even in the region B and the peak depth (∿1600 Å) corresponds to the average projected range of 150 keV-Ar ions in Si. From these facts, it may be said that these centers are associated with implanted Ar ions. However, it has already been shown from the V-I measurements that they hardly contribute to the change of the barrier height. Similarly, the centers existing in a deeper portion than 600 Å will be due to Ar ions in the region C. Analysis of those existing in the shallower portion has not been done at present. Because of these centers, the built-in potential could not be derived from the C^{-2}-V plot. These centers will be able to be annihilated by optimizing the implantation conditions (energy, dose, ion species, etc.) and the annealing conditions.

In conclusions, it has been shown that the Schottky barrier height can be controlled by the knock-on doping method and that optimization of the process such as use of Si beams is necessary to annihilate the donor centers due to ion beams.

[References] 1) J.M.Shannon; Appl.Phys.Lett., 24 (1974) 369 2) T.Hariu et.al; Proc. IEEE, 63 (1975) 1523

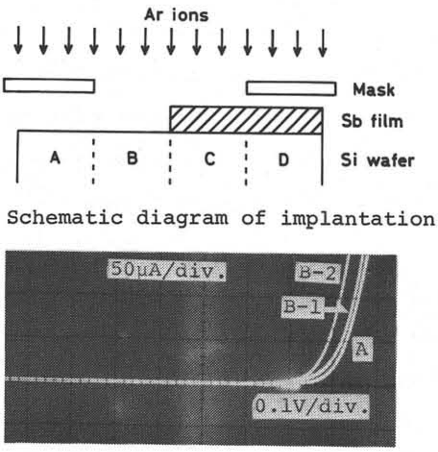

Fig.1 Schematic diagram of implantation.

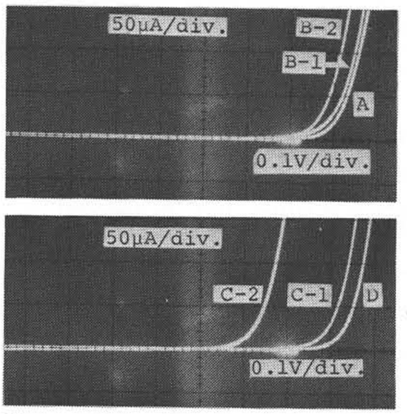

Fig.2 V-I characteristics of Au-Si diodes. Alphabet of each diode corresponds to Fig.1. Implantation conditions; 150 keV, $5\times10^{12}cm^{-2}$ for No.1, 5×10^{13} cm^{-2} for No.2. Layer thickness; 500 Å

Diodes	ϕ_{BN} (eV)	n-value
A	0.74	1.34
B-2	0.70	1.49
C-2	0.60	1.17

Table 1 ϕ_{BN} and n-values of Au-Si diodes.

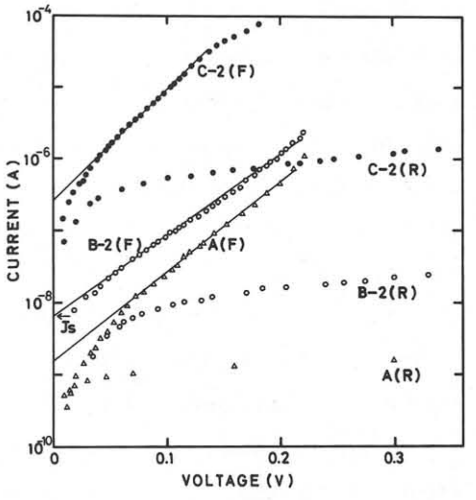

Fig.3 V-I characteristics of Au-Si diodes. F and R show the forward and reverse characteristics.

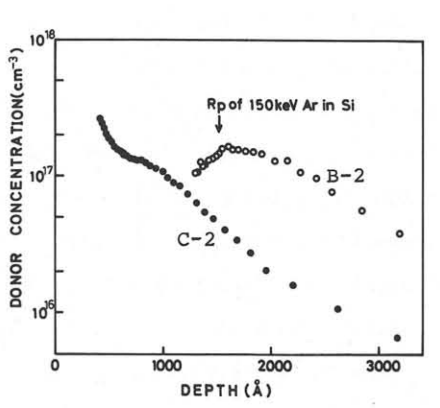

Fig.4 Donor concentration of implanted layers