Effects of Ar beam irradiation on Si-Based Schottky contacts

S.Hisamoto, J.Liang, and N.Shigekawa
Graduate School of Engineering
Osaka City University
Sumiyoshi Osaka Japan

Abstract—**Effects of Ar beam irradiated during the surface-activated bonding process on n-Si and p-Si based Schottky barrier diodes (SBDs) were investigated by atomic force microscope measurements. Charges in the electrical characteristics of SBDs were attributed to the variation in Schottky barrier heights due to the Ar beam irradiation.**

Keywords: surface-activated bonding, Si, Ar beam, Schottky contact

I. INTRODUCTION

Surface-activated bonding (SAB) technologies have widely been applied for fabricating novel heterojunctions [1] and heterojunction-based functional devices [2] such as tandem solar cells since materials with different crystal structures, lattice contacts, and thermal expansion coefficients can be bonded to each other. In the SAB process, the surfaces of samples are activated by irradiating beam of Ar atoms, which is assumed to inevitably introduce damages on sample surfaces similarly to the case of Ar-ion bombardment [3]. We previously reported variations of electrical characteristics of SAB-based Si/Si junctions due to the post-bonding annealing, which suggested that the annealing played a role of reducing the density of interface states on the surfaces of Si substrates [4]. In this work, effects of Ar beam irradiation on Si surfaces were examined by measuring the characteristics of Schottky contacts fabricated on substrates that passed through the surface activation process.

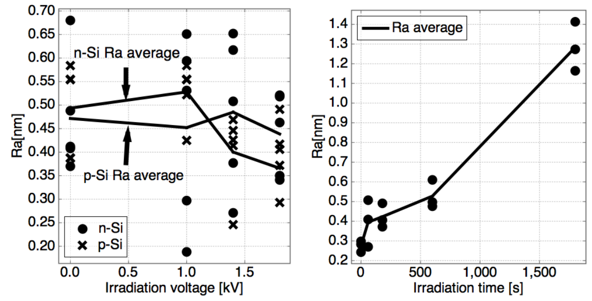
II. EXPERIMENTAL

We used phosphorus (P)-doped n-Si (100) substrates and boron (B)-doped p-Si (100) substrates for Ar fast atom beam (FAB) irradiation experiment. Hall measurements at room temperature revealed that the resistivity and carrier concentration were 0.14 Ωcm and 4.8×10^{16} cm^{-3} for the n-Si substrates. Those of the p-Si substrates were 0.11 Ωcm and 2.4×10^{17} cm^{-3}, respectively. Ohmic contacts on the backsides of p-Si substrates were formed by evaporating Al/Ni/Au and an annealing at 400°C for 60s in N_2 gas ambient. Subsequently the mirror-polished surfaces were irradiated with the FAB of the Ar using the SAB facilities. Schottky barrier diodes (SBDs) were fabricated by evaporating Ti/Au on the surfaces. Similarly the surfaces of n-Si substrates were exposed to the FAB in similar manners after Ti/Au-based ohmic contacts were formed on their backsides. We fabricated n-Si SBDs by evaporating Au as Schottky contact metal. The voltages for the FAB irradiation were varied between 1 and 1.78 kV as shown in Table I, while the time of irradiation was 180s in most cases. We measured current-voltage (I-V) and capacitance-voltage (C-V) characteristics of diodes at room temperature. The C-V measurements were performed at 100 kHz. We also observed the structure of surfaces prior to evaporating the Schottky contact metals by using an atomic force microscope (AFM).

Table I The irradiation condition of the surface to Si substrates.

Sumple No.	Polarity	Target Voltage(kV)	Measured Voltage(kV)
1	N	1	0.94~0.99
	P		0.97~1.01
2	N	1.2	1.21~1.29
	P		1.24~1.34
3	N	1.4	1.35~1.45
	P		1.34~1.44
4	N	1.6	1.53~1.65
	P		1.54~1.66
5	N	1.78	1.71~1.83
	P		1.76~1.85

III. RESULT AND DISCUSSIONS



(a) (b)

Fig.1 Relationship of the roughness average and (a) irradiation voltage and (b) irradiation time.

The relationships between the roughness average Ra and the irradiation voltage and those between Ra and the irradiation time are shown in Figs. 1(a) and 1(b), respectively. The results shown in Fig. 1(b) were achieved for an irradiation voltage of 1.78 kV. It is found form Fig. 1(b) that Ra is markedly larger for a longer irradiation time. In contrast, as shown in Fig. 1(a), no clear correlation is observed between Ra and the irradiation voltage.

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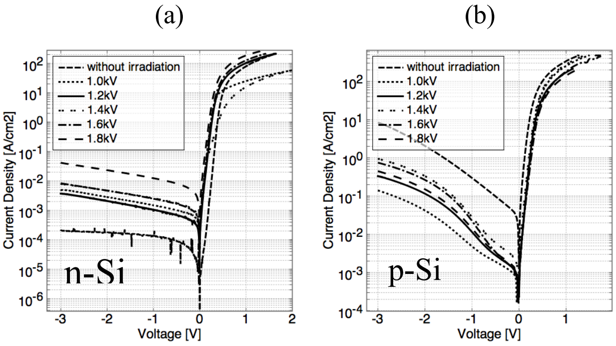

Fig.2 *I-V* characteristics of (a) Au/n-Si and (b) Ti/p-Si SBDs.

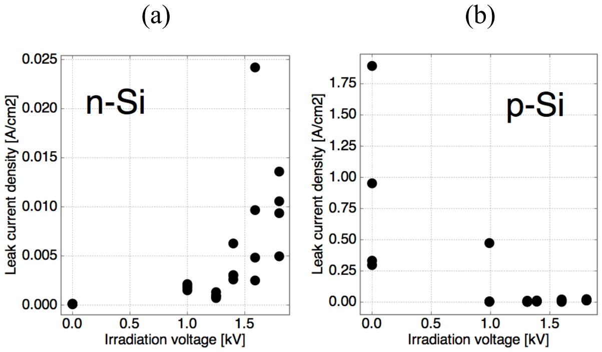

Fig.3 Relationship between the revers-bias current at -1 V and the irradiation voltage for (a) Au/n-Si and (b) Ti/p-Si SBDs.

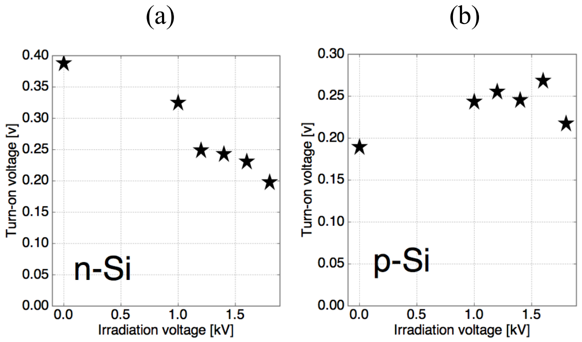

Fig.4 Relationship between the turn-on voltage and the irradiation voltage for (a) Au/n-Si and (b) Ti/p-Si SBDs.

I-V characteristics of Au/n-Si and Ti/p-Si SBDs are shown in Figs. 2(a) and 2(b), respectively. Note that the substrates were grounded in the measurements for n-Si diodes while the Schottky contacts were grounded in the measurements for p-Si diodes. The magnitudes of the reverse currents at -1 V of both diodes are shown in Figs. 3(a) and 3(b). These figures indicate that the reverse current increased as the irradiation voltage increased for Au/n-Si SBDs. The reverse-bias current for Ti/p-Si SBDs, in contrast, decreased as the irradiation voltage increased.

The turn-on voltages of the two diodes, which were obtained from their forward-bias characteristics, are shown in Figs. 4(a) and 4(b). As the irradiation voltage was raised, the turn-on voltage for Au/n-Si SBDs decreased while the turn-on voltage for Ti/p-Si SBDs increased.

The flat-band voltage (V_{FB}) extracted from the C-V characteristics of Au/n-Si and Ti/p-Si SBDs are shown in Figs. 5(a) and 5(b), respectively. It is found that V_{FB} of Au/n-Si SBDs decreases and that of Ti/p-Si increases as the irradiation voltage increases.

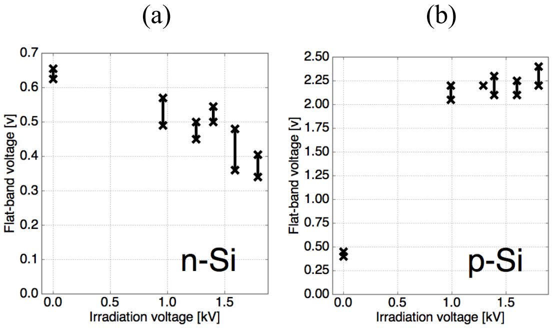

Fig.5 Flat band voltage extracted from *C-V* characteristics for (a) Au/n-Si and (b) Ti/p-Si SBDs.

The changes in the reverse-bias current, turn-on voltage, and V_{FB} in Au/n-Si SBDs [Figs. 2(a), 3(a), 4(a), and 5(a)] are likely to be explained by the scheme that the Schottky barrier was lowered when n-Si surfaces were irradiated with the FAB. The changes in Ti/p-Si SBDs [Figs. 2(b), 3(b), 4(b), and 5(b)] imply that the Schottky barrier was heightened due to the irradiation of FAB. The variation in the Schottky barrier heights, which was similar to a previous report for changes in characteristics of Si SBDs exposed to the implantation of Ar ions [3], suggests that the introduced damages work as donor-like defects on the surface of Si.

IV. CONCLUSION

Changes in the characteristics of n-Si and p-Si SBDs as well as in the surface roughness of Si substrates due to the irradiation of FAB of Ar were investigated. Measurements of I-V and C-V characteristics indicated that the heights of Schottky barrier of n-Si (p-Si) decreased (increased) due to the FAB irradiation for 180s. The surface roughness got more marked for longer periods of the FAB irradiation. The variation in the Schottky barrier height was assumed to be attributable to the possible formation of donor-like defects.

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