Penetration depth of effects of irradiation of Ar fast atom beams in n-Si surfaces

°Y. Matsumoto, S. Hisamoto, J. Liang, and N. Shigekawa
Graduate School of Engineering
Osaka City University
Sugimoto 3-3-138, Sumiyoshi, Osaka 558-8585, Japan

Abstract—**Characteristics of damages in n-Si due to irradiation of Ar fast atom beams (FAB) are examined. Their penetration depth is estimated to be ≈ 50 nm by analyzing current-voltage characteristics of n-Si Schottky barrier diodes that are fabricated on wet-etched surfaces after irradiation of Ar FAB.**

Keywords: surface-activated bonding, Si, Ar fast atom beams, depth of damages

I. INTRODUCTION

Surface-activated bonding (SAB) technologies have widely been applied for fabricating novel heterojunctions [1] and electrodes with a thickness of several-ten microns [2] since materials with different crystal structures, lattice constants, and thermal expansion coefficients can be bonded to each other. In the SAB process, the surfaces of samples are activated by irradiating Ar fast atom beams (FAB), which is assumed to inevitably introduce damages on sample surfaces similarly to the case of Ar-ion bombardment. We previously reported that an amorphous-like layer with a thickness of 7.5 nm was observed at a Si/Si interface fabricated using SAB [3]. We also reported effects of irradiation on n-Si and p-Si based Schottky barrier diodes (SBDs) [4]. In that work we obtained results suggesting the heights of Schottky barrier of n-Si (p-Si) decreased (increased) due to irradiation of Ar FAB. In this work, we fabricated SBDs with Schottky contacts on surfaces of n-Si substrates that were wet-etched after irradiation of Ar FAB. The penetration depth of effects of FAB irradiation was estimated by examining the relationship between the current-voltage *(I-V)* characteristics of SBDs and the etching depth.

II. EXPERIMENTAL

We used phosphorus (P)-doped n-Si (100) substrates. Hall measurements at room temperature revealed that the resistivity and carrier concentration were 0.05 ~ 0.2 Ωcm and 3.9×10^{16} cm^{-3} for the n-Si substrates. Initially a SiO_2 layer was formed on both sides of Si substrates by wet oxidation. Ohmic contacts on the backsides of Si substrates were fabricated by evaporating Ti (100 nm) /Au (100 nm) after removing the SiO_2 layer using buffered HF (BHF). Subsequently, a major part of the SiO_2 layer on the mirror-polished surfaces was removed by BHF and the exposed Si surfaces were irradiated with Ar FAB. The acceleration voltage and time for the FAB irradiation were the same as the typically used in the conventional SAB process. The Si surfaces were etched using tetramethylammonium hydroxide (TMAH) with mask of SiO_2. Next, the remaining SiO_2 layer was removed by BHF. The etching depth, which was estimated by characterizing steps on Si surfaces due to the partial coverage by SiO_2, was formed to be ranging between 5 and 350 nm. Finally, we fabricated n-Si SBDs by evaporating Au (100 nm) as Schottky contact metal. We measured current-voltage (*I-V*) characteristics of SBDs with 300-μm-by-400-μm Schottky contacts at room temperature. The entire process for fabricating samples is shown in Fig. 1.

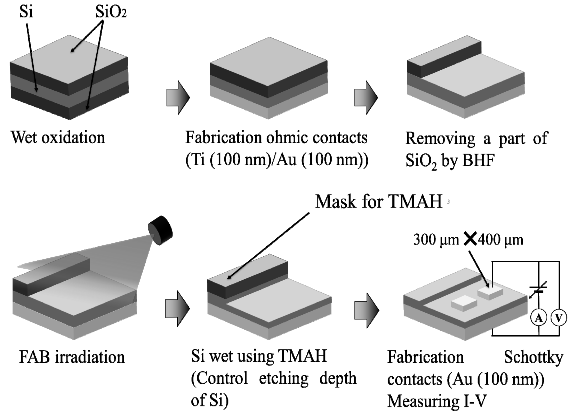

Figure 1. Entire process for fabricating samples.

III. RESULTS AND DISCUSSIONS

I-V characteristics of SBDs on Si surfaces (1) without FAB irradiation, (2) irradiated with FAB (without etching after irradiation), and (3) 50-nm etched after FAB irradiation are shown in Fig. 2 (a). The relationship between depth of etching and the magnitudes of the reverse current density at -1 V is shown Fig. 2 (b). As is typically seen from Fig. 2 (a), the reverse current density was increased due to irradiation of Ar FAB, and decreased by more deeply etching Si surfaces. The change in the reverse current due to FAB irradiation was in agreement with our previous work [4]. The reverse current density for an etching depth ≥ 50 nm was similar to that of SBDs without FAB irradiation. We extracted Schottky barrier height (SBH) from the respective *I-V* characteristics. The relationship between SBH and the etching depth is shown in Fig. 3. In accordance with behavior of the reverse current, SBH was decreased due to irradiation of Ar FAB, and increased by increasing the etching depth. Finally, SBH was close to that of SBDs without FAB irradiation for an etching depth ≥ 50 nm. Their results indicated that effects of FAB irradiation on the electrical properties of

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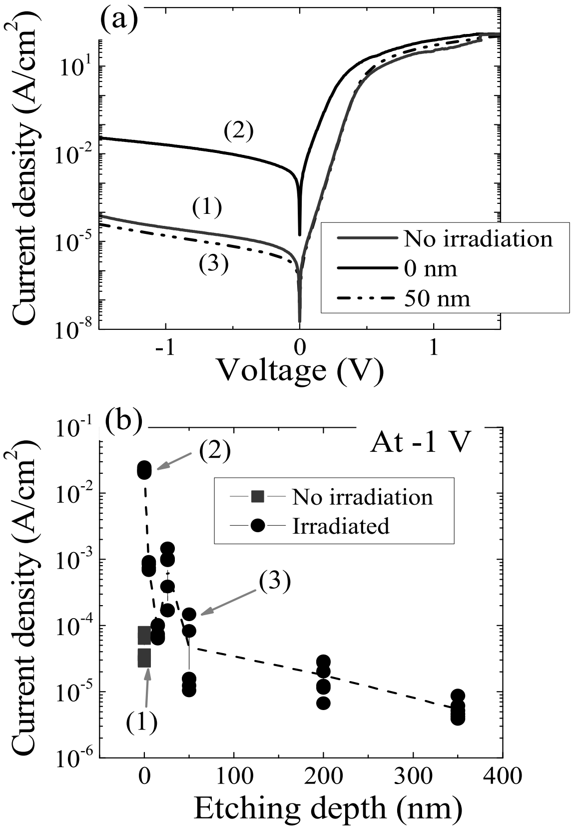

Figure 2. (a) *I-V* characteristics of SBDs on Si surfaces (1) without FAB irradiation, (2) irradiated with FAB (without etching after irradiation), and (3) 50-nm etched after FAB irradiation. (b) Relationship between reverse current density at -1 V obtained from *I-V* characteristics and etching depth.

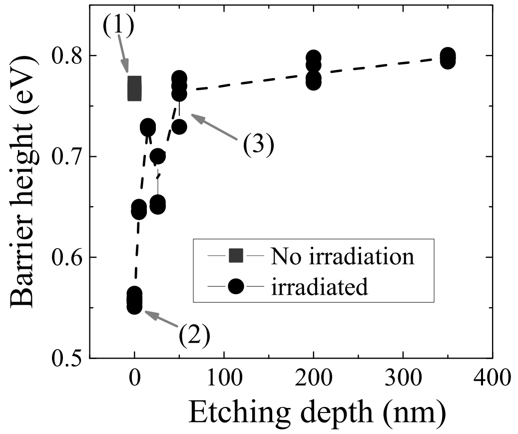

Figure 3. Relationship between Schottky barrier height extracted from *I-V* characteristics and etching depth.

SBDs, which were possibly due to damages formed in Si, were apparent in a ≈ 50-nm-thick region near the surface. It is notable that the penetration depth of FAB irradiation effects obtained in this work was much larger than the thickness of an amorphous-like layer formed at a Si/Si interfaces, or the depth of a region in which Si lattices were deformed due to FAB irradiation. We observed a singular peak at 26 nm. The origin of the peak is not clear for the present.

IV. CONCLUSION

Penetration depth of effects of irradiation of Ar fast atom beams (FAB) in the Si (100) substrates was investigated by measuring current-voltage characteristics of n-Si Schottky barrier diodes fabricated on etched surfaces of the FAB irradiation. The penetration depth was estimated to be ≈ 50 nm, which was much larger than the thickness of an amorphous-like layer formed at a Si/Si interfaces fabricated using surface-activated bonding.

REFERENCES

[1] Naoteru Shigekawa, Sae Shimizu, Jianbo Liang, Masato Shingo, Kenji Shiojima, and Manabu Arai, "Transport characteristics of minority electrons across surface-activated-bonding based p-Si/n-4H-SiC heterointerfaces", Jpn. J. Appl. Phys. **57**, 02BE04 (2018).

[2] Jianbo Liang, Katsuya Furuna, Moeko Matsubara, Marwan Dhamrin, C-VBonding as Prototypes of Ultra-Thick Metal Contacts in Devices", ECS J. Solid State Sci. Technol., 6 (9) pp. 626-632 (2017).

[3] Masashi Morimoto, Jianbo Liang, Shota Nishida and Naoteru Shigekawa, "Effects of annealing on electrical properties of Si/Si junctions by surface-activated bonding," Jpn. J. Appl. Phys. **54**, 030212 (2015).

[4] S. Hisamoto, J. Liang, and N. Shigekawa, "Effects of Ar beam irradiation on Si-based Schottky contacts" IMFEDK, pp. 40-41 (2016).