

## Soft X-ray Photoelectron Spectroscopy on Chemical Bonding States of Boron Doped in Si Fin Structures

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### 1. Introduction

Three dimensional transistors, such as FinFETs, must be important in future LSIs. Because doping technique is a significant issue in the process technologies of the three dimensional structures, new methods of doping such as plasma doping [1] are investigated as well as conventional ion implantation. The depth profiling and activation of impurities doped in three dimensional structures are also an important issue. Application of SSRM [1, 2] and SIMS [2] to these issues were used to evaluate depth profiles of carrier and impurity concentrations.

We have evaluated chemical bonding states of impurities and their depth profiles in Si shallow junctions by combining soft X-ray photoelectron spectroscopy (SXPS) and step by step etching techniques [3]. This approach enables us to reveal concentrations of both activated and non-activated impurities and to classify impurity clusters having various sizes. In this study, we applied this approach to Fin structures doped with B for the first time, and demonstrated feasibility of detecting the difference in the depth profile of impurities doped on top and side of the Fins.

### 2. Experimental

The long Fin structures (width: 300nm, height: 200nm, space between neighboring Fins: 900nm) formed in parallel on SOI substrates (Fig.1) were doped with B by plasma doping up to a dose of  $1 \times 10^{15} \text{cm}^{-2}$  followed by spike-RTA (spike-rapid thermal annealing) at 1000°C. The three samples were prepared as follows. One is a sample without any treatment after the spike-RTA. The second sample was treated by diluted HF solution to remove native oxide formed on the surface of Fins and to etch BOX between Fins in depth of a few tenth nm. The third sample was shallow-etched sample, in which the Fin surface was removed by the isotropic etching with 1 nm after the diluted HF treatment used for the second sample. For the isotropic etching, we employed the step-by-step etching in which a couple of processes of surface oxidation in an atmosphere containing ozone at room temperature and removal of the formed oxide by HF treatment was repeated until an etch depth reaches 1 nm.

B  $1s$  and Si  $2p$  photoelectron spectra were excited by soft X-rays having a low photon energy of 500 eV. The measurements were carried out at the beam line 27 in Super Photon Ring 8 GeV (SPring-8) facility. These photoelectron spectra were measured for the two configurations as shown in Fig. 2. In the case of detecting photoelectrons emitted parallel to the side-wall (having the largest area) of Fins (parallel geometry) as shown in Fig. 2(a), photoelectrons arising from top surface of Fins and surface of BOX are mainly detected and those arising from side walls of Fins are hardly detected because the grazing take-off angle (TOA) for the side walls of Fins. On the other hand, in the case of grazing TOA (grazing geometry) to the top surfaces of Fins as shown in Fig. 2(b), photoelectrons arising from top surfaces of Fins are remarkably reduced and those arising from the side walls of Fins are mainly detected. Here, photoelectrons arising from surface of BOX are blocked by the Fins.

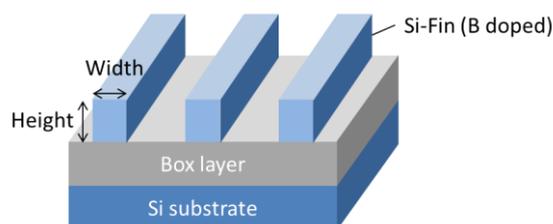


Fig. 1 Schematic of Fin structure.

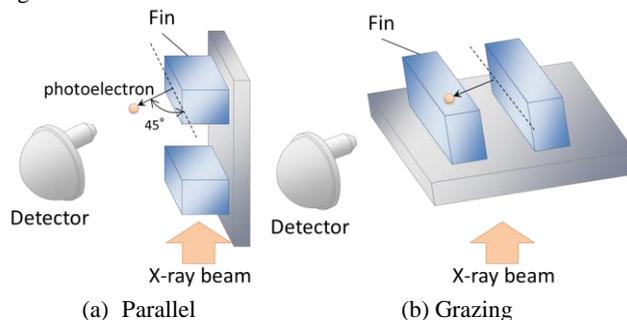


Fig. 2 Schematic of sample geometry for SXPS measurements. (a) Parallel: photoelectrons from top surfaces of Fins are mainly detected. (b) Grazing: photoelectrons from side walls of Fins are mainly detected.

### 3. Results and Discussion

Figure 3 shows B 1s spectra arising from the samples with and without HF treatment placed in the parallel geometry. The observed B 1s spectra can be decomposed into four spectra whose binding energy (BE) are 188.3 eV (referred to hereafter as BEM), 189.6 eV (referred to hereafter as BEH), 193.2 eV (referred to hereafter as BE(BO<sub>1</sub>)) and 194.3 eV (referred to hereafter as BE(BO<sub>2</sub>)). The spectra having BEM and BEH were observed for the B doped on a flat Si surface [3], while the spectra having BE(BO<sub>1</sub>) and BE(BO<sub>2</sub>) were correlated with oxidized B in silicon oxide [3]. B detected in the parallel geometry arises from the top surface of Fins and the surface of BOX.

After the HF treatment, spectrum having BE(BO<sub>2</sub>) disappeared. This indicates that spectrum having BE(BO<sub>2</sub>) are correlated with oxidized B on the surface of BOX, since the oxidized B was etched away by HF treatment. The spectrum having BE(BO<sub>1</sub>), on the other hand, is considered to arise from oxidized B in native oxide formed on the surface of Fins. The BE(BO<sub>1</sub>) is different from BE(BO<sub>2</sub>) presumably because thickness of native oxide is extremely small as compared with that of oxide formed during spike-RTA.

The spectra having BEH and BEM can be correlated with non-activated B clusters with two sizes [3]. Here, electrically activated B having BE of 187.1 eV is hardly observed since concentration of the activated B is much lower than those of clustered B in the near surface region.

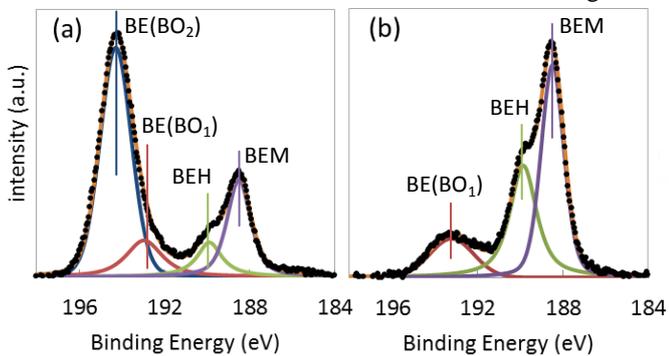


Fig.3 B 1s spectra for parallel geometry measured (a) before HF treatment and (b) after HF treatment.

Figure 4 shows B 1s spectra measured for two geometries for the sample after HF treatment and that after shallow etching with the depth of 1nm. It can be seen from this figure that for both samples the intensity ratio of the spectrum having BEH with respect to the spectrum having BEM for parallel geometry is different from that for grazing geometry, in other words, the intensity ratio for the side wall is higher than that for the top surface.

The intensities of B 1s spectra having BEH and BEM shown in Fig. 4 normalized by the intensities of corresponding Si 2p<sub>3/2</sub> spectra were analyzed to obtain B concentration calculated for B 1s spectra having BEH and BEM (abbreviated in the following as B (BEH) and B (BEM)) on top and side wall for two geometries. The results are shown in Fig. 5. It can be seen from this figure that total concentration of B, which is summation of concentra-

tion of B (BEH) and B (BEM), decreases after the shallow etching. Total concentration of activated B on the top surface of Fin was found to be roughly the same with that on the side wall of Fin. However, for B clusters the ratio of concentration of B (BEH) with respect to that of B (BEM) on the top surface of Fin is different from that on the side wall of Fin.

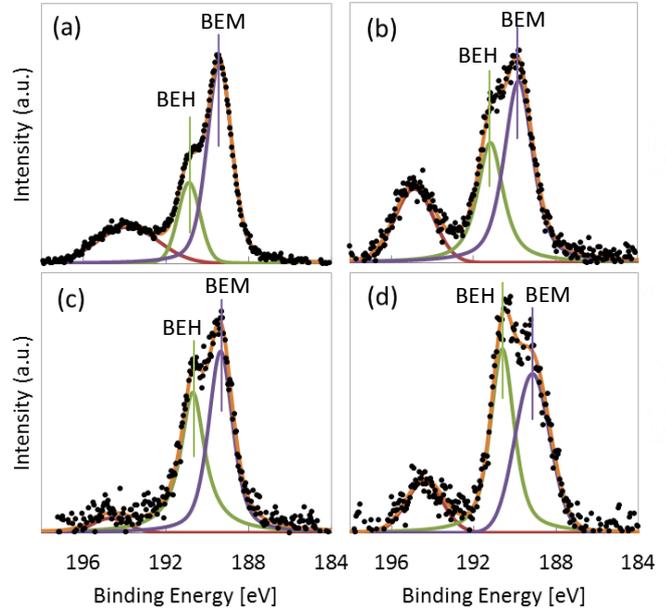


Fig.4 B 1s spectra measured after HF treatment for (a) parallel and (b) grazing geometry. B 1s spectra measured after 1-nm-etching for (c) parallel and (d) grazing geometry.

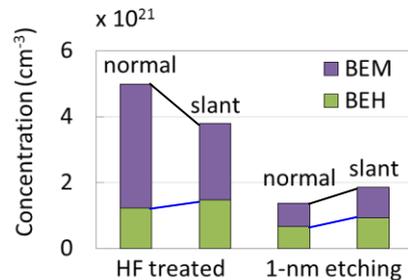


Fig.5 Concentration of B (BEH) and that of B (BEM) determined for sample after HF treatment and that determined for sample after 1-nm etching, measured for parallel and grazing geometry.

### 4. Conclusion

Concentration and chemical bonding states of B on the Fin structures were evaluated by XPS. It was found that concentration of activated B is roughly the same on the top surface and sidewall of the Fin, but ratio of concentration of non-activated B (BEH) cluster with respect to concentration of non-activated B (BEH) on the top surface of the Fins are different from that on the side wall of the Fins. One of the possible origins are the difference in the doping profile on top surface and on the side wall of the Fins.

### References

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