NO-POA を行った SiO_2/4H-SiC(0001)と(1-100)のバンドアライメント及び電流伝導機構の観点での比較

Comparisons of band alignments and current conduction mechanisms between SiO_2/4H-SiC (0001) and (1-100) systems with NO-POA

[1]Dept. of Materials Engineering, The Univ. of Tokyo, [2]DENSO CORPORATION
°Tae-Hyeon Kil[1], Atsushi Tamura[1], Masato Noborio[2], Sumera Shimizu[2] and Koji Kita[1]
E-mail: thkil@scio.t.u-tokyo.ac.jp

[Introduction] For Si-face 4H-SiC, the post-oxidation annealing in NO (NO-POA) is the most common method to reduce D_{it}. However, the effects of NO-POA on the current conduction mechanism has not been well studied, even though our previous study revealed that POA has a significant impact on SiO_2/SiC band alignment [1]. In addition, it would be also important to see the crystal orientation dependence of such NO-POA effects. In this work, we compared the effects of NO-POA on the band alignment and the leakage currents of 4H-SiC MOS capacitors fabricated on (0001) Si-face and (1-100) m-face.

[Experiments] N-type 4H-SiC Si-face and m-face wafers with epitaxial layers (N_D~1.0×10^{16} cm^{-3} and 5×10^{15} cm^{-3}, respectively) were dry oxidized at 1300°C, with 100% for Si-face and 2% oxygen (diluted with N_2) for m-face, respectively. NO-POA (1150°C, 33% NO with N_2) were performed on both substrates for 0.5–8hr, followed by the deposition of electrodes (top: Au, bottom: Al). Gate leakage currents were measured with varying temperatures from -150 to 150°C. The conduction band offset of each sample was also estimated from valence band spectra with XPS after thinning of oxides down to ~3 nm by BHF etching.

[Results & Discussions] Fig. 1 shows the gate leakage currents of both MOS capacitors on Si-face and m-face, measured at −150°C, to obtain the pure Fowler-Nordheim (F-N) tunneling current component. Note that we cannot fairly compare the noise level currents (E<~4 MV/cm) due to the inconsistent electrode size between the two crystal faces. First, if we compare the case of w/o POA (black line), the F-N current level was similar on both crystal faces. However, after NO-POA, F-N current decreased on Si-face, whereas it increased on m-face. Therefore, after 2−8 hours of NO-POA, the F-N current levels were significantly different (lower on Si-face). Fig. 2 shows the change of the conduction band offset (ΔE_c) with varying NO-POA duration on Si-face and m-face 4H-SiC, estimated from F-N barrier height and also from valence band XPS. Before NO-POA, we can see similar conduction band offsets on Si-face and m-face, which sounds consistent with the result in Fig. 1. However, by introducing nitrogen, we could see the barrier height enlargement with increasing nitrogen concentration on Si-face, whereas the reduction of the barrier height was clearly seen on m-face, as shown in Fig. 2. We already discussed a possible origin of such phenomenon from the viewpoint of the dipole layer formation at the interface [1]. The significantly different effects of NO-POA on FN leakage currents (Fig. 1) for between Si-face and m-face capacitors are attributed to the change of the conduction band offset by NO-POA. For further comparisons of the current conduction mechanism between those capacitors, we measured leakage currents at various temperatures (from RT to +150°C). By assuming the leakage current consists of F-N and Poole-Frenkel (P-F) currents [2], the P-F current component was extracted by subtracting J_{FN} (F-N current) from the whole current (J_{all}), by taking account of the certain temperature dependence of J_{FN} [2, 3]. Figure 3 shows the calculated P-F plot for each crystal orientation. From those linear plots, we can deduce the effective trap levels in oxides on each capacitor. For Si-face and m-face capacitors, there was not a significant difference in trap levels (~1.7 eV and ~1.5 eV, respectively), which is not conflicting with the suggested C-related defect levels from simulation study [4]. Therefore, the P-F conduction mechanism, which will dominate the leakage current at higher temperatures, will be commonly determined by the identical oxide traps on both crystal orientations.

[Conclusions] After NO-POA the F-N current, which dominates the leakage current at low temperature, was quite lower on Si-face than on m-face, which is attributed to the difference in the band alignment between those faces. However, the P-F current component, which appears only in higher temperature regions showed almost identical conduction mechanisms for the MOS capacitors on both faces. Thus, the difference in leakage properties between them is mostly coming from the band alignment difference.

References [1] T. H. Kil and K. Kita, 80th JSAP Autumn Meeting, Sapporo (2019). [2] M. Sometani et al., J. Appl. Phys. 117, 024505 (2015). [3] A. Tamura et al., ICSCRM 2019, Kyoto. [4] F. Devynck et al., Phys. Rev. B. 84, 235320 (2011).

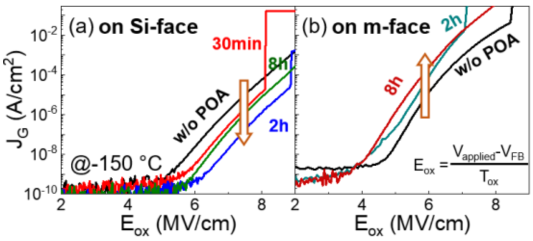

Fig.1 Gate leakage at -150 °C on (a) Si-face & (b) m-face MOS capacitors.

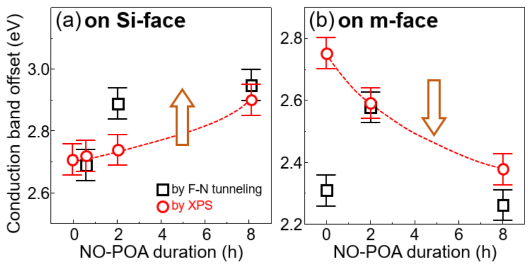

Fig.2 Estimated ΔE_c by F-N tunneling and XPS on (a) Si-face & (b) m-face.

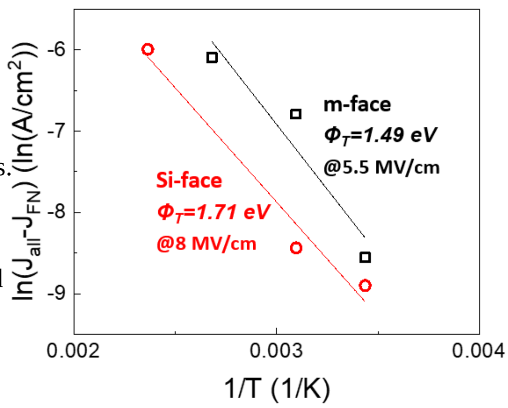

Fig.3 Poole - Frenkel plot for MOS capacitors on m-face (black and square) and Si-face (red and circle).