Non-destructive Characterization of Oxide/Ge Interface by Photoluminescence Measurement

Univ. of Tokyo[1], JST-CREST[2] °S. Kabuyanagi[1, 2], T. Nishimura[1, 2], T. Yajima[1, 2] and A. Toriumi[1, 2]

E-mail : kabuyanagi@adam.t.u-tokyo.ac.jp

[Introduction] The performance of Ge MOSFETs has been dramatically improved by achieving good oxide/Ge interfaces[1]. For adopting Ge to actual circuits, non-destructive, fast and in-line characterization techniques probing the interface are needed. The objective of this work is to evaluate the oxide/Ge interface by photoluminescence (PL) analysis, which has been used for characterization of oxide/III-V semiconductor interface[2]. In addition, it should be noted that PL analysis can directly characterize only the oxide/Ge interface, while electrical properties such as C-V curve include information about inside of oxide as well.

[PL from Ge] Although Ge is a indirect band-gap semiconductor, it is well known that the strong direct transition photoluminescence can be observed by increasing the excitation laser power, because Γ-valley minimum is very close to L-valley one[3]. At the oxide/Ge interface with high-D_{it}, however, electrons in the L-valley are recombined in a non-radiative way through the interface gap-states. In addition, Γ electrons are also reduced due to the fast relaxation process to L-valley, which is much faster than the radiative recombination[4]. As a result, the direct-PL intensity becomes much lower than that in the low-D_{it} case. In this way, direct-PL intensity is expected to be a good indicator to evaluate the oxide/Ge interface quality.

[Experiment] 30-nm-thick Y_2O_3 was deposited on HF-last p-Ge (100) substrates by rf-sputtering, followed by the annealing at 550°C for 30 min in O_2, N_2 or N_2+O_2(0.1 %) ambient. The steady-state PL measurement at room temperature was carried out through oxides on Ge. The second harmonic of Nd:YVO_4 laser with λ=457 nm and 3 μW/μm^2 was used as the excitation laser. Meanwhile, to investigate the impacts of the band bending at the interface, MIS capacitor were fabricated. Nb:TiO_2 and Al were deposited as the transparent electrode and contact metal, respectively.

[Results and Discussion] **Fig. 1** shows the PL spectra of Y_2O_3/Ge stack after annealing in various ambient. The higher direct-PL intensity were observed after annealing in O_2 than in the other ambient. It indicates that the non-radiative recombination center is well passivated in oxide/Ge with good interface after annealing, and results of the present PL analysis were consistent with the fact that oxide/Ge interface can be well passivated by the existence of the mixture of Y_2O_3 and GeO_2[5]. In addition, the PL spectra of Y_2O_3/Ge was almost independent on the gate bias as shown in **Fig.2**. Although the surface recombination velocity is affected by the band bending at the interface[6], it is indicated that the PL intensity is not affected so much in steady-state PL. Finally, we investigated impacts of forming gas annealing (FGA) on oxide/germanium interface by using the present PL analysis. **Fig. 3** shows the PL spectra of Y_2O_3/Ge stack after O_2 annealing, followed by FGA at various temperature. The direct-PL intensity was not changed or even worse at high temperature by forming gas annealing, indicating that FGA does not work for Ge passivation.

[Reference] [1] C. H. Lee et al., IEDM Tech. Dig., p.32 (2013). [2] M. Passlack et al., IEEE Electron Device Lett. **29**, 1181 (2008). [3] H. Driel et al., Solid State Commu. **20**, 837 (1976). [4] A. Othonos, J. Appl. Phys. **83**, 1789 (1998). [5] C. Lu et al., J. Appl. Phys. **116**, 174103 (2014). [6] M. Rommel et al., Microelectron. Eng. **80**, 50 (2005).

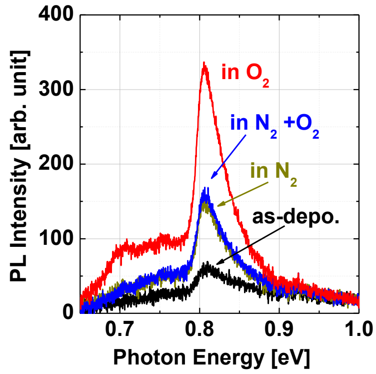

Fig. 1 PL spectra of Y_2O_3/Ge stack after annealing in various ambient.

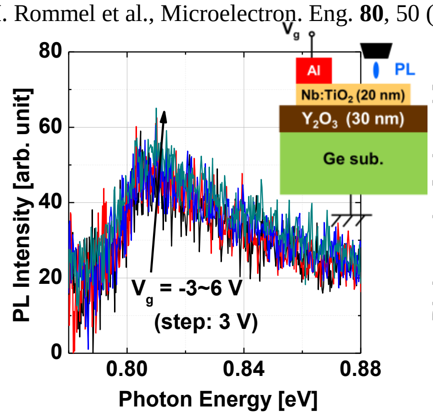

Fig. 2 PL spectra of Y_2O_3/Ge after O_2 annealing with the gate bias. Inset shows the sample structure.

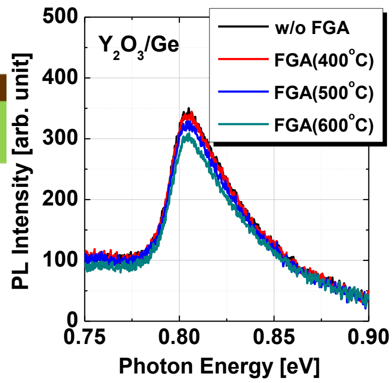

Fig. 3 PL spectra of Y_2O_3/Ge after O_2 annealing, followed by forming gas annealing.

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