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

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[Introduction] The performance of Ge MOSFETs has been dramatically improved by achieving good oxide/Ge interfaces\textsuperscript{[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\textsuperscript{[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\textsuperscript{[3]}. At the oxide/Ge interface with high-D\textsubscript{g}, 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\textsuperscript{[4]}. As a result, the direct-PL intensity becomes much lower than that in the low-D\textsubscript{g} 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\textsubscript{2}O\textsubscript{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\textsubscript{2}, N\textsubscript{2} or N\textsubscript{2}+O\textsubscript{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\textsubscript{4} laser with λ=457 nm and 3 μW/μm\textsuperscript{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\textsubscript{2} and Al were deposited as the transparent electrode and contact metal, respectively.

[Results and Discussion] Fig. 1 shows the PL spectra of Y\textsubscript{2}O\textsubscript{3}/Ge stack after annealing in various ambient. The higher direct-PL intensity were observed after annealing in O\textsubscript{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\textsubscript{2}O\textsubscript{3} and GeO\textsubscript{2}\textsuperscript{[5]}. In addition, the PL spectra of Y\textsubscript{2}O\textsubscript{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\textsuperscript{[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\textsubscript{2}O\textsubscript{3}/Ge stack after O\textsubscript{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.


![Fig. 1 PL spectra of Y\textsubscript{2}O\textsubscript{3}/Ge stack after annealing in various ambient.](image1)

![Fig. 2 PL spectra of Y\textsubscript{2}O\textsubscript{3}/Ge after O\textsubscript{2} annealing with the gate bias. Inset shows the sample structure.](image2)

![Fig. 3 PL spectra of Y\textsubscript{2}O\textsubscript{3}/Ge after O\textsubscript{2} annealing, followed by forming gas annealing.](image3)