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Y ドープ GeO_2 界面層の Y 濃度に依存した界面酸化膜形成

Influence of Yttrium concentration on the oxidation barrier effect of Y-doped GeO_2 interfacial layer

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[Introduction] The formation of high-quality Ge/GeO_2 interface is expected to be one of the best solutions for realizing high-performance Ge CMOS [1-3]. Many attempts have been made to control the growth rate of GeO_2 to achieve EOT scaling in the gate stacks [4, 5]. In this work, we examine the oxidation of Ge/Y_2O_3 stack for the purpose of controlling GeO_2 interfacial layer (IL) growth. The influence of yttrium incorporation on the GeO_2 IL growth is discussed.

[Experiment] Various thickness of Y_2O_3 (1.5 to 5 nm) was deposited on HF-last pGe substrate by rf-sputtering. Thermal oxidation of Ge/Y_2O_3 stacks was carried out at different temperatures (500 and 550 °C) and in different P_{O2} (1 and 70 atm), as schematically shown in **Fig. 1**. The thicknesses and chemical states of GeO_2 IL were estimated by Ge *3d* core level spectra of XPS measurements. To characteristic the electrical properties, Au and Al were deposited by vacuum evaporation for the gate electrode and substrate contact of the MOSCAPs, respectively.

[Results and discussion] Fig. 2(a) shows GeO_2 IL thickness as a function of oxidation time. The GeO_2 IL growth is relatively fast at the initial stage (noted as region A) and becomes much slower as oxidation time increases, indicating that self-limited GeO_2 IL is grown (noted as region B). Interestingly, the thickness of GeO_2 IL is dominated by oxidation temperature, while no major influence on GeO_2 IL thickness is observed from different Y_2O_3 thicknesses (1.5 to 5 nm) and P_{O2} (1 and 70 atm). These results suggest that there is a different GeO_2 growth mechanism at Ge/Y_2O_3 stack from thermal oxidation [4]. In order to understand the oxidation mechanism in Ge/Y_2O_3 stack, we investigated the chemical states of GeO_2 IL formed at Ge/Y_2O_3 stack as a function of oxidation time, as shown in **Fig. 2(b)**. The oxidation was carried out at 500°C in 1 and 70 atm P_{O2}, respectively. Lower chemical shift than pure GeO_2 was observed for the IL of both stacks, indicating the doping of Y into the GeO_2 IL. At the initial stage of the oxidation, larger percentage of Y is observed in the GeO_2 IL according to the relatively lower chemical shift. With longer oxidation time, the chemical shift becomes higher, indicating the decrease of the Y concentration in the IL by the further growth of GeO_2. The change of Y concentration greatly influences the growth rate of GeO_2 IL during oxidation. With high Y concentration, the GeO_2 IL grows fast (corresponding to region A in **Fig. 2(a)**). On the other hand, relatively lower Y concentration in GeO_2 forms a strong oxidation barrier (data not shown), which limits the further growth of IL (corresponding to region B in **Fig. 2(a)**). This strong oxidation barrier effect might be attributed to a stable configuration of GeO_2 IL with a low oxygen potential achieved by the small percentage of Y doping.

[Conclusion] A strong oxidation barrier effect is found by doping a low concentration of Y into GeO_2, which limits the growth of the IL at Ge/Y_2O_3 stack during oxidation.

[Reference] [1] A. Toriumi *et al*, *IEDM*, 646, (2011). [2] S. Takagi *et al*., *IEDM*, 372, (2012). [3] C. H. Lee *et al*., *IEEE TED*, 58, 1295 (2011). [4] C. H. Lee *et al*., *APEX*, 5, 114001 (2012). [5] R. Zhang *et al*., *IEDM*, 642, (2011).

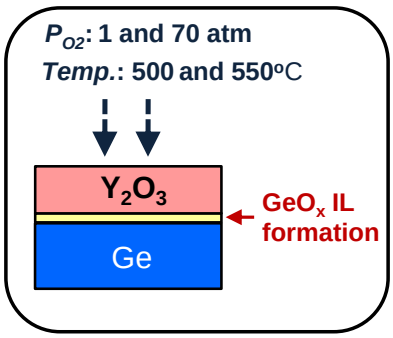

Fig. 1 Schematic of oxidation applied to Ge/Y_2O_3 stack. There is ultrathin GeO_2 IL formation during oxidation.

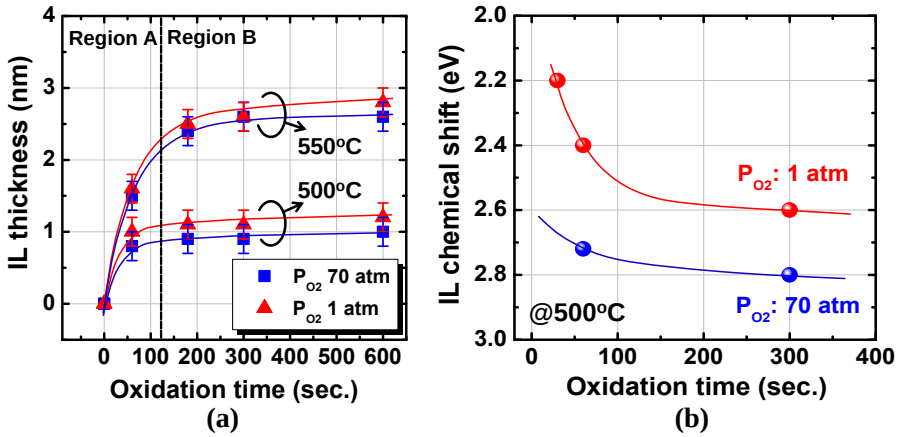

Fig. 2(a) The IL thickness estimated by XPS as a function of oxidation time. Note that the Y_2O_3 thickness is varying from 1.5 to 5 nm, while its influence on the IL thickness is negligible (included in the error bar). **(b)** Chemical shifts of IL in Ge *3d* spectra as a function of oxidation time.