Introduction of high tensile strain into Ge-on-Insulator structures by oxidation/annealing at high temperature

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1. Introduction Ge is a promising channel material for future generation MOSFETs because of the high hole and electron mobility. An ultrathin body Ge-on-Insulator (GOI) structure is mandatory for scaled CMOS in terms of suppression of short channel effects. It has been proved in Ge that compress and tensile strain can boost hole and electron mobility, respectively[1-2]. In order to realize high performance Ge CMOS, technologies to separately introduce compressive and tensile strain in Ge channels on a wafer are desired. We have recently reported that additional high temperature oxidation can change strain in GOI fabricated by Ge condensation from compressive strain to tensile one[2], enabling to realize compressive- and tensile-strain MOSFETs on the same wafer. However, the effects of the process conditions on tensile strain and the origin of the strain generation have not been examined yet. In this work, the effects of oxidation and annealing on strain are systematically studied by using (100) GOI substrates fabricated by Ge condensation. A combination of oxidation and annealing at 850 ºC is found to introduce tensile strain up to 0.56 % on GOI. A possible physical origin of tensile strain is also discussed.

2.Experiments Fig. 1 shows the process flow for condensation (100) GOI substrates. Ge condensation is a unique technique for fabricating GOI by oxidizing SiGe on SOI with changing temperature, resulting in high quality pure GOI with high compressive strain[3]. After completing GOI formation, successive oxidation in O_2 plus additional annealing in N_2 is performed at 850 ºC. Raman spectroscopy is used to evaluate strain and crystallinity. The strain values are estimated from the Raman peak shift from the bulk Ge peak. The GOI thickness is measured by spectroscopic ellipsometry.

3. Results and Discussions The additional oxidation at 850 ºC keeps consuming Ge, resulting in thickness reduction from initial 16 nm to 2 nm after 3h oxidation. Fig. 2 shows RMS of the GOI surfaces measured by AFM. With increasing the oxidation time, the surface roughness first decreases and, after 1 hour, increases together with generating pin holes, observed by AFM. Fig. 3(a) shows the strain change as a function of oxidation time and N_2 annealing time. It is clearly confirmed that strain changes from initial compressive strain to tensile one by oxidation, while only N_2 annealing cannot release initial compressive strain. The highest strain of 0.56 % is obtained after 3h oxidation, while the remaining thickness is only 2 nm with rough surfaces and large peak broadening. The strain after additional annealing following oxidation is shown in Fig. 3(b). It is found that annealing after oxidation enhances strain, whereas the saturated strain become higher with an increase in the initial oxidation time. These facts indicate that oxidation time controls the upper limit of strain, while annealing helps to increase the strain to the upper limit. However, a clear peak broadening is observed after too long oxidation and annealing. As a result, 1.5h oxidation followed by 2h annealing at 850 ºC, which produces 0.47 % strain, can be the optimized condition to maintain high strain without thermal damages.

On the other hand, the physical origin of generating such high tensile strain up to 0.56 % has not been understood yet. Judging from the obtained data, initial oxidation, the long and high temperature process and thin GOI thickness seem to be critical to introducing high tensile strain. The necessity of initial oxidation could be related to Ge oxide formation at the Ge/buried oxide interfaces, which can soften the constraint due to the tight Ge bonding with buried oxides. Also, it is well known for Ge-on-Si structures that tensile strain in Ge can be induced by thermal expansion mismatch between Si and Ge[4]. On the other hand, SiO_2 has the much smaller thermal expansion coefficient than Ge and Si[5-7]. According to calculation, the Ge-Si mismatch from 850 ºC to room temperature can provide tensile strain of ~0.3 %, while the Ge-SiO_2 mismatch can lead to ~0.6 %, which is close to our experimental highest strain of 0.56 %. Although very thick Si substrates must dominate strain induced into top GOI films, the present results might suggest any influence of SiO_2 buried oxides on strain into Ge in terms of any structural or interfacial effects.

4. Conclusions We have shown a new method for generating high tensile strain up to 0.56 % in GOI structures without any special patterning and external stressors. The process condition of 1.5h oxidation followed by 2h annealing at 850 ºC has provided tensile strain of 0.47 % without severe thermal damages.

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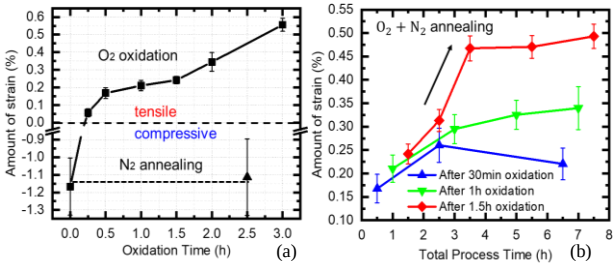

Fig. 3(a) Tensile strain increases as oxidation time increases.
(b) strain as a function of total process time of oxidation plus annealing.

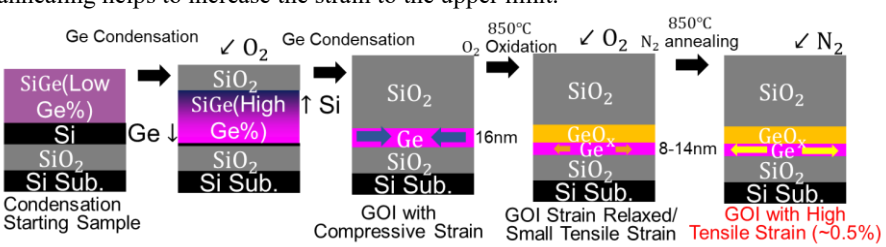

Fig. 1: Process flow of the additional high temperature process for tensile strain generation.

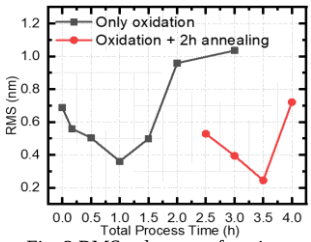

Fig. 2 RMS values as a function of the total process time.