酸化濃縮プロセスにおける冷却方法が GOI 中の圧縮ひずみに及ぼす効果

Effect of cooling process on compressive strain in GOI layers fabricated by Ge condensation

°金佑彊，竹中充，高木信一
東大院工
°Wu-Kang Kim, Mitsuru Takenka and Shinichi Takagi
The University of Tokyo,
Email: wukangkim@mosfet.t.u-tokyo.ac.jp

【Background】 Ge has high potential for a next generation channel material because of the high elecrtron and hole mobility and easy introduction into the Si platform. Moreover, a UTB (Ultra-thin body) GOI (Ge-on-Insulator) structure is very important to suppress the short channel effect. Among the several GOI fabrication methods, the Ge condensation method [1, 2] is one of the most promising techiniques to fabricate UTB GOIs. However, one of the problems in Ge condensation is the relaxation of strain during the condensation process [3], which not only causes defects on GOI layers but also prevents high performance in pMOSFETS. Therefore, it is crucial to suppress the strain relaxation during Ge condensation. We have recently reported that compressive strain remains in GOI layers by reducing temperature cycles with slow cooling process during the Ge condensation [4]. However, the impact of the cooling time on remaining strain has not been examined yet. In this study, we examine the effect of the cooling time after Ge condensation on distributions of compresive strain in the GOI layers.

【Experimnetal】 Fig. 1 shows the process flow of UTB GOI layers with the Ge condensation process, where the oxidation temperature is changed from 1100 °C, 1050 °C, 1000 °C, 950 °C to 900 °C. After each oxdiation step, intermixing annealing was performed in N_2 at 1050 °C, 1000 °C and 950 °C [5]. In the conventional Ge condensation, SiGOI wafers were taken out from an oxidation furnace after each oxidation step to check the Ge composition. On the other hand, the new Ge condensation process [4] employ the oxidation/annealing in the furnace without taking out the wafers during the process (Fig. 2). In this study, GOI wafers were cooled down in 3 different ways after the new Ge condensation (Fig. 3), in order to examine the impact of the cooling process on the strain relaxation. Natural cooling and 4-hour slow cooling was performed in addition to the conventional rapid cooling. The strain over GOI layers was evaluated from the Ge peak shift in Raman spectroscopy. The measurement was performed at a distance of 10 μm with a measurement spot size of around 1 μm to get strain distributions in the GOI layers.

【Results】 Fig. 4 shows the strain distributions in the GOI layers with the size of 100 μm x 100 μm, fabricated by the conventional (left) and new Ge condensation with 4-hour cooling (right). While the GOI layer fabricated by the conventional method is almost fully relaxed, the GOI layer with new Ge condensation method is compressively strained. The effect of the cooling time on strain is shown as the cumulative strain destributions in Fig. 5. The mean strain values in GOI layers after 4-hour linear cooling, natural cooling, and rapid cooling is estimated as 1.17, 1.06, and 0.79, respectively. Also, the standard deviation amounts to 0.23, 0.26, and 0.29. These values indicate that slower cooling can contribute to higher compressive strain and the tighter strain distribution. As a result, we can conclude that rapid decrease in temperature can cause strain relaxation, presumably due to the difference in themal expansion coefficient between Ge and SiO_2/Si. This is consistent with fully-relaxed GOI layers under the conventional method, which includes many cycles of temperature change.

【Conclusion】 We have examined the effect of cooling time in Ge condensation method on strain in GOI. The slower GOI cooling process with the continuous oxidation/ annealing in furnaces resulted in higher compressive strain in GOI layers, which is expected to provide higher hole mobility in pMOSFETs.

【Acknowledgment】 This work was partly supported by a Grant-in-Aid for Scientific Research on Priority Area (No. 26249038) from the Ministry of Education, Culture, Sports, Science, and Technology in Japan.

【Reference】 [1] S. Nakaharai *et al.*, APL **83**, 3561 (2003) [2] K. Ikeda *et al.*, SSDM, 32 (2008) [3] T. Tezuka *et al.*, APL, 90 (2007) [4] W.-K. Kim et al., JSAP spring meeting, 21a-S422-7 (2016) [5] W.-K. Kim et al., TED **61**, 3379 (2014)

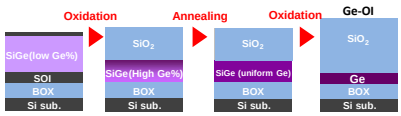

Fig. 1 Process flow of Ge condensation.

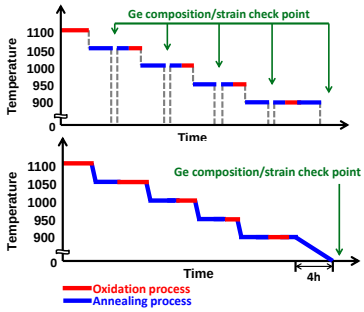

Fig. 2 Conventional (above) and new Ge condensation (below) recipes

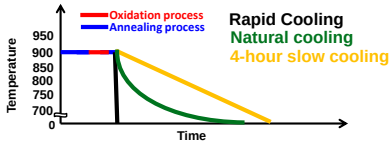

Fig. 3 3 different cooling processes after the new Ge condensation recipe

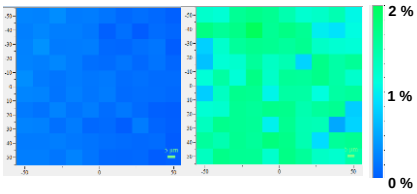

Fig. 4 Compressive strain distributions in GOI layers after conventional (left) and new (right) Ge condensation with slow cooling

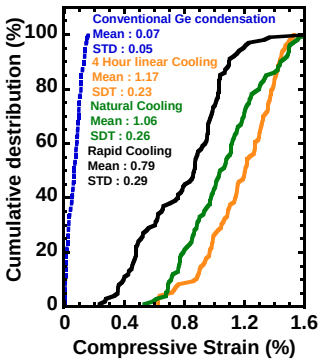

Fig. 5 Cumulative strain distributions in GOI layers with different cooling times after the new Ge condensation recipe.