Formation Mechanism of Ge-on-Insulator Layers by Ge-condensation Technique

S. Nakaharai,[1] T. Tezuka,[1] N. Sugiyama,[1] and S. Takagi[2,3]
MIRAI(ASET),[1] MIRAI(AIST),[2] Univ. of Tokyo[3]
1, Komukai-Toshiba-cho, Saiwai-ku, Kawasaki 212-8582, Japan
email:shu-nakaharai@mirai.aist.go.jp

An Ultra-Thin-Body (UTB) Ge-on-Insulator (GOI) MISFET is one of the promising candidates for CMOS device structures in future technology nodes because of high mobility of electrons and holes in Ge and the immunity to short-channel effect due to the UTB structure. Also, the drive current in such a GOI-MISFET is expected to exhibit significant enhancement compared to conventional bulk Si or SOI-MOSFETs in the ballistic transport regime[1]. In order to reduce the short-channel effect in 45 nm technology node, for example, required GOI layer thickness is less than 10 nm. For this purpose, we have fabricated a 7-nm-thick GOI layer[2] by the Ge-condensation technique[3]. In this article, we discuss the formation mechanism of GOI layer by the Ge-condensation technique.

The Ge-condensation process is described as follows: At first, a SiGe layer was grown epitaxially on an SOI substrate with the initial Ge fraction, x_i, of 0.15. Next, dry oxidation was carried out at temperatures lower than the melting temperature of SiGe. In this oxidation process, Si atoms in the SiGe layer were oxidized selectively and Ge atoms were rejected from the SiO_2 layers, resulting in the increase of Ge fraction in the SiGe layer up to nearly 100%.

The formation of GOI layer was judged from the extinction of Si-related peaks in Raman spectrum. The purity of GOI layer was estimated by taking a SIMS profile of one of the fabricated GOI layers as shown in Fig. 1. In this measurement, the signal of Si was at the background noise level of 10^{18} cm^{-3}, corresponding to the Si fraction of 0.01%. During the condensation process, the total amount of Ge was conserved. This is evident from Fig. 2, in which T_{GOI} value is close to the product of T_i and x_i, independent of T_{GOI}. This result implies that the selective oxidation of Si atoms in the SiGe layer occurred throughout the Ge-condensation process. The conservation of Ge atoms in the SGOI or GOI layers is important because it enables us to control the GOI layer thickness by setting adequate T_i and x_i. As a result, we successfully fabricated a GOI layer as thin as 2 nm from a SiGe layer with T_i = 13 nm, x_i = 0.15, as shown in Fig. 2.

In order to clarify the mechanism of GOI layer formation, we simulated the time evolution of Si fraction profile in the Ge-condensation process by solving numerically the one-dimensional diffusion equation of Si atoms in Ge crystal using a reported diffusion coefficient value[4] and a measured oxidation rate. In this simulation, we assumed that the selective oxidation of Si atoms in SiGe layer continues while the Si flux incoming to the oxide interface compensates the Si consumption by oxidation. This assumption is based on the Ge conservation in the condensation process shown in Fig. 2, and also on an experimental result of EDX measurements in which no Ge signal was detected in the SiO_2 layers[3]. We stopped the simulation when the residual Si fraction at the interface became zero. As a result, the final averaged Si fraction was 0.03 %, which is in the same order as the detection limit (~0.01 %) of the SIMS measurement shown in Fig. 1, implying that the simulation reproduced adequately the formation process of the GOI layer. From this simulation, it was confirmed that the Si consumption by oxidation at the interface was sufficiently compensated by Si supply due to thermal diffusion, which is obvious from the uniformity of the Si fraction profile shown in Fig. 3.

In summary, we demonstrated the fabrication of GOI layers by the Ge-condensation technique with the residual Si fraction less than 0.01% in the wide range of GOI layer thickness from 2 nm to 25 nm. The formation mechanism of GOI layer was explained by the model that the selective oxidation of Si atoms continues until the GOI layer is formed, which is supported by the fast thermal diffusion of Si atoms.

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[1]S. Takagi, *VLSI symp.* 2003, p.115.
[2]S. Nakaharai, *et al.* APL **83**, p.3516 (2003).
[3]T. Tezuka, *et al*., APL **79**, p1798 (2001).
[4]J. Raisanen *et al*., Solid-State Electron. **24**, p333 (1981).

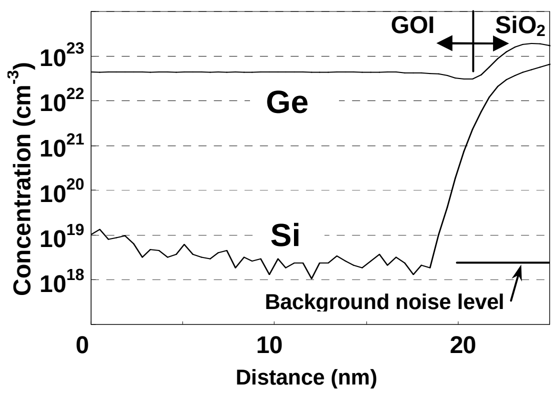

Fig. 1 SIMS profiles in a 25-nm-thick GOI layer. Si signal is at the background noise level.

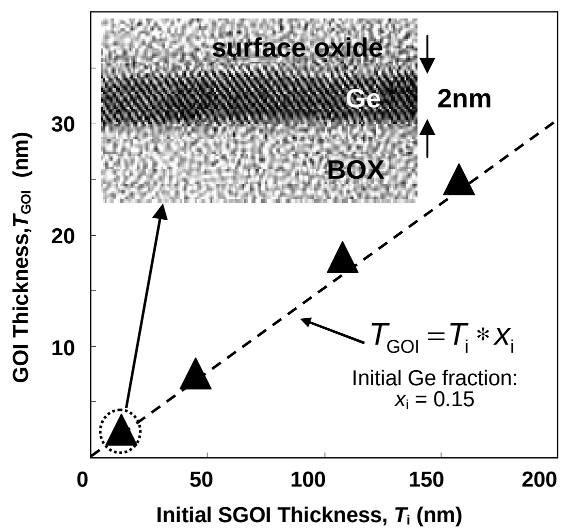

Fig. 2 Relation between obtained GOI layer thickness and initial SGOI layer thickness. Broken line expresses the conservation of Ge in the SGOI layer. Inset is the TEM image of a 2-nm-thick GOI layer.

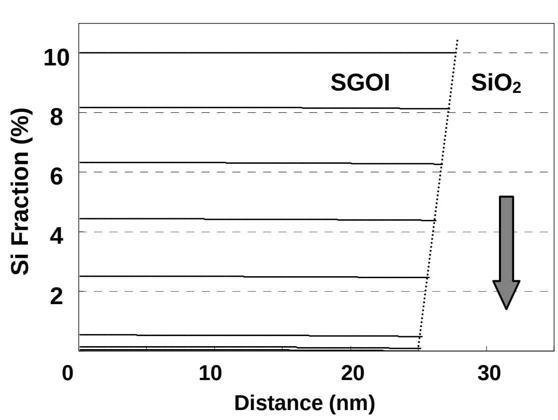

Fig. 3 Simulation of time evolution of Si profiles of an SGOI layer in the Ge-condensation process. Dotted oblique line expresses the $SGOI/SiO_2$ interface.