A comparative study of strain field in strained-Si on SiGe-on-Insulator and SiGe virtual substrates

Kentaro Kutsukake, Noritaka Usami, Toru Ujihara, Kozo Fujiwara and Kazuo Nakajima
Institute for Materials Research, Tohoku University
Katahira 2-1-1, Aoba-ku, Sendai 980-8577, Japan
Tel:+81-22-215-2013, FAX:+81-22-215-2011,
E-mail:kutukake@imr.tohoku.ac.jp

We performed a comparative study of strain field in strained-Si grown on SiGe-on-insulator (SGOI) and SiGe virtual substrates, and clarified the origin of the strain fluctuation in the strained-Si film. A periodic strain fluctuation, which reflects the strain field of underlying cross-hatch pattern, was observed in the sample on the virtual substrate. On the other hand, a feature-less strain fluctuation with suppressed amplitude was observed in the sample on SGOI substrate. By analyzing the correlation of the Raman peak positions of the Si-Si mode in strained-Si and SiGe, the compositional fluctuation in SiGe was found to be the origin of the strain fluctuation.

The fabrication process of SGOI substrate contained growth of 8nm amorphous Ge layer on a commercially available 30nm Si-on-Insulator (SOI) substrate using a solid-source molecular-beam-epitaxy (MBE) system, deposition of 300nm protective SiO_2 cap layer, and thermal treatment at 1100ºC for 1hour. By this simple process, SiGe (001) single crystal layer with relaxation ratio of more than 70% can be fabricated as confirmed by electron back-scattering pattern analysis (EBSP) and X-ray measurements.[1][2] The SiGe virtual substrate was grown by a gas-source MBE system (AirWater VCE-S2020) with Si_2H_6 and GeH_4 as source gases on a Si (001) substrate at 700ºC, which consisted of compositionally step-graded $Si_{1-x}Ge_x$ (x=0-0.22) and 1μm uniform $Si_{0.78}Ge_{0.22}$ layers. Both on SGOI and SiGe virtual substrates, 15nm-thick strained-Si layers were grown. Spatially-resolved micro-Raman spectroscopy (Tokyo Instruments Nanofinder) was carried out to investigate the strain fluctuation as well as its origin in strained-Si layer.

Figure 1 shows a typical Raman spectrum of strained-Si on SGOI. The three peaks located approximately at 508cm^{-1}, 515cm^{-1} and 520cm^{-1} are assigned as coming from the Si-Si vibration mode of the SGOI, the strained-Si layer, and the Si substrate under the buried oxide layer, respectively. The amount of the strain in strained-Si on SGOI was estimated to be 8.1x10^{-3} by the liner equation $\varepsilon=-\Delta\omega/832$, where $\Delta\omega$ is the shift of the strained-Si peak from the Si substrate peak in cm^{-1}. It is noted that this value is large enough to enhance the mobility of the electron, but is lower than 8.9x10^{-3}, which is estimated from coherently strained-Si on fully relaxed $Si_{0.78}Ge_{0.22}$. The residual strain in SGOI would be responsible for the reduction of the strain in strained-Si, and the relaxation ratio of SGOI is estimated to be about 91%.

Figure 2 shows 20μmx20μm mapping images of Raman shift of Si-Si mode in (a) strained-Si on SGOI (b) SiGe in SGOI (c) strained-Si on the SiGe virtual substrate, and (d) topmost uniform SiGe in the SiGe virtual substrate. In the image of the virtual substrate (Fig.2 (d)), bright and dark bands are seen to run along <110> direction, which reflects the cross-hatch pattern originating from dislocation networks introduced to accommodate lattice-mismatch between SiGe and Si. A similar strain fluctuation was observed in the strained Si on the SiGe virtual substrate (Fig.2(c)). On the other hand, no specific feature was observed in Fig.2 (a) and (b). This suggests that relaxation of SGOI proceeds without introduction of dislocation but through the slip at $SiGe/SiO_2$ interface during high-temperature treatment. Importantly, the amplitude of the strain fluctuation in strained-Si on SGOI is much smaller than that on the SiGe virtual substrate.

To clarify the origin of the strain fluctuation in strained-Si film, we investigated the correlation between the Raman shift of Si-Si mode of SiGe and the Raman shift of strained-Si. As a result, the stain fluctuation of underlying SiGe was found to be responsible for the strain fluctuation. On the other hand, the compositional fluctuation in SiGe was likely to be the origin of the strain fluctuation in strained-Si on SGOI.

In summary, strained-Si on SGOI was shown to have less strain fluctuation compared with that on the SiGe virtual substrate, which shows that SGOI is promising as a substrate for strained-Si. Reduction of the compositional fluctuation in SGOI will be effective for further reduction of the strain fluctuation to improve the carrier mobility in strained-Si.

This work was in part supported by Industrial Technology Research Grant Program of NEDO.

[1]K.Kutsukake *et al.* Jpn. J. Appl. Phys. **42** (2003) L234.
[2]K.Kutsukake *et al.* Appl. Surf. Sci. **95** (2004) 224.

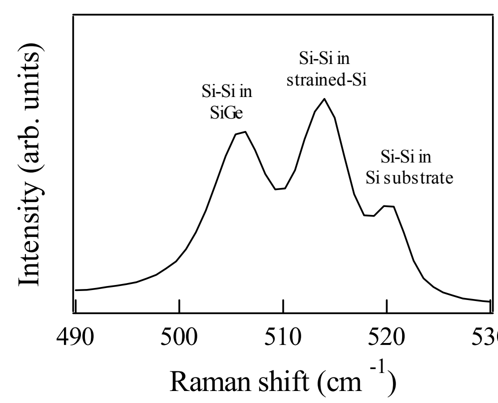

Fig.1 The typical Raman spectrum obtained from the strained-Si on SGOI.

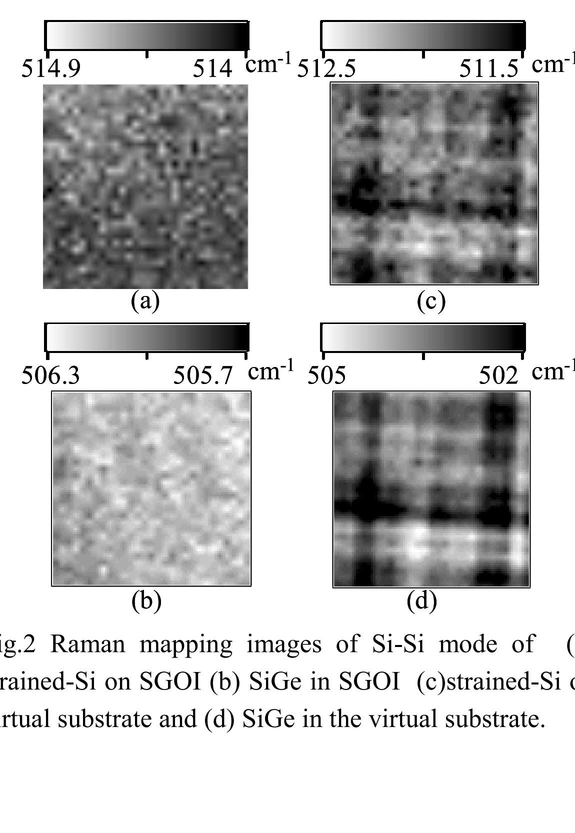

Fig.2 Raman mapping images of Si-Si mode of (a) strained-Si on SGOI (b) SiGe in SGOI (c)strained-Si on virtual substrate and (d) SiGe in the virtual substrate.