Optical Properties of Multilayered Staggered SiGe Nanodots Depending on Si Spacer Growth Temperature

Yuta Ito, Ryo Yokogawa, Wei-Chen Wen, Yuji Yamamoto and Atsushi Ogura

ECS Meeting Abstracts, Volume MA2024-02, G03: SiGe, Ge, and Related Compounds: Materials, Processing, and Devices 11: In Memory of Qizhi Liu

Citation Yuta Ito *et al* 2024 *Meet. Abstr.* **MA2024-02** 2341

DOI 10.1149/MA2024-02322341mtgabs

Abstract

Introduction

Uniformly ordered SiGe nanodot (ND) has the potential for optoelectronic device application. By engineering Si surface morphology, heteroepitaxial SiGe layer thickness distribution can be controlled by self-ordering [1]. The self-ordering is an attractive phenomenon for fabricating a vertically ordered stack of SiGe ND fabrication. Yamamoto *et al*. have successfully fabricated the SiGe staggered NDs by controlling the balance between the surface energy and the residual strain of the Si spacer [2]. We have evaluated the strain state, the optical characteristics, and the band structure of the SiGe staggered and dot-on-dot NDs by Raman and PL (Photoluminescence) spectroscopy, and clarified that the strain state not only in the SiGe NDs but also in the Si spacer affects the emission energy [3]. The surface energy can be controlled by the growth temperature of the Si spacer, and it is expected to modify the dot shape and size. Indeed, the cross-sectional transmission electron microscopy (TEM) observations show that the lower Si spacer growth temperature results in a smaller dot size. However, it has not been sufficiently clarified the effect of the strain induced in NDs and the optical properties of the multilayered staggered NDs realized by the difference in the Si spacer growth temperature. Therefore, we investigated the strain and the luminescence properties of those multilayered staggered SiGe NDs by Raman and PL spectroscopy.

Experiment

The staggered NDs (designated structure: {$Si_{0.6}Ge_{0.4}$ NDs /50 nm Si spacer} × 10 cycles) on the Si spacer with the growth temperature of 625, 650, 675, 700, and 725°C were prepared, which were fabricated on the Si substrate by a reduced pressure chemical vapor deposition. Figure 1 shows the cross-sectional TEM images of the staggered NDs on the Si spacers grown at 625 and 675°C. These samples were evaluated by Raman and low-temperature PL spectroscopy. The Raman spectrometer has a 2,000 mm focal length and a high resolution of approximately 0.1 cm^{-1}. A diode-pumped solid-state (DPSS) laser with a wavelength of 532 nm and a beam diameter of approximately 1 µm as the excitation source was used. The PL measurement setup was equipped with a spectrometer which contains an InGaAs diode array detector, with a measurable wavelength range between 0.9 and 1.7 µm. This spectrometer can control the sample stage temperature between 4 and 300 K with a helium compressor and a heater device. A He-Cd laser with a wavelength of 325 nm and a DPSS laser with a wavelength of 532 nm, here the beam diameters of approximately 50 µm, were utilized as the excitation source. The relatively wide slit of 100 µm enabled obtaining a high PL intensity with the wavelength resolution of approximately 4 nm.

Results and Discussion

Raman spectrum of the SiGe NDs on the Si spacer grown at the temperature of 625℃ is shown in Fig. 2. The Raman peaks of the Si-Si mode derived from Si spacers and SiGe NDs were observed around 520 cm^{-1} and 510 cm^{-1}, respectively. Figure 3 shows the Raman shift of Si-Si mode from the SiGe NDs on the Si spacers grown at 625, 650, 675, 700, and 725℃. The large compressive strain seems to be induced in the staggered SiGe NDs compared to the strain-free Raman shift of the single crystalline $Si_{0.6}Ge_{0.4}$ [4], and the higher growth temperature of the Si spacer leads to stronger compressive strain. Figure 4 shows the PL spectra derived from the SiGe NDs on the Si spacers grown at 625, 650, 675, 700, and 725℃. As shown in Fig. 4, we confirmed the TO-phonon-assist line derived from the Si spacer, transverse-optical (TO)-phonon-assist line, and Non-phonon (NP) line related to SiGe NDs. All staggered NDs show stronger SiGe-derived PL, compared to the TO-phonon-assist line derived from Si spacers. The transition energy of the TO-phonon-assist line derived from SiGe NDs indicates that the higher growth temperature for the Si spacer leads to a wider bandgap. This behavior of the transition energy might be caused by the strain in the SiGe NDs and/or the Si spacers. In conclusion, lower Si spacer growth temperature leads to a smaller size of the SiGe NDs and the red-shift of the luminescence due to the strain state of SiGe NDs and/or Si spacer in the staggered structure.

References

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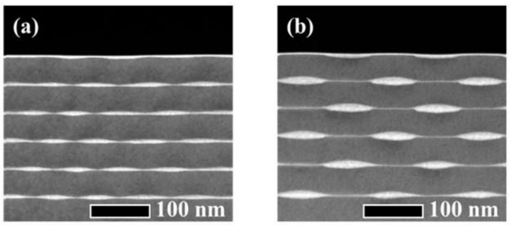

Fig. 1 Cross-sectional TEM images of the staggered SiGe NDs on the Si spacer grown at the temperature of (a) 625 and (b) 675°C.

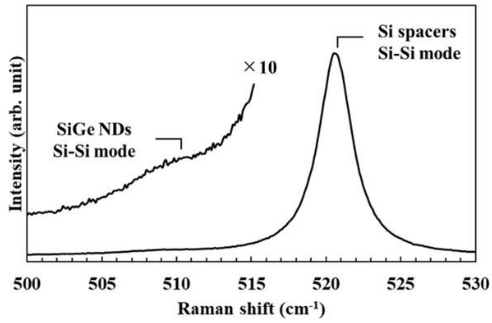

Fig. 2 Raman spectrum of the SiGe NDs on the Si spacer grown at the temperature of 625°C.

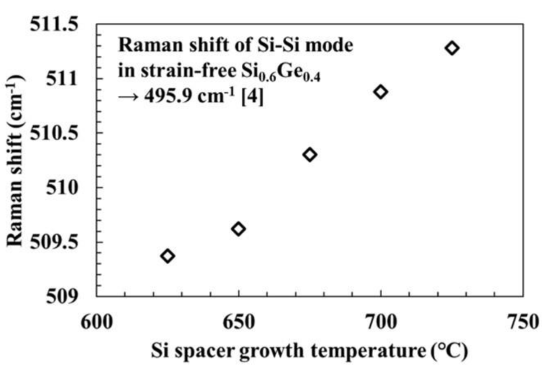

Fig. 3 Raman shift of Si-Si mode derived from the SiGe NDs on the Si spacer grown at the temperature range of 625-725°C.

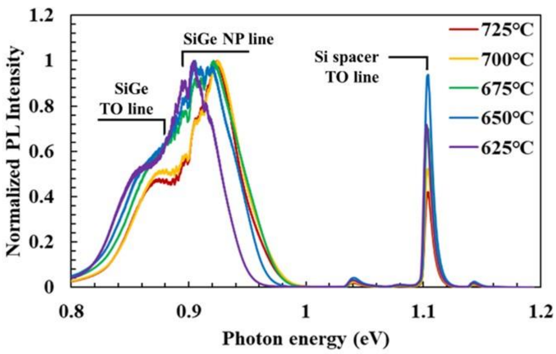

Fig. 4 PL spectra of the SiGe NDs on the Si spacer grown at the temperature range of 625-725°C. DPSS laser was used for these PL measurements as an excitation source, and the sample stage temperature was 35 K.

Figure 1