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Characterization of anisotropic strain relaxation after isolation for strained SGOI and SiGe/Si structure with newly developed high-NA and oil-immersion Raman method

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ABSTRACT

Local anisotropic strain relaxation at the free edge of the stained SiGe layers after isolation of strained SiGe layers was evaluated using the high-NA and oil-immersion Raman method adopting high numerical aperture (NA:1.4) lens and oil immersion techniques. It was confirmed that forbidden optical phonon mode (TO) can be effectively excited with the technique, and that the anisotropic strain measurement was realized for the strained-SiGe layers. It was found that the strain was more significantly relax in St-SGOI than in St-SiGe around each edge. The result implies that the relaxation mechanism of the SiGe mesas on the SiO2-Box layer and on the Si substrate may be different from each other.

1. Introduction

Strained-channel MOSFETs have been key technology to realize low-power consumption and high-speed devices. Strained SiGe channel pMOSFETs are attractive to enhance the current drivability over conventional Si p-MOSFETs. Taking account of recent reports [1], the strain in the channel depends on its size, shape, and process condition. Since the channel-strain is anisotropic in general, the anisotropic strain measurement is necessary to control the strain. Although, a conventional Raman spectroscopy measurement with a backscattering geometry against a (001)-oriented planar substrate is a useful tool to evaluate the strain in a strained SiGe layer, it detects only longitudinal optical phonon (LO) phonon-mode and cannot provide any information about anisotropy in the strain.

Recently, anisotropic strain in strained-Si mesa structures on a buried oxide layer were evaluated by a high-NA and oil-immersion Raman technique adopting a high numerical aperture (NA) lens and an immersion technique [2,3]. For the conventional Raman configuration, the incident angle of the electrical field of the excitation light parallel to the sample surface can only excite LO phonon mode by the electrical field of incident laser light. On the contrary, the aperture angle of incident beam becomes larger than that of conventional Raman configuration when a high-NA lens and oil-immersion technique is employed.

In this configuration, the angle of incident beam becomes larger than that of conventional Raman configuration, and transverse optical phonon (TO) mode phonons are also excited by the electrical field component vertical to the surface of the incident light as well as LO phonon modes. Then, we can calculate in-plane and orthogonal strain components along the width, and longitudinal channel direction using equation [3] by analyzing the observed Raman peak shift values for LO, and TO modes. To activate LO and TO phonon modes respectively, the active mode was switched by changing polarizer angle of the electrical field for the scattered light.

In this paper, we present characterization of local anisotropic strain relaxation at the free edge of the stained SiGe mesa structures using the high-NA and oil-immersion Raman method adopting high NA lens and immersion techniques, and NBD [4] techniques.

2. Experimental

In order to investigate the anisotropic strain variation within the SiGe strained layers, we prepared two types of (001) strained SiGe layers with pseudomorphic compressive strain on a Si substrate; a 33-nm strained SiGe layer epitaxially grown on Si substrate (St-SiGe/Si) and a 17-nm St-SiGe-on-insulator (St-SGOI) layer formed by the Ge condensation technique, as shown in Fig. 1. The Ge concentration, x, of the St-SiGe/Si layer, and that of the St-SGOI layer were 0.30, and 0.33, respectively. Using these two types of substrate, we prepared 10 μm mesa structures with long free edge which was parallel to the $[1\bar{1}0]$ direction with reactive-ion-etching (RIE) to evaluate strain relaxation at the edge of strained layer.

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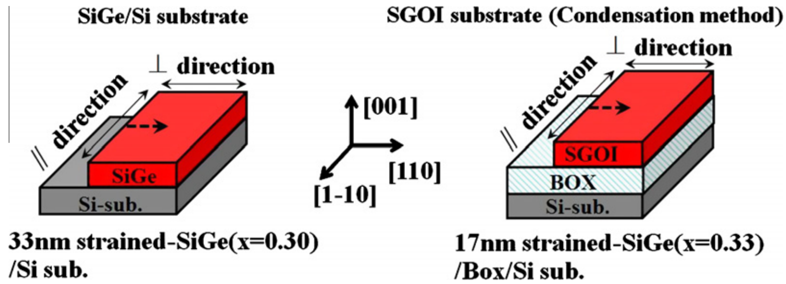

Fig. 1. Schematic structure of strained-(St-)SiGe substrates. Raman measurements were performed along dotted arrow.

Table 1
Conditions of low-NA mode and high-NA mode Raman configurations.

	High-NA mode	Low-NA mode
Lense (NA)	1.4 (Oil immersion)	0.7 (Air)
Excitation light	Nd:YAG (532 nm)	Nd:YAG (532 nm)
Resolution	0.2 cm^{-1}	0.2 cm^{-1}
Lateral resolution	300 nm	600 nm
Active mode	LO and TO	LO

Conditions of conventional and high-NA and oil-immersion Raman configurations were summarized in Table 1. The Raman spectra were taken by illuminating with the 532-nm second harmonic wave of a neodymium-doped yttrium aluminum garnet (Nd:YAG) laser. The diameter of incident beam was approximately 300 nm on the sample surface. A conventional Raman measurements were performed with a normal numerical aperture (NA = 0.7) lens. On the other hand, for the anisotropic strain measurements, a high numerical aperture (NA = 1.4) lens and an oil-immersion technique were employed to excite a TO phonon mode as well as a LO phonon mode. To excite the TO phonon mode and LO phonon mode separately, we switched the observable mode by changing polarizer angle of the scattered light. Since, the sample surface is free from stress, the σ_{zz} which is perpendicular to sample surface is considered to be zero. Then, the anisotropic stresses $\sigma_{||}$ along $[1\bar{1}0]$ axis parallel to the free edge direction, and $\sigma_{\perp}$ along [1 1 0] axis perpendicular to the free edge direction were calculated by using $\Delta\omega$(TO) and $\Delta\omega$(LO) values obtained with the TO mode and LO mode Raman spectra [3]. The relationship between the wavenumber shifts and the biaxial stresses are represented by Eq. (1) for 30% SiGe and Eq. (2) for 33% SiGe:

$$\begin{pmatrix} \Delta\omega_{TO} \\ \Delta\omega_{LO} \end{pmatrix} = \begin{pmatrix} -2.99 & -0.61 \\ -2.41 & -2.41 \end{pmatrix} \cdot \begin{pmatrix} \sigma_{xx} \\ \sigma_{yy} \end{pmatrix} \quad (1)$$

$$\begin{pmatrix} \Delta\omega_{TO} \\ \Delta\omega_{LO} \end{pmatrix} = \begin{pmatrix} -3.00 & -0.62 \\ -2.42 & -2.42 \end{pmatrix} \cdot \begin{pmatrix} \sigma_{xx} \\ \sigma_{yy} \end{pmatrix} \quad (2)$$

where $\Delta\omega$(TO) and $\Delta\omega$(LO) are the wavenumber shifts of the TO and LO phonon modes for $Si_{1-x}Ge_x$. σ_{xx} and σ_{yy} are the stresses along [1 1 0] and $[1\bar{1}0]$, respectively. Finally, the strain $\varepsilon(xx)$, and $\varepsilon(yy)$ were calculated using σ_{xx} and σ_{yy} according to the Hooke's law [5].

To confirm the validity of the Raman measurement, the strain variation within the SiGe layer was evaluated by a nano-electron-beam diffraction (NBD) measurement [4]. Size of a probe electron beam of the NBD was approximately 10 nm.

3. Results and discussion

Fig. 2a shows spectra of conventional Raman measurements obtained with LO active and to inactive (upper), and LO inactive and TO active (lower) configurations for SiGe/Si substrate at 1 μm apart from edge. In Fig. 2, the Raman peaks from the Si substrate with large intensities were subtracted from the raw data in order to analyze the Raman spectra accurately. Due to the configuration of forbidden optical phonon mode under a backscattering geometry for a (0 0 1) Si surface, Raman peak in TO mode was not detected. On the other hand, Fig. 2b shows Raman spectra obtained by the high-NA and oil-immersion method with LO active and TO inactive (upper), and LO inactive and TO active (lower) configurations. As shown in Fig. 2b, it was confirmed that the forbidden optical phonon mode TO (blue line) was clearly detected for the TO active configuration in addition to the LO phonon mode.

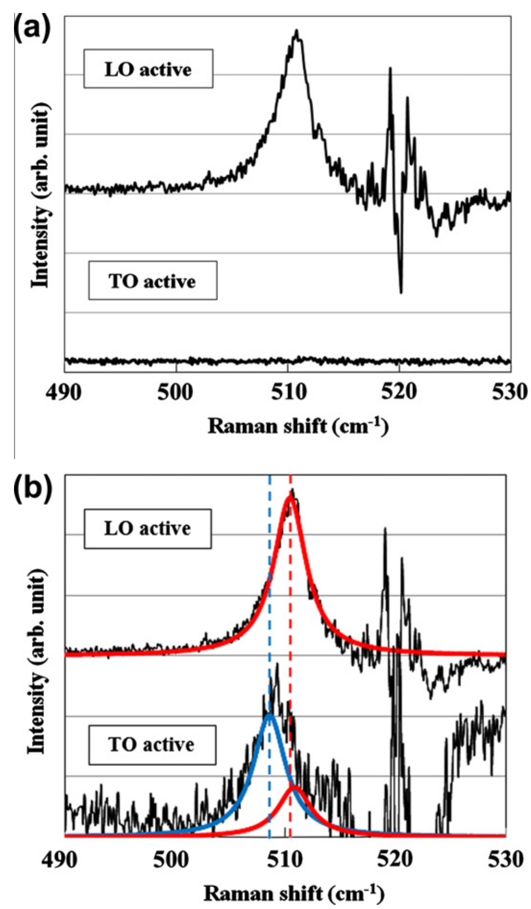

Fig. 2. Raman spectra obtained with LO and TO active configurations for conventional (a) and high-NA and oil-immersion Raman method (b) at 1 μm apart from edge of compressively strained SiGe/Si substrate. TO spectrum (blue) was clearly detected for TO active configuration with the high-NA and oil-immersion Raman method. Each spectrum was obtained by extraction of Si peak spectra (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)