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HREM Observation and Identification of the Causality of Twins in SiGe/Si (110)

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Strain control of semi-conductor thin films is very important to realize a high-speed field-effect-transistor (FET) because elastically strained semiconductors sometimes show very high carrier mobility due to their band-structures. K. Arimoto and other members of our group have been studied the crystal growth mechanism of lattice-strained-Si/lattice-relaxed-SiGe/Si (110) heterostructure as fundamental investigations to produce high hole-mobility FET [1-3]. Recently we reported the cross-sectional transmission electron microscopic (TEM) observations of the twins in the Si/SiGe/Si (110) [4]. In this study, we investigated the causality of these twins using high-resolution transmission electron micrography (HREM) and fast Fourier transformation (FFT). Especially, we focused whether they were growth twins or stress-induced ones.

In our previous studies, it was exhibited that the twins were made during the SiGe growth. Therefore, we produced simple SiGe/Si (110) instead of using Si/SiGe/Si (110) using solid source molecular beam epitaxy (SS-MBE). The temperature of the substrates were 600 C and the thickness of the SiGe films were 370 nm. The composition of the Ge was 13at% which was evaluated by using X-ray reciprocal mapping (XRM). The foil for the TEM observation was fabricated by using focused ion beam (FIB) with the acceleration voltage of 40 kV. TEM (FEI Tecnai Osiris) without any Cs correctors was utilized with an acceleration voltage of 200 kV for this study. FEI's software TIA was utilized to carry out FFT.

It is considered that there are three types of twins in the SiGe films as follows.

A: Growth twins as a results of island growth on the substrate.

B: Stress-induced twins due to the lattice mismatch between the SiGe films and the Si substrates.

C: Twins epitaxially grown onto the stress-induced twins mentioned in B.

Stress-induced twins (type B mentioned above) tend to have less width in comparison with the growth twins and tend to have many plane defects inside themselves. In addition, the matrix crystals across the growth twin (type A mentioned above) must have parallel orientations each other. However, if the twin is a stress-induced one there are two options: the matrix crystals across the twin have parallel orientations or they are rotated about 55 degrees each other. This depends on whether the number of stacking faults is even or odd. (In the case of growth twin, it must be even number 2.) Based on these directions, we observed the SiGe/Si (110) specimens using TEM. Unfortunately, this direction is not enough to distinguish case B and C, however, at least we can distinguish case A and case B/C.

Figure 1 is one of the HREM results taken from the SiGe area of the SiGe/Si (110). Figure 2 is a corresponding FFT result. Figures 2-1 and 2-3 show different orientations and they are rotated about 55 degrees each other. The relationship between Figures 2-3 and 2-4 are as same as that of Figures 2-1 and 2-3. These results mean the number of stacking faults between the area 2-1 and 2-3, between the 2-3 and 2-4 in Figure 1 are odd numbers. This exhibit those are must be type B/C twins. Figures 2-5 and 2-6 are FFT patterns from these areas. They include streaks, which appears when there are many parallel plane defects. This fact also supports that they must be type B/C twins. On the other hand, Figures 2-1 and 2-2 show almost identical patterns. It means those area in Figure 1 have parallel orientations. At this point, there are no clear evidence that the area between 2-1 and 2-2 is a type B/C twin. However, it can be assumed that this are is a type B/C because the width is only about several nanometers and it seems that there exist many stacking faults in between area 2-1 and 2-2 in Figure 1. In Figure1, there is an interface between the area 3 and 4 and Figures 2-3 and 2-4 shows that the orientations of these areas are different each other. This might be the result that the area 2-3 and 2-4 was epitaxially grown onto the stress-induced twins individually and they produce this interface.

In summary, we carried out HREM observations and FFT for the Si-13at%Ge/Si (110) and the following results were exhibited: (1) It is still difficult to distinguish the original stress-induced twins and the twins epitaxially grown onto the stress-induced twins. (2) However, it is concluded that there exist stress-induced twins which were introduced during the SiGe crystal growth under the condition of this experiment.

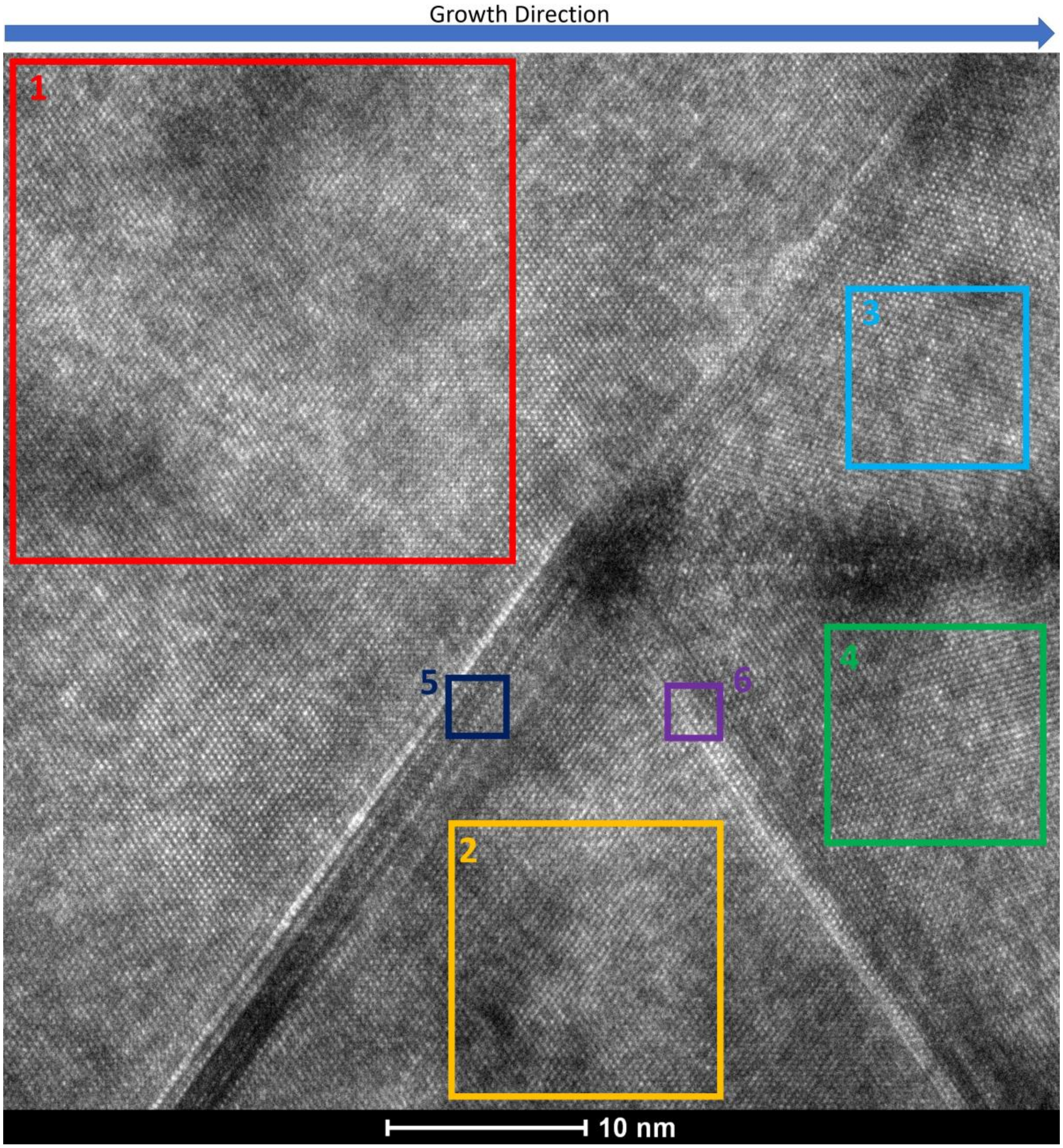

Figure 1. Figure 1. A HREM image taken from the SiGe area of the SiGe/Si (110). The incidental beam direction was [-1 1 0]. Insertions 1 to 6 are FFT areas and they are corresponding to the sub-numbers in Figure 2.

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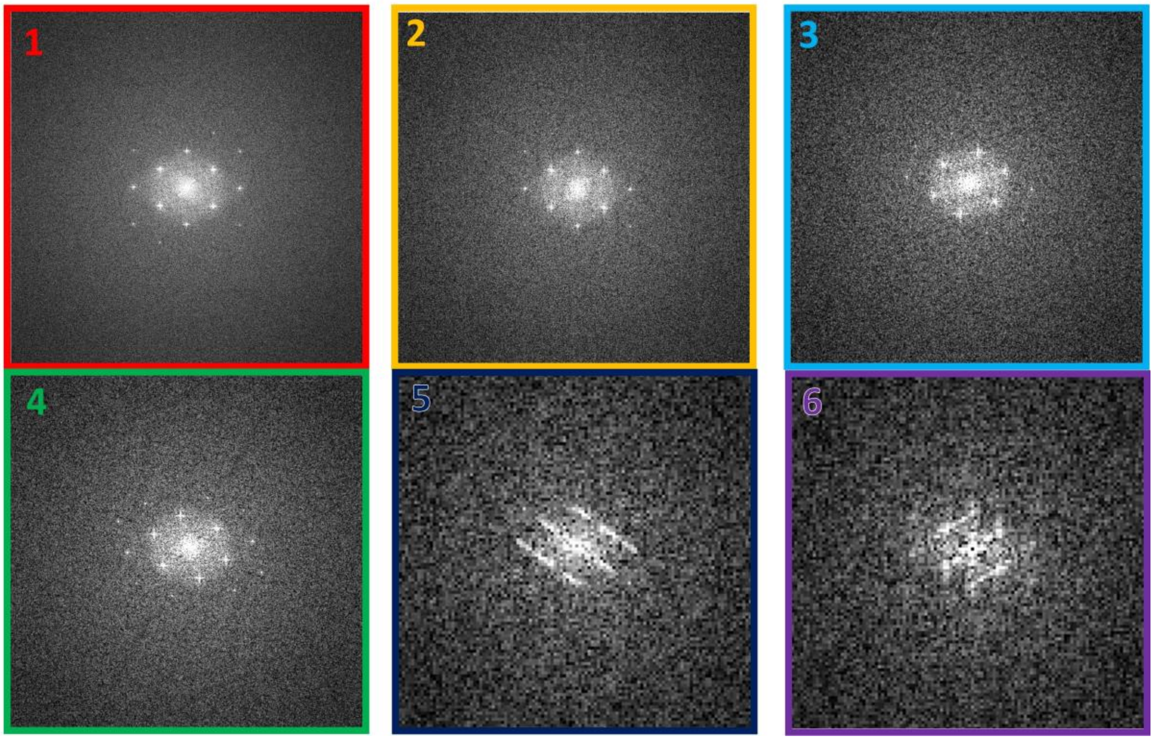

Figure 2. Figure 2. FFT patterns taken from the inserted areas in Figure 1. Sub-figure-numbers in this figure are corresponding to the insertion numbers in Figure 1.

References
[1] Keisuke Arimoto et al., Thin Solid Films, (2006) vol. 508, pp.132-135.
[2] Keisuke Arimoto et al., J. Cryst. Growth, (2009) vol. 311, pp.809-813.
[3] Keisuke Arimoto et al., J. Cryst. Growth, (2017) vol. 468, pp.625-629.
[4] Junji Yamanaka et al., Journal of Materials Science and Chemical Engineering, (2018) vol. 6, pp.25-31.

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