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Evaluation of Lattice-Spacing of SiGe/Si by NBD using Two-condenser-lens TEM

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Nano-beam electron diffraction (NBD) is one of the important methods to collect crystallographic information from nanometer-order area. There are many attractive reports that NBD technique, including so-called 4-D STEM, is utilized to evaluate local area lattice spacing or lattice strains. In many cases, three-condenser-lens TEMs were utilized for this purpose.

In the case that the two-condenser-lens TEMs are utilized, it is impossible to achieve the low convergence angle of the incidental electron beam and wide range image observations simultaneously. When we need both wide range conventional TEM observations and diffraction patterns from nanometer-order area, the convergence angle must be large and, as a result, the diffraction patterns are formed by not spots but disks. It has been considered that diffraction disks are not suitable to evaluate lattice spacings. This might be the main reason why the NBD taken by the two-condenser-lens TEMs were not utilized for the precise lattice-spacing analyses.

Our motivation is realizing a precise lattice-spacing analysis using two-condenser-lens TEM, which has the cost advantage in comparison with three-condenser-lens TEM. We considered that it was possible to evaluate lattice spacings by finding out the exact center of the diffraction disks.

The specimens in this study were $Si_{0.68}Ge_{0.32}$ thin films epitaxially grown onto Si substrates by using MBE. The Ge composition were evaluated by X-ray reciprocal mapping. We fabricated the specimens for TEM observations using FIB. A two-condenser-lens TEM, FEI's Tecnai Osiris was utilized for this study with an acceleration voltage of 200 kV. Conventional TEM images and NBD data were recorded using 2048 x 2048 CCD camera. Then we analyzed the NBD data as follows:

(1) The diffraction disks data were binarized to clarify the outer boundary of them.
(2) Draw the outer circle for each diffraction disks.
(3) The positions of the center of the circles were read out.
(4) The data taken from the Si substrate were unitized as in-specimen standard.
(5) Calculate the crystal-plane spacings.
One example including above mentioned process is shown in Figure 1.

We repeated this procedure ten times and the calculated data are shown in Figure 2. There still be some discrepancies in the data, however, we clearly distinguish the $Si_{0.68}Ge_{0.32}$ from Si. The lattice mismatch of them are about only 1 percent. In conclusion, we succeeded in improving the accuracy of the NBD which was taken using two-condenser-lens TEM. We believe this technique will contribute to many researchers who do not have high-end TEM.

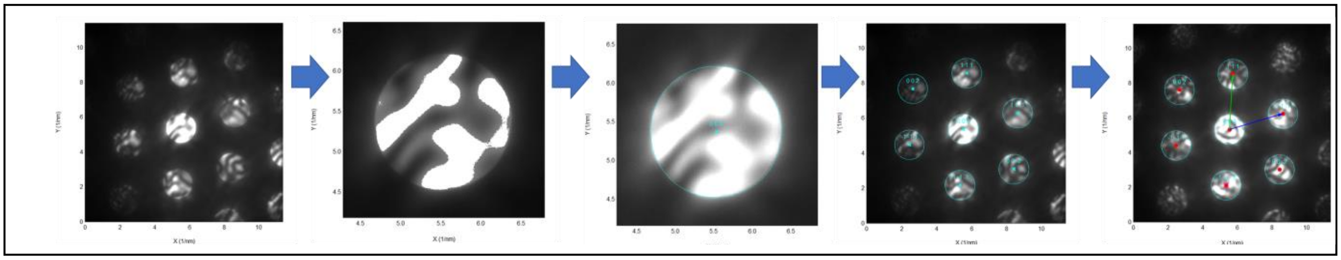

Figure 1. One example how we analysed the NBD diffraction disks. This figure shows the raw data, binarized data to clarify the outer boundary of the diffraction disks, drawing outer circle and finding the center, the data after defining the centers for all major diffraction disks, and the defining independent g-vectors.

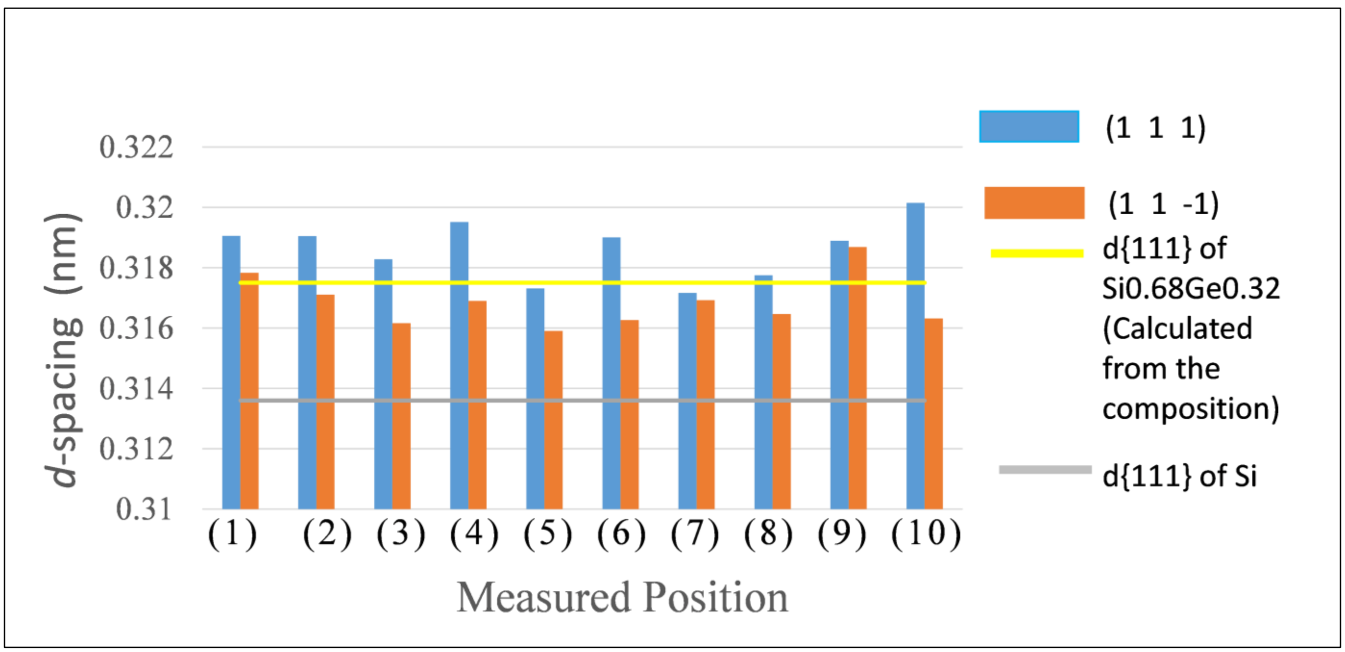

Figure 2. The results of the *d*-spacing analysis. The numbers on the horizontal axis basically shows measured positions on the specimen (one exception: number 10 data was taken from the position almost same as the number 1, on different day).

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