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# Inelastic Electron Scattering Observation Using Energy Filtered Transmission Electron Microscopy for Silicon-Germanium Nanostructures Imaging.

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**Abstract:** In this communication we propose a method for Si-SiGe observation using the inelastic electron interaction information at low energy loss. This is obtained by processing the ratio of two energy filtered TEM images (90 eV, 60 eV). The elastic interaction (diffraction) is eliminated and the contrast is insensitive to poly-crystal grains orientation and specimen thickness.

**Introduction:** As a key material speeding the high frequency MOS compatible bipolar transistors the silicon-germanium system has been used for many years in ICs [1,2]. The physical observation of SiGe structures can be done at the nanometer scale using scanning TEM (STEM) Z-contrast [3]. However this technique is restricted to analytical STEMs equipped with field emission gun (FEG) and large angle annular detector. Moreover the Z-contrast originates from the electron elastic scattering and it is therefore strongly dependant of crystal orientation and specimen thickness. In this communication we propose pure inelastic contrast extraction to observe Si-SiGe systems. Using the jump ratio processing of two low energy loss filtered TEM images we show that the contrast is independent of poly-crystal texture and specimen thickness.

**Experimental details:** The SiGe structures are fabricated by non selective epitaxy (STMicroelectronics BiCMOS process). The specimens are thinned using focused ion beam (FIB) MICRION 9500EX model at a thickness lower than 100 nm and with a final low energy cleaning (10 keV). The EFTEM and STEM Z contrast observations are carried out at 200 keV using FEI TECNAI F20 microscope equipped with energy filter Gatan GIF 200 model.

**Results and discussion:** Figure 1 presents the electron energy loss spectra (EELS) obtained in pure silicon and in SiGe (15% Ge) for the same specimen thickness (around 100 nm or less). In the entire energy range (0 eV - 50 eV) the spectra are very similar, the plasmon amplitude and width being equal. Figure 2 shows the Si-SiGe magnified spectra for the window of higher electron energy loss (40 eV to 150 eV). The Si and Ge spectrum intensities which are almost the same at 50 eV start to separate and the difference is maximum at 100 eV just before the Si-L2,3 ionization edge. This behavior could be explained by the tail of the Ge-M4,5 ionization edge at 29 eV. If an EFTEM image was acquired at 90 eV energy loss it should reveal a contrast between Si and SiGe but will also contain the diffraction contrast (strong in poly-crystal). As an alternative we propose to map the EELS background slope (pure inelastic information) in the 50-100 eV range using the ratio processing of two EFTEM images acquired at 90 eV and 60 eV. The Ge distribution inside SiGe layers will be revealed by the EELS slope variation whereas the image ratio will eliminate diffraction effects. Figure 3 shows a zero loss (elastic) TEM bright field image of a Si-SiGe cross section structure. The SiGe layers are weakly visible in the mono-crystalline area and not at all in the poly-crystal part. Figure 4 presents the jump ratio map of two filtered images (90eV/60eV) revealing clearly the SiGe layers both in crystalline and polycrystalline areas. The discontinuous growth and nucleation of SiGe over $SiO_2$ is evidenced. The images acquisition time is only few seconds therefore radiation damages and specimen drift are minimized. This would not be the case if the Ge map was obtained using the Ge-L2,3 ionization edge (1217 eV) since in this case up to three minutes exposure time would be required. Figure 5 presents a line profile intensity (recorded on the area indicated in figure 4) showing that the contrast can be used to extract the Ge profile. This contrast which varies from 0.43 for pure Si to 0.55 for SiGe(12%) is only dependent of the objective aperture size and EFTEM images energy. It is almost linear with the Ge concentration and could be use for absolute quantification. For comparison figure 6 shows a STEM Z-contrast line profile obtained on the same area than the one of figure 5. It confirms the qualitative Ge profile but in this case the specimen thickness variation induces a slope in the profile. Also in the poly-crystalline SiGe area, the Z-contrast imaging shows intensity random variation (diffraction artifacts) not observed when the proposed EFTEM inelastic imaging technique is used.

**Conclusion:** A technique using the ratio of two low loss EFTEM images is presented and applied to Si-SiGe nanostructures observation. The germanium is clearly revealed by the pure inelastic contrast which is free of diffraction and specimen thickness artifacts.

**References:**

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[2] S. Jouan et al., IEEE Trans. On Electron Devices, 46 (1999) 1525
[3] T. Walther, and C.J. Humphreys, (1999) Journal of Crystal Growth 197, 113

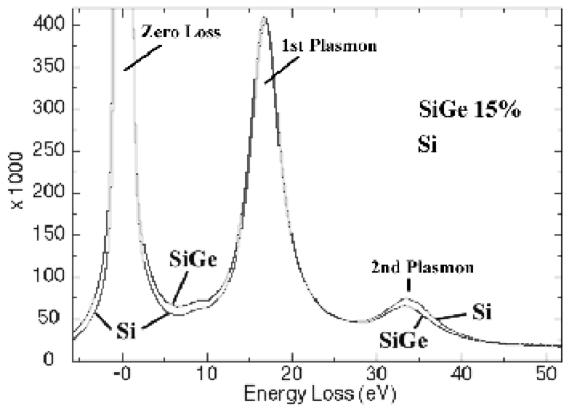


**Figure 1:** Si and SiGe (15%) Electron Energy Loss (EELS) spectra, 0 eV - 50 eV energy loss range.

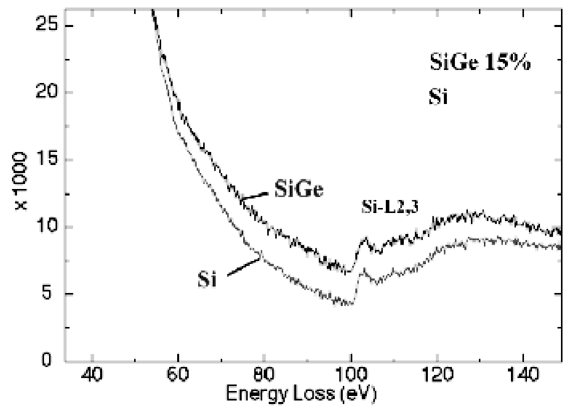


**Figure 2:** Magnified Si and SiGe(15%) EELS spectra , 40 eV -150 eV energy loss range.

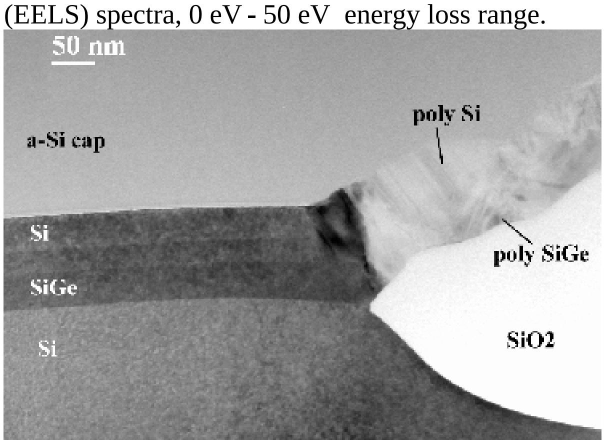


**Figure 3:** Zero loss (elastic) EFTEM bright field image of a Si-SiGe structure.

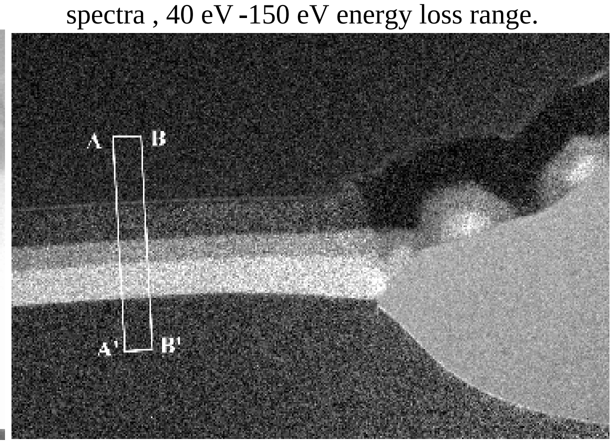


**Figure 4:** Inelastic image of the Si-SiGe structure: ratio of two filtered images (90 eV/60 eV).

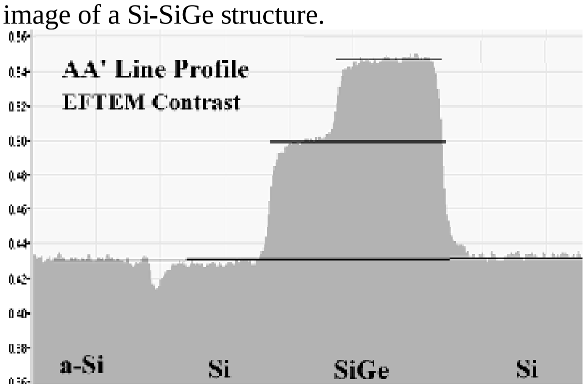


**Figure 5:** **AA'** line profile intensity extracted from the inelastic image (see figure 4).

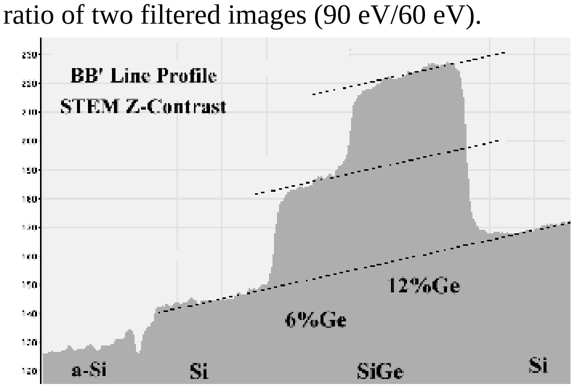


**Figure 6:** **BB'** STEM Z-contrast line profile obtained on the same area (see figure 4).

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