2018
doi:10.1017/S1431927619010821

Microsc. Microanal. 25 (Suppl 2), 2019

Precession Electron Diffraction (PED) Strain Measurements in Stacked Nanosheet Structures

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Non-planar semiconductor devices, such as vertical fin-based field-effect transistor (FinFET) devices have been developed that include multiple vertical fins serving as conducting channel regions to enable larger effective conduction width in a small layout area. However, as circuits are scaled to smaller dimensions, it has become increasingly difficult to improve FinFETs device perfomrance. Stacked nanosheet strucure is a good candidate for the replacement of concention FinFET at 5 nm technology and beyond. A stacked nanosheet FET may include multiple nanosheets (SiGe and Si) arranged in a three dimensional array on a substrate with a gate stack formed on the channel region of the nanosheets, which enables larger effective conduction width in a given small layout area.

Channel strain engineering has been used since the 90nm node [1]. It is critical to understand the strain distribution in the advanced 3D nanosheet FET structures. In this paper, precession electron diffraction (PED) technique was used to measure strain in the stacked nanosheet device. Fig.1 a) shows the cross scetional HAADF STEM image of the multilayer Si/SiGe nanosheet stacks. PED technique was used to determine the lattice deformation within these nanosheet stacks, and Fig. 1 b) and c) confirm that SiGe layers were fully strained with respect to unstrained Si substrate. Fig.1 d) and e) show the relative Ge centration inside the as-grown SiGe layers accquired by electron energy loss spectroscopy (EELS). Fig.2 a) shows the cross scetional STEM image of the patterned Si/SiGe nanosheets and the corresponding lattice deformation maps along in plane (Fig.2 b)) and out plane (Fig.2 c)) orientations. The maps were determined from nano-beam precession electron diffraction (PED) patterns acquired with a convergence semi-angle of 2.5 mrad, a beam precession at 200Hz at an angle of 0.35° and an exposure time of 50 ms. The unstrained Si reference is taken from the Fin base further away from the nanosheet stacks. The precision of the measurement is about $3x10^{-4}$. Color maps shows the relaxations in SiGe layer, especially from both SiGe edge locations. The SiGe strain relaxations also generate tensile strain in Si layer. It can be clearly seen in rotation map (as shown in Fig.2 d)) that the lattice is diagonally distorted at the edges by the interaction between the relaxing SiGe sheets and the restoring forces generated in Si sheets. Fig.3 shows the finite element mechanical simulation results and good matching with PED results was obtained [2].The investigation of strain distribution in the nanosheet at various device fabrication steps will be discussed. For example, Fig.4 show the strain mapping results from Si nanosheet stacks after metal gate formation. Compressive in plane strain has been observed. Further strain analysis along the channles will be discussed to understand the strain distribution in the final device structure.

In summary, precession electron diffraction technique has been demonstrated that it can provide the high spatial resolution and high strain sensitivity for strain analysis in nanosheet semiconductor materials [3].

References:

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[3] This work was performed by the Research Alliance teams at various IBM Research and Development Facilities.

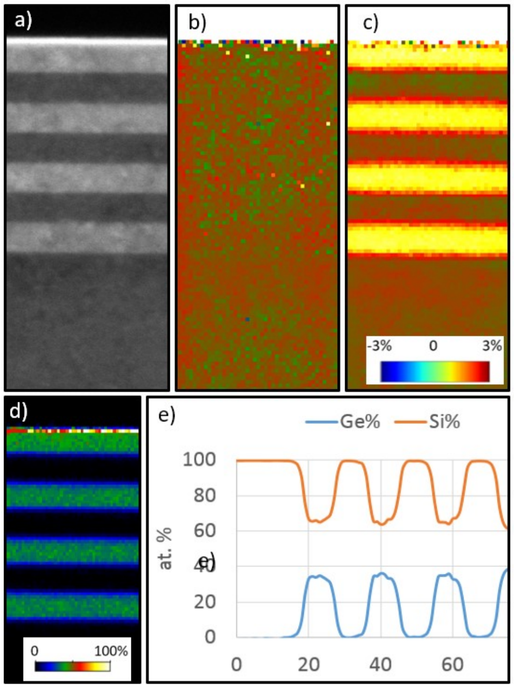

Figure 1. a) HAADF STEM image; b) In plane (220) lattice deformation map; c) Out plane (002) lattice deformation map; d) EELS Ge% map ; f) Ge% line profile across the SiGe/Si nanosheet stacks.

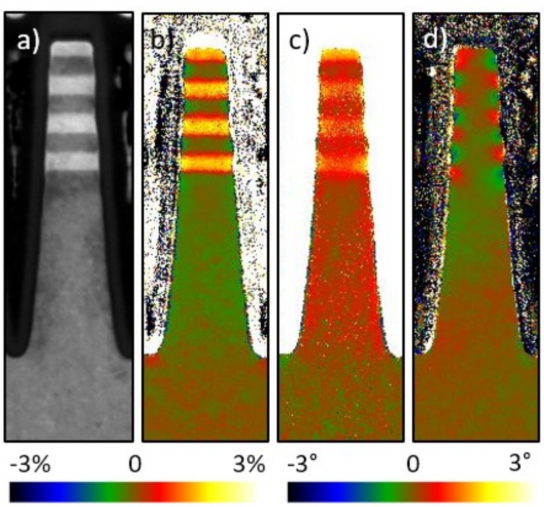

Figure 2. a) Cross-sectional dark-field STEM image of nanosheet Fin; b) Out plane (002) lattice deformation map; c) In plane (220) lattice deformation map; d) Rotation map.

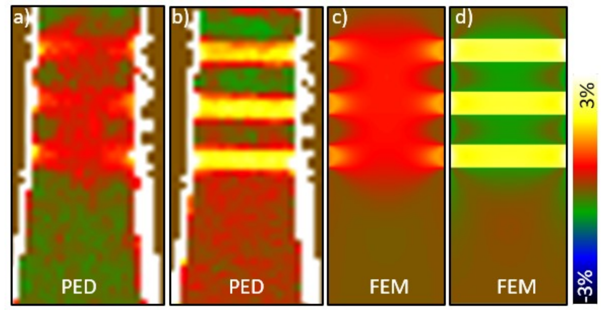

Figure 3. a) In plane and b) out plane lattice deformation map obtained by PED; Finite element simulation results for c) in plane and d) out plane orientation.

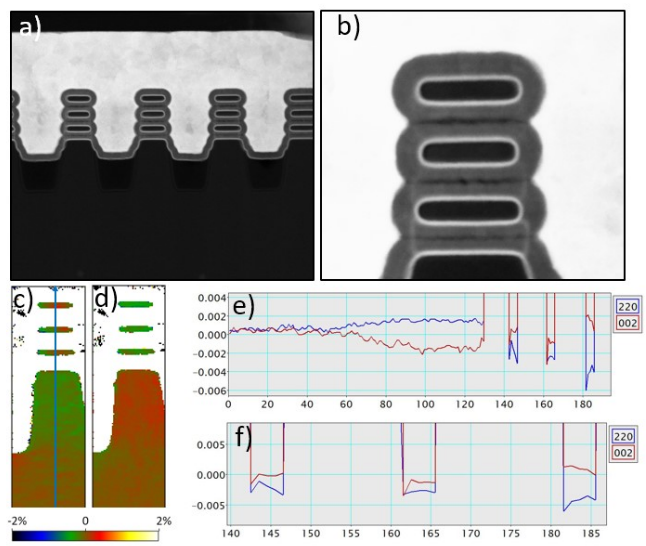

Figure 4. a-b) Cross-sectional dark-field STEM image of nanosheet fin wrapped around by metal gate; c) Out plane (002) strain map; d) In plane (220) strain map; e) Strain line profile extracted from the center of Si nanosheet stacks; f) Detailed plot extracted from the stacked sheet region.

https://doi.org/10.1017/S1431927619010821 Published online by Cambridge University Press