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Nanobeam Diffraction and Geometric Phase Analysis for Strain Measurements in Si/SiGe 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 FETs have been developed to further enable larger effective conduction width in a given small layout area. 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.

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, nanobeam beam electron diffraction (NBD) and geometric phase analysis (GPA) were used to measure strain in the SiGe/Si nanosheet. Mechanical simulations were also performed using a finite element method to solve the balance force equations. Fig.1 (a) shows the cross scetional high resolution HAADF image of the patterned Si/SiGe nanosheets. Fig.1(b) and (c) show the Si and Ge EDX maps, indicaing the Ge distribution is uniform in these SiGe layers. Nano-beam electron diffraction technique was to determine the lattice deformation within these nanosheet stacks. 4nm electron probe was scanned in STEM mode and a diffraction pattern is acquired at each point. The unstrained Si reference is taken from the Fin base further away from the nanosheet stacks. Fig.2 shows in plane (a) and out plane (b) lattice deformations, respectveily. The NBD map was also accquired from the same sample and the map size is 50nm×120nm. Color maps shows the relaxations in SiGe layer, especially from the both SiGe eage locations. The SiGe strain relaxations also generate tensile strain in Si layer. The HAADF STEM image for GPA were collected and the deformation maps were generated by GPA program for the [110] and [001] directions, as shown in Fig.3(b) and (c). The HAADF STEM image analysed here had a 0.055nm pixel size with a 2048 × 2048 scannning pixels. Line profiles were also extracted from the color maps along the yellow and blue solid line boxes, which locate at the center and edge of the nanosheet stacks. Profiles integrated from 8 nm width in the centre and edge of the Fin are shown in Fig. 4 (c) and (d). For the line profile from the center, in plane deformation is about 0.5% in both SiGe layers and Si layers. For line profile taken form the edge, in plane deformation in SiGe increase to 1%, corresponding to edge relaxation post Fin patterning. Similarly, the Si in plane deformation become 0, indicating the Si tensile strain loss in the Si sheets. Fig.5 shows the finite element mechanical simulation results and good matching with GPA results was obtained.The investigation of strain distribution in the nanosheet at various device fabrication steps will be discussed. Similar study on Si/SiGe nanosheets on SOI substrate will also be discussed.

In summary, NBD and GPA technique and FE simulation have been demonstrated that it can provide the high spatial resolution and high strain sensitivity for strain analysis in nanosheet semiconductor materials. [2]

References:

[1] T. Ghani *et al.*, IEDM, p.1161, 2003.
[2] This work was performed by the Research Alliance teams at various IBM Research and Development Facilities.

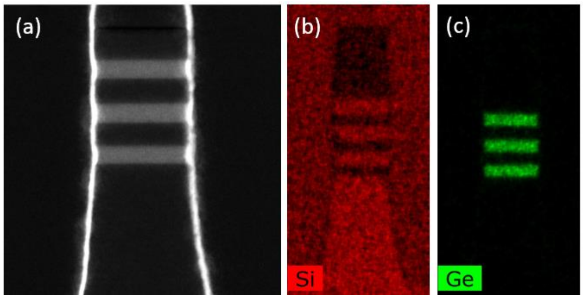

Figure 1. (a) High resolution STEM image of blanket SiGe/Si nanosheets on bulk Si substrate; (b,c) Si and Ge EDX maps.

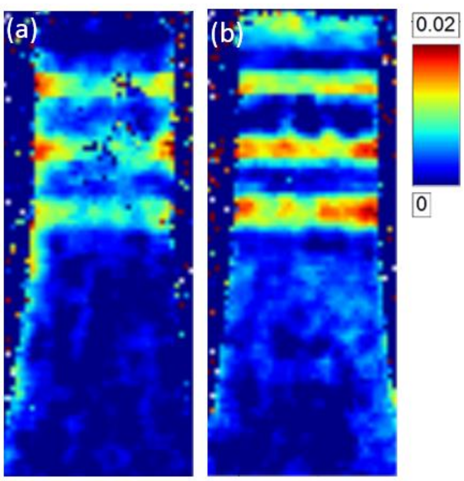

Figure 2. (a) In plane (220) lattice deformation map and (b) Out plane (002) lattice strain map.

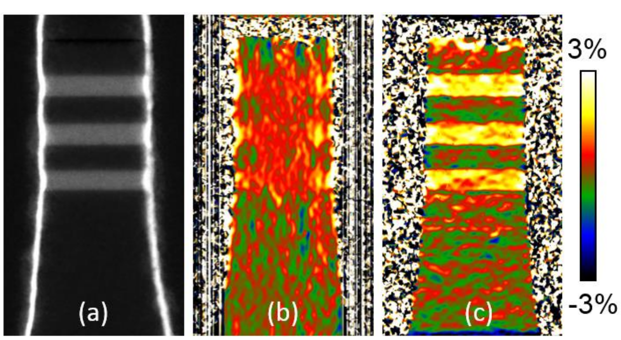

Figure 3. L(a) High-resolution STEM iamge, (b) and (c) in plane and out plane lattice strain maps obtained by GPA.

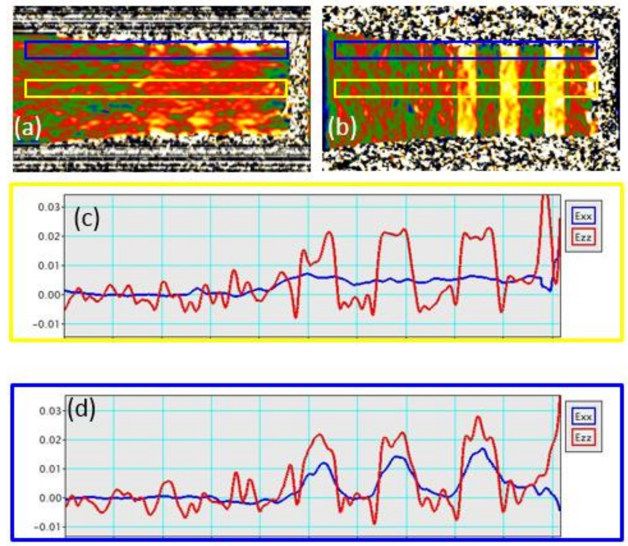

Figure 4. (a) and (b) in plane and out plane lattice strain maps obtained by GPA; (c) and (d) are profile extracted from center (yellow)and edge (blue) portion in nanosheet stacks.

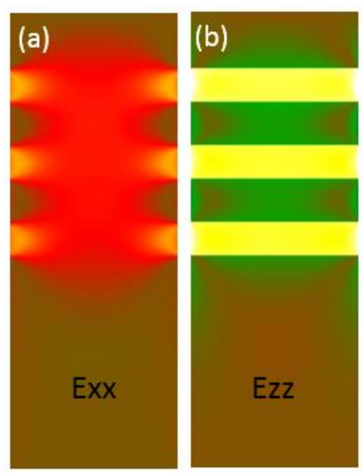

Figure 5. Finite element simulation result of the strain maps for (a) Exx and (b) Ezz.

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