Nanobeam diffraction strain analysis of released Ge gate-all-around horizontal nano-wires: challenges and limitations

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The gate-all-around (GAA) device architectures are considered an evolution of Si finFETs and good candidates as ultimate CMOS device scaling because of their optimal electrostatic control [1]. To further increase the intrinsic device speed, high mobility materials such as strained Ge are being studied to replace the Si nanowires (NW) [2]. As the geometries of these new electronic devices become more complex, it is important to understand how strain develops at the nanoscale by revealing eventual local disuniformities in the strain field.

To our knowledge this is the first study showing successful strain measurements on released, vertically stacked, horizontal Ge NWs (Figure 1). Main challenges for obtaining a TEM specimen valuable for strain analysis of GAA NWs are that:

- only one wire is present in the thickness of the TEM specimen;
- there is no/minimal overlap of different crystalline materials of the gate stack;
- there is uniform specimen thickness, i.e. no curtaining;
- as for all TEM specimens, there is minimal damage;
- there is no strain relaxation in the thin TEM lamellae.

To illustrate these issues, GAA strained Ge single and double nanowires are investigated by nanobeam diffraction (NBD) at various stages of the GAA processing. A description of the growth flow can be found in reference [3]. Initially the Ge layers, embedded between sacrificial SiGe layers, are strained. Strain is then lost after spacer recess-etch but it is afterward restored during source/drain epitaxial deposition and further maintained after wire release and gate dielectric deposition.

In some cases, such as for end of process devices, the overlap of Ge NWs and tungsten of the gate stack is inevitable for TEM specimens prepared along the wire length but it can be limited in all other process steps by preparing very thin TEM lamella, well centered on the NW itself. It has been observed that while the NBD strain analysis procedure mostly fails on these end of process devices, GPA on HRSTEM images can still provide acceptable results (Figure 2). Curtaining artifacts engender variation of intensities in the diffraction spots and, as a consequence, noisier NBD results. Substrate FIB thinning is recommended to minimize these effects.

[1] K. J. Kuhn, Trans. Electron Devices, vol. 59, no. 7, p.1813, 2012.
[2] H. Mertens et al., VLSI Tech. Dig. 2015, p.142
[3] E. Capogreco et al., VLSI 2018, submitted
[4] Geometric Phase Analysis (GPA) of Strain in HRSTEM images with ImageEval software, UniBremen, Electron Microscopy Group Prof A. Rosenauer

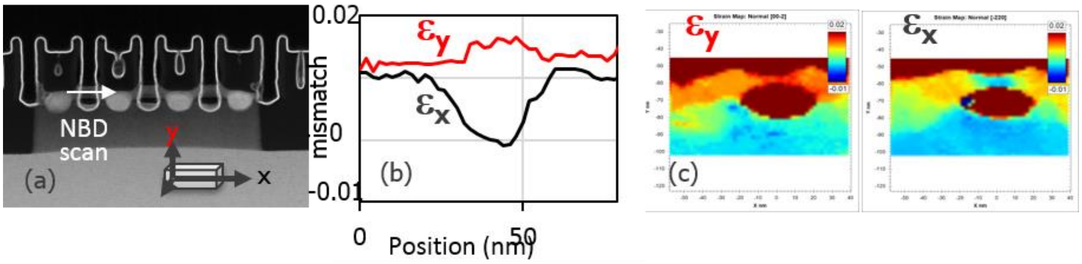

Figure 1 HAADF-STEM imaging (a) NBD strain profile (b) and mapping (c) on released wire

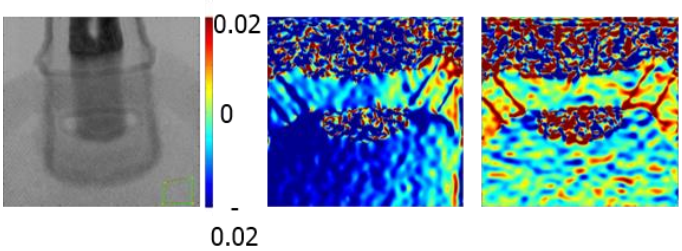

Figure 2 GPA [4] when germanium and tungsten overlap