Combining TEM and 3D scanning spreading resistance microscopy, a hybrid approach, to the analysis of Ge gate-all-around nano-wires

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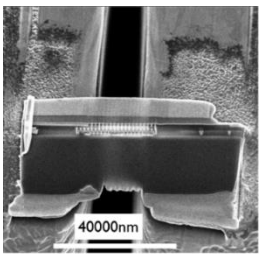
Semiconductor device characterization requires more than one technique and experimental set-up in order to be accurate and complete. A hybrid metrology approach tries to combine results coming from different and complementary techniques applied to a single unique device. The aim of the present work is to characterize a single, fully processed strained Ge gate-all-around (GAA) nano-wire device [1] combining scanning spreading resistance microscopy (SSRM) and transmission electron microscopy (TEM) techniques including chemical and strain analysis. GAA are among the most advanced device architecture and are considered good candidates as ultimate CMOS device scaling because of their optimal electrostatic control.

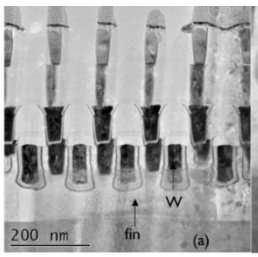
A proof of concept of this hybrid SSRM-TEM approach has been carried out successfully on Ge fins by correlating TEM, STEM, EDS and 3D scalpel SSRM analysis [2] thus allowing to combine dopant concentration and electrical fluctuation information to high spatial resolution imaging and compositional information. To measure the same device by both SSRM and TEM, the specimen needs to be electron transparent for TEM and, mechanically stable and in electrical contact with the TEM grid for SSRM. To satisfy such requirements, the TEM specimen is anchored on top of a slit previously milled in the copper TEM grid (Figure 1) and contains sufficient conductive material on top to assure the electrical contact between the device of interest and the TEM grid.

Preliminary results on GAA NWs in such configuration are shown in figures 1 (FIB-SEM) and 2 (TEM (a) and annular bright field ABF-STEM (b)). The wires are well connected to the top contacts through the epi S/D assuring electrical contact for the SSRM analysis. EDS inspection (figure 3) clearly shows the Ge NWs surrounded by the HfO2 layer and connected to the Ge epi source/drain (S/D). Due to the overlap of tungsten and germanium NWs in the thickness of the TEM specimen, it is not possible to measure strain in the NW while it is possible in the S/D. Strain maps (figure 4), obtained by Geometric Phase Analysis (GPA), although noisy because of the curtaining artifact and the overlap of different materials in the thickness of the TEM specimen, show partial relaxation in the S/D. The correspondent conductive SSRM image is shown in figure 5. The contacts including S/D and gates are immediately recognized on the SSRM image of the as-prepared TEM lamella (figure 5b), while the NW becomes revealed after tip-induced removal of material as shown in figure 5d. Once exposed, the NW is visible as a small region embedded in the gate area showing reduced conductivity (Figure 5c) w.r.t. S/D. These first attempts of hybrid TEM-SSRM analysis on GAA NW devices have shown that hybrid TEM-SSRM analysis is possible: the specimen is sufficiently robust to withstand the tip-induced material removal from SSRM but still electron transparent to allow TEM techniques. More effort needs to be put in minimizing artefacts in the specimen to have clearer images especially for high resolution TEM and strain analysis. Further experiments will involve a few iterations between TEM and SSRM to gain more insight in the 3D structure.

[1] Witters L. et al., VLSI Tech. Symp. Proc., p. 194 (2017).

[2] Celano U. et al.,FCMN Tech. Dig. 2017





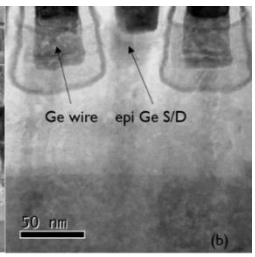


Figure 1 FIB-SEM during milling Figure 2 TEM (a), ABF-STEM (b)

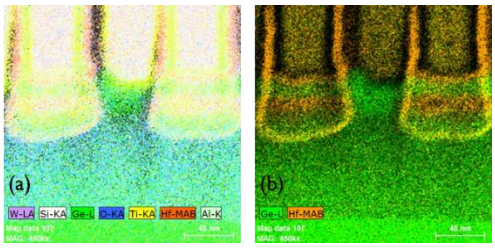


Figure 3 EDS maps: All elements (a); Ge and Hf maps only (b)

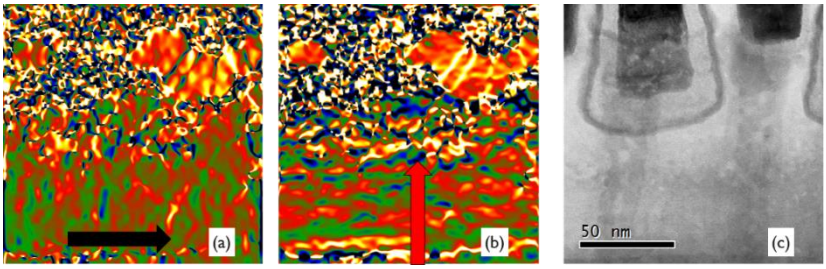


Figure 4 Strain analysis by GPA along (a) and perpendicular (b) to the NW, and correspondent ABF-STEM (c)

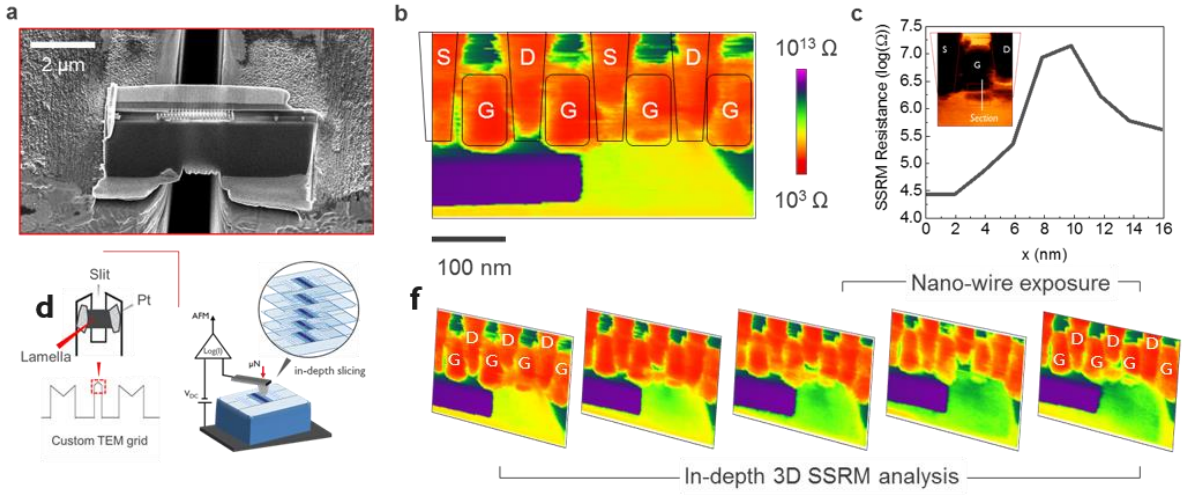


Figure 5 FIB-SEM image (a), first SSRM image (b), NW SSRM resistance profile (c), schematic of the SSRM set-up (d), in depth 3D SSRM sequence (f)