Advanced CMOS technology for the sub-22nm nodes has seen the introduction of new device architectures (FINFET, FDSOI) and new materials, and requires characterization techniques capable of performing atomic scale 2D or 3D imaging, chemical composition or strain measurements. We will present several examples of how transmission electron microscopy techniques are being used to meet the current needs of strain, chemical or dopant (Boron, Phosphorus and Arsenic) characterization in the field of advanced microelectronics:

The use of precession electron diffraction (PED) dedicated to the strain measurement has been introduced in 2013 by J-L. Rouvière [1] at CEA Grenoble and developed in collaboration with ThermoFisher Scientific (formerly FEI). This technique provides an excellent strain precision of around 5×10^{-4} due to the increased number of diffracted disks and the removal of intensity fluctuations (mostly due to dynamical effects) within each disk. An additional benefit of precession is the use of higher convergence angles providing electron beams smaller than 2 nm. In the framework of the 3DAM project, PED has been applied to Si-SiGe heterostructures to quantitatively determine the Ge content in SiGe layers and the degree of relaxation in embedded multilayer fins. We will also show how PED can be performed in combination with mechanical modelling using finite element simulations to determine the developed stresses in a stressor Si3N4 film, which cannot be directly measured using conventional TEM techniques due to the amorphous state of Si3N4 [2].

Low loss EELS experiments allow the detection of substitutional boron atoms in doped amorphous silicon layers used for photovoltaic applications [3]: the energy shift of the silicon volume plasmon peak is accurately measured and this shift is related to valence electronic density and varies linearly with dopant concentration. We successfully implemented this technique, at 80kV using a Cs image and probe corrected FEI Titan Ultimate microscope with a GATAN Quantum ER energy filter, on a reference boron doped crystalline silicon specimen. Zero loss and silicon volume plasmon peak energy positions were determined for each spectrum and subtracted to give the effective plasmon peak energy related to active boron concentration using a Hyperspy [4] routine. A 70 meV offset is measured between highly doped layer and the silicon substrate. A good linearity between EELS and boron concentration (SIMS measurements) is obtained and sensitivity can dramatically be improved by averaging. Measuring the total concentration of arsenic or phosphorus as dopants in silicon is also possible in a TEM using EELS or EDS [5]. In our case, we first applied STEM-EDX technique on the source-drain region of phosphorous doped Nanowire based devices. STEM-EDX experiments were then performed at 200 kV using a FEI Titan Themis equipped with a Cs probe corrector and a SuperX® system including four SDD EDX detectors. Different strategies of signal acquisition exhibit a phosphorous concentration down to 5×10^{20} at/cm³ with a nanometer resolution.
Finally, as 3D characterization at the nanometer scale is becoming mandatory for advanced 3D devices like FinFETs or vertically stacked Nanowire FET devices [6], we will introduce results obtained on an arsenic doped (implantation) device. In this third example, a needle shaped FIB specimen was prepared and attached on an on-axis sample holder in order to perform an electron tomography experiment using a FEI Titan Ultimate at 200 kV. 23 STEM-EELS maps projections were acquired between -90° and +90°.

PCA denoising and standard extraction of O K, As L_{2,3} and Si K elemental tilt series were then processed. Alignment and 3D reconstruction of the tilt series were finally performed with a home-made software [7] showing arsenic clustering in the source-drain region (Figure 1.).

![Figure 1. a) STEM HAADF image of the needle shaped specimen including the FinFET, b) Elemental maps of Silicon, Oxygen and Arsenic at 70°, c) 3D reconstruction of each element obtained with the 23 elemental projections, d) Overlay of 3D elemental volumes, e) x,y slice through the As elemental reconstruction showing As clustering.](image)

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