Advanced 3D Characterization of Semiconductor Devices: Hybrid Metrology Correlating STEM-EDXS and Atom Probe Tomography

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Materials characterization to atomic scale revealing the precise location and chemical nature of the atoms has always been a researcher's dream, which led to a steady advancement of multiple high-end microscopy and spectroscopy analysis techniques. However, challenges still remain in achieving structural and compositional analysis with high accuracy and reproducibility. Particularly in semiconductor industry, with an ever-increasing structural complexity, elemental heterogeneity and miniaturisation of semiconductor devices, it has become of utmost importance to know the 3D structure and quantified elemental distribution of devices at sub-nanometer (or even atomic) level so as to understand their functional character and performance, and hence to design the road map for future technological developments.

In this respect, atom probe tomography (APT) has been extensively exploited in the last decade as it allows to determine and quantify the elemental composition with high spatial resolution and sensitivity, even for light elements. However, when applied to heterogeneous samples, APT might suffer from artefacts such as image distortions or biased compositional analysis. Hence, the device morphology and elemental distribution cannot always be solely concluded from such an analysis. Moreover, the destructive nature of the technique (atom by atom field evaporation) is a drawback for repetitive measurements often desired for optimization of instrumental conditions for enhanced data acquisition and accuracy. Here, scanning transmission electron microscopy (STEM) using the high angle annular dark field detector (HAADF) to obtain elemental Z (atomic number) contrast forms a perfect counterpart as the 2D images are free from distortions, and highly resolved 3D volume reconstructions (tomogram) can be achieved by maximising the number of 2D projections and minimising the missing wedge artifacts. Its combination with energy dispersive X-ray spectroscopy (EDXS) analysis can render quantitative elemental composition and distribution in 3D. Therefore, STEM-EDXS emerged as a powerful characterisation method for a wide range of materials. However, EDXS is still limited by multiple factors like detector positioning, its efficiency, detection limits (element concentration and atomic mass), sample holder design, scattering cross-section of specimen and poor signal to noise ratio, which brings down the theoretically achievable resolution of the technique. Several reports are published validating the potential of both techniques where the advantage and limitations of both methods are discussed with proposal of combining the two techniques in 3D analysis[1]. This has become an intriguing and extensive research topic worldwide. We envisage on the pros and cons of both methods and implement a hybrid procedure approach to combine APT and STEM-EDXS tomography to obtain both morphology and quantitative elemental distribution.

The presentation will provide an overview of this hybrid metrology correlating APT and STEM-EDXS tomography, the proof of concept results from various semiconductor devices such as SiGe fin-FETs and semiconductor nanowires. The methodology focuses on delivering highly resolved 3D device characterizations for next generation technologies. The discussions on advantage/disadvantage of this new approach will be taken up in detail.

References:

[1] Michael K. Miller, Thomas. F. Kelly, Krishna Rajan and Simon P. Ringer; The Future of Atom Probe Tomography, Mat. Today, 2012, 15(4), 158-165