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# Application of EFTEM and XEDS Elemental Mapping to Characterization of Nanometer Devices in Semiconductor Wafer-Foundries

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Precise characterization of the elemental distribution in the nanometer semiconductor device with high spatial resolution is an essential element of the Physical Failure Analysis (PFA) Laboratory to help develop and manufacture next generation of devices [1][2][3]. Nowadays state-of-the-art analytical TEM instruments possess the x-ray energy dispersive spectroscopy (XEDS) and/or the electron energy loss spectroscopy (EELS) capabilities to fulfill this goal. The acquisition of XEDS spectra on modern instruments is relatively straightforward and does not require an extensive training of the TEM analyst. It has high sensitivity to species with medium and high atomic number [4][5]. These features made it attractive for application in PFA. However, XEDS may not be the method of choice for the following reasons. First, it is not very sensitive to light elements, (e.g., B, C) [4][5], which are typically found in semiconductor devices. Second, peaks of a number of elements which are used in device structures overlap in the XEDS spectrum. Examples include Cu ($K_{\alpha 1}$) vs. Ta ($L_{\alpha 1}$), P ($K_{\alpha 1,\beta 1}$) vs. Pt ($M_{\alpha 1,\beta 1}$) or Zr ($L_{\alpha 1,\beta 1}$), etc. This makes it challenging to directly interpret results without further processing. Third, spurious x-ray peaks originating from excitations of components inside the electron microscope can also contaminate the observed XEDS spectrum. To answer this, EELS should be used as a complimentary method to provide the full elemental analysis. It is more sensitive to light atomic weight elements [4][5]. In the STEM configuration only the region of the sample under the electron probe contributes to the EELS spectrum. Therefore EELS data provide results with higher spatial resolution as compared to XEDS. The energy resolution of the EELS spectrum in non-aberrated instruments is $\Delta E<1eV$, which makes it possible to detect individual edges of most elements used in semiconductor structures without having to deconvolute the edges. However, the analyzed samples need to be thin, i.e. less than 50nm, and have surfaces free of redeposition. Moreover, subtraction of the spectrum background, processing and interpretation of the results requires an in-depth understanding of the analytical TEM configuration and electron diffraction physics. Since no single method can provide a full solution of the problem, analysts in the PFA Lab are challenged to find the optimum plan to analyze the problem in the shortest time.

Presented here are examples of how we combine both methods to quickly provide engineering solutions for semiconductor process integration on an SRAM device. Fig. 1 displays a TEM, an overlay and individual EFTEM elemental maps, which revealed details of elemental compositions inside the bridging portion between the dummy gates. Fig. 2 is a STEM on the same structure, and XEDS counterparts acquired by a Super-X with Bruker Esprit analysis software. Even with the primitive version of EELS by EFTEM mapping, details of the defect can still be delineated (arrowed). In contrast, the XEDS elemental mapping yields more ambiguous results, due to its intrinsic disadvantage of spatial resolution relative to EELS. However, EFTEM can only process one element at a time and maybe subjected to artefacts caused by the background subtraction problems. For features with only a few light elements present in the structure with high content (see the example), or in case when the structure is not sensitive to electron beam damage, EFTEM is very useful for applications demanding a fast turnaround with medium spatial resolution. For complex device structures consisting of both medium and light

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elements, or if high spatial resolution is essential, we suggest to use XEDS, and then complement results by STEM-EELS mapping.

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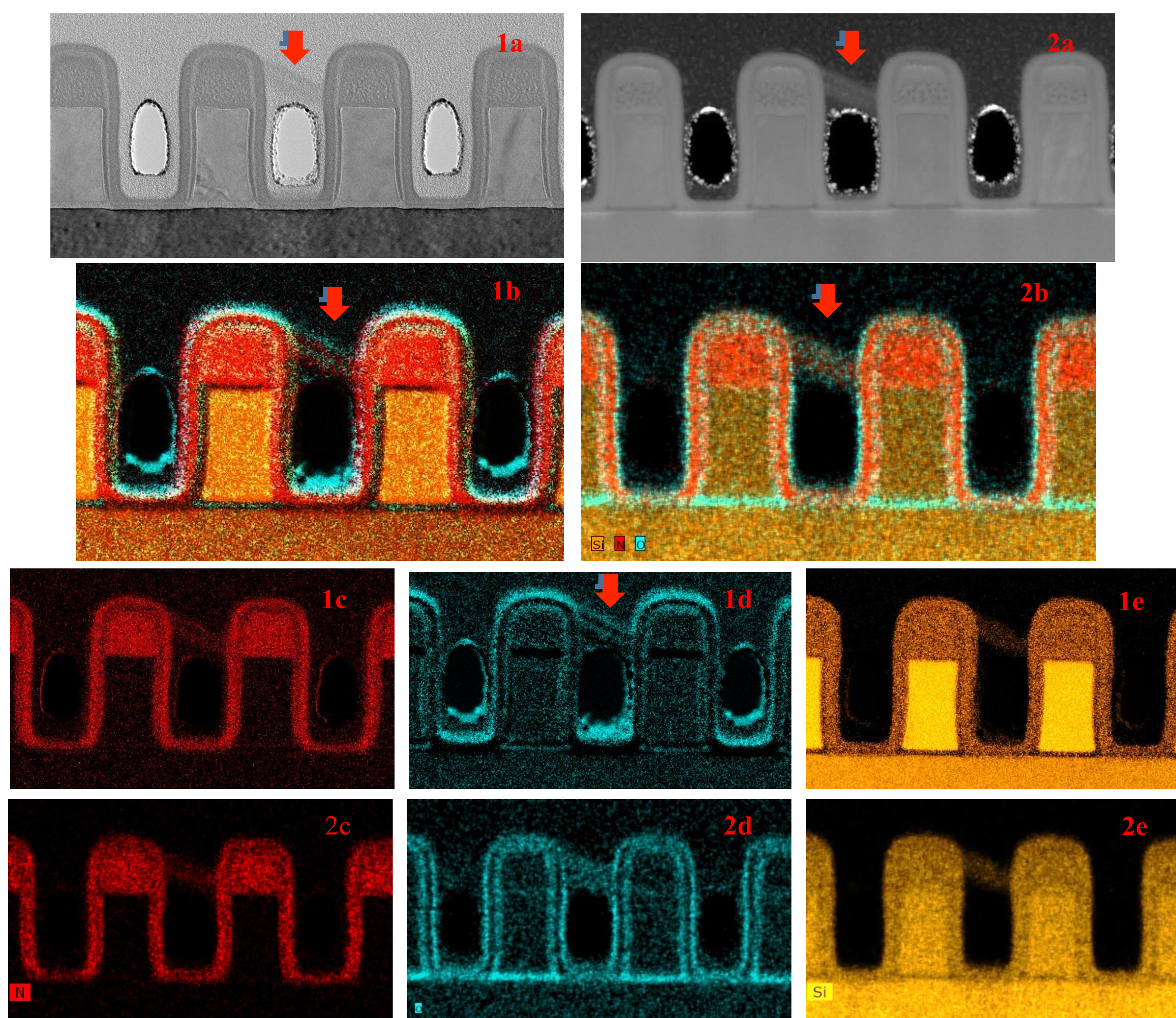


**Figure 1.** (a) TEM image; (b) an overlay of EFTEM maps; and individual elemental map by EFTEM, (c) N (red); (d) O (cyan); and (e) Si (yellow).
**Figure 2.** (a) HAADF-STEM image; (b) an overlay of XEDS maps, and individual elemental map by XEDS, (c) N (red); (d) O (cyan); and (e) Si (yellow).

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