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Correlative Analysis in the Semiconductor Industry

DJ Larson[1,*], TJ Prosa[1], I Martin[1], A-S Robbes[2], A Merkulov[2], N Bernier[3], V Delaye[3], P van der Heide [4], O Dulac[2], DA Reinhard[1] and RM Ulfig[1]

[1] CAMECA Instrument Inc., Madison WI, USA.
[2] Cameca SAS, Gennevilliers, France.
[3] Université Grenoble Alpes, CEA, LETI, Grenoble, France.
[4] IMEC, Leuven, Belgium.
* Corresponding author: david.larson@ametek.com

Technology advances in the semiconductor industry are motivated by minimization of feature size and optimization of process time. This is well captured in the recent literature by the statement that expectations for metrology data are "as precise as possible" and "as fast as possible" [1]. Ideally, this applies to all measurements ranging from statistical process control (SPC) methods to more esoteric methods used for failure analysis or development feedback. This is not feasible, of course, and we settle for using fast, non-invasive methods for SPC and revert to slower, often destructive, but also often more informative, methods in situations where high spatial resolution information is required. It is highly desirable to have an understanding of the level of correlation across such measurements. In this work we explore indium concentration (or dose) correlation for InGaAs finFET type test structures (Fig. 1) using low energy electron probe microanalysis (LEXES) [2], scanning transmission electron microscopy (STEM), secondary ion mass spectrometry (SIMS) [3,4], and atom probe tomography (APT) [5]. Fig. 2 shows example high angle annular dark field STEM images for InGaAs fin widths of 20 nm (a) and 100 nm (b). Nominal In-layer concentrations (Fig. 3) are x=15 at.% and y=25 at.% (y varies with fin width).

Correlation of total dose measurements between LEXES and SIMS is shown in Fig. 4 for Ga and In (two repeats of each finFET width of 20, 50, and 100 nm) with an R^2 of ~0.8. General LEXES repeatability was measured (nine points with five seconds per point) at less <0.83% for In, Ga, and As. Fig. 5 shows STEM energy dispersive spectroscopy mapping of In concentration in a 20 nm fin. Mean concentrations in the upper and lower fin regions are 27.7% and 13.7%, respectively (Fig. 3). Similarly, mean values for these two regions are 27% and 13.5% for 1.5D SIMS (4) and 22% and 10% for APT. Fig. 6 adds spatial (depth) information for STEM, SIMS, and APT data. Although the APT (and STEM) data indicates very good spatial resolution at the upper/lower region interface, the APT In concentrations are lower than the SIMS and STEM (and nominal) data. Future efforts will optimize APT data collection parameters in order to better match these concentrations. LEXES and SIMS average over many devices but have the potential to be fast. STEM and APT can measure a single device and have good spatial resolution, but are slower. APT has the advantage of having three-dimensional information and also good detection sensitivity for light elements. If these method correlate, then they can form the basis for a range of required metrology [6].

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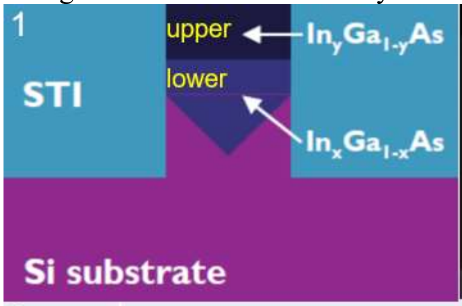

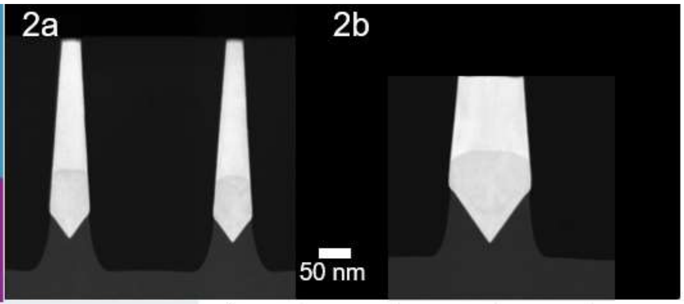

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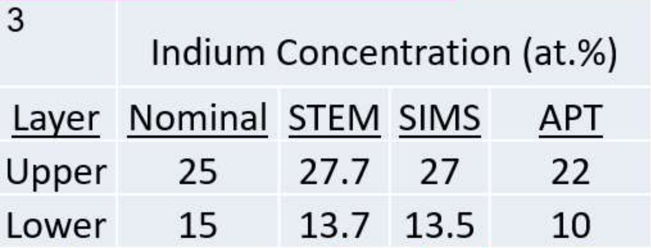

Layer	Nominal	STEM	SIMS	APT
	Indium Concentration (at.%)			
Upper	25	27.7	27	22
Lower	15	13.7	13.5	10

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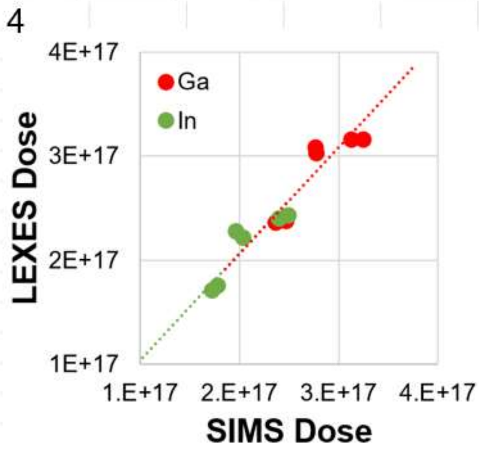

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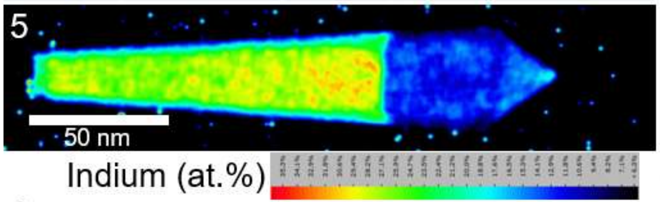

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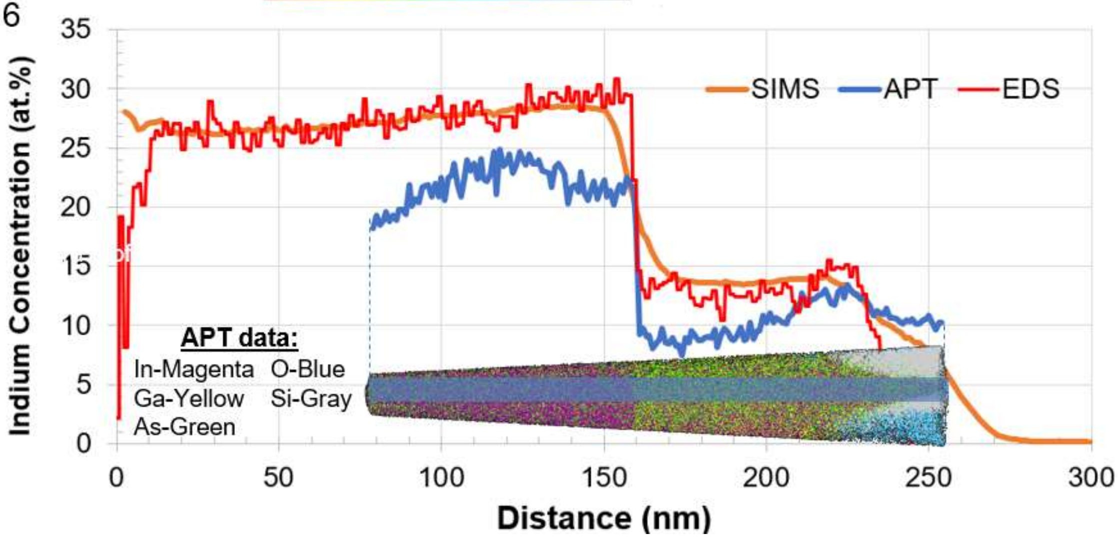

Figure 1. Schematic of the InGaAs device (x=15 at.% and y=25 at.%, y varies some with fin width).
Figure 2. High angle annular dark field STEM image of InGaAs fins with a) 20 nm and b) 100 nm width.
Figure 3. Summary of In-layer concentrations for nominal, STEM, SIMS, and APT.
Figure 4. Correlation of total In and Ga dose measurements between LEXES and SIMS.
Figure 5. Quantitative STEM EDS indium mapping for a 20 nm InGaAs finfet.
Figure 6. SIMS, APT, and DTEM-EDS data for a 20 nm InGaAs finFET showing the transition from the upper to lower In-region near 160 nm. Since the APT did not start measurement from the original surface, the depth is arbitrary, and chosen to match the SIMS position of the Indium interface.