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Applications of SIMS in advanced nano-electronics R&D

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We will give an overview of various (ToF-)SIMS applications, ranging from characterization of novel thin-film electronic materials and processes in an explorative R&D setting to inline monitoring of mature baseline processes in an advanced CMOS production environment. Also, we will discuss how SIMS characterization can be enriched with complementary external techniques, *e.g.* quantification of ToF-SIMS surface analysis (TXRF, XPS) or DSIMS depth profiling (static ARXPS vs. XPS profiling, etc…). We will illustrate this by highlighting selected examples:

- Continued dimensional scaling demands for progressive improvement of depth resolution. This has been enabled by continuous instrumental developments to provide high-density, stable, and low-impact energy primary ions beams to enable sub-nm depth resolution. I will give some examples of high-resolution DSIMS analysis of thin-film (epitaxial) stacks and Ultra-Shallow Junctions and use of variable rastering technique to improve dynamic range for ULE implant characterization.
- Integration of novel and heterogenous material stacks demands novel SIMS calibration methods and/or quantification protocols. Potential solutions to deal with the high complexity are cross-calibration with absolute external techniques, together with multi-standard approaches for explicit correction of SIMS yield variations with matrix composition. To this end, we will address some aspects of the Cs_nM^+ cluster technique, which can help to mitigate matrix effects in selected binary and ternary materials systems (III-V compounds, metal-silicides, etc…). A challenge in the Cs_nM^+ method is the long surface transient to reach steady state [Cs], complicating quantification in ultra-thin film structures. We will demonstrate use of complementary (AR)XPS profiling to improve characterization of thin-film structures and surface modifications for phase-change memory materials (GeSbTe).
- Introduction of novel materials and non-conventional species poses unique challenges regarding monitoring and controlling trace impurities in a semiconductor production / pilot line. We will demonstrate quantitative ToFSIMS protocols for less commonly used metals (Nb, Ir, …) and chalcogenide materials (Ge, Sb, Te), established through TXRF cross calibration. We will elaborate on use of pre-sputtering (low energy O_2^+ / Cs^+) to improve instrumental back grounds while stabilizing Si surface condition for better reproducibility and accuracy in monitoring of impurities.
- Advanced IC development in a manufacturing context demands at-line SIMS metrology with high throughput and reproducibility, often requiring small area analysis on patterned wafers. We will discuss implementation of an inline SIMS system, matching with laboratory SIMS, and development of alternate protocols based on O_2^+ beam, in close collaboration with IBM Albany Nanotech team [1].

[1] S. Schoehe *et al.*, ‘From lab to fab: In-line SIMS for process control in Nanosheet GAA device manufacturing’, SPIE advanced lithography and patterning, San Jose (CA, US), Feb. 2024