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From atomic layers, 3D nanostructures to full wafer thickness – the versatility of the SIMS technique

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One of the benefits of establishing dedicated measurement procedures – tailored for specific samples – is the ability to match a desired level of accuracy for each sample, proving the versatility of the SIMS technique. A recent development of the SIMS methodology enabled the characterization of 2D materials with atomic depth resolution [1]. In this case, however, the total sampling depth is just a few nanometers.

Semiconductor superlattices, on the other hand, usually consist of very thin layers but the total thickness can be in the micrometer scale. The biggest challenge of the analysis of 300 periods of InAs/InAsSb superlattice with 8/2nm layers thickness is not the depth resolution but the possibility of its deterioration after sputtering through several microns of the material. To validate the procedure, measurements have been performed from both sides and the results from front- and backside SIMS have been compatible.

Switching from planar to 3D structures brings additional challenges. It is not possible to directly measure an array of nanowires (NWs) since the primary ions would simultaneously interact with their tops, sides, and even with the substrate. Thus the structure has been embedded in an organic matrix. However, for standard measurement conditions, the sputtering rate of the organic material is more than an order of magnitude higher than that of the silicon. The application of high incident-angle ion bombardment eliminates this difference and boron dopant distribution can be quantified [2].

For a nanostructured silica fiber doped with germanium and ytterbium, the expected distance between two doped regions can be less than 30 nm. Thus even the state-of-the-art spectrometers with the best lateral resolution would not be sufficient to precisely quantify the diffusion of dopants. Thus a numerical approach has been devised to extract the information about the 3D diffusion from a 1D depth profile.

Last but not least, measurement procedure can also be established in such a way as to enable profiling through full wafer thickness, i.e. in millimeter scale. Thus it is possible to monitor the diffusion of copper through a silicon wafer, confirm the gradient of dopant in GaP crystal of observe hydrogen penetration in steel.

[1] Michałowski, P.P. et al. Oxycarbide MXenes and MAX phases identification using monoatomic layer-by-layer analysis with ultralow-energy secondary-ion mass spectrometry. Nat. Nanotechnol. 17, 1192–1197 (2022).

[2] Michałowski, P.P. et al. Secondary ion mass spectrometry quantification of boron distribution in an array of silicon nanowires. Measurement 211, 112630 (2023).