Optimizing ToF-SIMS depth profiles of semiconducting heterostructures

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In order to meet the demand for increased performance with progressive miniaturization, microelectronic components are being developed into multilayer structures with increasing complexity. Since the material composition, the layer thickness and the diffusion behavior between the individual layers have a sensitive effect on both the performance and the service life of the components, such a development is only possible through analytical monitoring of the materials properties on an atomistic scale.

A suitable analytical method to investigate semiconductor multilayer structures is Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS). The particular strength of the method is the possibility to determine all elements including their isotopes. In addition, the information depth of only about 0.5 nm (< 3 monolayers) makes SIMS a very surface-sensitive tool. By sputtering it becomes possible to obtain the composition of materials in deeper layers.

In this presentation we focus on optimizing ToF-SIMS depth profiling of semiconductor heterostructures. As model system, we investigate while varying sputter parameters a state-of-the-art Molecular Beam Epitaxy (MBE) grown multilayer structure consisting of ultra-thin layers with 2 nm in thickness. We measure atomic concentration profiles and use an error function based description model to quantify layer thicknesses as well as interface sharpness. Using this approach the multilayer structure is well resolved. The optimized instrumental setting for high depth resolution in ToF-SIMS profiling is applied to analyze a MBE grown SiGe/28Si/SiGe heterostructure. The strained and isotopically purified 28Si layer of this structure represents a Quantum Well that has been proven to be an excellent host for an electrostatically defined electron spin qubit [1].

[1] Struck, T.; Hollmann, A.; Schauer, F.; Fedorets, O.; Schmidbauer, A.; Sawano, K.; Riemann, H.; Abrosimov, N. V.; Cywiński, ; Bougeard, D.; Schreiber, L. R. Low-frequency spin qubit energy splitting noise in highly purified 28Si/SiGe. npj Quantum Information 2020, 6, 2056–6387.

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