Secondary Ion Mass Spectrometry Measurements of Non-Planar Materials and Devices

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Recent advancements in materials science and device engineering have underscored the critical need for analytical techniques capable of high-resolution chemical characterization of complex, non-planar structures. In this context, the adaptation of secondary Ion Mass Spectrometry (SIMS), renowned for its exceptional sensitivity and elemental specificity, to non-planar materials is of paramount importance. Traditionally optimized for flat surfaces, SIMS is now being redefined to meet the demands of emerging materials such as MXenes, silicon nanowires (NWs), and vertical-cavity surface-emitting lasers (VCSELs) with their three-dimensional architectures.

MXenes, a versatile class of two-dimensional transition metal carbides and nitrides, exhibit intricate compositions with surface terminations that significantly influence their properties. The optimized SIMS measurement procedure, with its layer-by-layer characterization, has proven to be a reliable tool, identifying oxygen in the X-layers.[1] This precision has led to the discovery of the existence of oxycarbide, oxynitride, and oxycarbonitride subfamilies. By implementing advanced deconvolution protocols, SIMS has shown that it can achieve atomic depth resolution and precise quantification of elemental distributions within individual layers.[2]

Similarly, the analysis of NWs—key components in next-generation nanoelectronics—presents challenges due to their high aspect ratio and non-uniform doping. Conventional SIMS fails to resolve dopant distributions along nanowire heights due to a non-uniform sputtering process. However, a novel self-flattening approach, where nanowires are embedded in an organic matrix and analyzed at high incident angles, has revolutionized the field by allowing for accurate depth profiling of dopants, with detection limits as low as 5×10^{16} atoms/cm^3.[3] This approach has significantly improved our ability to understand and optimize the performance of nanowire-based devices.

The complexity of VCSEL structures, comprising hundreds of alternating semiconductor layers with nanoscale quantum wells, further necessitates refined SIMS methodologies. Standard SIMS suffers from matrix effects and depth-resolution degradation, making precise characterization difficult. Recent improvements, including impact energy modulation, optimized extraction parameters, and in-situ ion polishing, have led to artifact-free profiling, capturing the realistic distribution of elements within the device. This enhanced approach enables accurate quantification of dopants and contaminants combined with subnanometer depth resolution needed to analyze quantum wells. Interestingly, the measurements can be performed not only on epi-structures but also on fully processed devices.[4]

These advancements in SIMS methodologies are critical for accurately characterizing non-planar materials and devices. By addressing limitations inherent to conventional SIMS, these innovations pave the way for improved understanding, optimization, and application of complex nanostructured materials with non-planar geometries in electronics, such as advanced semiconductor devices, and photonics, including high-performance lasers and photodetectors, and beyond.

References

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