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ABSTRACT:

Defect Engineering and Nanoscale Characterization of Functional Materials

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Ion implantation provides a powerful route for defect and strain engineering in functional materials. In both complex oxides and semiconductors, implantation-induced displacement damage generates defect complexes and local strain fields that can significantly modify structural and functional properties [1-4]. However, establishing clear relationships between controlled damage and the resulting nanoscale structural modifications remains challenging.

In this work, we investigate noble gas ion implantation in two classes of materials: the degenerate semiconductor ScN and the ferroelectric perovskite $BaTiO_3$ (BTO) single crystal. The use of inert species such as helium, neon, and argon enables controlled defect introduction without chemical doping, allowing the study of purely defect- and strain-driven mechanisms. In ScN, defect engineering is used to reduce thermal conductivity while preserving the electronic properties of the semiconductor, whereas in $BaTiO_3$ implantation-induced damage is used to perturb the lattice and modify the local polarization landscape.

The implanted regions were primarily characterized using a multimodal transmission electron microscopy approach combining TEM, STEM, and four-dimensional STEM (4D-STEM), enabling direct observation of implantation-induced defects and quantitative mapping of local crystallography and strain. Complementary techniques—including thermoelectric measurements, X-ray diffraction, optical spectroscopy, and Raman spectroscopy—were used to correlate nanoscale structural modifications with macroscopic material response.

This work establishes a framework for using ion implantation as a precise tool to design defect landscapes, opening new opportunities for the rational control of functional properties in advanced semiconductors and oxide materials.

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