Structural Fluctuations in Quantum Devices: Nanoscale Insights with Synchrotron Radiation

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Microscopic structural fluctuations and defect distributions play a pivotal role in dictating the properties and functionality of quantum materials and devices. To harness these materials for quantum technologies—including quantum communication, sensing, and computation—comprehensive, multi-scale characterization is essential. Synchrotron-based X-ray diffraction microscopy has emerged as a powerful platform for quantitatively mapping strain, lattice distortions, and defect densities across diverse crystalline systems, enabling insights that are crucial for both material optimization and device reliability.

This poster will showcase cutting-edge diffraction microscopy methodologies tailored for the investigation of quantum and advanced materials, heterostructures, and thin films. Where each technique offers unique advantages, making them suitable for different research applications.

Dark-Field X-ray Microscopy (DFXM): Enabling non-destructive mapping of deeply embedded strain fields and crystalline orientation with sub-100 nm resolution, ideal for sensitive quantum materials and in-situ dynamic experiments[1].

Scanning X-ray Diffraction Microscopy (SXDM): Providing nanoscale resolution (~30 nm) strain mapping in ultra-thin films and heterostructures, with compatibility for multimodal techniques such as fluorescence and X-ray Beam Induced Current (XBIC), key for integrated quantum devices [2,3].

Advanced X-ray Topography Techniques, including Rocking Curve Imaging and section topography, delivering quantitative insights into local lattice distortions and depth-resolved defect characterization across mm-scale fields of view[4].

Through exemplary case studies—ranging from epitaxial quantum semiconductor layers to bulk diamond and additive-manufactured metals—we demonstrate how precise strain and defect mapping can drive innovations in quantum technologies. The integration of in-situ and operando capabilities further enhances understanding of process-structure-property relationships vital for next-generation quantum systems.

References

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[2] C.Corley-Wiciak et al., ACS Applied Materials & Interfaces, 15 (2023) 3119-3130
[3] C. Corley-Wiciak et al., Phys. Rev. Appl., 20 (2023) 024056
[4] T. N. T. Caliste et al., Microelectronic Engineering 276 (2023) 112012.

Figures

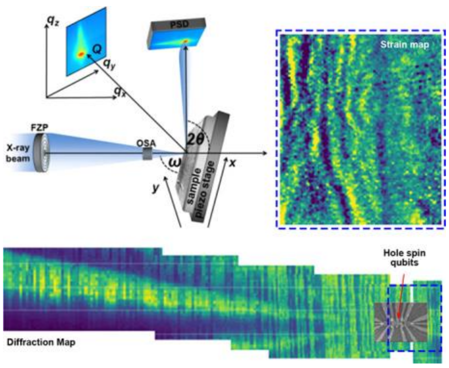

Figure 1: (a) Schematic of the SXDM setup at ID01, (b) map of the eps_zz strain tensor component around two functional hole spin qubits, (c) large scale diffraction map with inset SEM image of the quantum processor [2]