Beam Induced Processes for Microelectronics and Quantum Applications

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Exotic materials such as van der Waals systems, topological materials, and their complex heterostructures appear poised to contribute to next generation computing architectures. Beyond fundamental materials physics questions on functionality, their emergence from laboratory curiosities to viable computational or memory elements hinges on our ability to fabricate, shape, and create functional devices from these materials. Given that many of these systems rely on either preservation of pristine structure or deterministically induced defects to bring about their unique properties, novel nanofabrication processes that are highly controllable in these regards is essential.

Focused beam induced direct write processes offer exciting new opportunities in providing new means of processing complex, sensitive materials with nanometer spatial control. Perhaps more importantly, they allow access to unique energy transfer mechanisms that offer potential to alter these materials in beneficial ways. Here, we will present recent progress in utilizing focused beam processes—electron and ion—for a variety of microelectronics and quantum science applications.

Electron-beam-induced etching (EBIE) of two-dimensional transition metal dichalcogenides (TMDs) using XeF_2 (Figure 1) will be highlighted with an emphasis on characterization of etch efficiency of MoS_2, peripheral damage, and how they affect field effect transistor fabrication [1]. Expanding into additional fluorine etch compatible TMDs will be discussed in the context of understanding differences in etch mechanisms between the materials. Computational modeling via *ab initio* molecular dynamics is yielding greater insights into relevant etch mechanisms and give insights into our ability to control defect evolution during the etch process. Additionally, superconducting films that are integral to quantum architectures may also display sensitivity and degradation when subjected to standard nanofabrication processes. We also explore. As such we will present results of electron beam induced etching of these films, the limitations of the process, and techniques to reduce undesirable spontaneous etching that compromises resolution.

Ion beam induced defect engineering will be presented, highlighting the emergence or enhancement of ferroelectric properties in hafnium oxides [2] and aluminum nitrides. We will also present the emergence of color centers in hexagonal boron nitride with a discussion of the effects of ion species in the occurrence of these light emitting defects. Finally, we will present recent work on the use of reactive focused ion species to tailor the morphological, compositional, and electrical properties of materials deposited by ion beam induced deposition (IBID).

[1] Lasseter, J. *et al., Selected Area Manipulation of MoS2 via Focused Electron Beam-Induced Etching for Nanoscale Device Editing*. ACS Appl. Mater. Interfaces, **2024**, 16, 9144.

[2] Kang, S. *et al., Highly enhanced ferroelectricity in* HfO_2*-based ferroelectric thin film by light ion bombardment.* Science, **2002**, 376, 731.

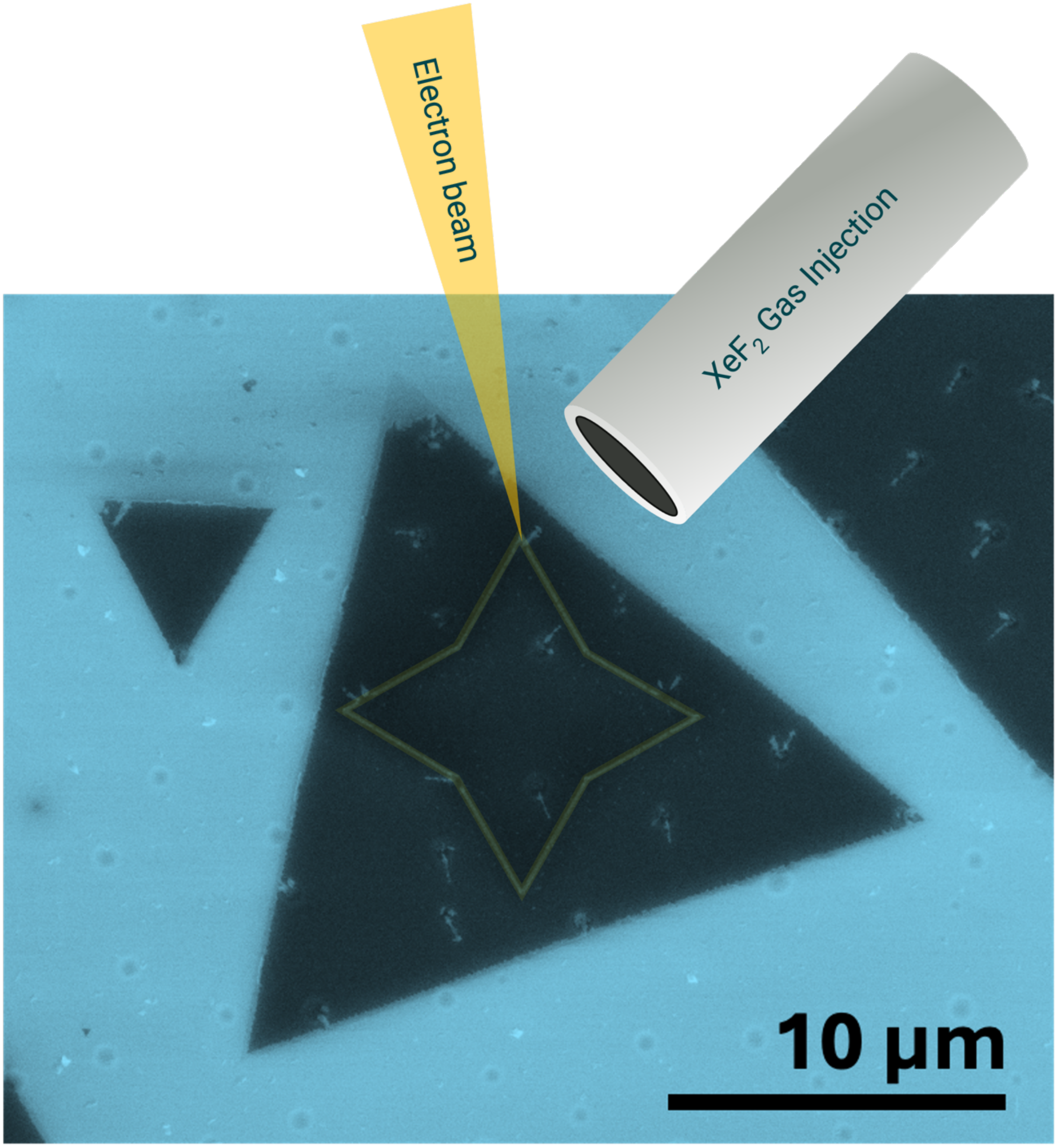

Figure 1. MoS_2 etched via electron beam induced etching to isolate a star-shaped pattern from the bulk flake.