Contribution ID: **52** Type: **Poster Only**

Focused Helium Ion Beam for Direct Patterning of Monolayer MoS2 Nanoribbon Field Effect Devices

Helium focused ion beam (FIB) has emerged as a powerful technique to directly pattern nanostructures below 10 nm due to its high-resolution capabilities, the inert nature of the helium ion source, and high penetration depths as compared to heavier ion sources. These attributes make He FIB particularly interesting for patterning two-dimensional (2D) materials such as transition metal dichalcogenides (TMDs) to investigate transport phenomena at ultra-scaled dimensions. We demonstrate the effective use of helium ion microscope (HIM) FIB for fabricating MoS2 nanoribbon array devices, enabled by a volatile XeF2 precursor for gas-assisted FIB-induced etching (FIBIE), which allows for reduced ion dose compared to direct sputtering. While excellent pattern definition is achieved, the resulting devices exhibit significant performance degradation with decreasing nanoribbon width. This is attributed to delocalized damage extending up to 150 nm beyond the patterned edge. Incorporating a thin top encapsulation layer of hBN is found to improve device performance by one order of magnitude, although the lateral extent of damage remains unchanged. These findings suggest that the spatial distribution of damage is primarily determined by the forward- and back-scattered ions and electrons trajectories. The use of the hBN encapsulation layer is found to substantially reduce the damage from XeF2-related processes in unexposed regions. Raman and photoluminescence (PL) measurements corroborate these findings, while ion/solid interaction simulations further elucidate the resolution limits imposed by substrate interactions. This work provides critical insights and a practical pathway for utilizing HIM FIBIE in 2D TMD functional device patterning.

Topical Area

Hard matter: quantum, electronic, semiconducting materials

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