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Patterning and Functionalization of 2D Materials via Environmental E-Beam Chemistry

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The ability to spatially tailor the expansive property-space (e.g., conduction behavior, optical emission, surface interactions etc.) of 2D materials is of special interest for applications in sensing, bioelectronics, spintronics/valleytronics and more. Current methods of property modulation focus on the modification of the basal surfaces and edge sites by the introduction of defects, functionalization with organic or inorganic moieties, alloying, heterostructure formation, and phase engineering. A majority of these methods lack the resolution and control for the development of next-generation nanoscale devices or are limited in the types of functionalities for efficient property modification. In this study, we utilize electron-beam patterning on graphene and monolayer transition metal dichalcogenindes (TMDs) in the presence of a controlled atmosphere enabled by an environmental scanning electron microscope (eSEM). A series of parametric studies show the effect of acceleration voltage, beam current, pressure, and electron dose on the defect densities and consequently on the optical and electronic properties of the materials. We further present evidence for the mechanism of functionalization based on the changes in spectral signatures. Finally, we show the ability to achieve a pattern resolution of ~ 60 nm on the basal plane of the 2D materials, demonstrating a robust method to achieve nanoscale functionalization with high fidelity.