Unusual Nanostructuring and Morphology-tuning by FIB: Self-Organization, Self-Assembly and Site-Specific Defect Engineering on the Functional Surfaces

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Focused Ion Beam (FIB) has been extensively used for direct milling for Nano- and Micro-structures. The foremost leverage using FIB, as compared to conventional lithography processes, for nanofabrication is that it is a mask-less (direct-writing) and single-step nanopatterning technique; however, it operates on a pixel-by-pixel dwelling, and the effective beam size of FIB restricts minimum feature size. Self-organization of the patterned surfaces and self-assembly effects induced by FIB-material interactions can be useful to fabricate unusual nanostructures with FIB, which are difficult or impossible to fabricate via conventional processes.

Here, we present self-organization and self-assembly attempts on 2D van der Waals materials such as hexagonal Boron Nitride (hBN) and Molybdenum Trioxide (MoO_3). When we irradiate Xe^+ plasma focused ion beam (PFIB) over the hBN samples, we can create localized boron vacancies (V_B^-), and the material becomes photoluminescent at the patterned regions. In addition to this defect engineering induced by Xe^+ PFIB irradiation, deterministic and optimized irradiation approaches also lead to creating surface morphologies such as periodic nanoripples/nanopolygons (Figure 1) on the hBN surface via nanoscale-controlled surface self-organization. Hence, by controlling the pitch and morphology of self-organized structures, we are able to fabricate grating-like hBN nanostructures, which are also quantum emitters of photons. This defect engineering, in addition to controlled structural morphologies, provide the pathway towards unconventional optoelectronic devices and photonic properties.

We also demonstrate kirigami for MoO_3 flakes on a Silicon substrate with Ga^+ FIB irradiation. We call this process kirigami because we can fold and bend 2D materials with FIB process, which is similar to the origami art processes (Figure 2). Conventionally, the literature reports FIB-induced kirigami on thin-metal films that are suspended in air. Here, we propose kirigami for the MoO_3 flakes placed on a Silicon substrate. As MoO_3 being an important metamaterial for photonic systems, the capability of bending and creating 3D kirigami structures with FIB irradiation could be a promising aspect due to its added functionality.

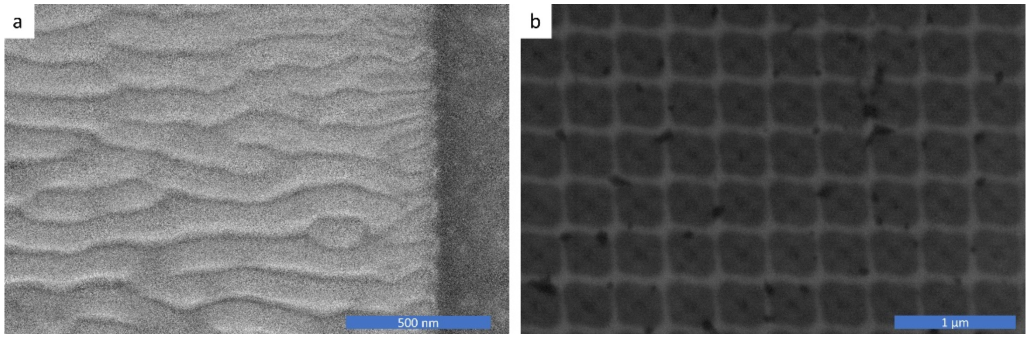

Figure 1: Xe^{+} PFIB irradiation induced nanoripples (a) and nanopolygons (b) on the hBN surface via surface self-organization.

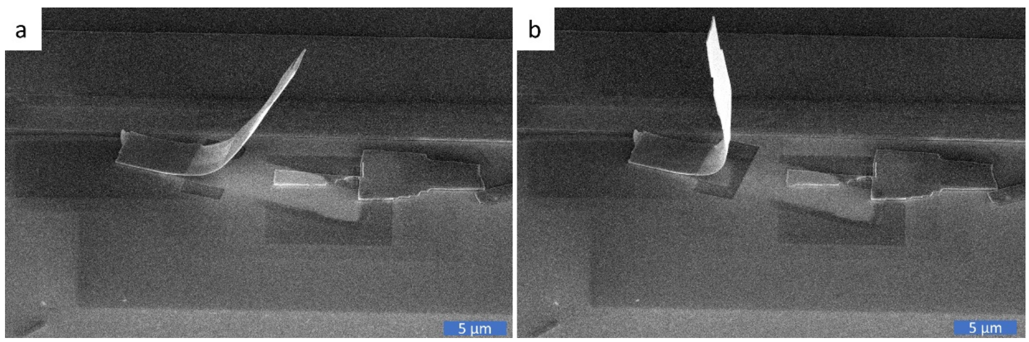

Figure 2: Ga^{+} FIB irradiation induced bending of MoO_3 flakes on Silicon substrate.