Optimizing FIB-material Interactions for Self-Organization induced Nanofabrication, Self-Assembly, and Local Defect Engineering

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The prime advantage of using a focused ion beam (FIB), as compared to traditional lithography processes, for nanofabrication is that it is a direct-writing and single-step nanopatterning technique; however, it is slow and inefficient due to its pixel-by-pixel operation and minimum feature size depending on the beam size. Hence, to overcome such limitations, I will discuss devising a unique fabrication strategy by harnessing the ion-induced self-organization toward hierarchical, highly-ordered, and 3D nanostructures in this talk. With the FIB-induced nanoscale control on the surfaces, an easy and single-step self-organizing process can manipulate the morphology of individual nanoholes via FIB irradiation. Through nanoscale control over these self-organization dynamics on the surfaces, periodic and protruding (3D) nanoscale polygons are realized.[1-3] Theoretical insights on these self-organization approaches by molecular dynamics simulations suggest the crucial role of thermodynamics and local heating during ion impingement on the material surface. Such a nanofabrication approach leads to prevailing challenges toward miniaturization.

The latter part of the talk focuses on FIB-induced defect engineering and self-assembly of materials. Local defect creation and lateral patterning of the semiconducting metamaterials can enhance the optical and transport properties of the metamaterial surfaces at the nanoscale. Here, I'll discuss deterministic defect writing and enhancement of optical/transport properties of 2D vdW and epsilon-near-zero (ENZ) materials.[4] Traditionally, for FIB-induced kirigami to occur, nanostructures must be suspended. However, making suspended structures is a complex process, so here, we report a successful kirigami for the 2D vdW materials placed on a Silicon substrate. The presented results have been achieved by optimizing the synergetic balance of FIB-induced strain and the interaction of Si-substrate with the FIB-induced charge accumulated on the 2D vdW materials.

[1]B. Kamaliya *et al.*, Adv. Mater. **33**, 2008668 (2021).
[2]B. Kamaliya *et al.*, Microsc. Microanal. **26**, 1684 (2020).
[3]B. Kamaliya *et al.*, APL Mater. **6**, 036106 (2018).
[4]M. Tolchin *et al.*, Bulletin of the American Physical Society (2024).