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Low Damage NanoFabrication for 2D Material Devices and Beyond

NanoFrazor lithography – or thermal scanning probe lithography (t-SPL) - has recently entered the lithography market as first true alternative to electron beam lithography (EBL) [1]. Core of the technology - which has its origins at IBM Research and their Millipede project - is a heatable, ultrasharp probe tip which is used both for patterning and simultaneous inspection of complex nanostructures. The heated tip creates very high-resolution (down to <10 nm half-pitch) nanostructures by locally evaporating resist materials at a patterning speed comparable to high-resolution Gaussian shaped EBL [2]. The written nanostructures are inspected by the cold tip in parallel with the patterning process, enabling very accurate markerless overlay with sub-5 nm accuracy having been demonstrated [3,4]. Pattern transfer by reactive ion etching [5], lift-off [5], directed self-assembly [6] and more have been demonstrated. Here, we show how devices based on low-dimensional materials such as MoS_2 (Figure 1) or graphene flakes, carbon nanotubes and nanowires can be fabricated by NanoFrazor. The topography of the atomically thin 2D materials can be imaged through the resist enabling easy and accurate overlay. Furthermore, the patterning process involves no injection of charged particles into the sensitive materials which enables measurements and applications at as near as their pristine state as possible.

References

[1] Garcia et al., *Nature Nanotechnology* **9**, 577 (2014).
[2] Paul et al., *Nanotechnology* **22,** 275306 (2011).
[3] Rawlings et al., *ACS Nano* **9**, 6188 (2015).
[4] Rawlings et al., *Transducers* 2167-0021 (2017).
[5] Wolf et al., *J. Vac. Sci. Technol. B* **33**, 02B102 (2015).
[6] Gottlieb et al., *Nanotechnology* **28**, 175301 (2017).

Figures

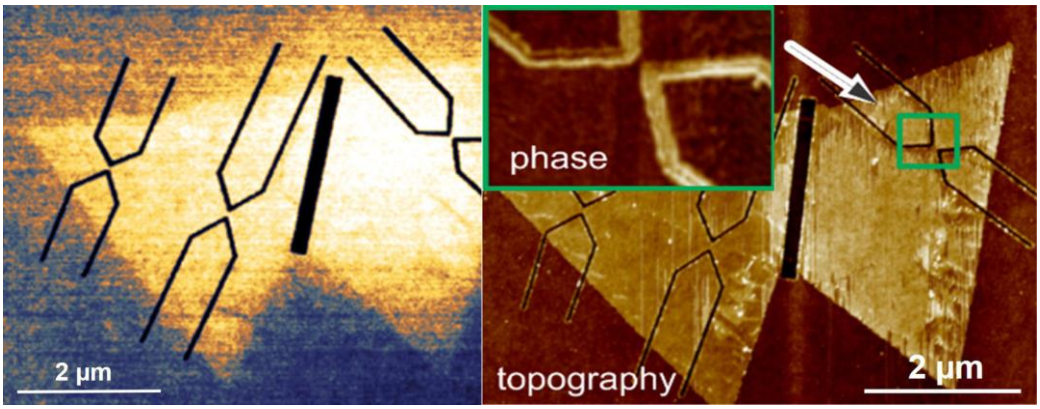

Figure 1: Left: NanoFrazor image of CVD grown single-layer MoS_2 flakes (courtesy of EPFL) after NanoFrazor patterning. The atomically thin material is clearly visible under the resist layer enabling very accurate overlay of the patterns. Right: AFM images of the same flake after the patterns have been etched into the material.