

# NanoFrazor – A Nanolithography Tool for 2D & 3D Devices

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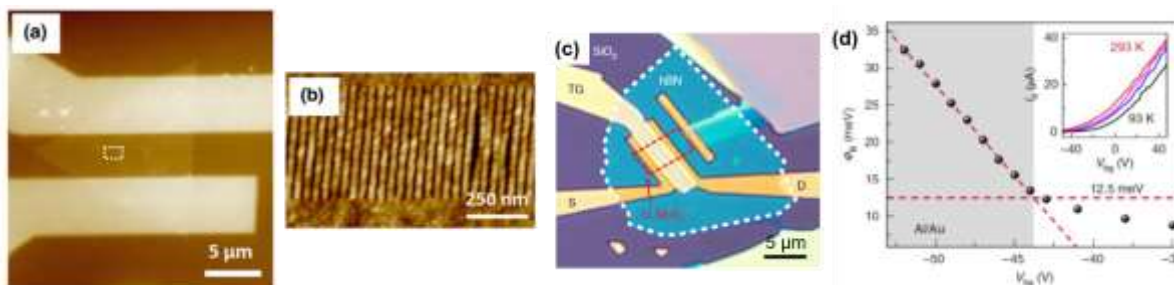
NanoFrazor systems are nanofabrication instruments based on thermal scanning probe technology. They can be used for a wide range of surface manipulation methods like nanolithography as recently summarize by Howell [1]. Core of the technology is a heatable probe tip that is used for both patterning and simultaneous inspection of complex nanostructures. The heated tip can pattern very high-resolution ( $< 10$  nm half-pitch) nanostructures by locally evaporating resist materials. The structures are inspected by the cold tip in parallel with the patterning process, enabling stitching and markerless overlay with sub-5 nm accuracy [2]. The technique is compatible with all the common pattern transfer processes [3,4,5].

Shaping 2D materials into narrow ribbons, Hall bars etc. is often required in order to study their properties. Another challenge is formation of high-quality electrical contacts on them. Predominant fabrication process - i.e. EBL followed by etching or lift-off of metal - has its resolution limited by proximity effects, may require complex overlay procedures and typically yields poor quality non-ohmic metal contacts with high Schottky barriers and large contact resistances [6]. Here, we show that NanoFrazor lithography can be used for shaping 2D materials with very high precision (Figure 1a-b) [7] and for forming high-quality metal contact electrodes on them (Figures 1 c-d) [5]. The fabricated devices exhibit vanishing Schottky barrier heights (around 0 meV, Figure 1d).

## References

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- [6] Allain *et al.*, *Nature Materials* **14**, 1195–1205 (2015).
- [7] Ryu and Knoll, *Electrical Atomic Force Microscopy for Nanoelectronics*, 143-172 (Ed. U. Celano), Springer Nature Switzerland AG (2019).

## Figures



**Figure 1:** a) AFM image of 18-nm half-pitch 1L MoS<sub>2</sub> nanoribbon array patterned along the zigzag direction. (b) A close-up of the region marked with a white dashed box in (a). Figures (a) and (b) from Ref [7]. (c) Optical image of a 1L MoS<sub>2</sub> FET with a h-BN gate dielectric where the source, drain and top-gate electrodes have been patterned with a NanoFrazor. (d) Gate voltage dependence of Schottky barrier height of a 1L MoS<sub>2</sub> FET with Al/Au contacts ( $V_{ds} = 2$  V). The deviation from the linear response at low  $V_{bg}$  (dashed red line) defines the flat band voltage and the SBH. Inset, corresponding temperature-dependent transfer curves ( $V_{ds} = 2$  V). Figures (c) and (d) from Ref. [5].