Application Note

Bilayer Lift-Off for NanoFrazor Lithography

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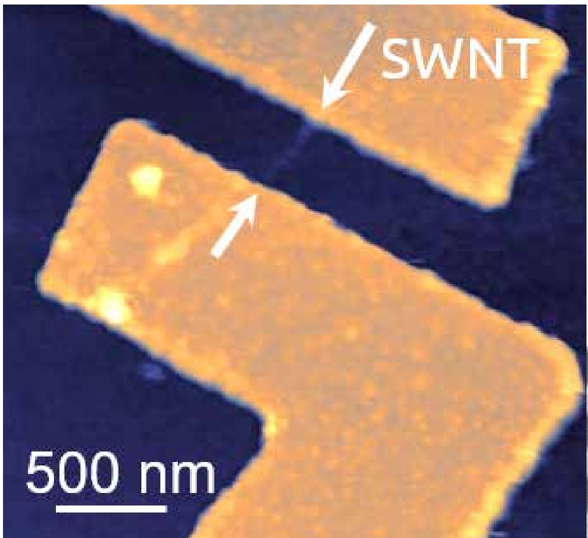
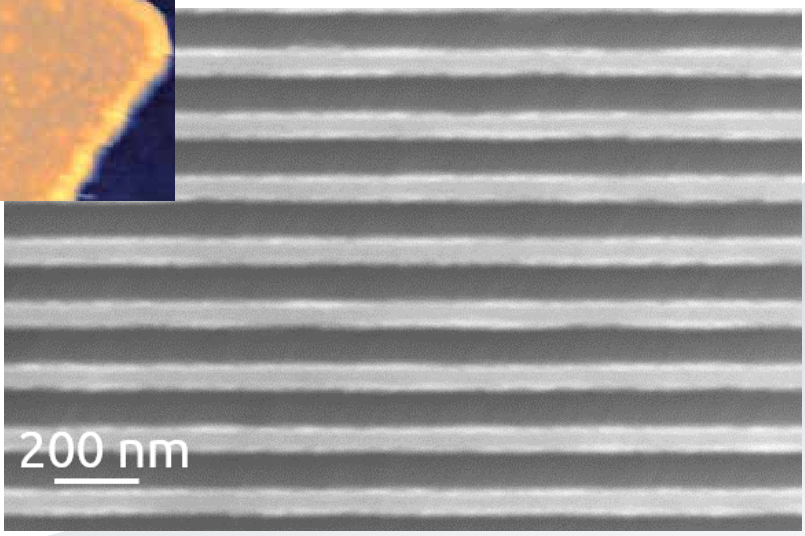
This application note describes process details for bilayer lift-off combined with NanoFrazor lithography. We discuss advantages and limitations of this approach and show examples of extremely good quality contacts and top gates on sensitive 2D materials, and structures with features down to 7 nm.

Bilayer lift-off is a simple and well-established process for micro- and nanofabrication. It is very versatile and fits smoothly into the thermal scanning probe lithography process flow. The top resist layer is for patterning by the NanoFrazor, and the bottom one is for creating the undercut. Standard steps like metal evaporation and lift-off follow after that. Different resists and developers can be used, depending on the sample material and the application.

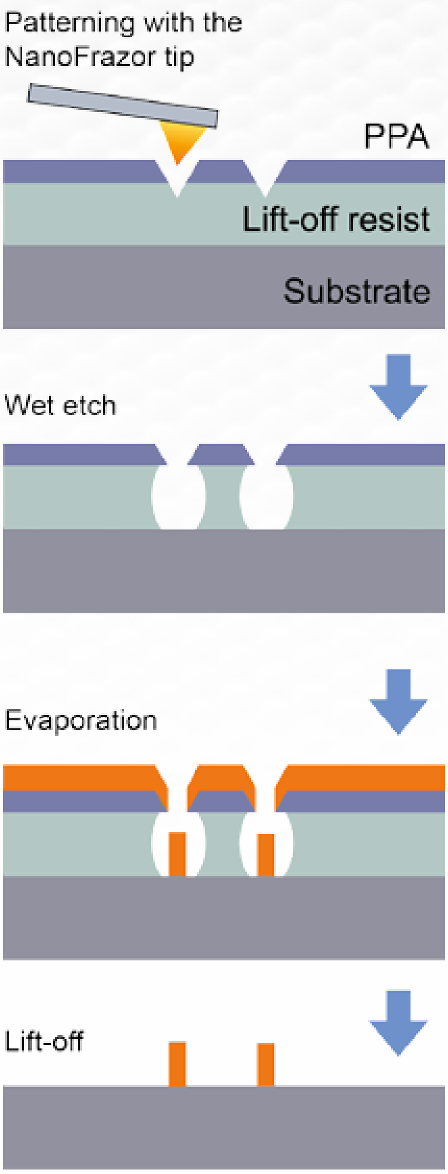


A single-walled carbon nanotube contacted by two metal electrodes, which were patterned via the bilayer lift-off process. The in-situ overlay capability was used to detect the location of the nanotube.



70 nm half-pitch metal lines produced by the NanoFrazor and the bilayer lift-off process

PROCESS DETAILS



1. Spin-coat the sample with a lift-off resist as the bottom layer, and with thermally sensitive Polyphthalaldehyde (PPA) polymer as the top layer.
2. Pattern the PPA layer by the hot NanoFrazor tip (or the focused laser of the NanoFrazor Direct Laser Sublimation add-on).
3. Isotropically dissolve the lift-off resist layer in a developer solution to form an undercut.
4. Evaporate metal or other materials (max. 40% of the thickness of the lift-off resist layer). The undercut prevents the formation of a continuous deposited layer.
5. Dissolve the lift-off resist in a suitable solvent to remove the exessive deposited material.

The choice of lift-off resist layer depends on several factors:

- Is the sample hydrophilic or hydrophobic?
- Is the sample sensitive to water /solvent / pH value / plasma?

SEM view of a patterned bilayer resist with an undercut and evaporated metal before the lift-off

	PMGI	PMMA/MA
Substrate pre-treatment	HMDS priming	O_2 plasma
Soft-bake temperature	225° C	180° C
Thickness range	20 - 300 nm	20 - 500 nm
Solvent	Cyclopentanone + PGME	PGME or ethyl lactate
Developer	Base (TMAH in water)	Solvent (IPA/DIW or ethanol)
Stirring required?	No	Yes
Remover for Lift-off	NMP or DMSO	Acetone or DMSO

Characteristic properties of possible bottom (lift-off) layers

EXAMPLES: FIELD-EFFECT TRANSISTORS BASED ON 2D MATERIALS

Quality of electrical contacts on 2D materials can suffer from many factors, such as resist residues and damage from charged particles or heat. The advantage of patterning with the NanoFrazor is that PPA evaporates without leaving residues on the sample. Also, highly localized heat from the NanoFrazor tip does not reach the sample through two layers of resist. Thanks to that, thermal scanning probe lithography is a very gentle nanopatterning method, suitable for sensitive materials and for fabrication of high-quality electrical contacts.

In-situ imaging with the cold tip allows the NanoFrazor to find nanowires and single-layer flakes of 2D materials in order to align the pattern with the sample with a few-nm accuracy. Recent work on single-layer 2D materials and van der Waals heterostructures confirms the advantage of a bilayer lift-off approach combined with NanoFrazor lithography. The devices fabricated for this study show exceptional quality and vanishingly small Schottky barriers [1].

A double-gated field-effect transistor based on single-layer MoS_2 features:

- Linear I-V curves showing Ohmic behaviour of the contacts
- Vanishingly low Schottky barriers close to 0 mV
- Record-high on-off ratios of 109-10^{1}0
- Subthreshold swing of 64 mV/dec

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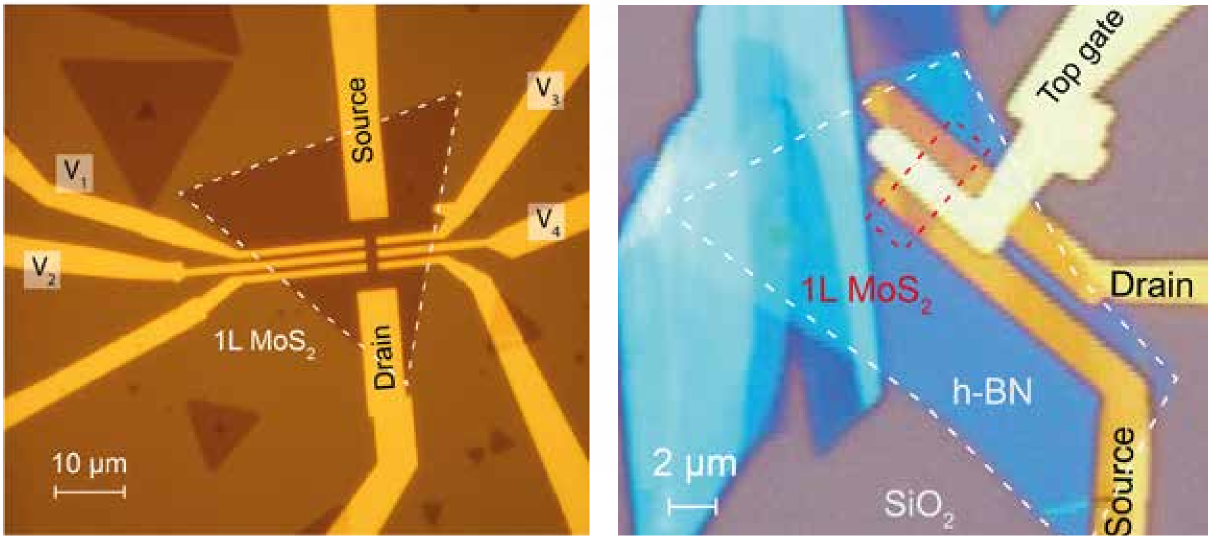


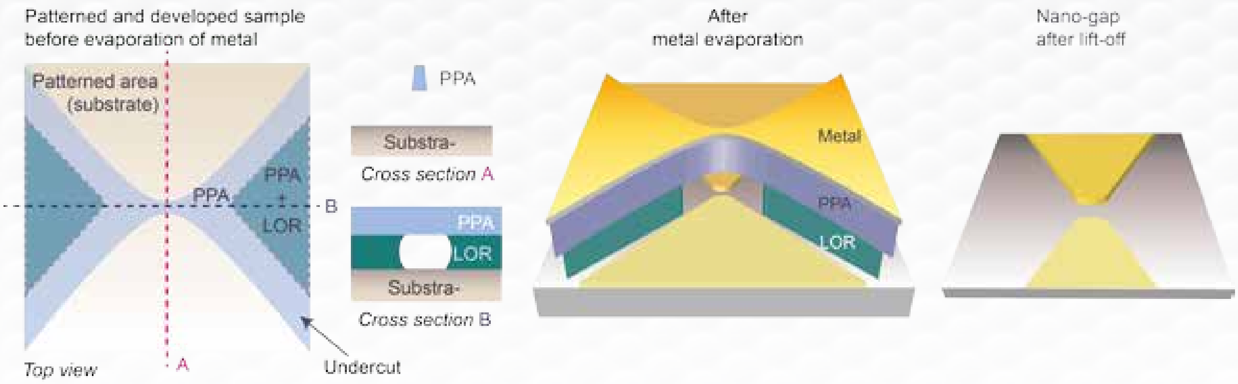
Left: A Hall Bar device on a single layer MoS_2 flake fabricated with the NanoFrazor and the bilayer lift-off. Right: Top-gated MoS_2 field-effect transistor with an h-BN top-gate dielectric and near-Ohmic electrical contacts.

Images on this page courtesy of Prof. Elisa Riedo

Reference:

[1] X. Zheng et al., "Patterning metal contacts on monolayer MoS_2 with vanishing Schottky barriers using thermal nanolithography," Nat. Electron., vol. 2, no. 1, pp. 17–25, Jan. 2019.

EXAMPLES: DEVICES WITH NM-SCALE FEATURES

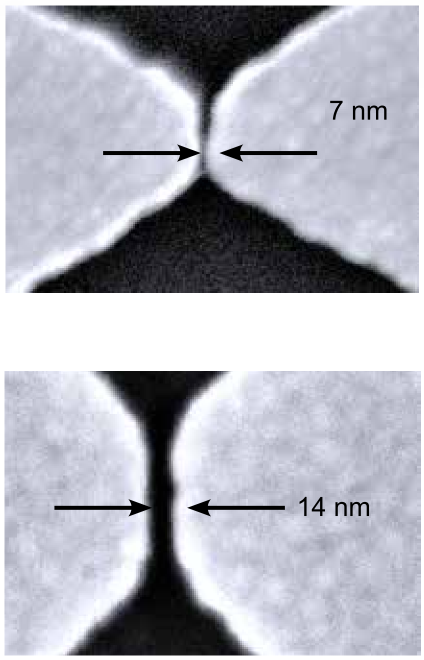


Suspended PPA bridge geometry works as a shadow mask to create very small gaps.

The main limitation of the bilayer lift-off process is the resolution: the undercut restricts the minimum spacing between nearby features to about double the thickness of the bottom resist layer. Certain geometries, however, allow for patterning of smaller gaps.

For example, a design with two tapering features produces a short suspended PPA bridge, which acts as a shadow mask for metal evaporation, yielding sub-10-nm gaps between the electrodes. The gap length is limited by the mechanical stability of the PPA bridge, which is on the order of a few hundred nanometers.

Such ultra-narrow gaps are useful for fabrication of plasmonic bow-tie antennae or quantum point contacts.



SEM view of tapered structures with gaps of 7 nm and 14 nm.

SwissLitho experts have developed many detailed recipes of bilayer lift-off for different applications and sample materials. Please feel free to ask for a consultation.

Acknowledgements

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