HEIDELBERG INSTRUMENTS

APPLICATION NOTE

ULTRA-HIGH RESOLUTION PATTERN TRANSFER FOR NANOFRAZOR® LITHOGRAPHY

by

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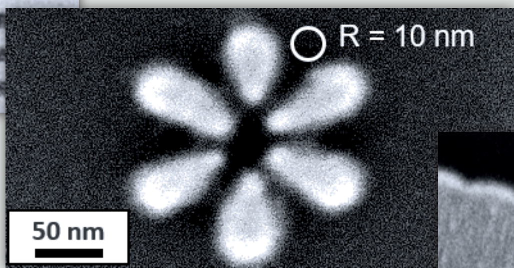
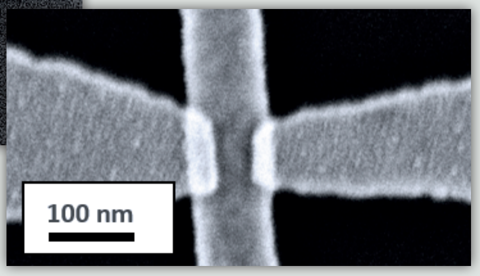
13.8 nm lines etched 65 nm deep in Si



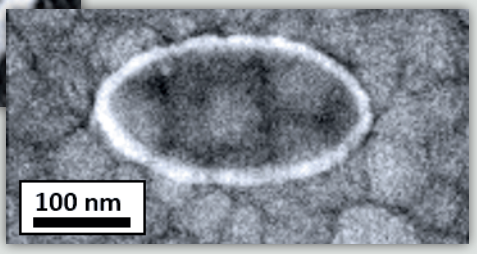
Plasmonic antennae (lift-off)



Contacts to a nanowire (lift-off)

18 nm lines etched in 20 nm Au

Asymmetric rings etched in 20 nm Au



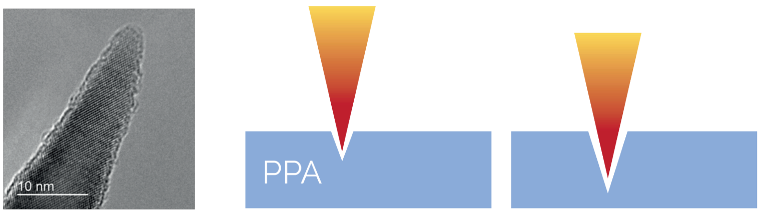
SiO2 ellipses (lift-off)

Detailed recipes are available to all our customers. Direct support by our experts in applications and processes is also an option.

High-resolution lithography is a central fabrication step not only for current transistor devices, but also for emerging quantum electronics and nanophotonics. Today's and tomorrow's applications dictate shrinking of the dimensions and increasing of the packaging density, so the resolution can't be too high. While the ultra-high resolution lithography (smaller than 50 nm) can be challenging on its own, pattern transfer – the next step after lithography – is often the actual challenge. Here, we introduce a few strategies for combining the ultra-high resolution NanoFrazor lithography with etching and lift-off that were developed over the last years.

NANOFRAZOR® LITHOGRAPHY

NanoFrazor lithography can create patterns with resolution down to a few nm in a fairly simple process. First, the ultra-sharp NanoFrazor tip patterns a thin layer (~10 nm) of PPA, which is spun on top of the multilayer resist stack. The purpose of the stack is to minimize the pattern spreading due to tip shape. The pattern is then etched into a few-nm-thick inorganic hard mask via reactive ion etching (RIE), and transferred further into the underlying organic transfer layer in another RIE etch step (oxygen plasma) to minimize the undercut and distortion of pattern dimensions. This process works for different transfer layer thicknesses and for different material combinations. Furthermore, it is suitable for both high-resolution lift-off and etching the patterns into underlying material (see the examples below).



The NanoFrazor tip is extemely sharp (left) but due to its conical shape the patterning depth influences the pattern width (right).

NanoFrazor lithography usually uses polyphtalaldehyde (PPA) resist. Upon the contact with the hot tip, PPA readily decomposes into volatile monomers. The sublimation reaction is highly localized, making PPA excellently suited for high-resolution nanolithography. It has also proven to be compatible with various pattern transfer processes, including those described below.

MULTI-LAYER TRANSFER STACK

A multi-layer hard mask stack enables amplification of the shallow PPA resist patterns. Here are a few considerations for the transfer stack composition:

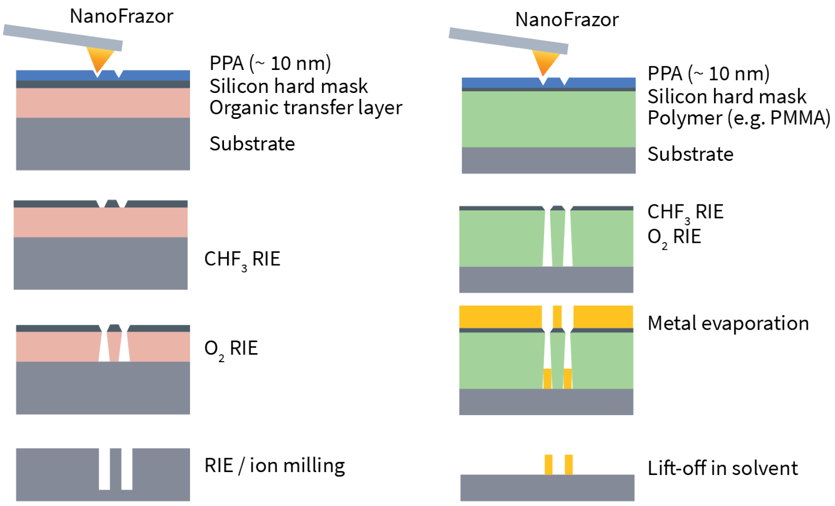
- Each layer is selected to have good coating properties and a high etch selectivity to the following layer.
- The first hard mask layer needs to be as thin as possible and completely resistant against oxygen plasma etching.

Our extensive tests showed that SiO_2 is the best inorganic hard mask material for this purpose. Suitably thin SiO_2 can be sputtered[1] or evaporated[2-3]. To simplify this process, Heidelberg Instruments Nano and PiBond Oy together developed a dedicated spin-coatable SiO_2 hard mask under the commercial name SH113. Our tests show that a thin SiO2 hard mask has an almost infinite selectivity to the underlying organic layers in oxygen plasma. After the SiO_2 hard mask is spin-coated, the organic contents in it need to be removed in an oxygen plasma process for a pin-hole free and continuous SiO_x-like film with a thickness of about 1.5 nm. With this process, we have achieved amplifications close to 1000 (1 µm-deep and 50 nm-wide holes in PMMA). The pattern is etched into the SiO_2 hard mask via reactive ion etching (RIE, CHF3 chemistry) and further to the organic layer below, again via anisotropic RIE (O_2). This process results in vertical sidewalls with minimal undercut. After opening the pattern transfer stack, the features can be further etched into the underlying material or metal can be evaporated followed by removal of the stack by solvent (lift-off process).

The choice of the underlying inorganic layers depends on the final application. For etching of almost any material, we recommend OTL400[4] – a spin-on-carbon from PiBond Oy, which has superior etch properties. For the lift-off processes requiring PMMA, we recommend to use the AR-P 670 series from Allresist.

Position	Etching	Lift-off
Top	A thin layer (~10 nm) of PPA	
Middle	Silicon dioxide hard mask layer (recommended spin-on-glass SH 113 series, PiBond Oy)	
Bottom	Organic transfer layer with superior etch properties (recommended spin-on-carbon OTL 400 series, PiBond Oy)	Easily soluble polymer (recommended AR-P 670 series, Allresist GmbH)

PROCESS FLOW



The transfer layer thickness can be easily adapted to suit different etching selectivities or film thicknesses. All the materials for the pattern stack are simply deposited by spin-coating and are available for order in small quantities and worldwide shipping.

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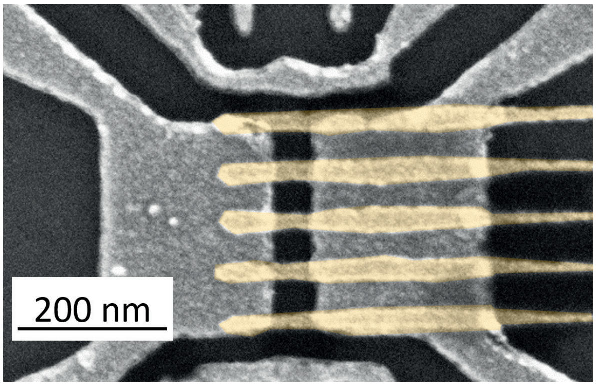
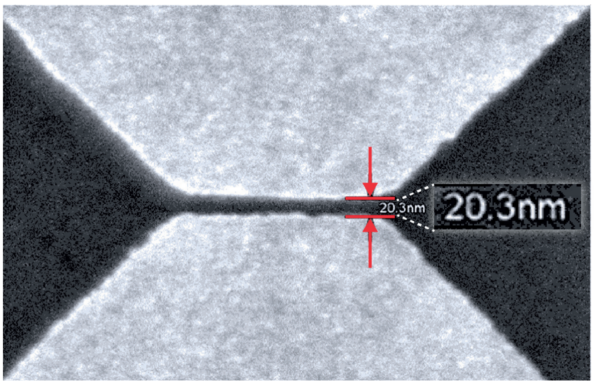
EXAMPLES

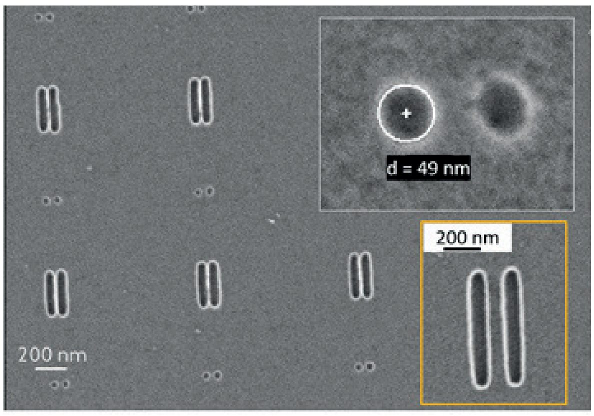


Top-gate electrodes aligned with bottom electrodes using the in-situ AFM imaging capability of the NanoFrazor[1]

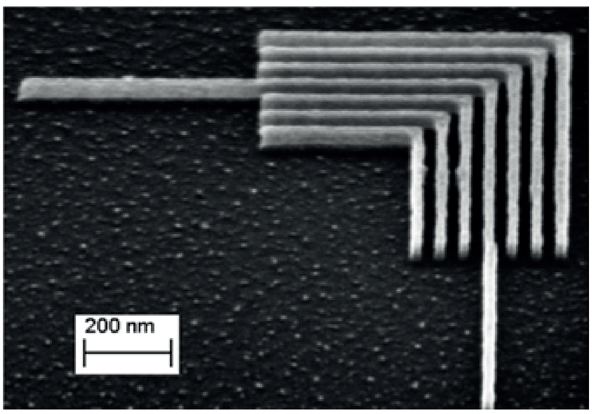


A 20 nm wide gap between metal electrodes

HIGH-RESOLUTION ETCHING PROCESS

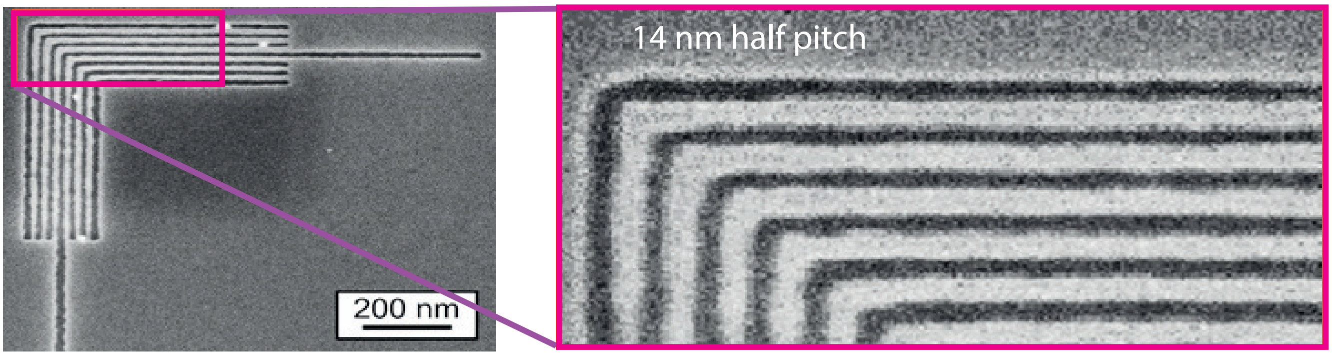


An array of 50 nm-half-pitch lines and dots etched into 50 nm-thick Cr layer in a Cl-RIE process. Inset: A close-up of a pair of dots with 49 nm diameter.



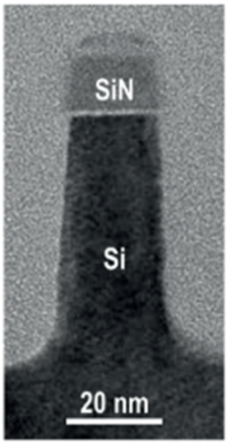
A tilted scanning electron micrograph of nested L-structures (half-pitch 27.5 nm) etched out from a silicon substrate

1 Cheong et al., Nano Letters (2013)
2 Wolf et al., JVSTB (2015)
3 Cho et al., ACS Nano (2017)
4 Available in small quantities from PiBond Oy



14 nm half-pitch L-shaped SiNWs, 9 nm trench with 2.3-nm line-edge roughness

ALTERNATIVE STRATEGIES FOR ULTRA-HIGH RESOLUTION PATTERN



Instead of the aforementioned etch transfer into a thin inorganic hard mask layer, one can also convert the patterned resist into an inorganic material directly. This has been done at imec[5] for lines written by the NanoFrazor into PPA. The scientists applied a technique called "sequential infiltration synthesis" (SIS) where they used atomic layer deposition (ALD) to convert the PPA into an Al2O3 hard mask with properties suitable for the subsequent etching yielding features with <10 nm half-pitch resolution.

Our experienced process and applications engineers continuously develop and improve pattern transfer processes to suit different materials and applications. Often we do that in close collaboration with our customers.

Please contact us if you want to know more recipe details for the pattern transfer and for setting up these processes in your laboratory.

5 de Marneffe et al., ACS Nano 12 (11), 11152-11160 (2018)

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HIMT AN4 V2.2 | 07/2023