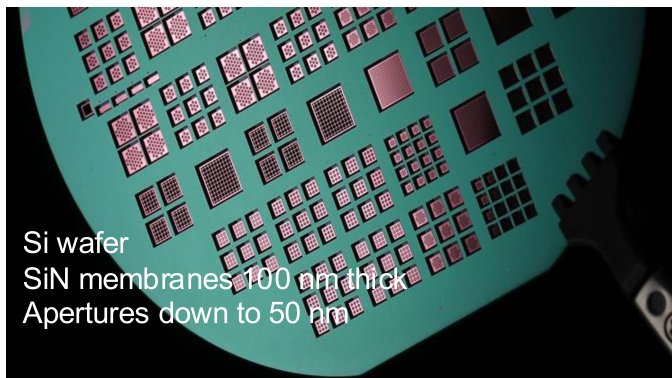
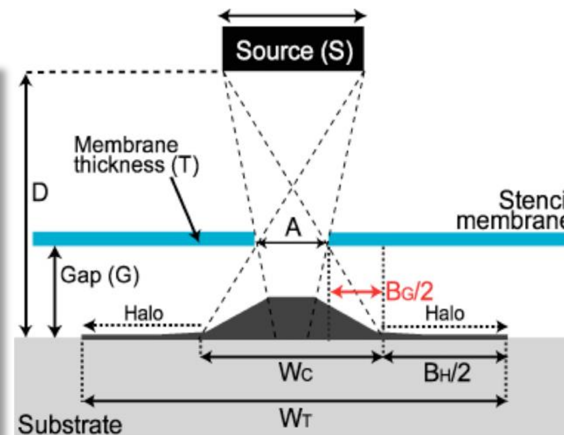
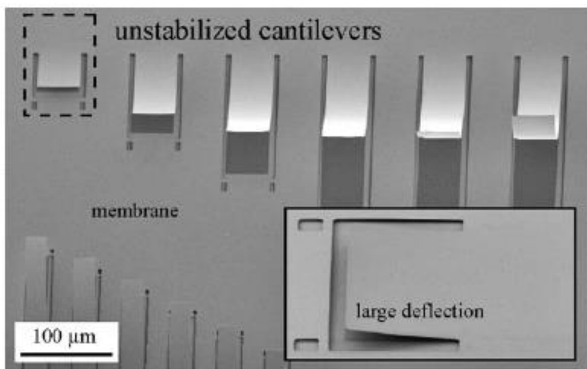
Nanostenciling

Juergen Brugger

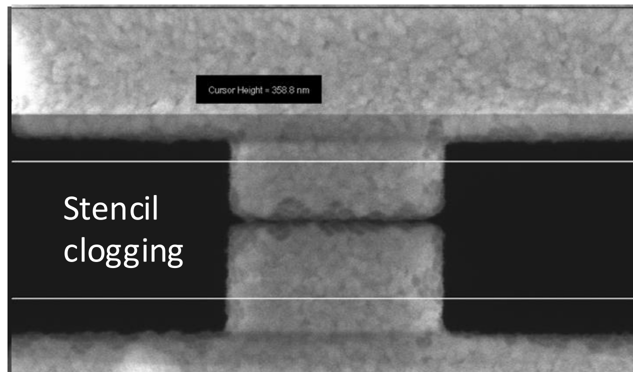




Problem: stress / bending



Problem: clogging



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Content

- Short recap on lithography resolution and lift-off on the blackboard
- Stencil lithography: basics and advanced
- T-SPL lithography: basics and advanced

Stencil lithography

- High resolution shadow masks
- Simple application examples
- Unique configurations where ordinary lithography would fail
- Blurring and diffusion issues
- Dynamic stencil

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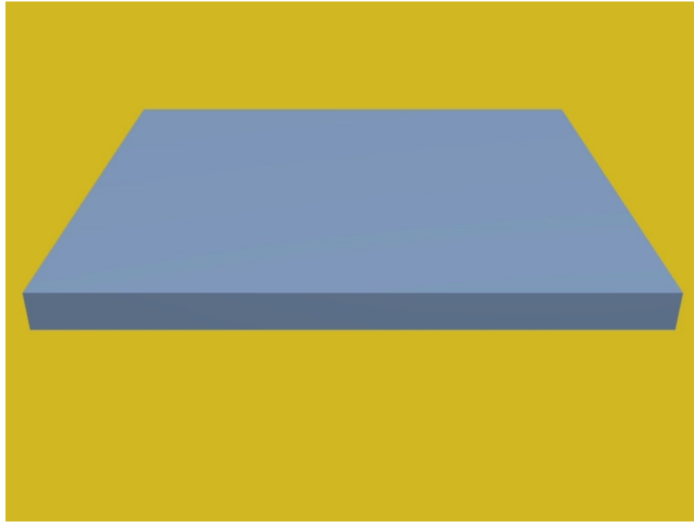
Prof. Oscar Vazquez-Mena
UC San Diego

Nanostencil lithography



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journal homepage: www.elsevier.com/locate/mee

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Review Article

Resistless nanofabrication by stencil lithography: A review

O. Vazquez-Mena [a,*], L. Gross [b], S. Xie [a], L.G. Villanueva [a], J. Brugger [a,*]

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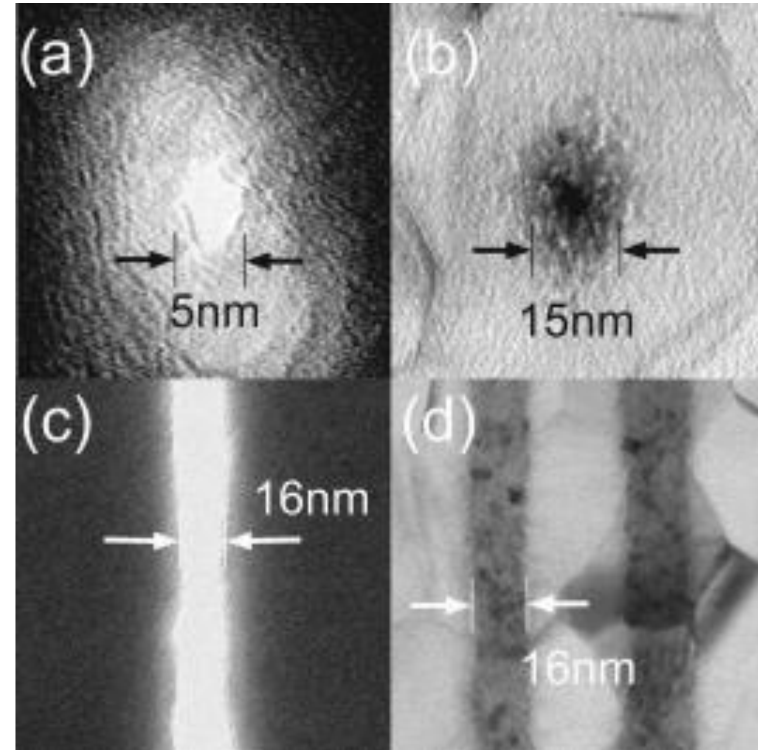
Many challenges:
Gap
Blurring
Membrane stability
Alignment

But also many opportunities:
Vacuum clean
No resist chemistry
Fast and simple, cost efficient nano
Wide choice of material & substrates
Mainly for PVD

Nanostenciling (1999)

Early works and probably world record

Bright-field STEM images. (a) A hole 5 nm in diameter etched through a silicon nitride membrane. (b) A metal dot made by evaporating 10 nm of Er through an orifice 5–10 nm in diameter onto an oxidized aluminum film held at room temperature. (c) Section of a 4 μm-long $\times$ 15–20-nm-wide line etched through a silicon nitride membrane. (d) Sections of 10-nm-thick Er lines which are deposited through an orifice similar to the one shown in (c), at room temperature onto an oxidized Al film. The two lines, 19 nm and 16 nm wide, were made by separate depositions of Er, from different angles, through the same linear hole



Deshmukh et al APL 1999

Stencil fabrication

LPCVD 50-500 nm thick SiN

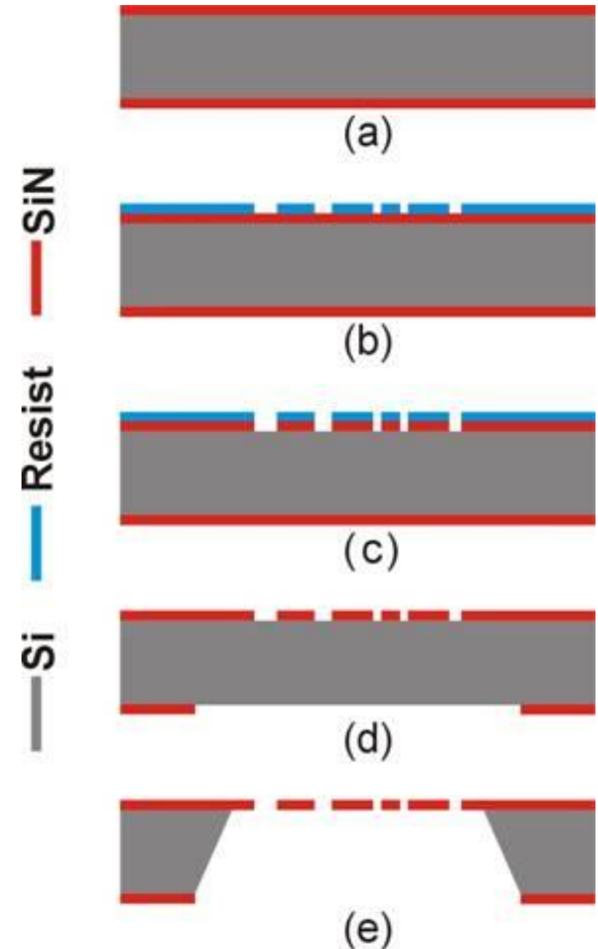
Pattern definition in photoresist

Pattern transfer into SiN

Membrane window definition and KOH etching

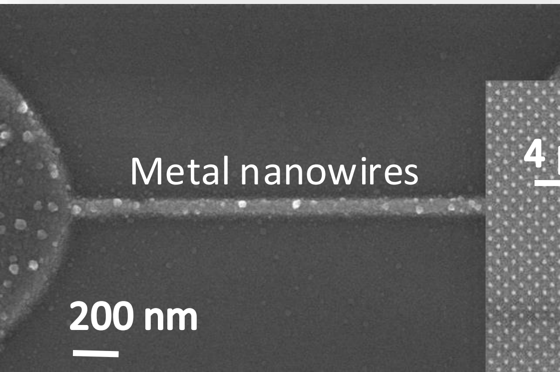
Fabrication of nanoscale apertures in membrane by:

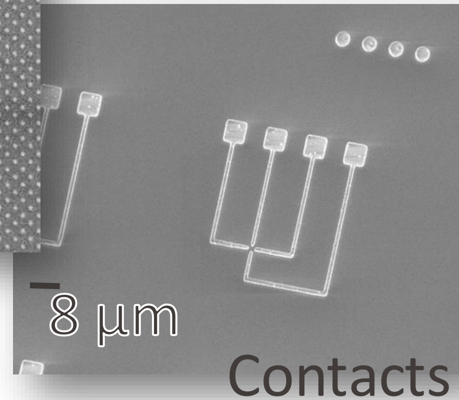
- Focused Ion Beam Milling
- Electron beam lithography
- Laser interference lithography
- Nanoimprint lithography
- Deep UV lithography

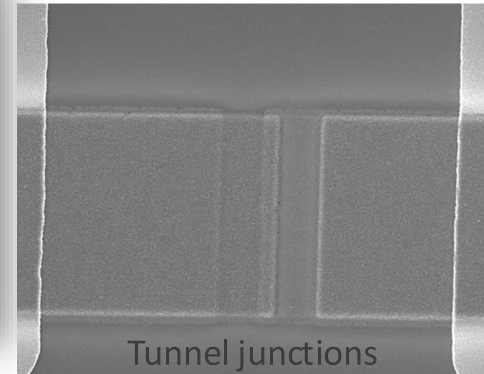


What can been done?

- Deposition of different metals
  - Aluminium, Gold, Chromium, Titanium, Platinum, etc.
- Metallic structures







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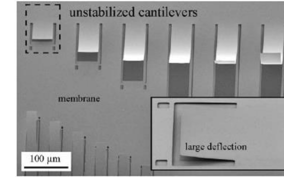
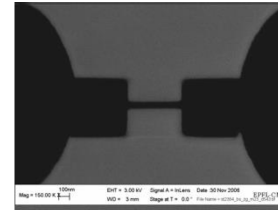
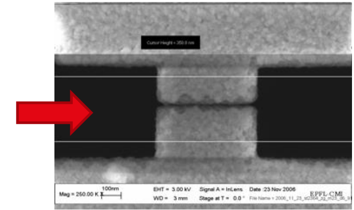
Major challenges

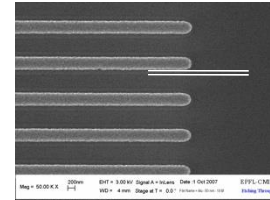
Membrane stability



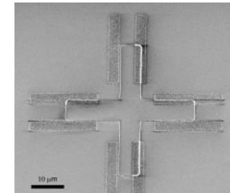
Clogging

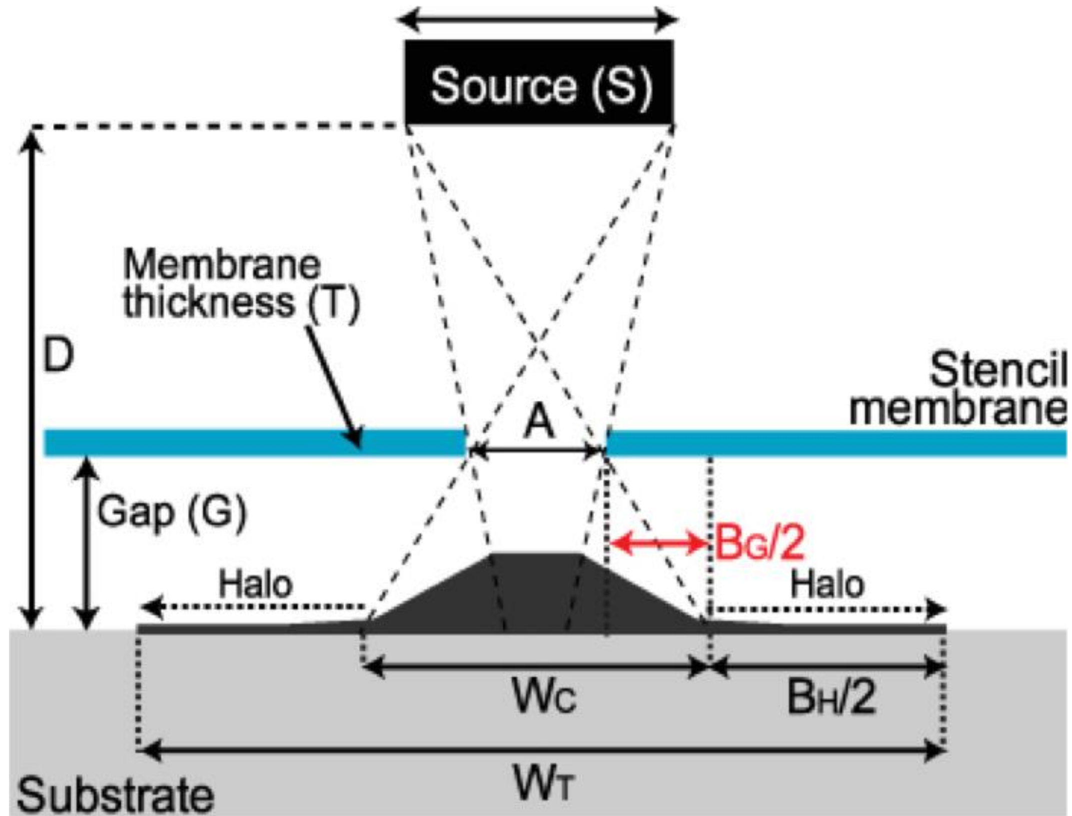
Blurring



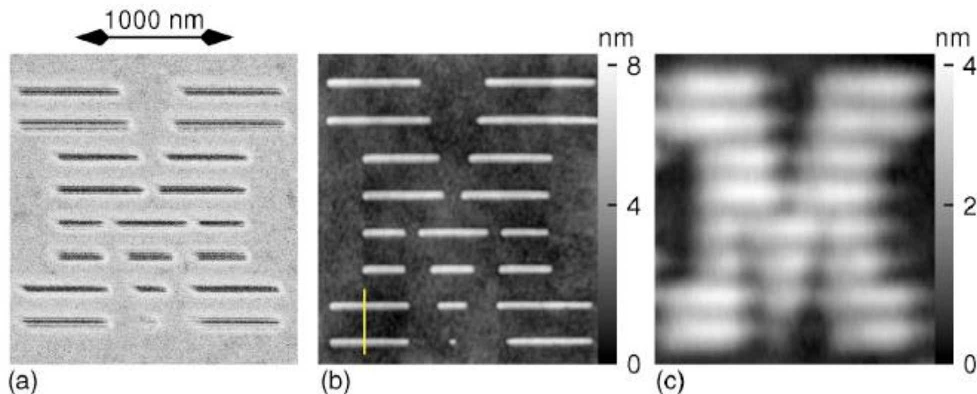
Alignment

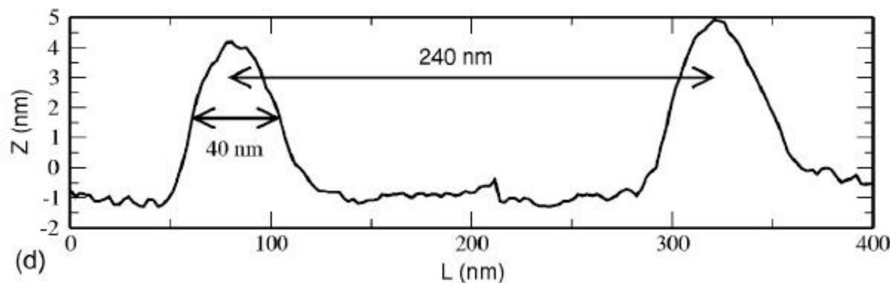


Stencil litho details

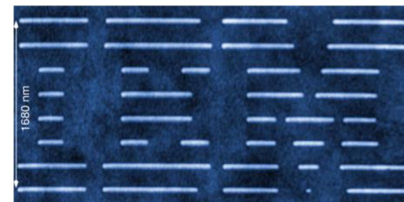


Watch out for surface diffusion





- (a) FIB image of the stencil mask used here
- (b) DFM image of the 40 nm wide Cu structure on SiO2
- (c) DFM image of the C60 structure (diffusion induced halo).
- (d) Line profile of the section marked.



Percy Zahl et al., Rev. Sci. Instrum. 76, (2005)

IBM Research Laboratory Ruschlikon

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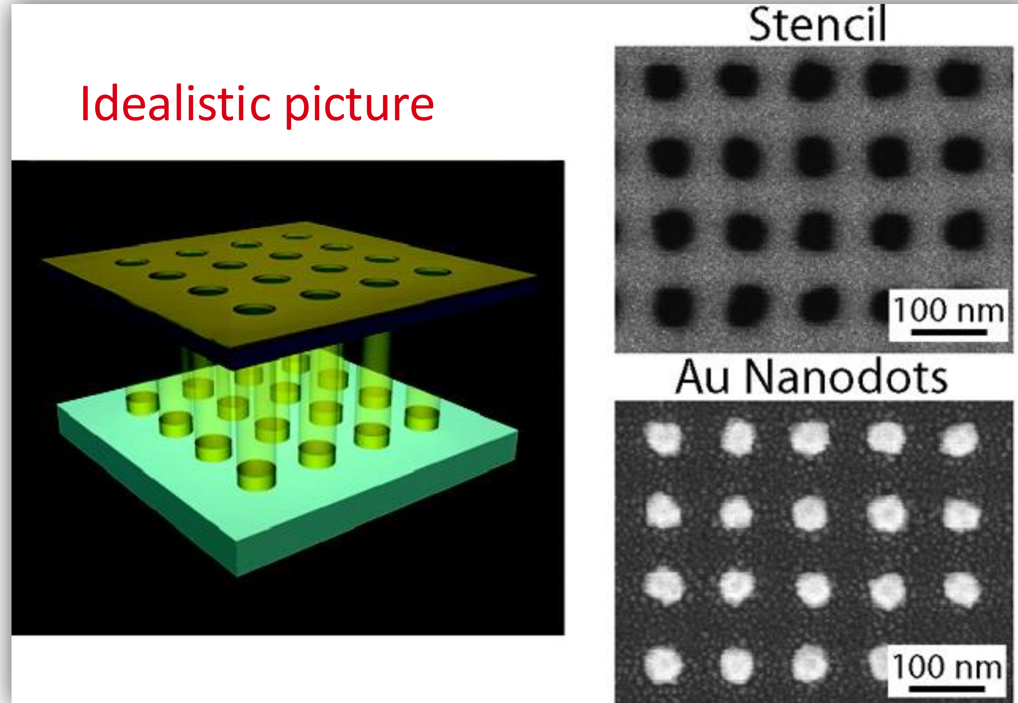
Metallic nanostructures stenciled



Reality
Blurring
Diffusion

5 nm Ti / 50 nm Au

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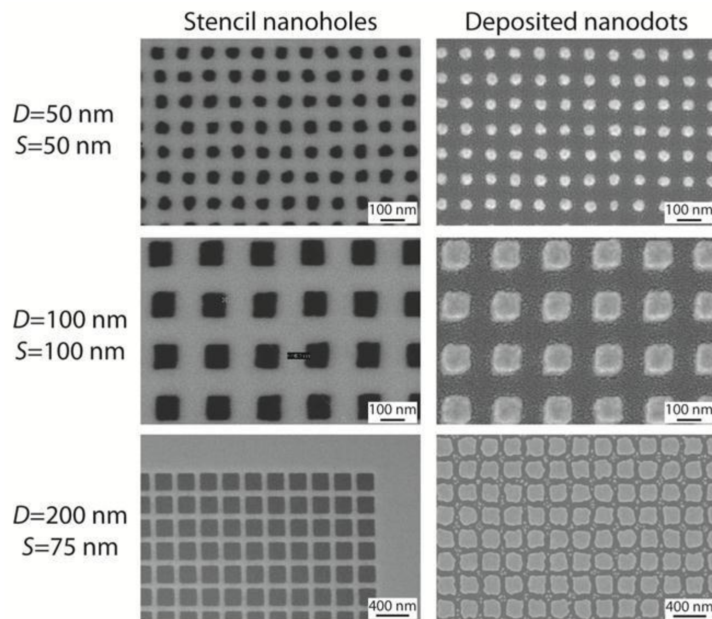
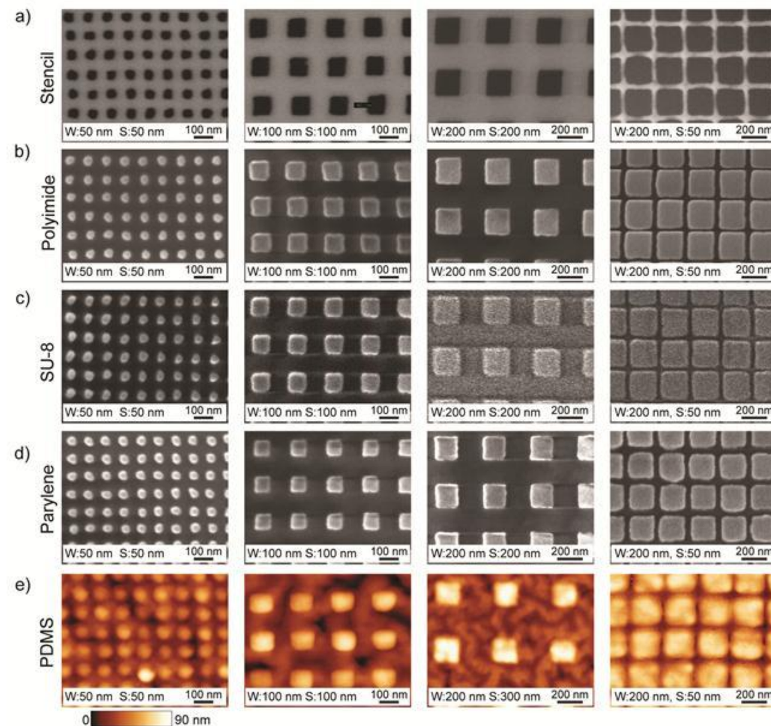
Metallic nanostructures stenciled onto …

5 nm Ti / 50 nm Au

… silicon (Au clusters)



… polymer (no Au clusters)



- Vazquez-Mena et al, ACS Nano (2010); ASC Nano (2012)

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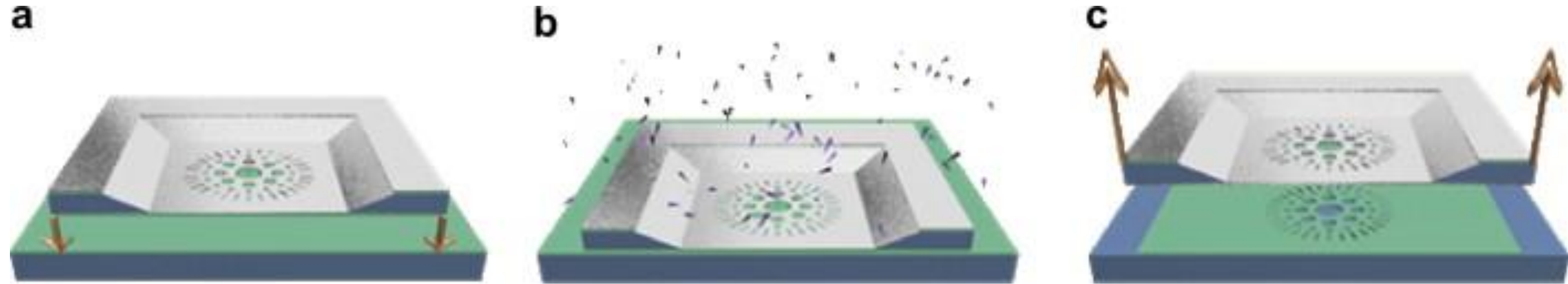
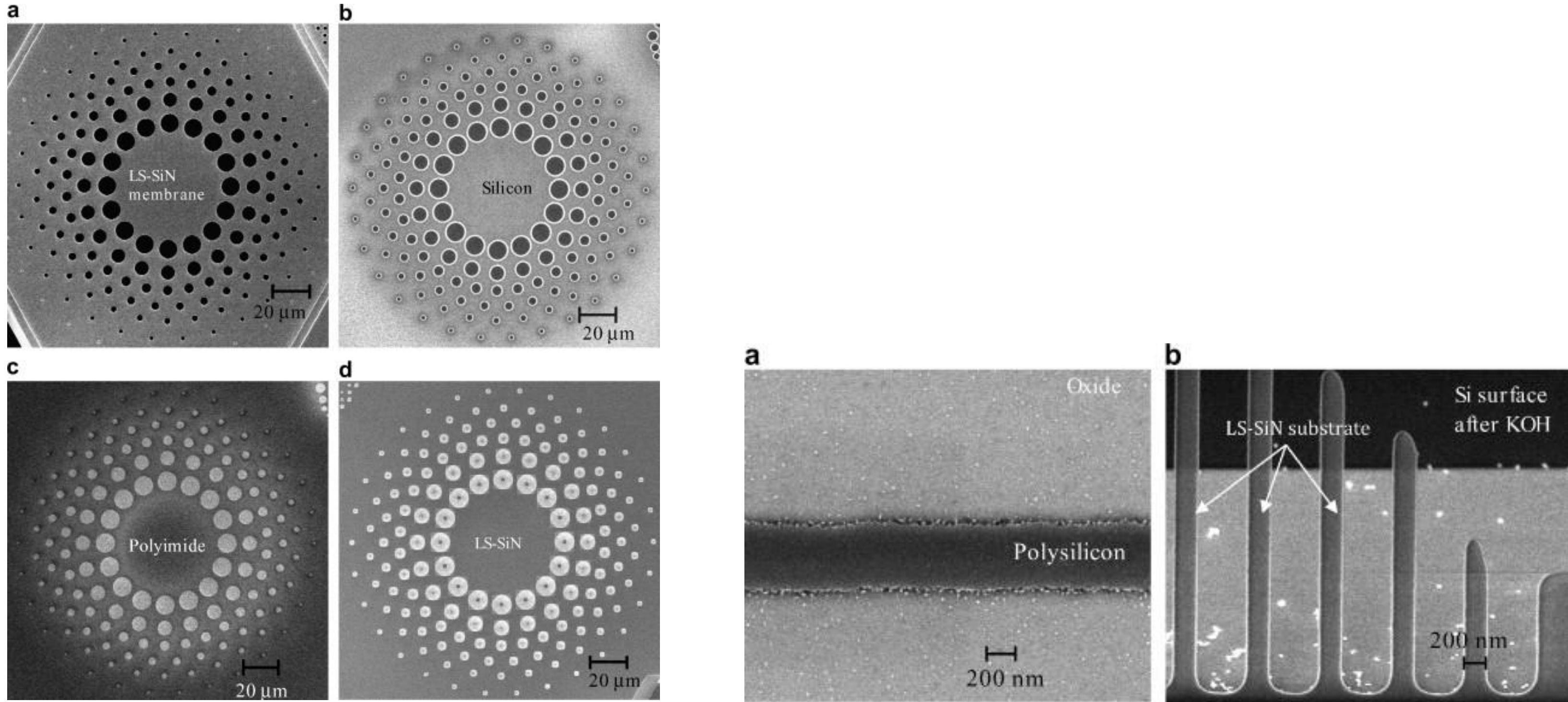
Etching through stencils



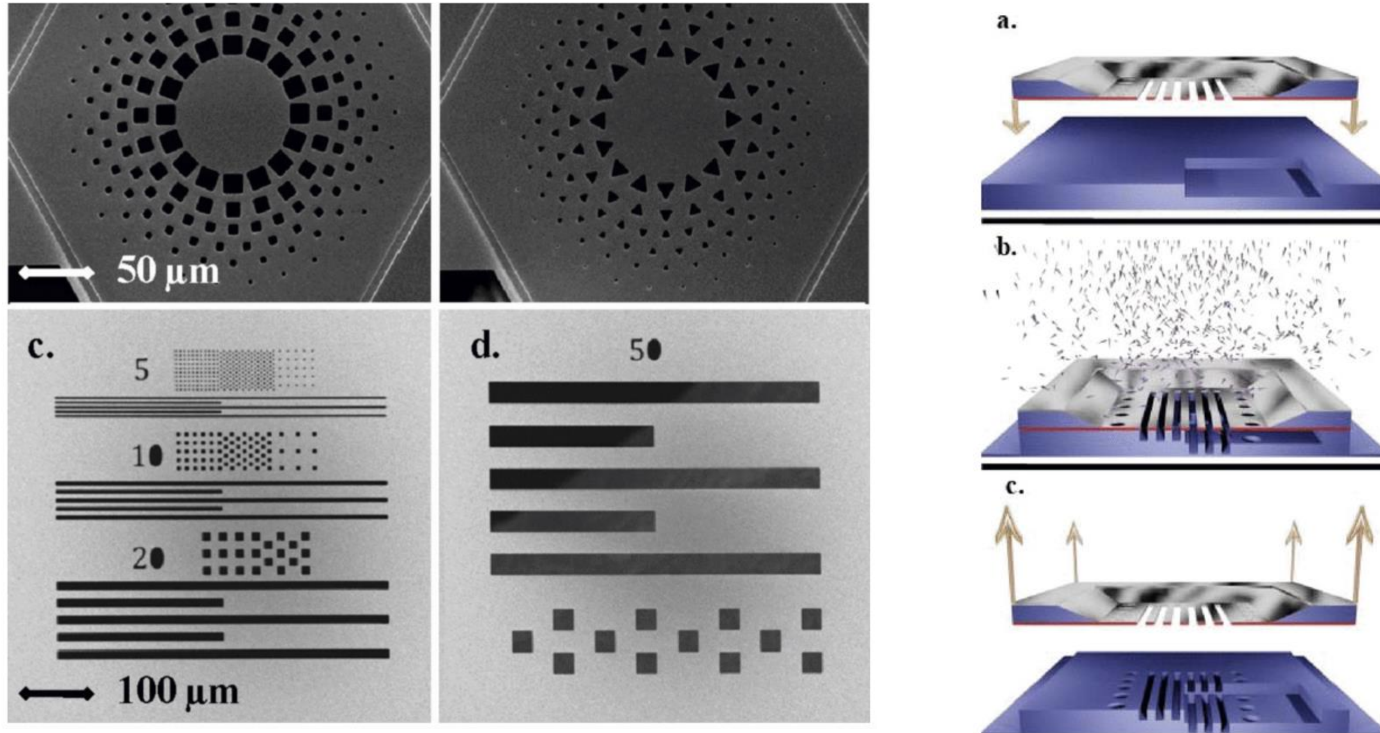
G. Villanueva, et al. Etching of sub-micrometer structures through Stencil, Microelectronic Engineering (2008)

Etching through stencils



G. Villanueva, et al. Etching of sub-micrometer structures through Stencil, Microelectronic Engineering (2008)

Deep Etching through stencils



G. Villanueva, O. Vazquez-Mena, C. Hibert and J. Brugger, "Direct Etching of High Aspect Ratio Structures Through a Stencil," 2009 IEEE MEMS conference

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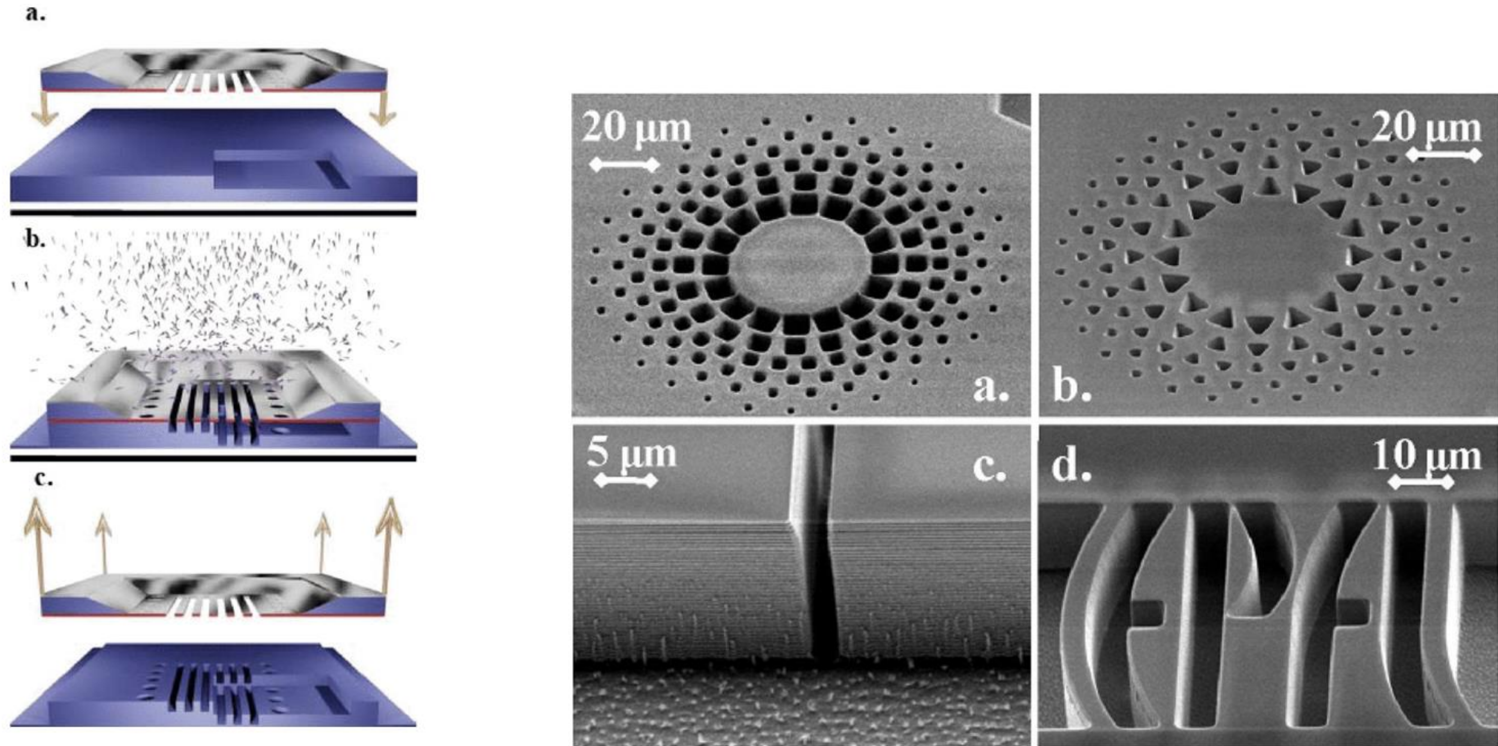
Deep Etching through stencils



G. Villanueva, O. Vazquez-Mena, C. Hibert and J. Brugger, "Direct Etching of High Aspect Ratio Structures Through a Stencil," 2009 IEEE MEMS conference

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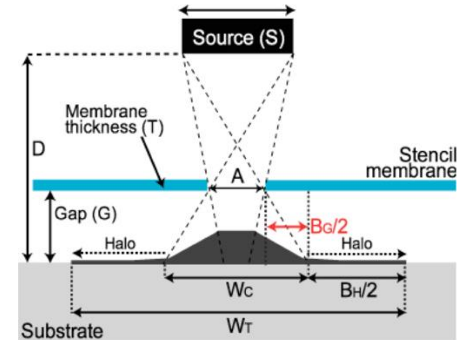
What else as local surface patterning method could be done through nanostencils?

- Deposition (PVD)
- Dry etching
- …

Nanostencil problem: ”forbidden” topology of closed loop patterns

Add bridges &
make use of blurring



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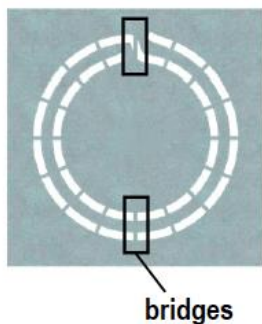
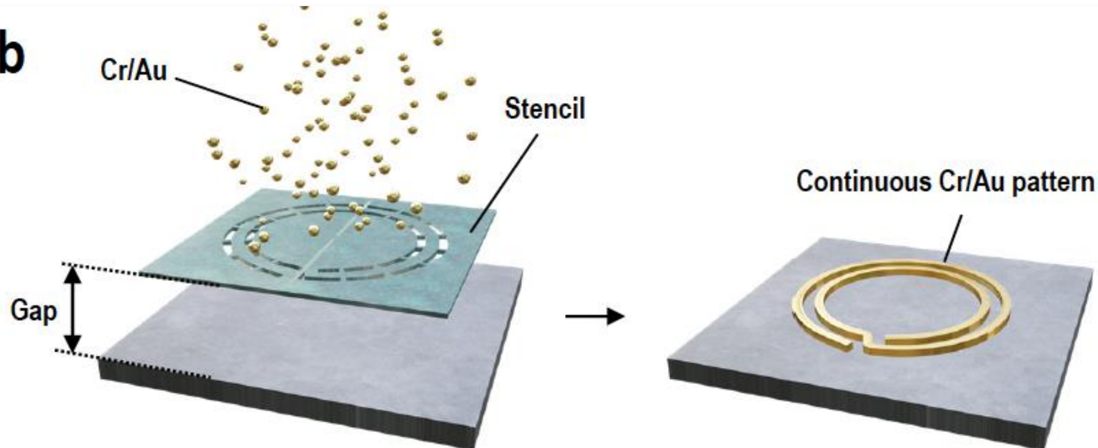
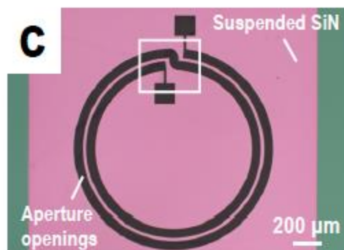
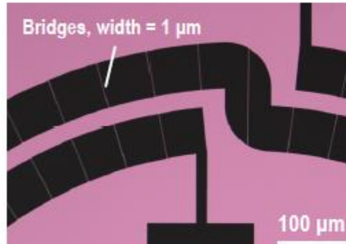
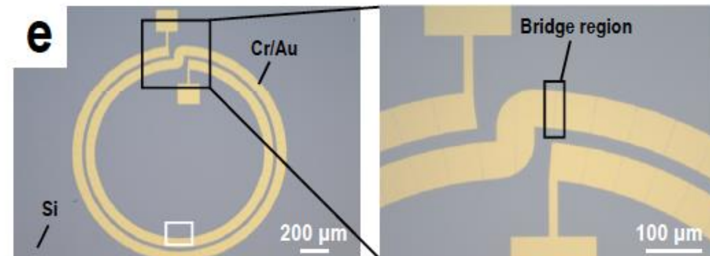
Bridge nanostencil: Split ring resonator on flexible substrate



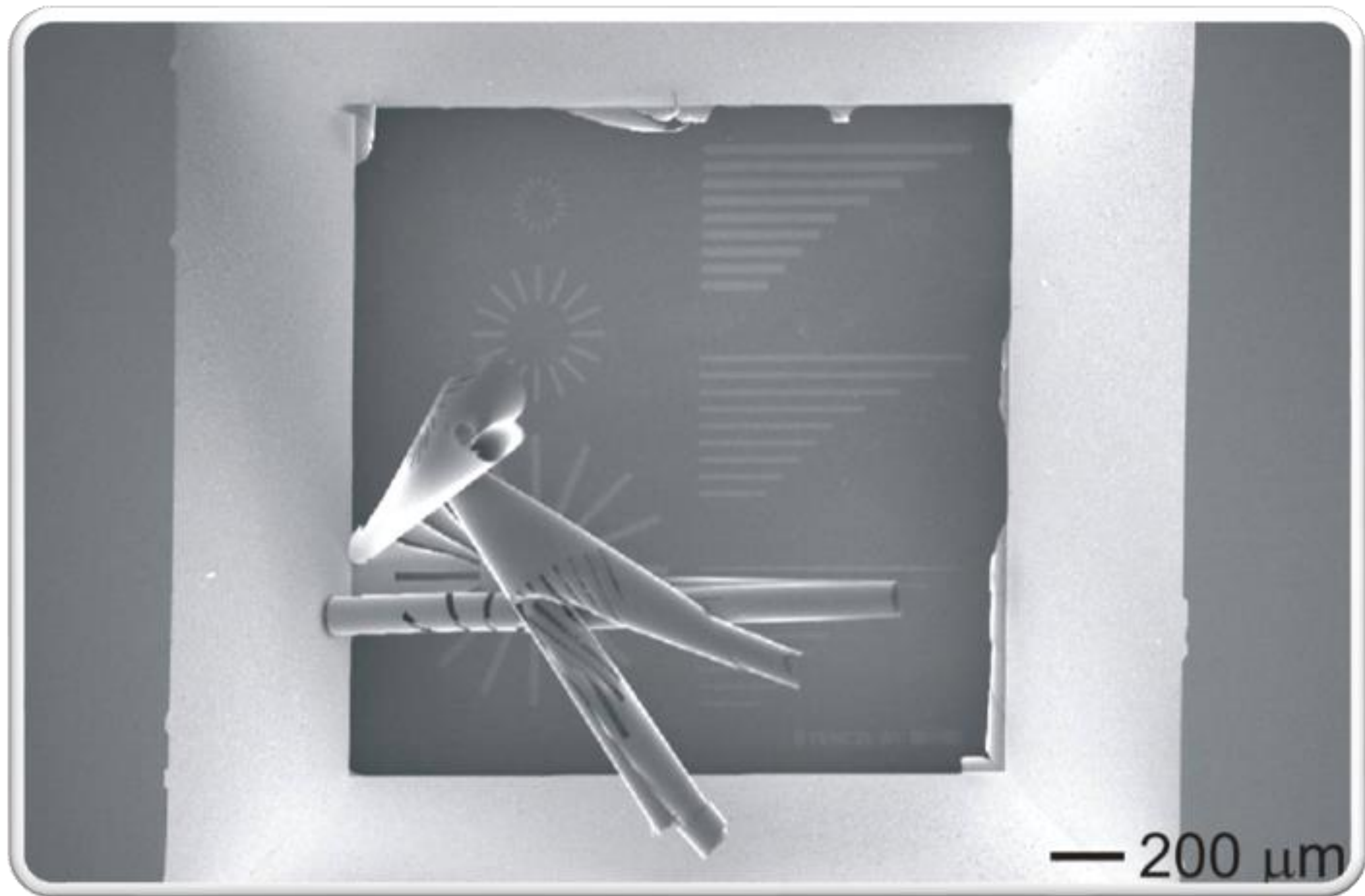








Y.C.Sun et al. *Advanced Materials Technologies (2022)*


200 µm

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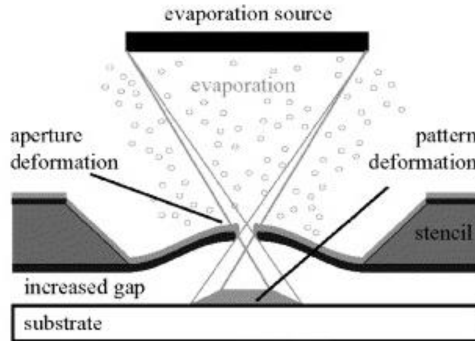
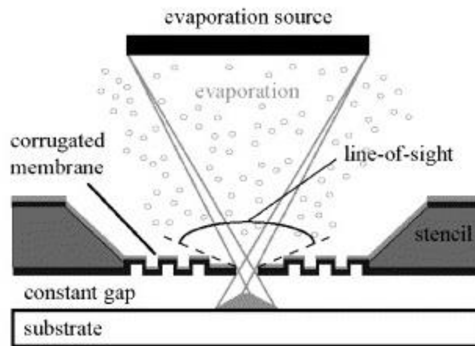
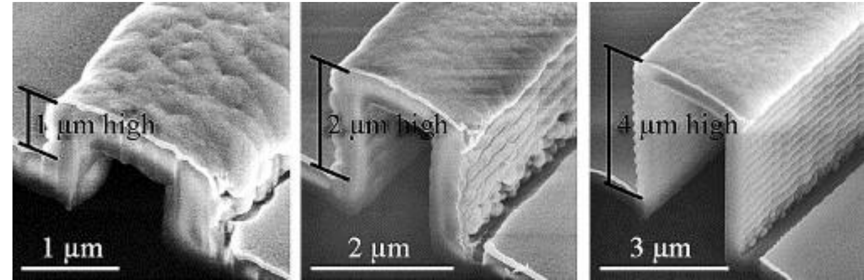
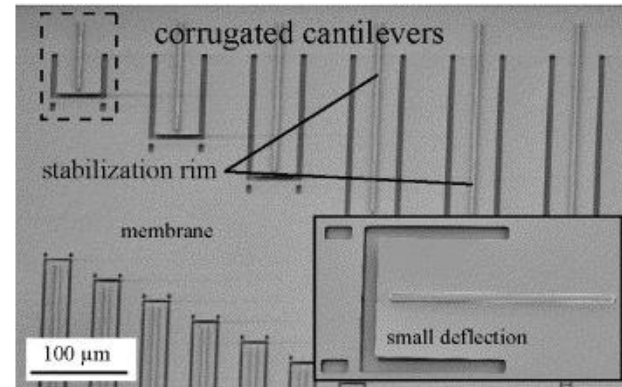
Solution to problem: increasing the moment of inertia by corrugation









M.A.F van den Boogaart et al., Sensors and Actuators A: Physical (2006)
Transducers 2005, Seoul

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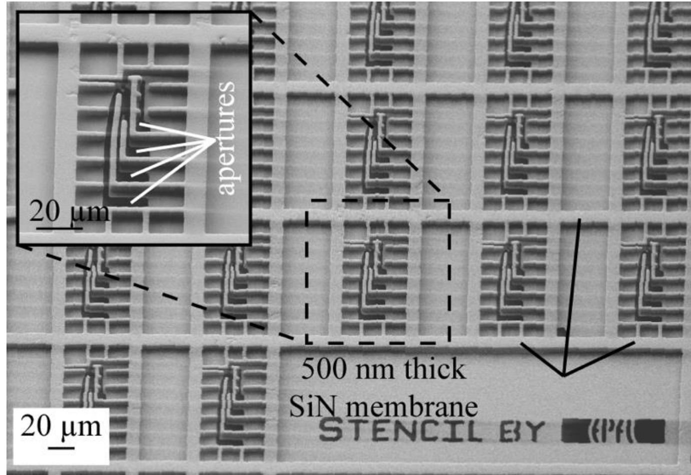
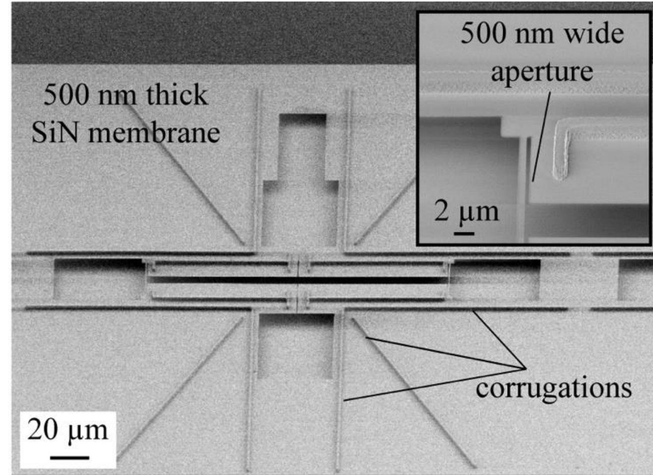
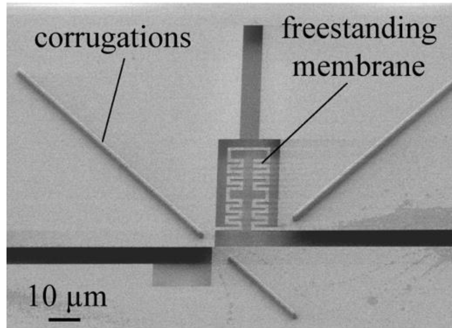
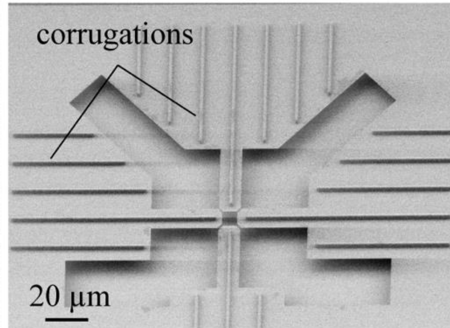
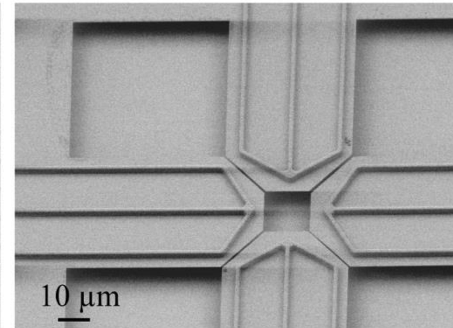




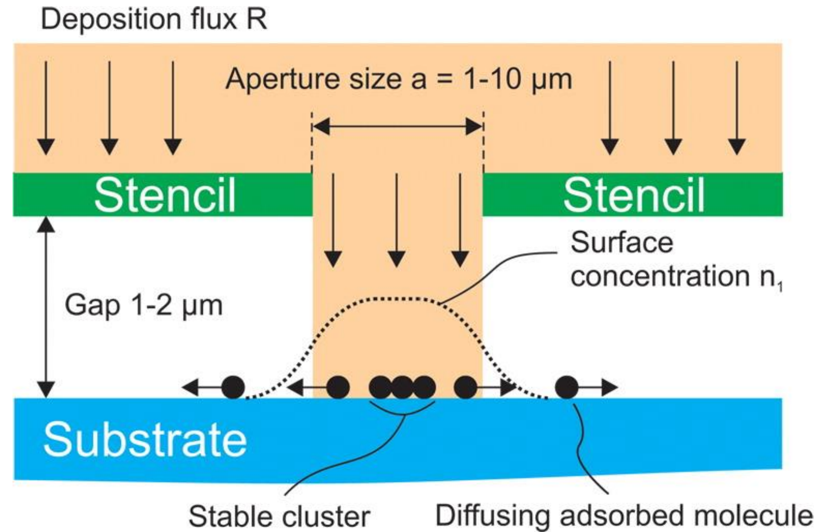






- Hammer (‘70s)
- Van den Boogaart et al. 2008

Arrays of Pentacene Large Single Crystals by Stencil Evaporation

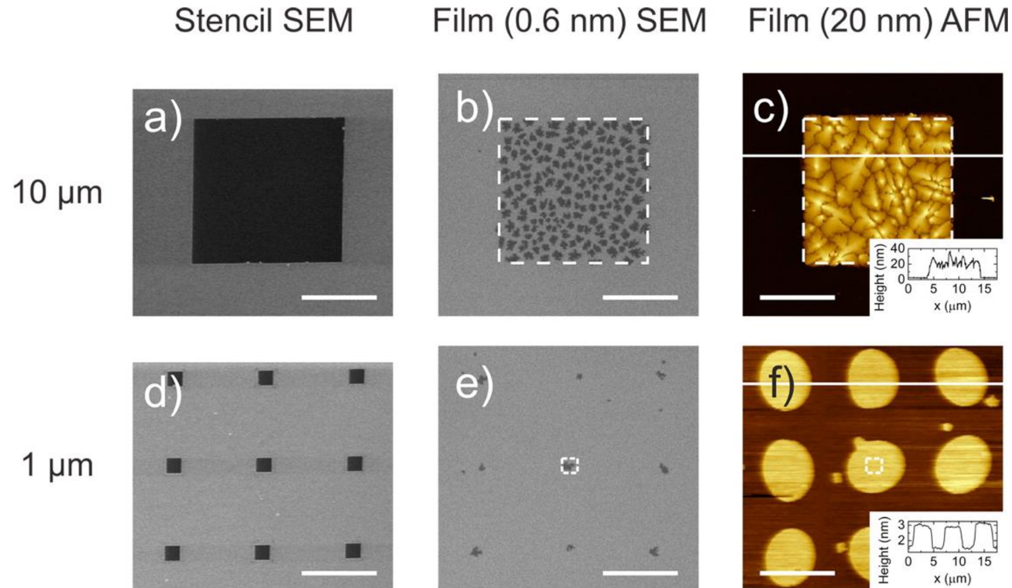


Arrays of pentacene single crystals Patterned on SiO_2 substrates through stencil evaporation Micron-scale apertures enables a control over nucleation and subsequent diffusive growth

P. Fesenko et al. Cryst. Growth Des. (2016)

Imec/KU Leuven

Arrays of Pentacene Large Single Crystals by Stencil Evaporation



P. Fesenko et al. Cryst. Growth Des. (2016)

Imec/KU Leuven

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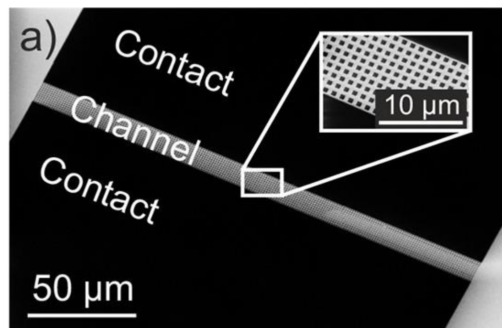
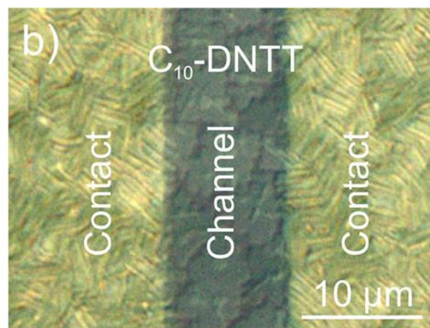
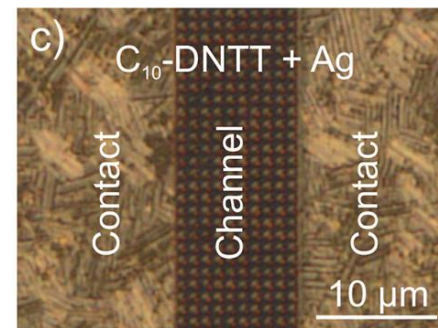
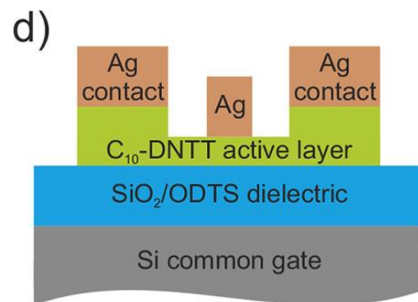
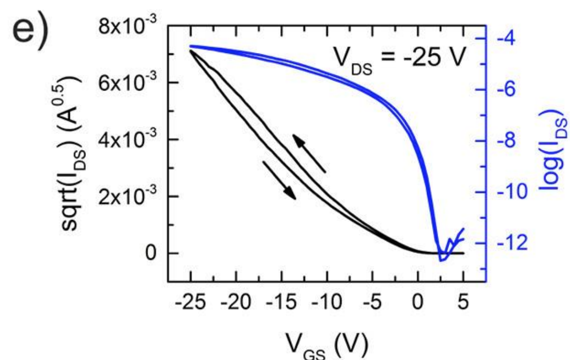
Depositing both, organic molecules and metal electrodes

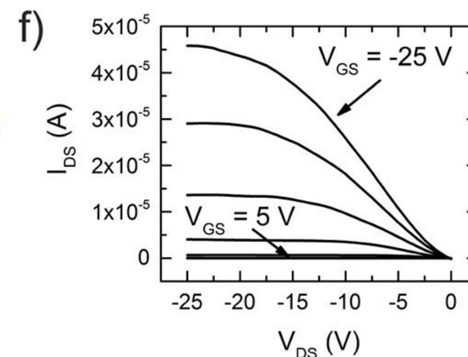












P. Fesenko et al. ACS Appl. Mater. Interfaces, 2017

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Appl. Phys. A 79, 743–745 (2004)
DOI: 10.1007/s00339-004-2749-0

Applied Physics A
Materials Science & Processing

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Exploring microstencils for sub-micron patterning using pulsed laser deposition

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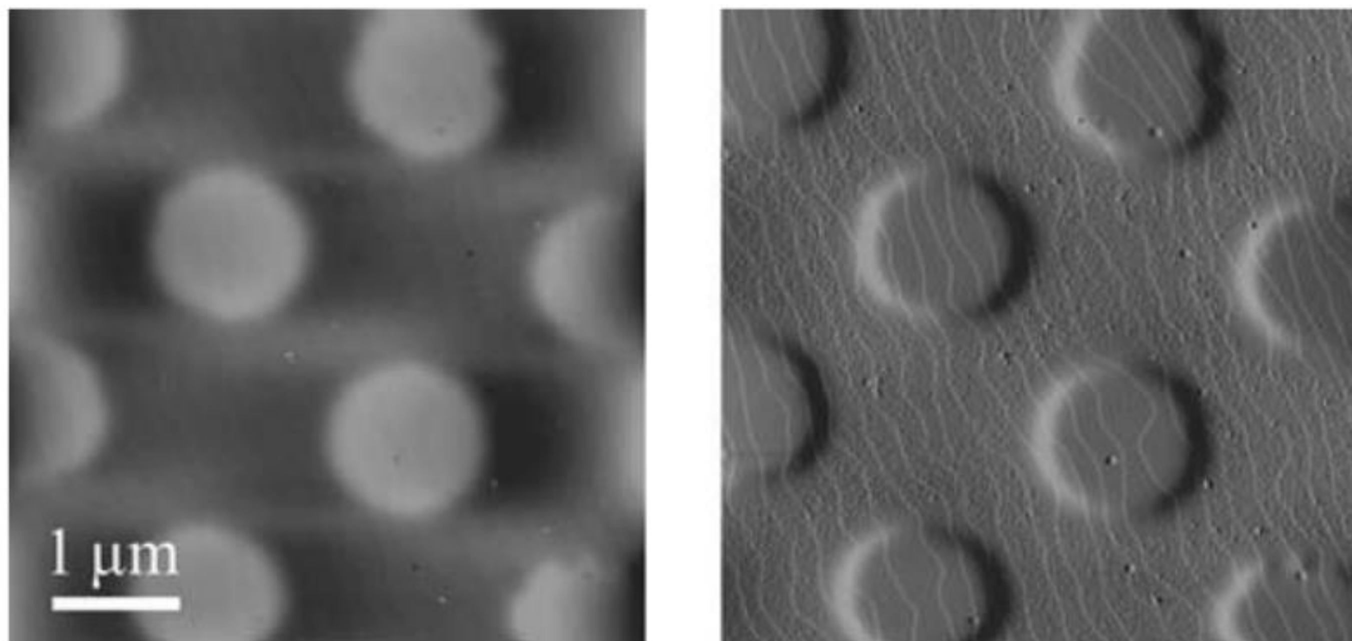
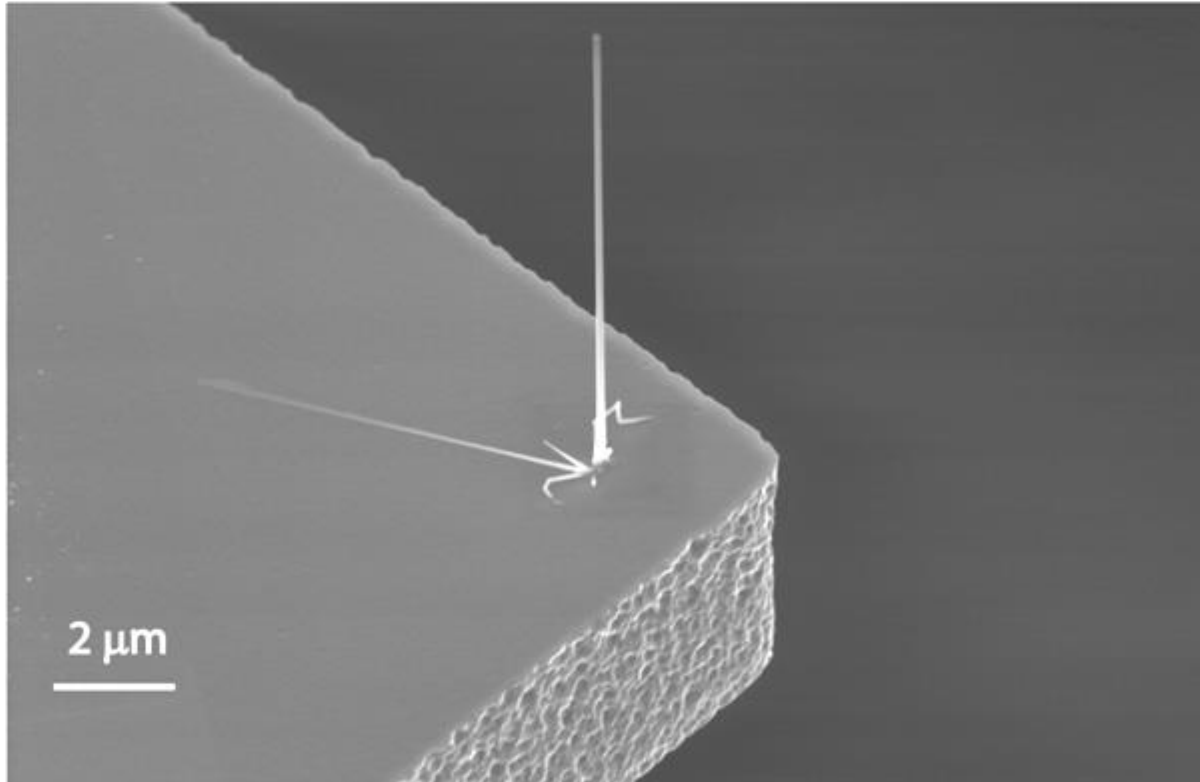


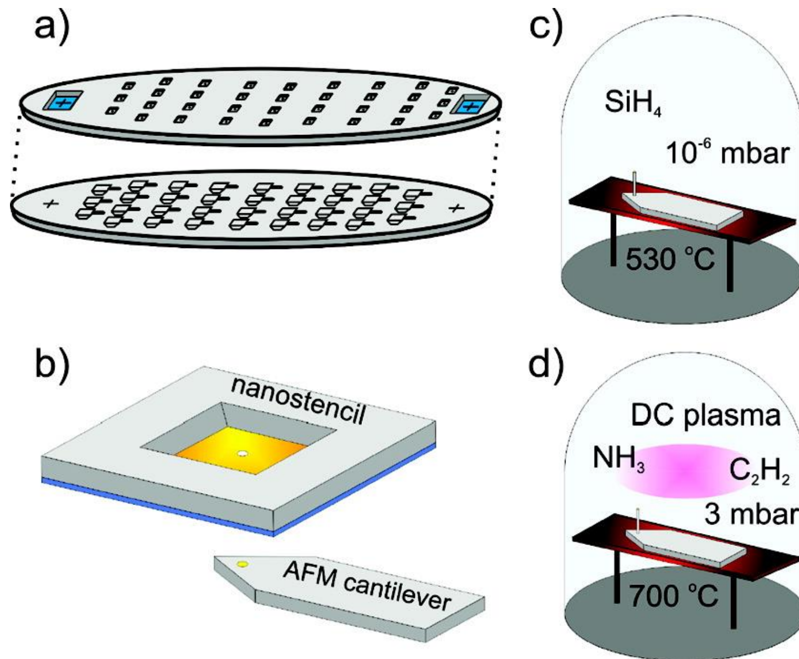
FIGURE 2 $5 \times 5\,\mu m^2$ CM-AFM image of 5.2-nm-high Ni islands on a $SrTiO_3$ substrate. Height (*left*) and deflection (*right*) images. The deposition parameters used are a $5.0\,J\,cm^{-2}$ fluence, 4.0×10^{-4} mbar Ar pressure, $2.5\,ml\,min^{-1}$ Ar flow and a 42.0 mm target–substrate distance

Unique examples



Stenciling on free-standing substrates

- Stencil fabrication for catalyst deposition
- Stencil alignment to cantilever full-wafer
- Catalyst deposition through aligned stencil
- CNT/Si NW growth
- AFM measurements



D. S. Engstrom et al., Nano Letters **11 (4), 2011**

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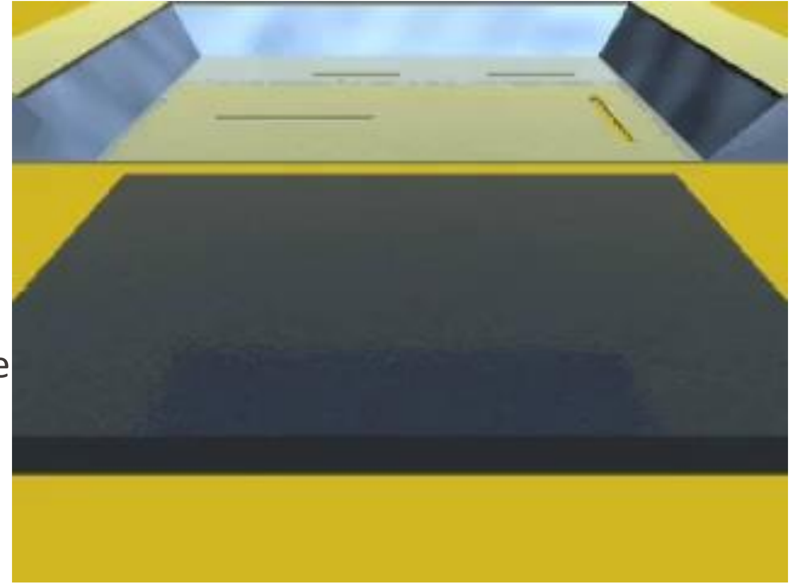
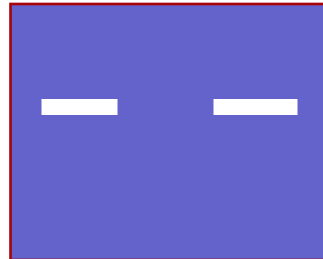
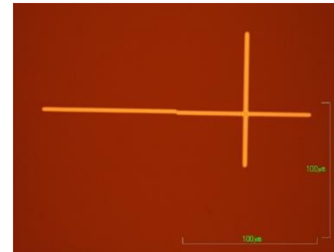
The moving shadow mask



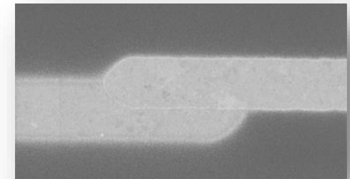
- Step and repeat
- Reposition stencil in vacuum between subseque deposition steps
- No exposure to atmosphere
- In-situ oxidation
- Clean surface/interface
- Tunnel junctions
- 2 materials (or more)



stencil



stitched



junctions

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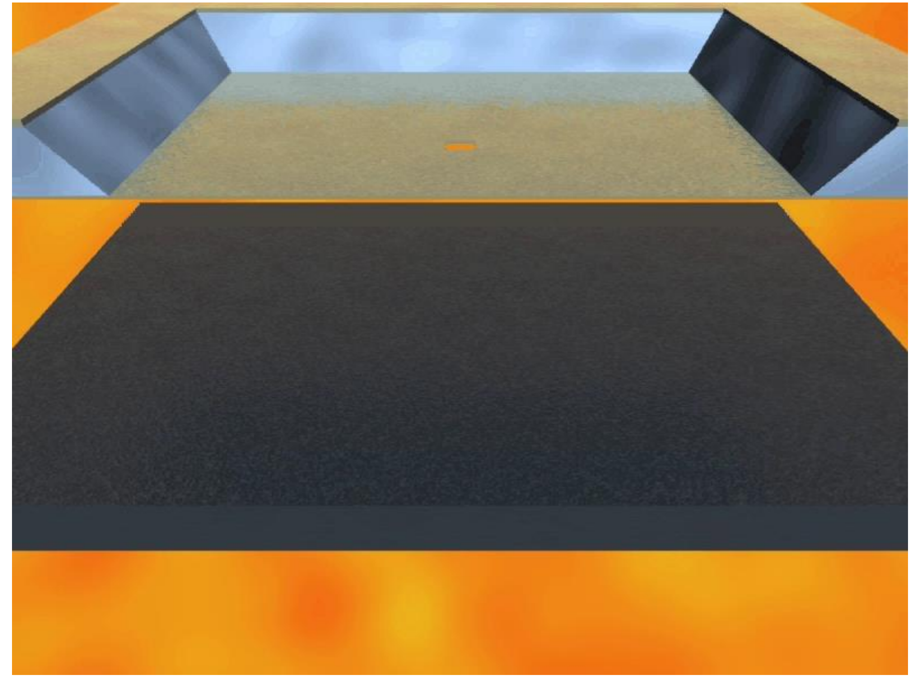
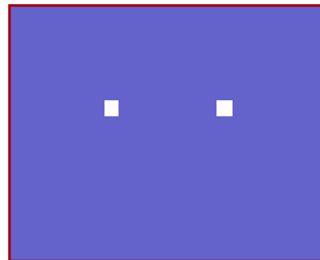
Dynamic stenciling

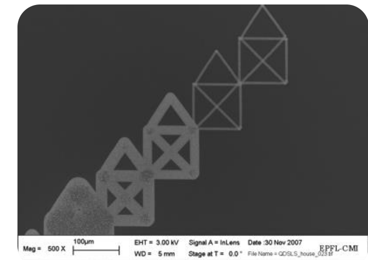
- Dynamic stencil
- Free motion in vacuum
- Rapid prototyping
- Flexible lithography
- PC controlled
- Parallel patterning
- Tapered film thickness





stencil

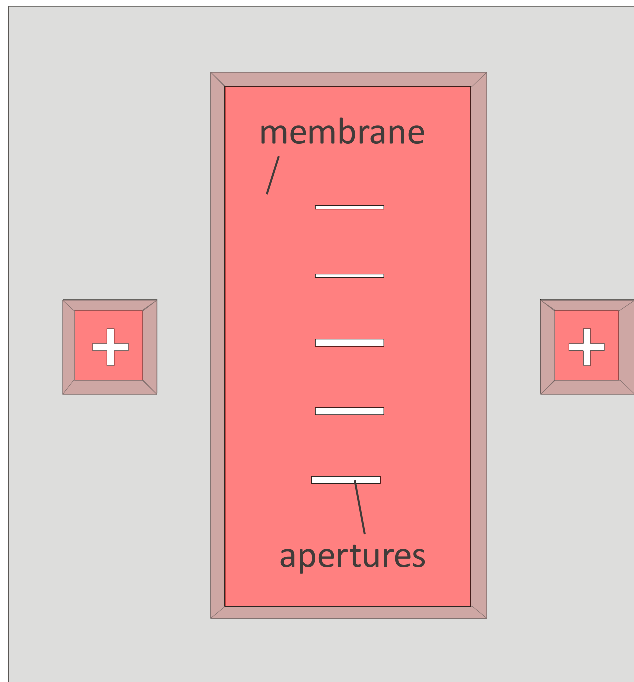
Free motion



SEM image

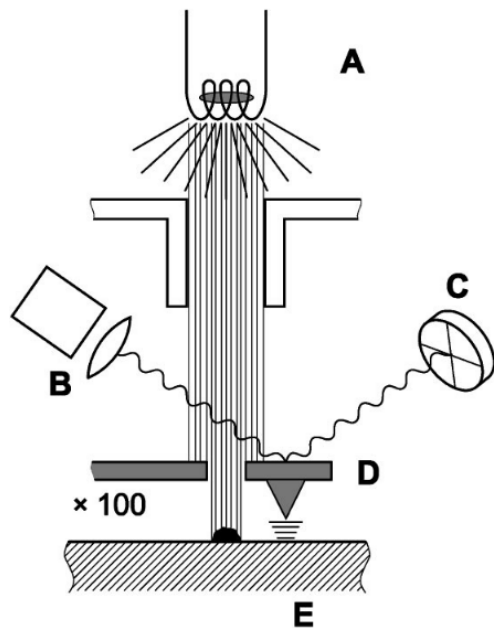
EPFL

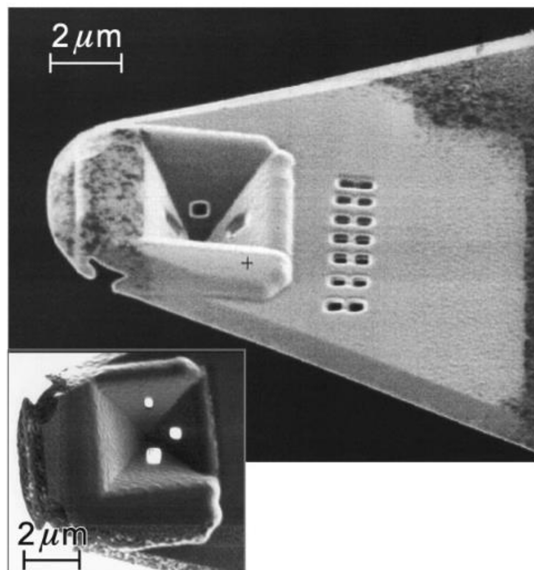
Stencil alignment

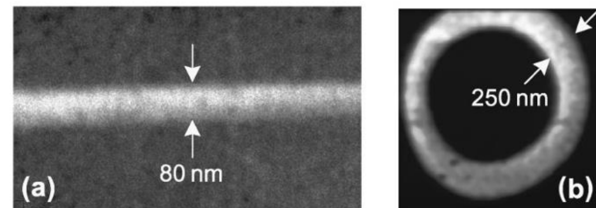


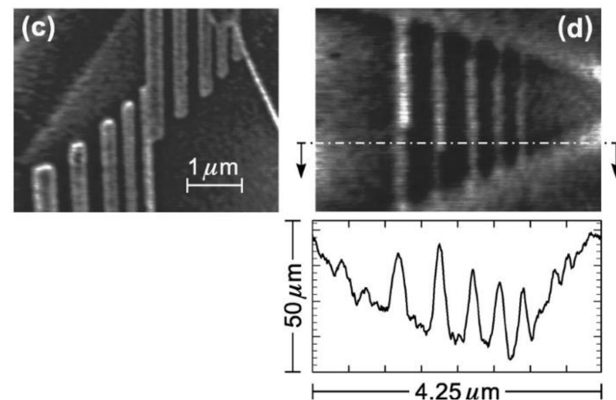
EPFL

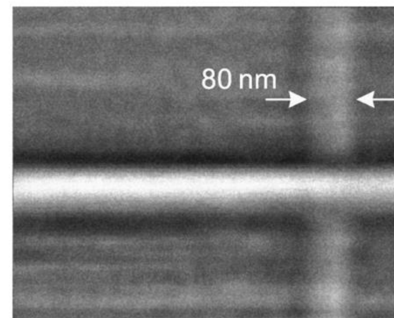
Dynamic nanostencil





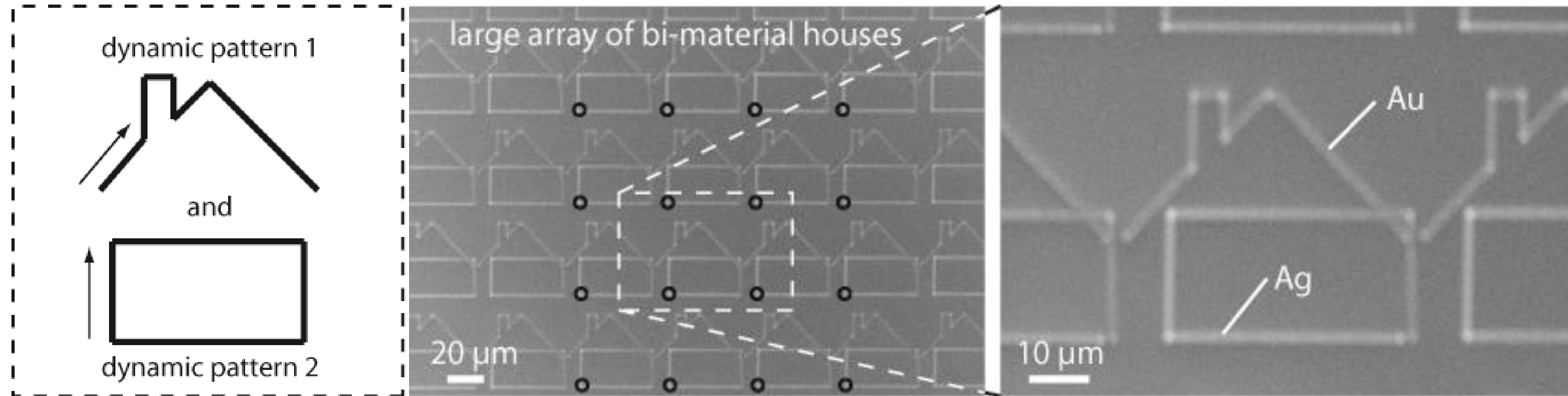




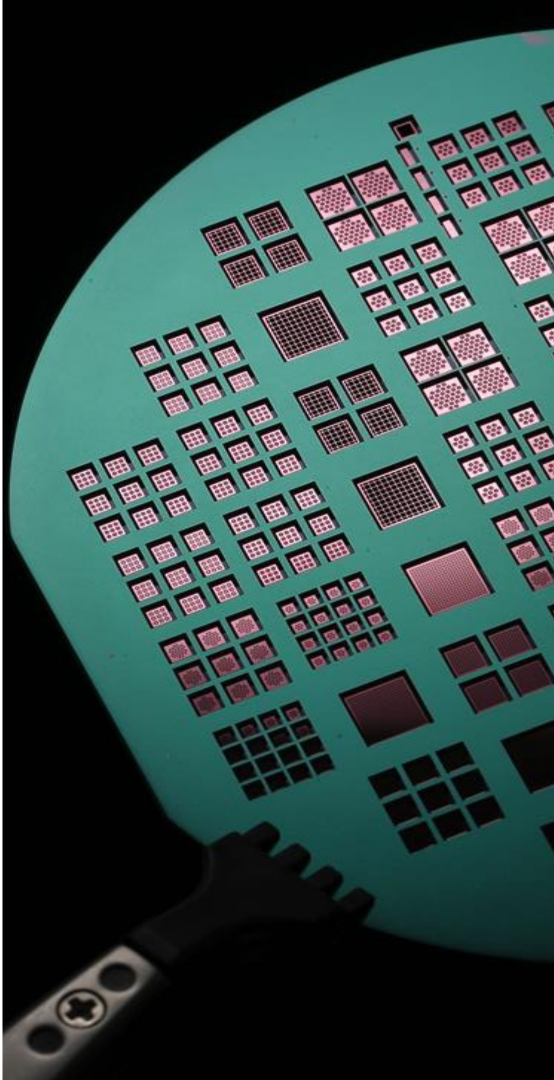


APL 1999

Dynamic stenciling



V. Savu, et al.,
J. Vac. Sci.Technol., 2008



Take away message Nanostencil

- Scalable to < 50 nm resolution
- Full wafer
- Vacuum clean
- No contamination of fragile materials
- Metal and organic materials, dielectrics

- Fine tuning of material flux
- Control crystal growth
- Micro-manufacturing of OE, flexible wearables, etc.