Course material

Course:

Micro and Nanofabrication (MEMS)

Video:

4.16 Lithography 7, Alternative patterning methods, II Replication methods

Concepts (extracted from automatically generated subtitles):

Right show. Nanoimprint lithography. Use of photo. Stencil lithography. Thin film of gold. So-called replication methods. Inverse pattern of the stamp. Typical examples of nil. Intimate contact. Optical images. Imprinting process. Silicon-quartz. Nano molding. Conventional photo lithography. Micro contact printing.

to video sequence search
(within Micro and Nanofabrication (MEMS).)

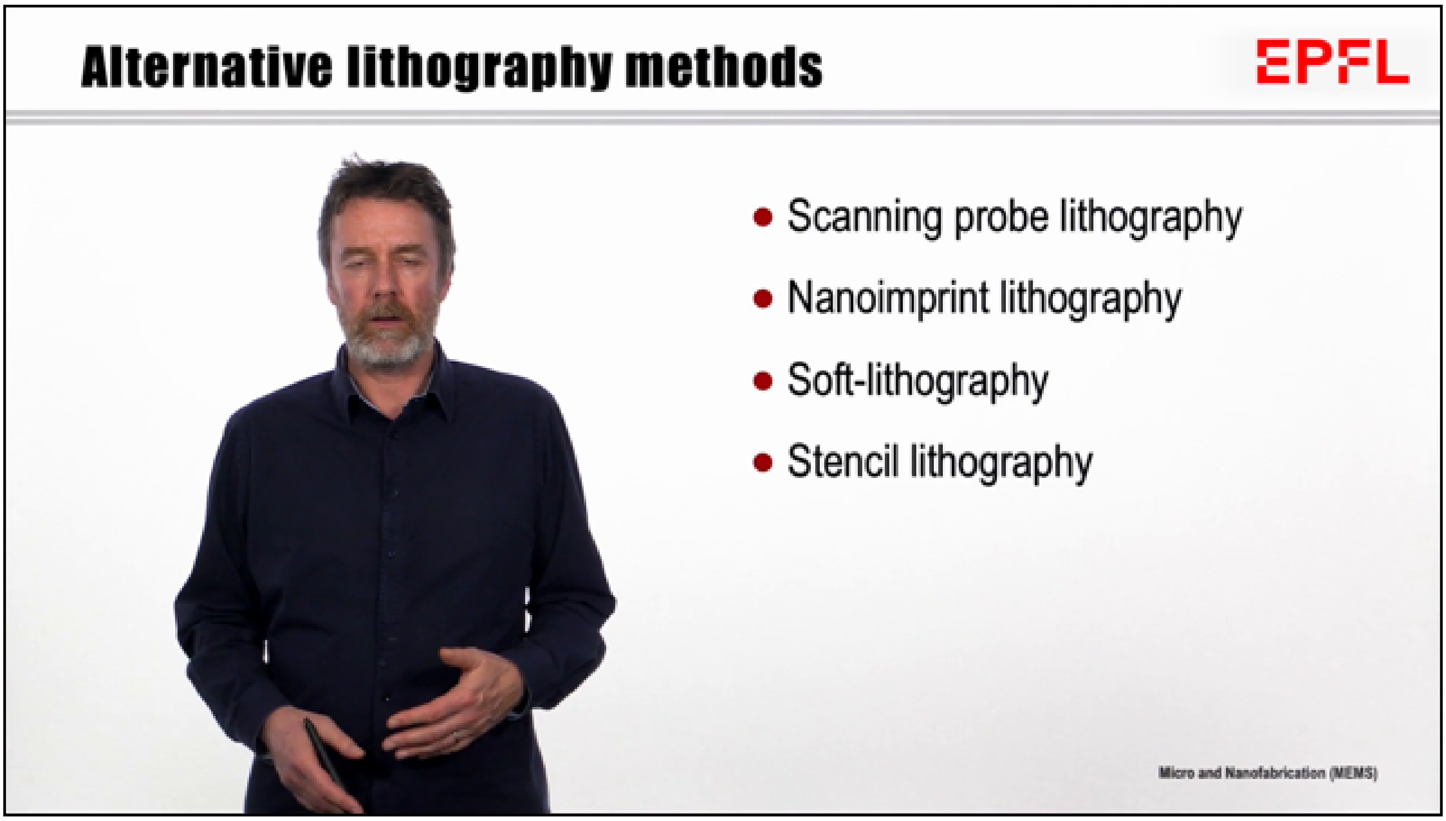
to video

...

notes

summary

0m 0s

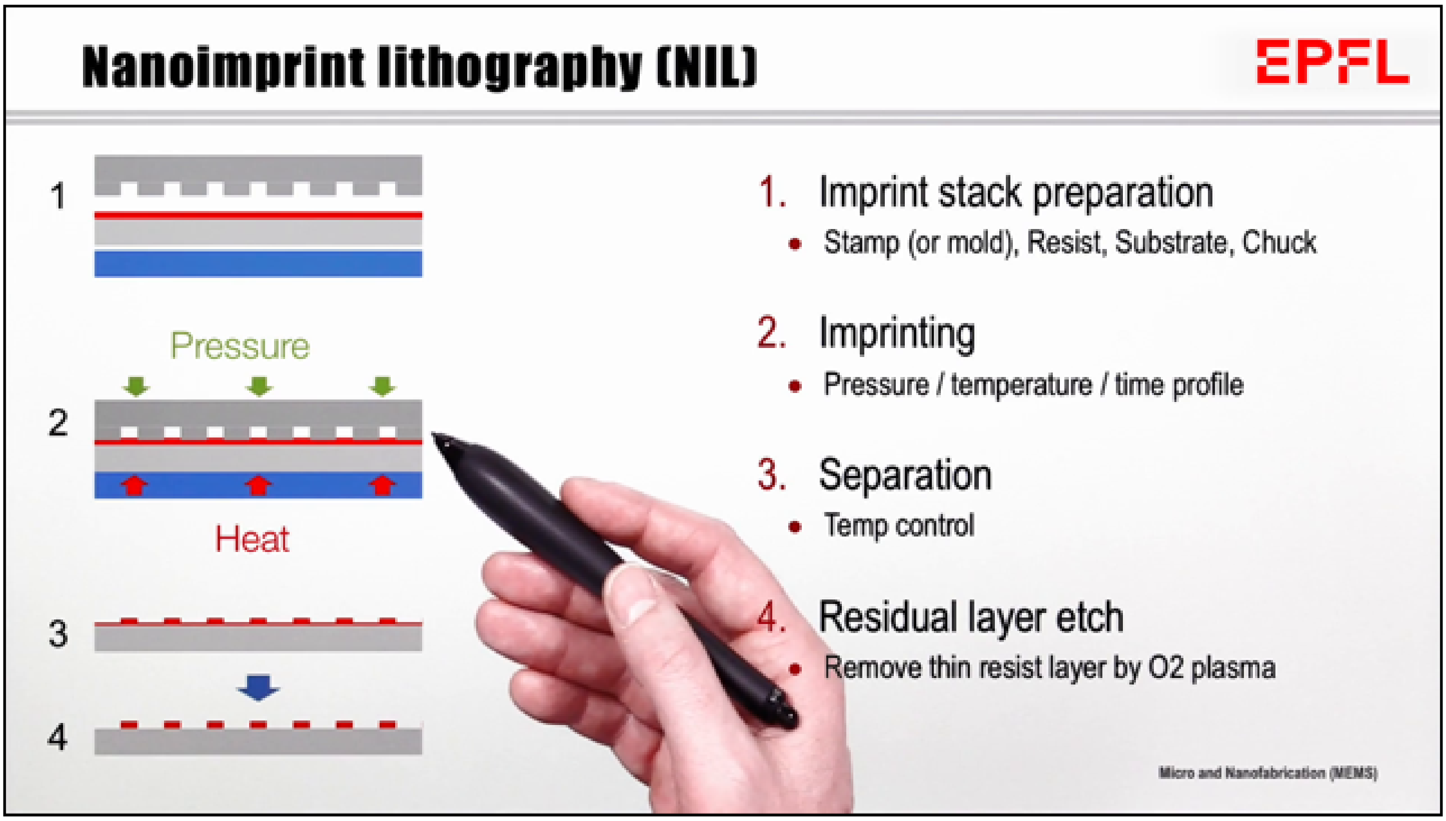


Scanning probe methods are single tip serial techniques.

notes

summary

0m 1s

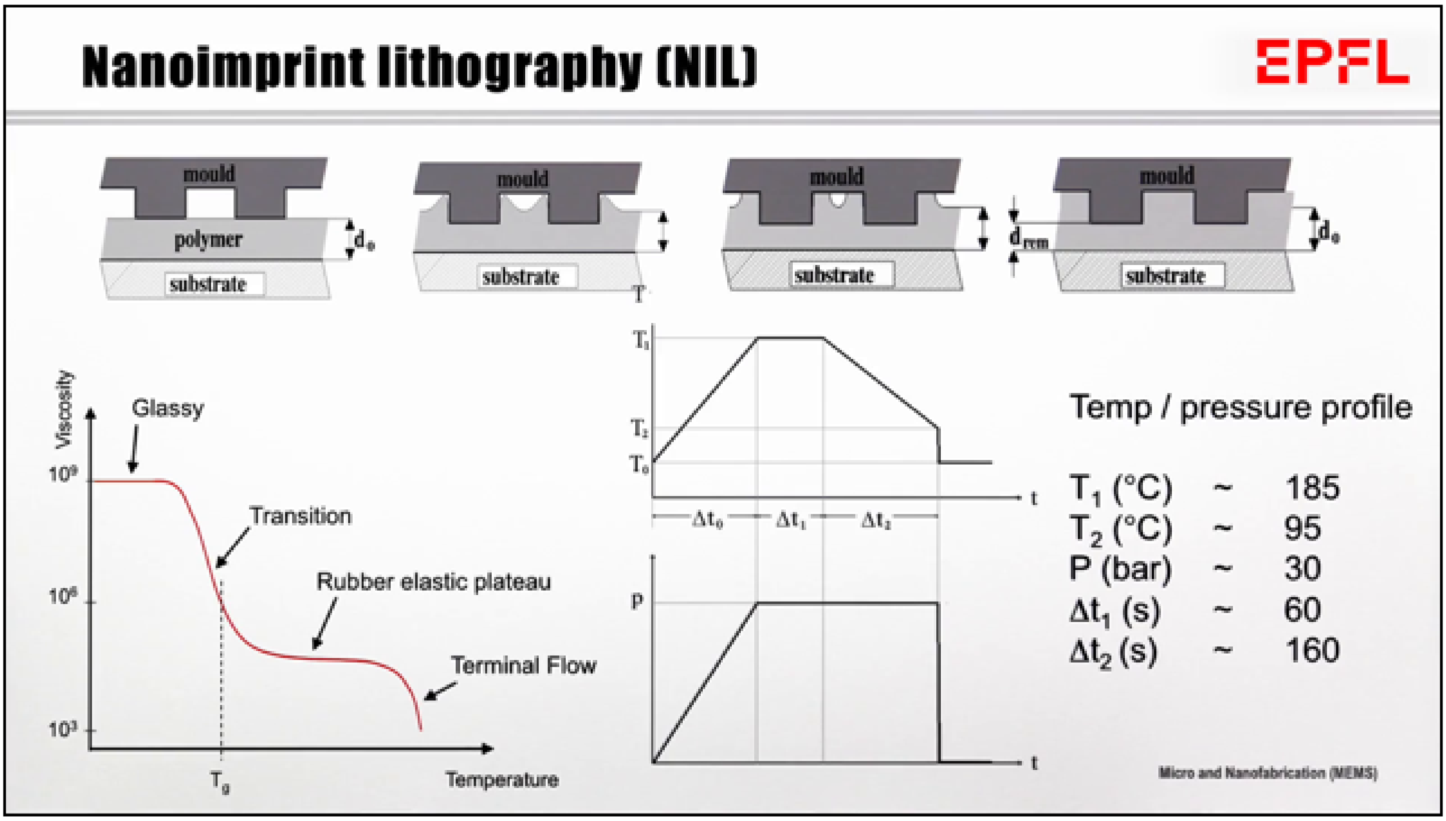


So they are very useful for direct writing and for rapid prototyping, but they are very slow for production. Hence, we will now look at so-called replication methods. The first one I will show is nanoimprint lithography. Nanoimprint lithography, or NIL, is already well advanced and industrialized and even appeared on the semi-conductor road map. It was indeed first shown already in the 1990's, that it is possible to directly imprint nano structures, from a stamp into a polymer at the 10 nanometre scale by a combination of heat and pressure. This outstanding achievement has triggered a lot of interest from the scientific and technical communities. It is foremost the simplicity of the imprinting technique that has some striking arguments, despite some serious drawbacks. As conventional photo lithography reaches the feature size limits due to light defraction and scattering effects, nanoimprint being a mechanical technique instead relies on a one-to-one master template that is replicated in an imprinting process. Using a silicon-quartz or nickel or polymer master the nanostructures can be replicated in the imprint tool using the following procedure. First, the template or stamp has to be fabricated. This is typically done by electron beam lithography and etching. Stamp and substrate are then put in intimate contact with each other, as well as with the chuck, in order to get optimal thermal contact to the imprinting polymer. The temperature and pressure is software controlled during the imprint process.

notes

summary

0m 5s



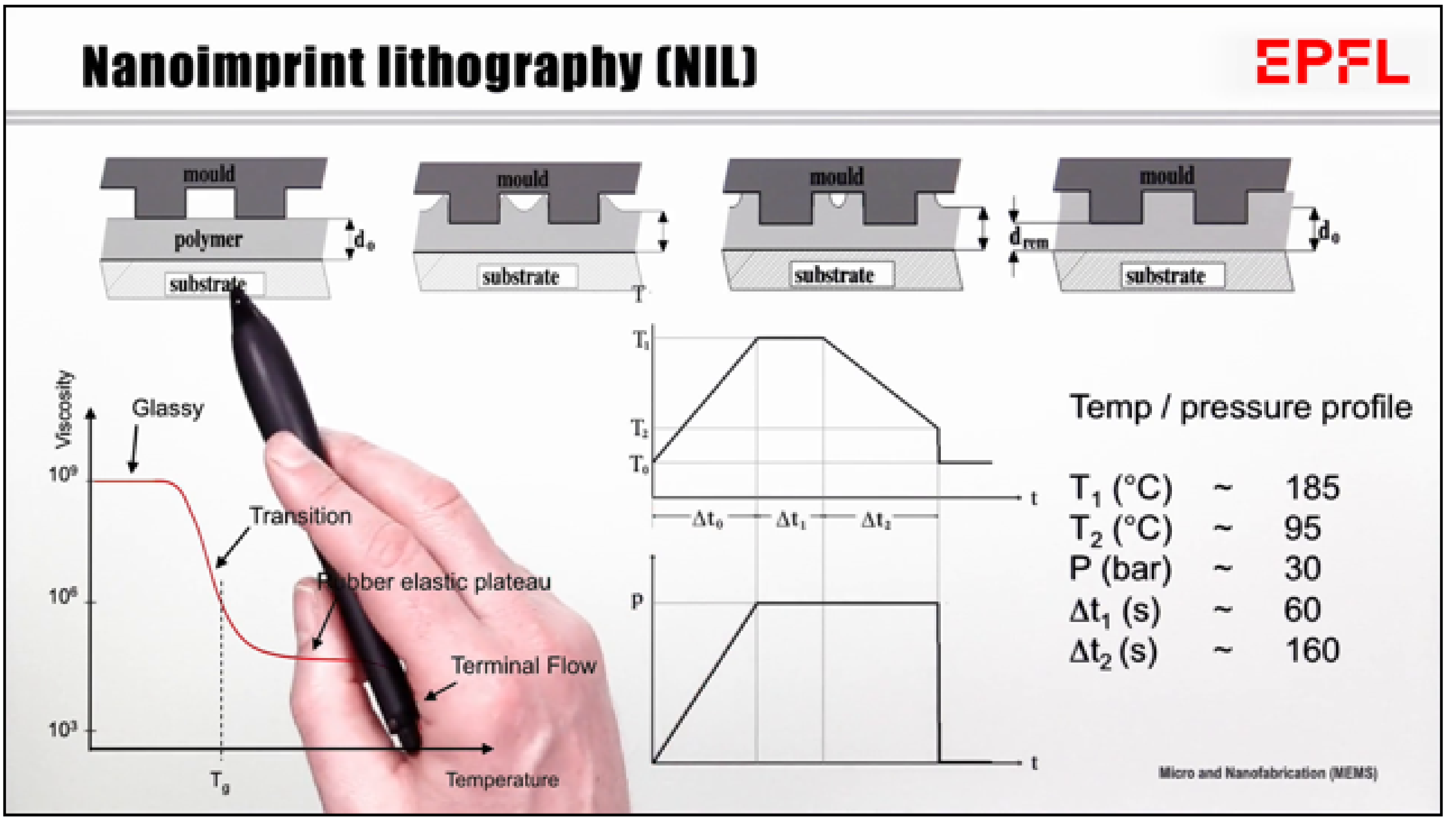
This process step replicates the inverse pattern of the stamp by viscous flow of the resist due to the pressure from the protrusions. Stamp and substrate are separated at the end of the process and the nanoimprint always leaves behind a so-called residual layer of resist underneath the stamp protrusions. This layer must be removed by a so-called residual layer etching, before further processing can be done on the substrate. NIL has been shown to deliver excellent results for regular features such as periodic lines for gratings or areas of dots for filters. It is more difficult or impossible to replicate very irregular geometries because of the resist rheology.

notes

summary

2m 1s

Nanoimprint lithography (NIL)

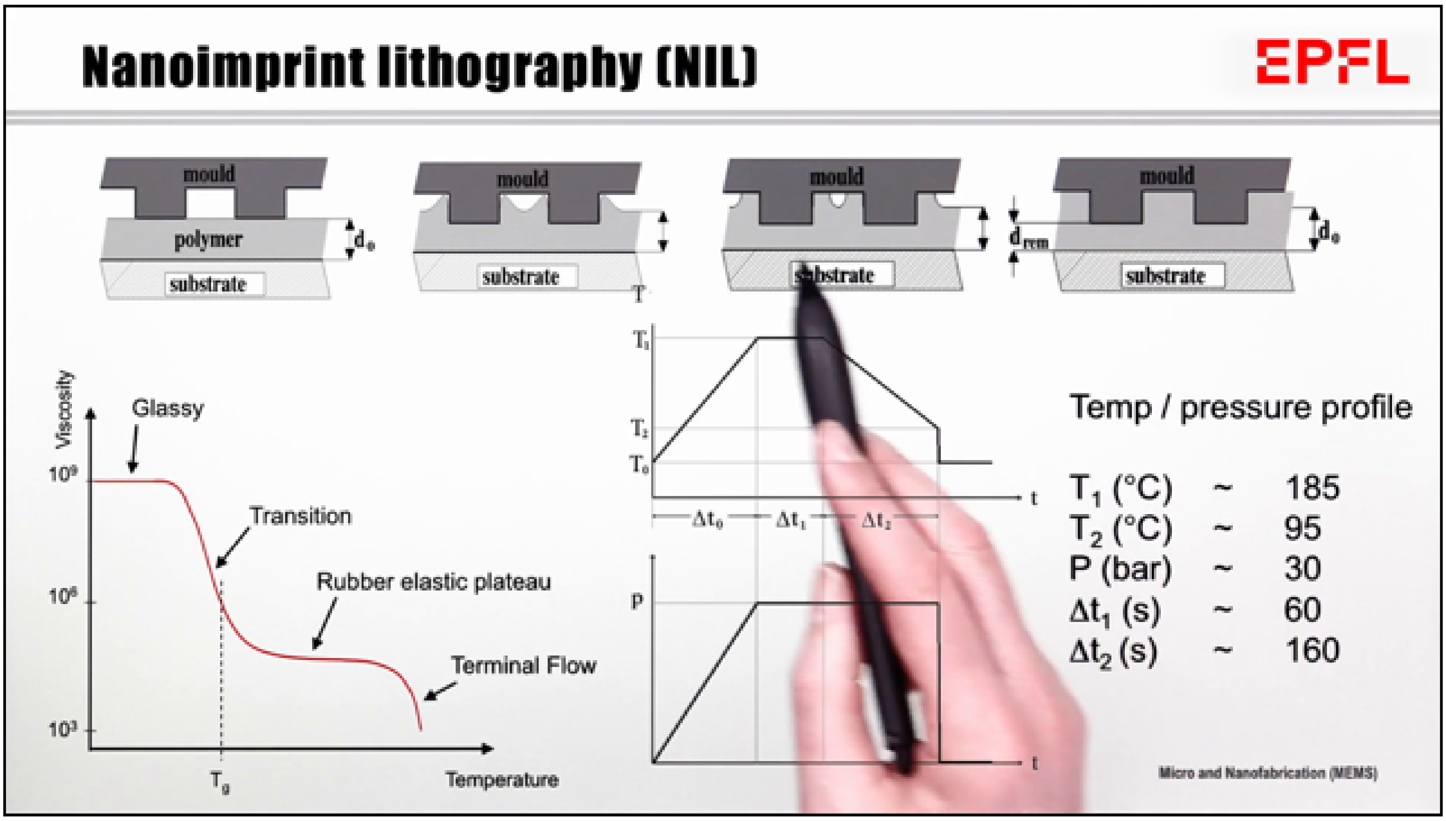


Here on this slide, we zoom into some details on the molding process and the imprinting process, where we see in particular how the polymer is displaced from the areas under pressure into the stamp cavities until they are completely filled, shown here from left to right.

notes

summary

2m 51s



Different stages of the imprint process until the cavity of the mold is completely filled

notes

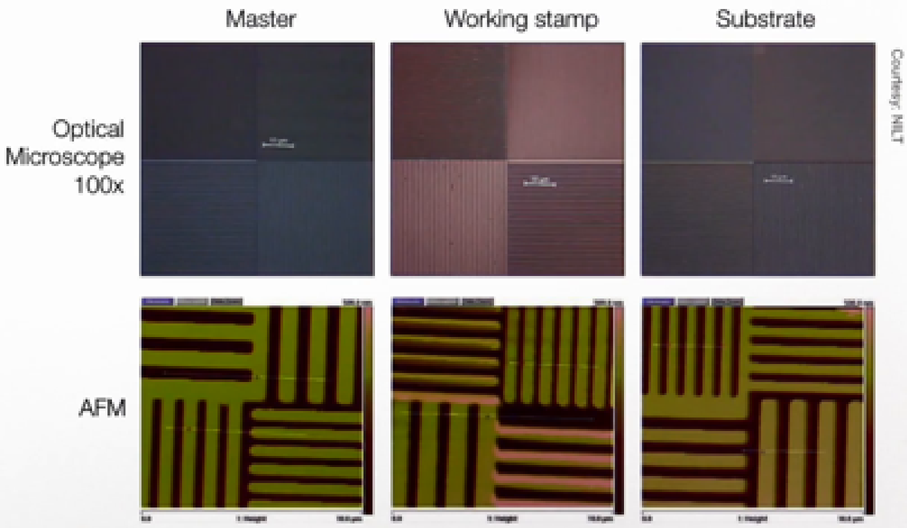
summary

3m 8s

Nanoimprint lithography

EPFL

- Master stamp is costly
- Replicate master in working stamp
- Use working stamp for substrate imprinting and for mass fabrication
- Working stamp can be Nickel, Polymer, etc.



Master depth is 514 nm, imprint depth is 503 nm.
Master to substrate replication
Residual layer thickness < 20 nm

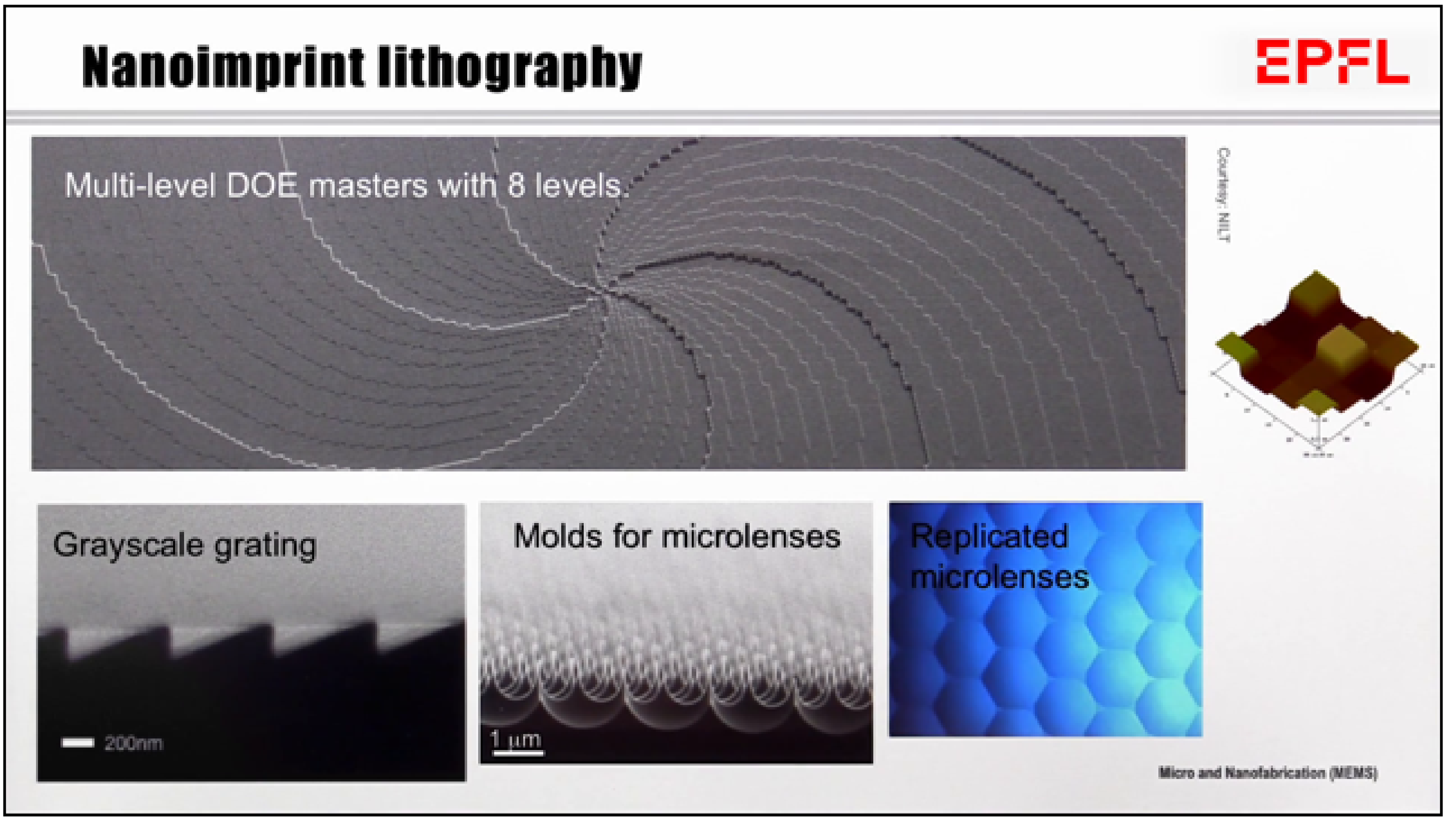
Micro and Nanofabrication (MEMS)

by the flowing polymer. The viscosity of NIL resists depends on the temperature. A typical temperature-viscosity curve is shown here, with the various transition temperatures of the polymer. Typical NIL processes follow a well defined temperature and pressure profile, some realistic numbers are shown here on the right side. Please note that some imprinting times can be several hours long. Current R&D; is focusing to speed up this step for high throughput manufacturing. Since the making of the first master mold by e-beam lithography is very expensive, one normally replicates it into working stamps.

notes

summary

3m 14s

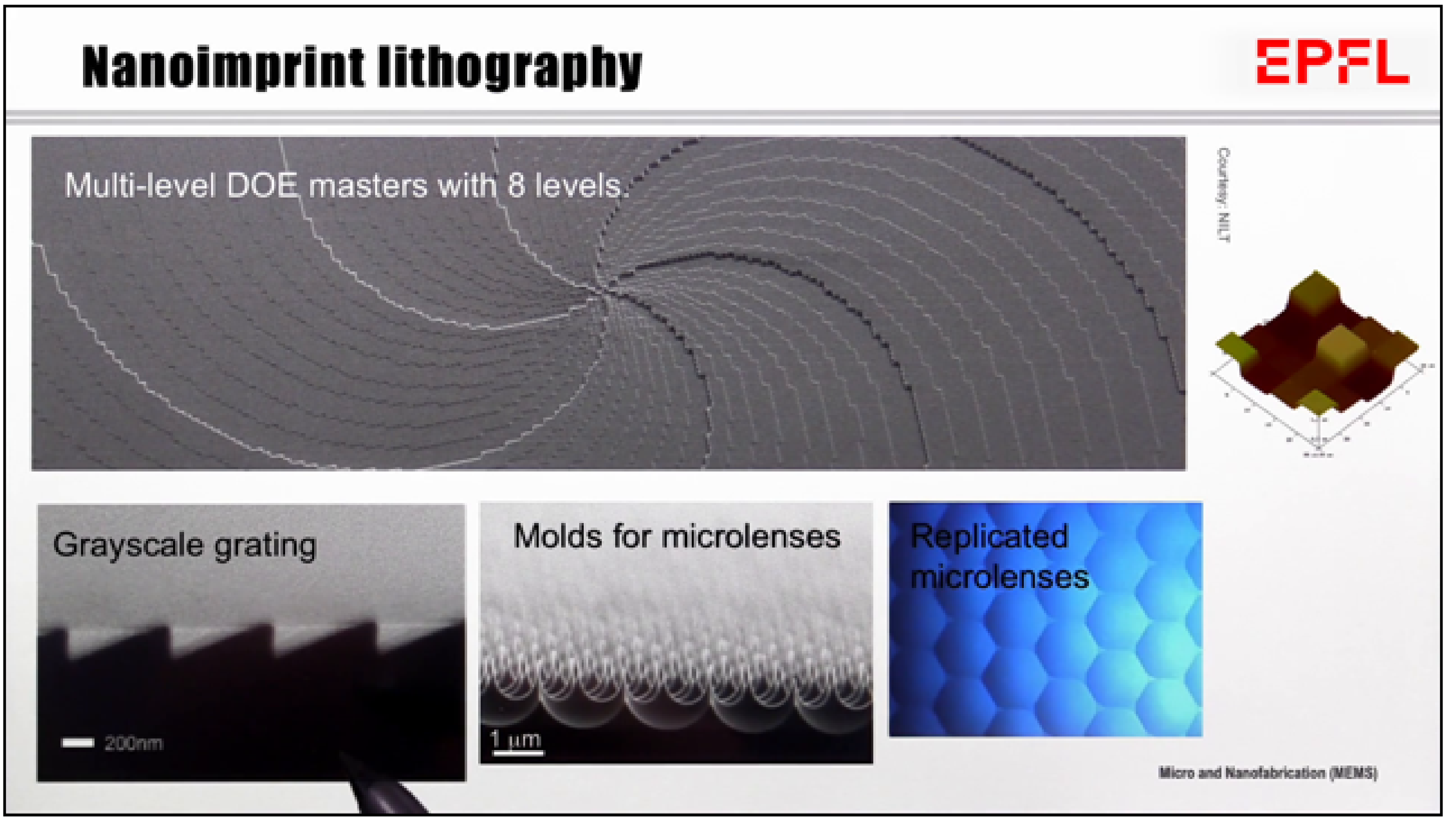


Here on this slide you can see some typical examples of NIL. On the top row, they are 100X magnified optical images taken by a microscope of sub-micrometer test features. The scale bar is 10 micrometers. This shows the master, the working stamp, and the substrate respectively. The lower row shows corresponding AFM images of the master, stamp, and substrate respectively. It shows the very accurate replication from the initial high-resolution master here, over the stamp and the final imprinted product. This is a demonstration of the supremacy of NIL for replication features at a sub micrometer scale, for example for optical effects. Here on this slide, there are some other unique

notes

summary

4m 1s

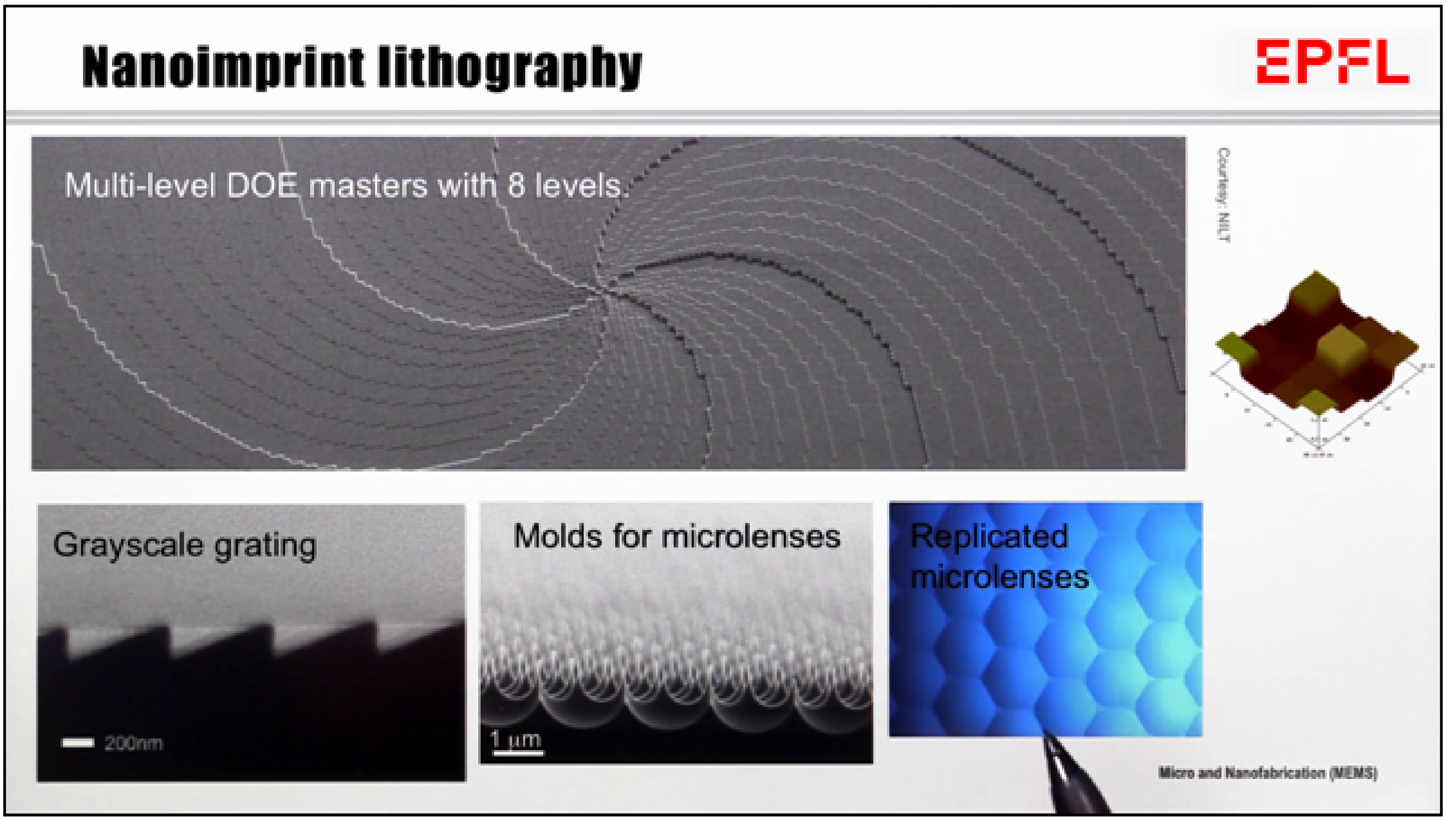


NIL samples such as diffractive optical elements with eight height levels, as shown here.

notes

summary

4m 58s



In the bottom images we can see from left to right, a grey-scale grating with extremely high resolution, and here some molds

notes

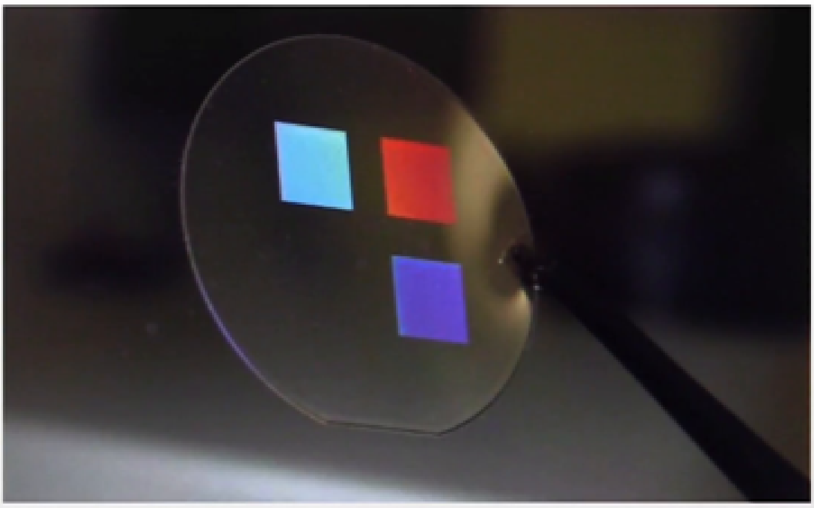
summary

5m 10s

Nanoimprint lithography

EPFL

Courtesy: NILT



Large area standard pillar stamp insert.

Micro and Nanofabrication (MEMS)

for microlenses, with the corresponding replicated lenses in polymer.

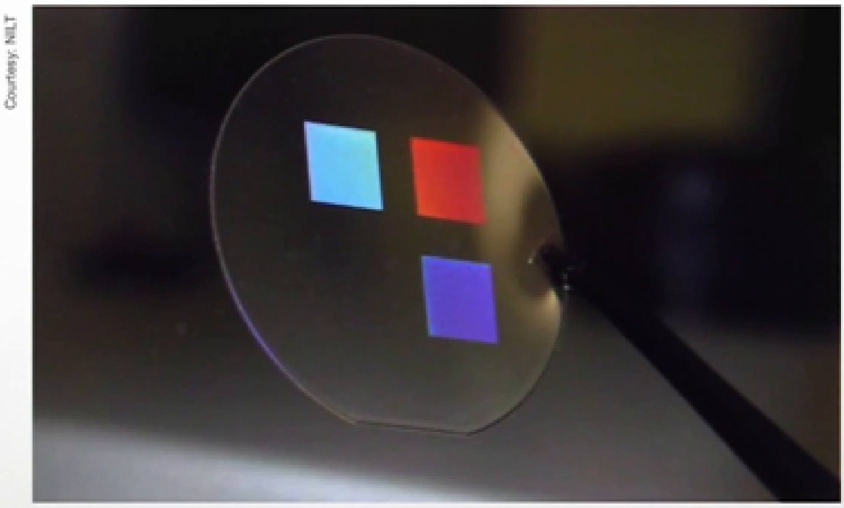
notes

summary

5m 20s

Nanoimprint lithography

EPFL



Large area standard pillar stamp insert.

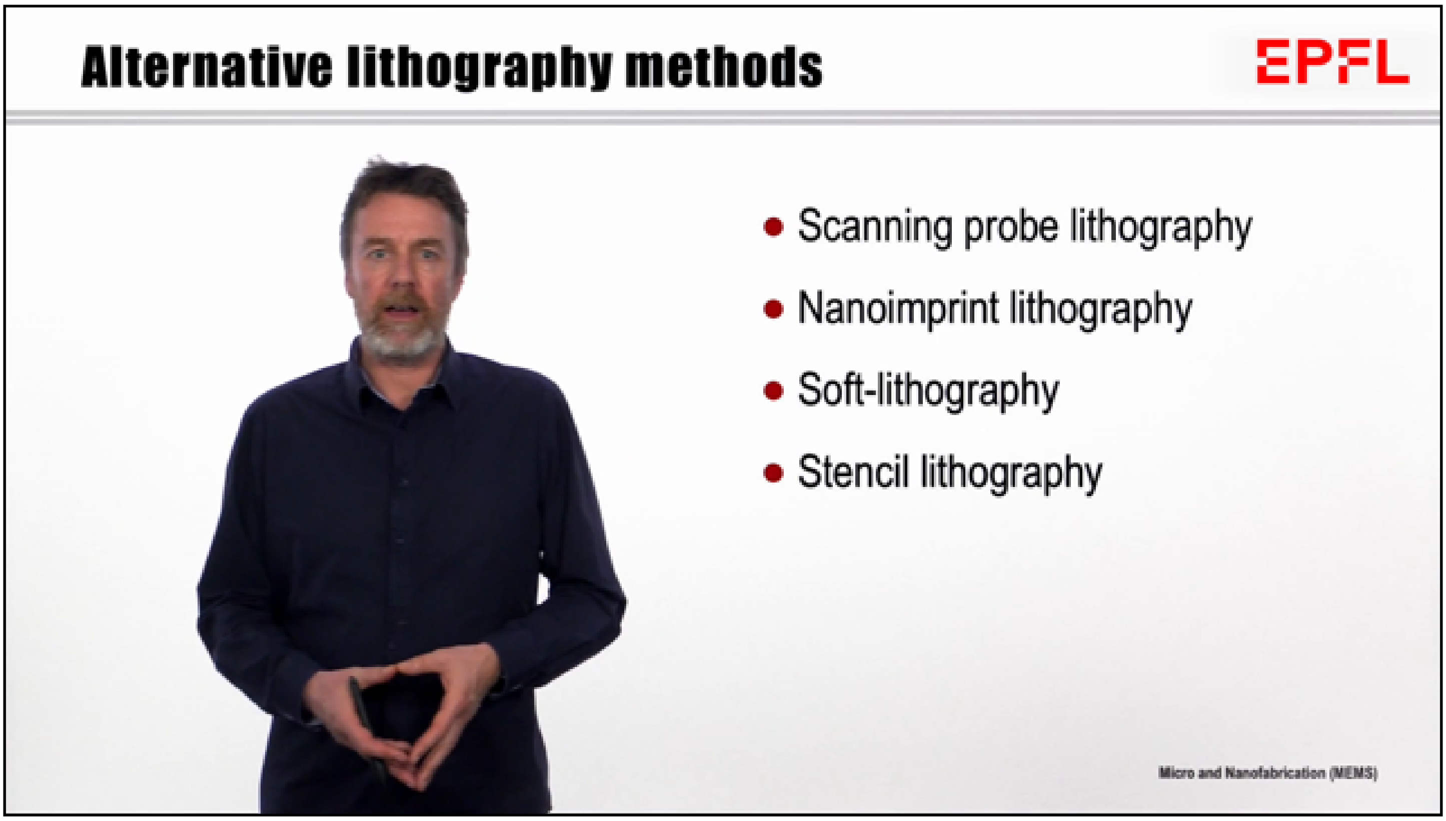
Micro and Nanofabrication (MEMS)

This image shows a photograph of a NIL stamp to be used for optical gratings. This is one of the most powerful and beautiful examples where NIL outperforms other lithography techniques in terms of resolution and throughput. One note please, these examples in fact use the NIL stamp to imprint

notes

summary

5m 26s



the feature into the surface. There is actually no pattern transfer into a layer underneath, so strictly speaking this should be called nano molding and not nano lithography.

notes

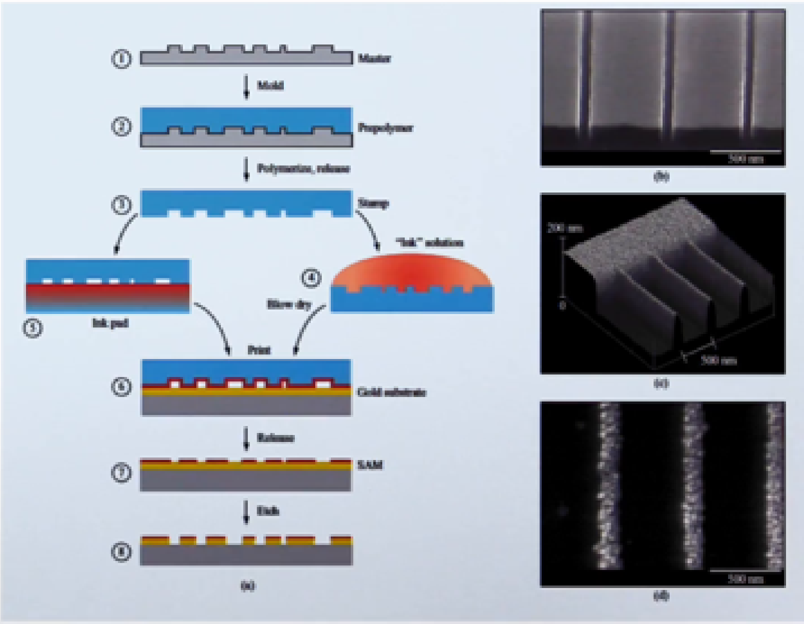
summary

5m 45s

Soft-lithography, micro-contact printing

EPFL

1. Master
2. Pre-polymer
3. Demolded stamp
4. Stamp inking by pad
5. Stamp inking by immersion
6. Printing on the substrate
7. Forming a SAM
8. Selective etching into layer



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Micro and Nanofabrication (MEMS)

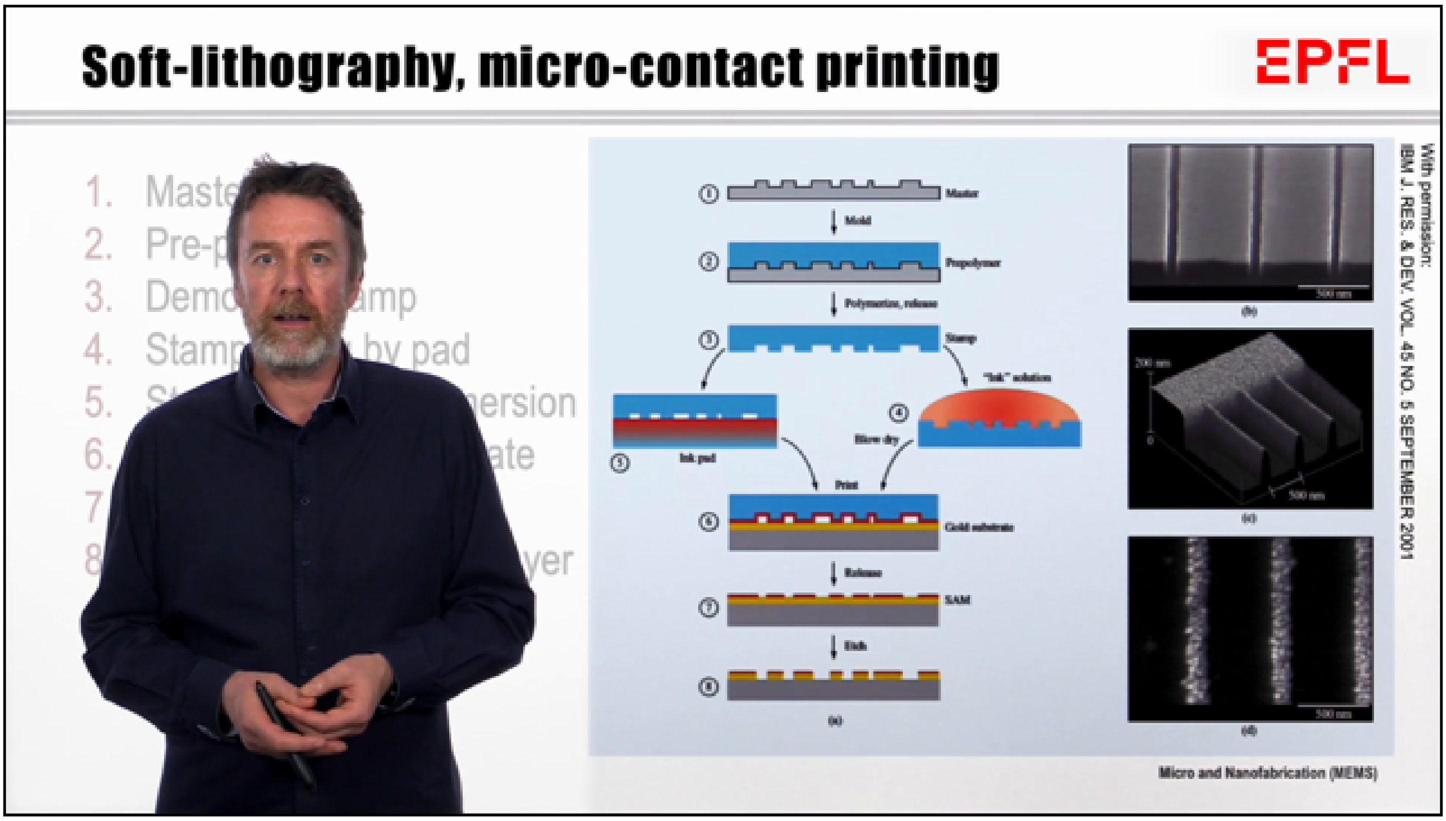
In the next section of this lesson, I will introduce soft lithography or micro contact printing. As the name already suggests, there is a soft or a gentle contact between a stamp and a substrate. Soft lithography is a collection of techniques based on printing, molding and embossing using an elastomeric stamp mostly based on PDMS polymer.

notes

summary

6m 1s

Soft-lithography, micro-contact printing

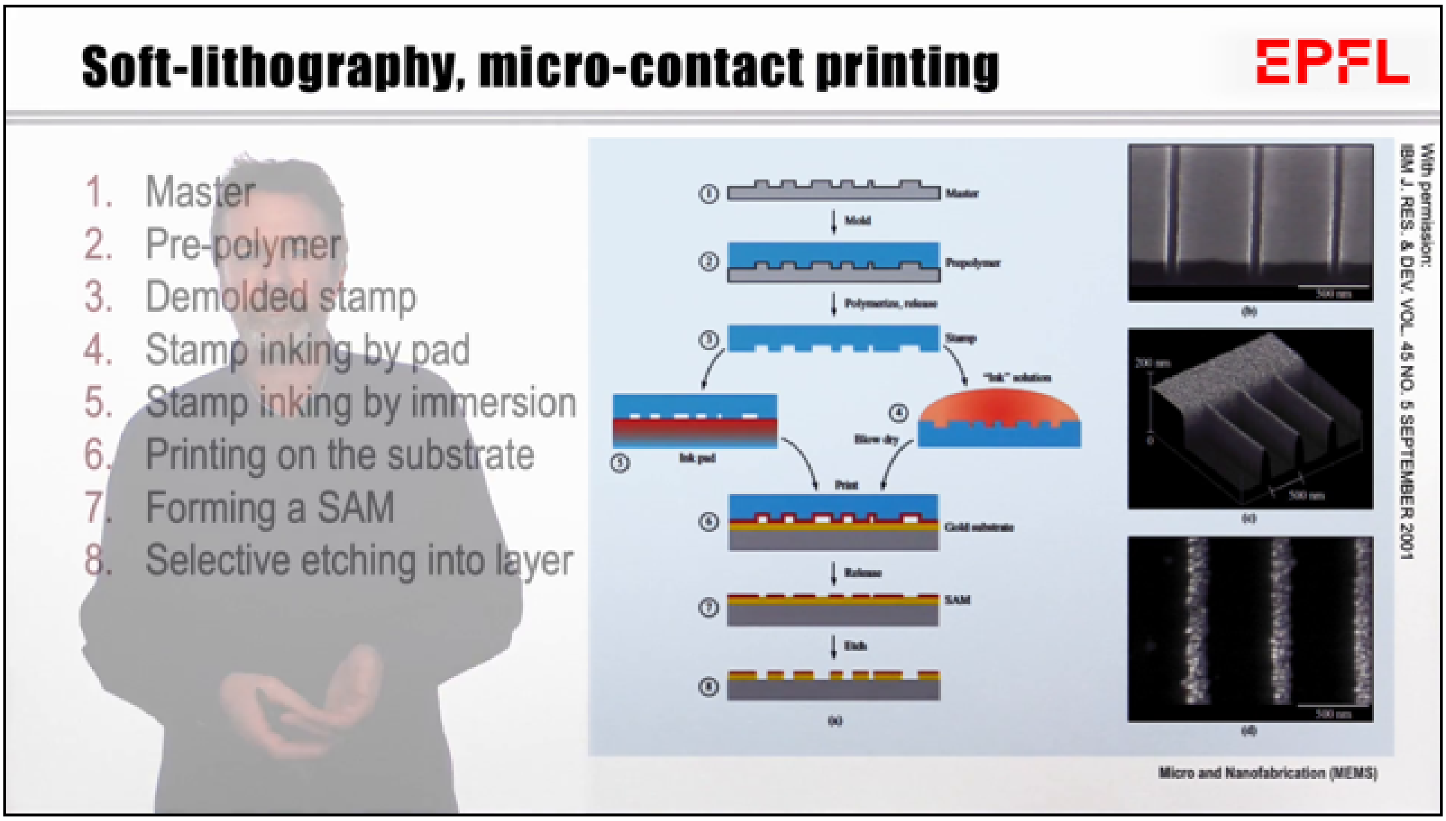


The key element of soft lithography is an elastomeric stamp, here in blue, with patterns as relief structures on its surface. The stamp is fabricated by casting a liquid polymer precursor onto a master, with the complementary structures. The mechanical properties of this stamp are critical to its ability to transfer a pattern with high fidelity. In principal, any elastomer can be used to cast the stamp, also most work has focused on the silicon based rubber, or cross-linked PDMS. The stamp, shown here again, is then inked with a liquid solution containing functional molecules. This can be done either by using a pad, shown here on the left, or by wetting the entire stamp with the liquid ink. The stamp thereby functions like a sponge where the ink diffuses into the PDMS, and later out again. The actual micro-contact printing step is then when the ink is transferred from the PDMS stamp to a surface. Depending on the ink, the print transfer can be done on a thin film of gold or silver supported on a silicon wafer, or on a glass slide, which is shown here. Conformal contact at the molecular scale between the PDMS stamp and the substrate surface is the key to successful transfer of ink molecules from the stamp to the substrate. Micro contact printing is widely used in printing alkyl-thiols on thin films of gold, silver, palladium and platinum and to a smaller extent and with more difficulties

notes

summary

6m 23s

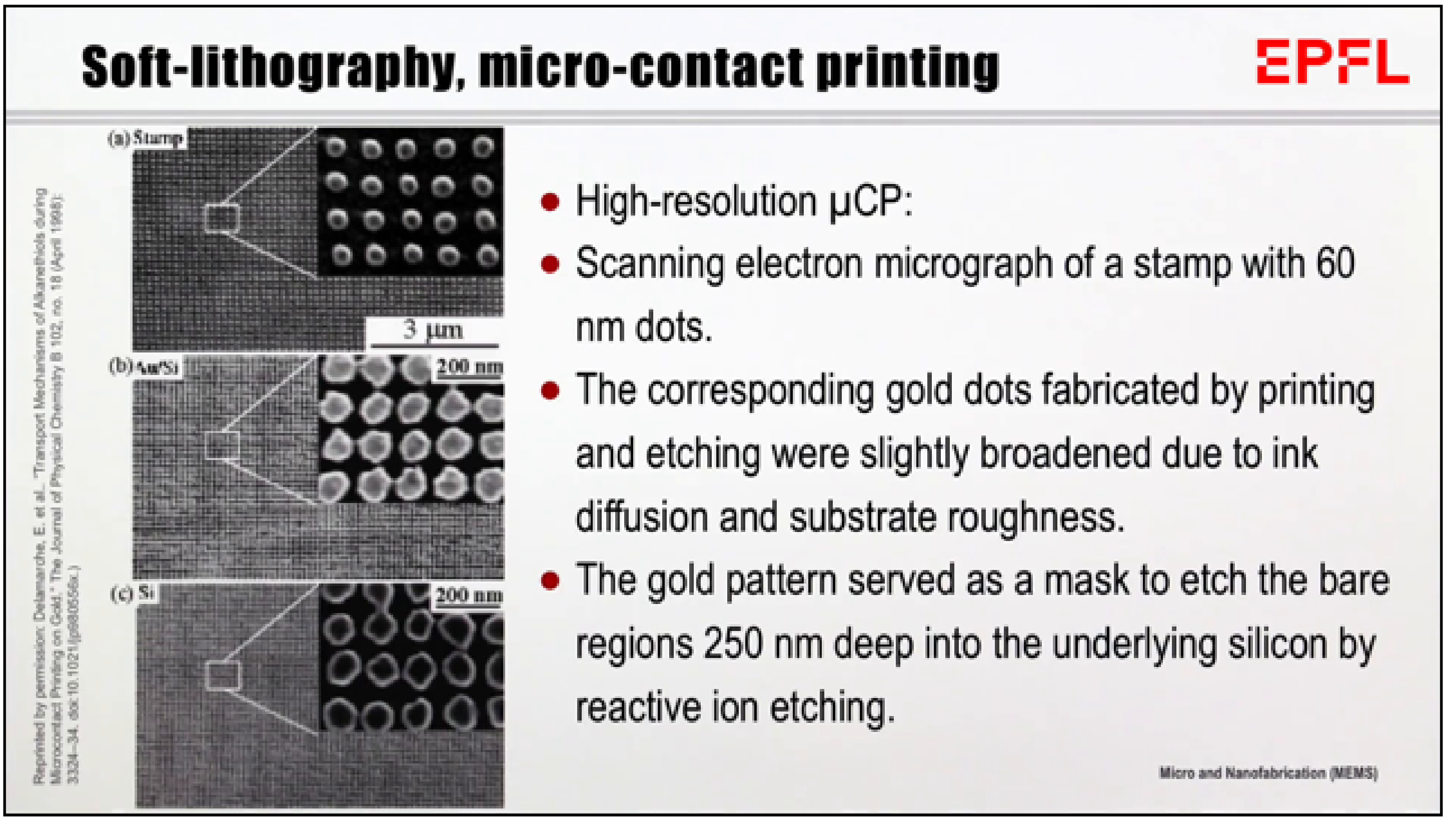


of alkyl-siloxanes on silicon and silicon-dioxide or glass. The ink molecules form self-assembled monolayers, or SAMs, on these surfaces during the imprinting process.

notes

summary

8m 13s

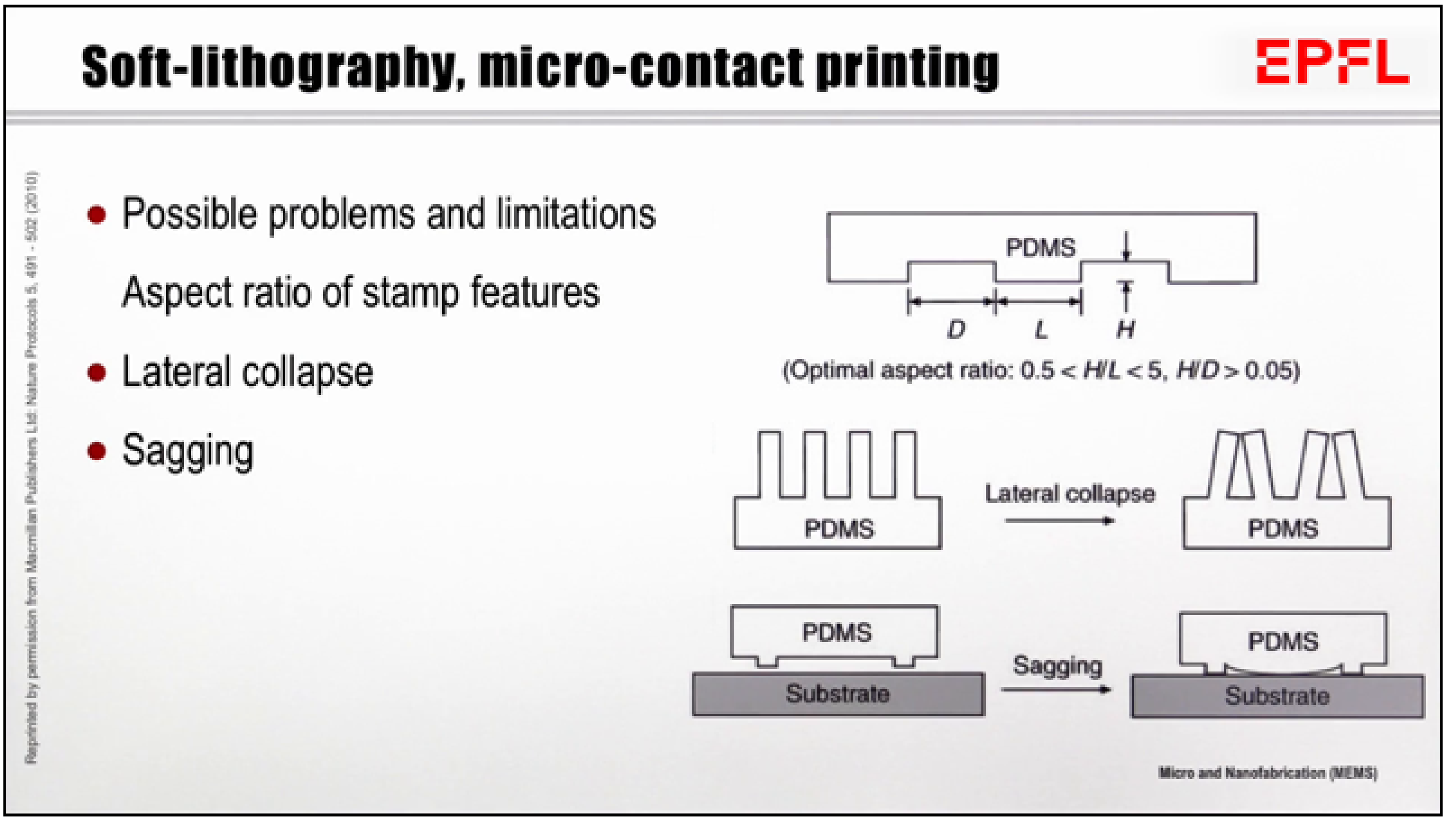


Here, the thiol-based SAM serves as an etch mask to transfer the printed pattern into gold. Which then is used as a mask for further etching. The photos on the right show some examples of high resolution soft lithography, with on top here the mold, the stamp, and the final gold pattern, from the top to the bottom.

notes

summary

8m 24s

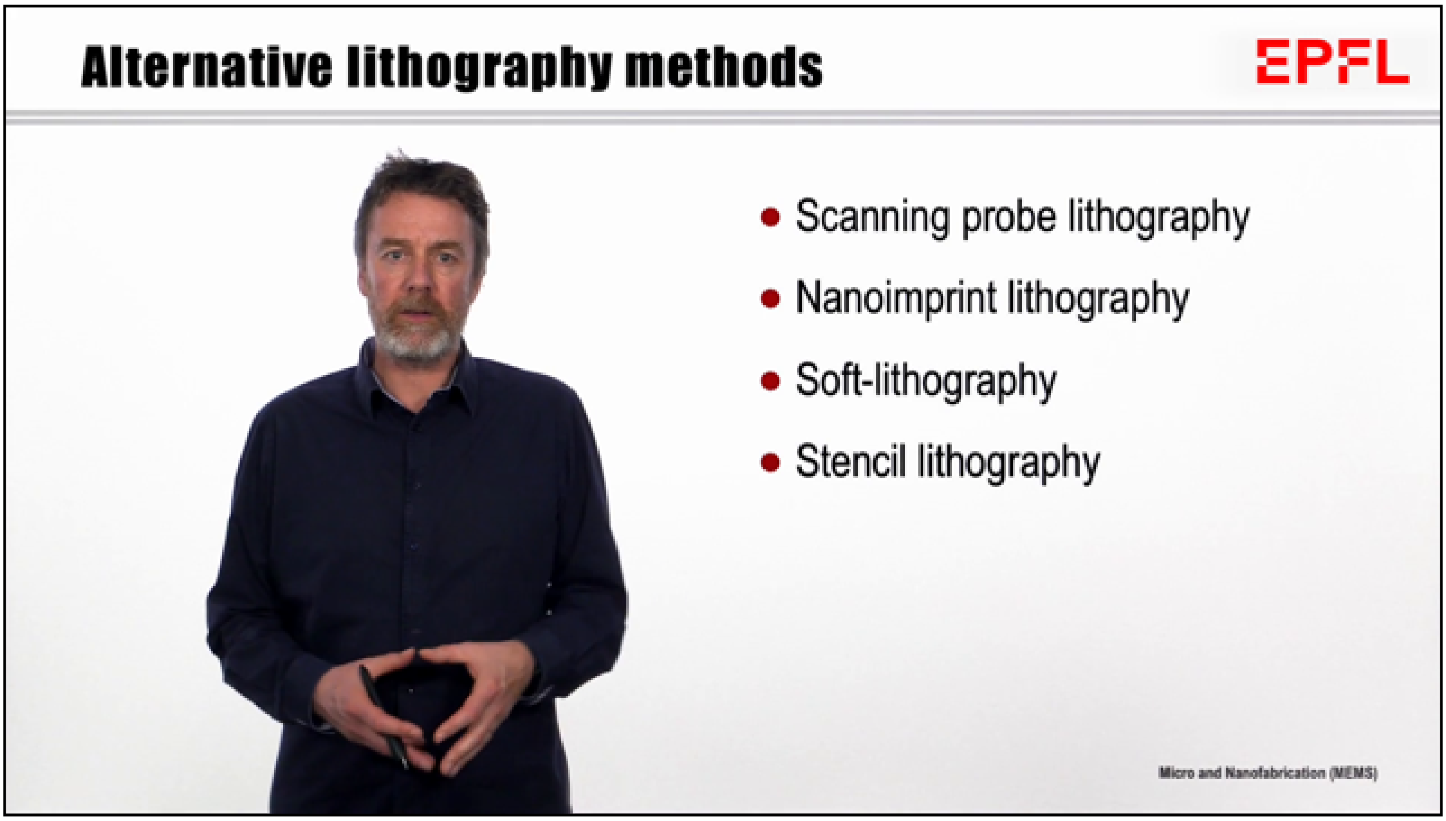


So this slide shows another example of high resolution soft lithography or micro contact printing, here is a SEM image of the PDMS stamp showing a regular area of pillars of 60 nanometers size, which has been used to transfer thiol on a gold surface, which then has been etched in the gold. We can see here that we lose some resolution due to the diffusion of the thiol molecules on the gold surface. And then using a gold pattern to transfer to the silicon we get here the final structure into the silicon. It is a nice example demonstrating how we can get from a relatively low cost PDMS stamp, via printing techniques to the final silicon structures at the sub 200 nanometer length scale. Here on this slide you can see the schematic illustration of a PDMS stamp and two possible problems that may arise due to the softness of the elastomer. One is the lateral collapse of the relief structures or commonly known as "pairing", where the aspect ratio H/L is typically bigger than five. The other problem is called "sagging of recessed structures" with aspect ratio where H/D is smaller than 0.05 during the printing. To avoid these issues one can rely on a hybrid stamp

notes

summary

8m 51s

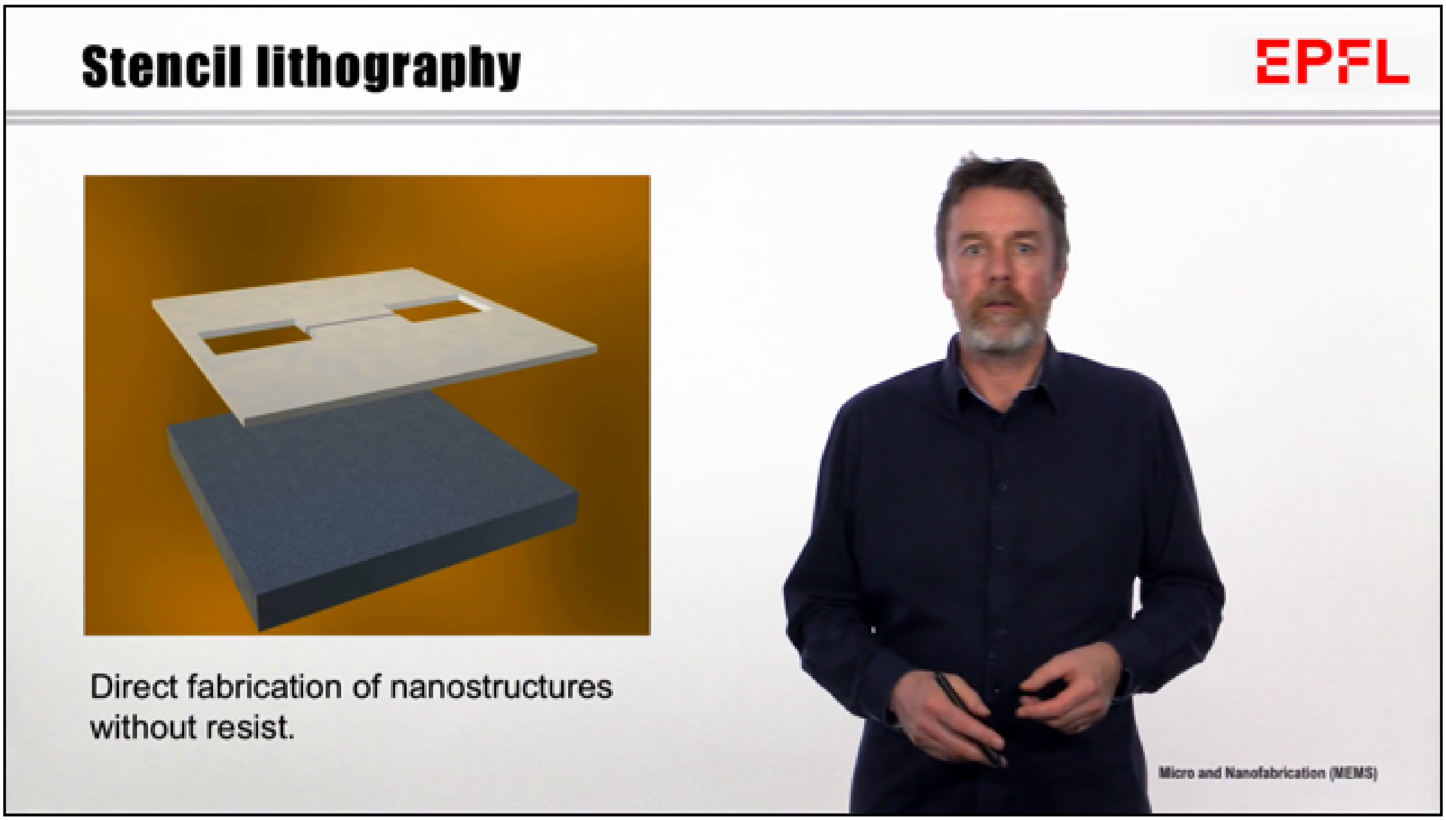


that is made of two different types of polymers with different Young's modulus to have an elastic layer on a more rigid stamp backbone. This is not shown in this slide.

notes

summary

10m 13s

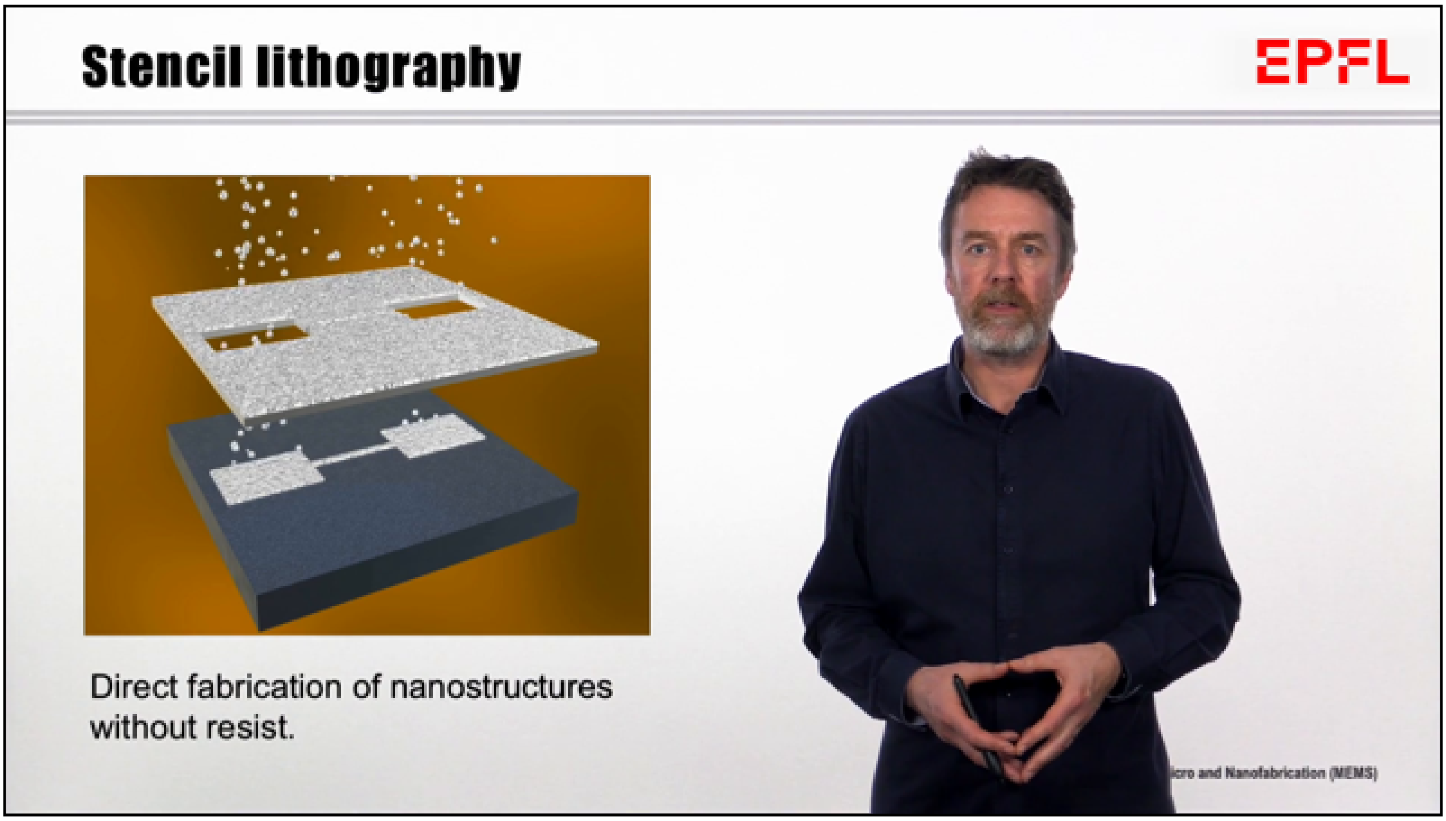


This brings me to the last example of alternative lithography which is called "stencil lithography".

notes

summary

10m 25s

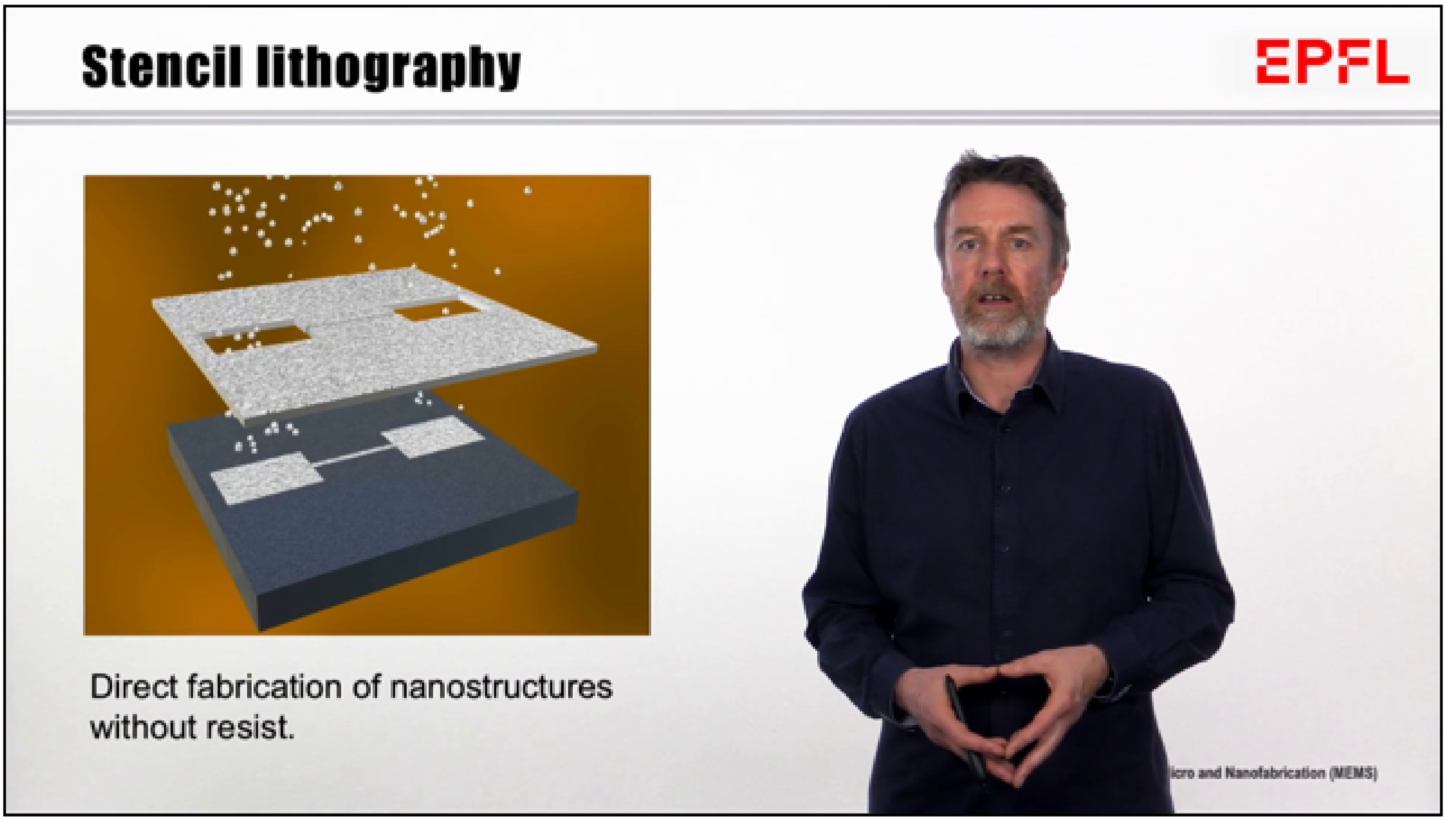


Vacuum deposition through micro nano stencils, also called "lens lithography", is based on a very thin

notes

summary

10m 31s

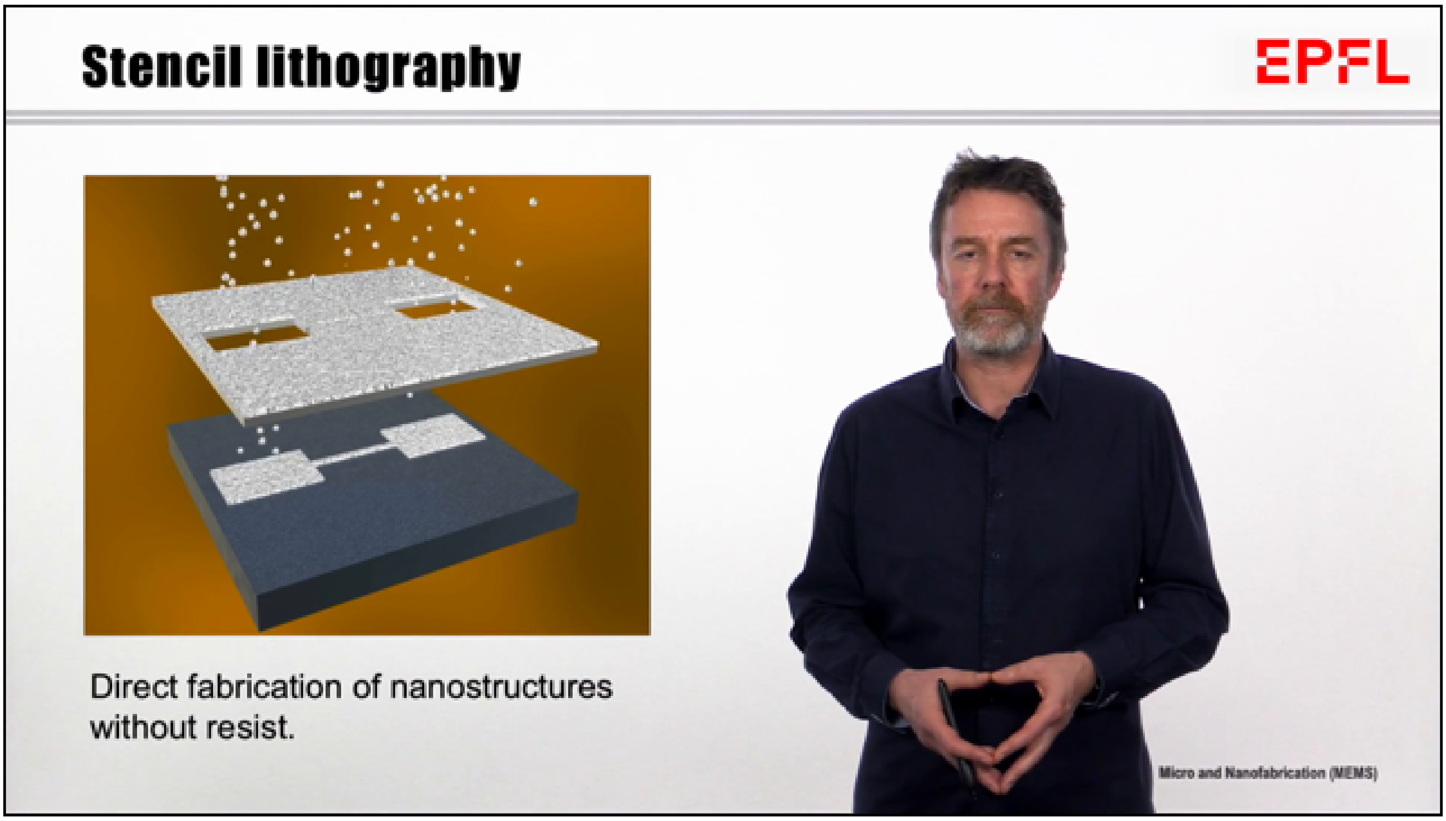


membrane with engineered apertures that is approached to a surface, like shown here. When using physical vapor deposition, such as thermal evaporation, the flux of the incoming atoms will be partially blocked by the mask and only where the membrane stencil has apertures, atoms can reach the surface.

notes

summary

10m 39s



This allows creation of metal patterns without the use of photo resist and associated process steps such as development and baking. It is therefore applicable to virtually any surface and substrate material.

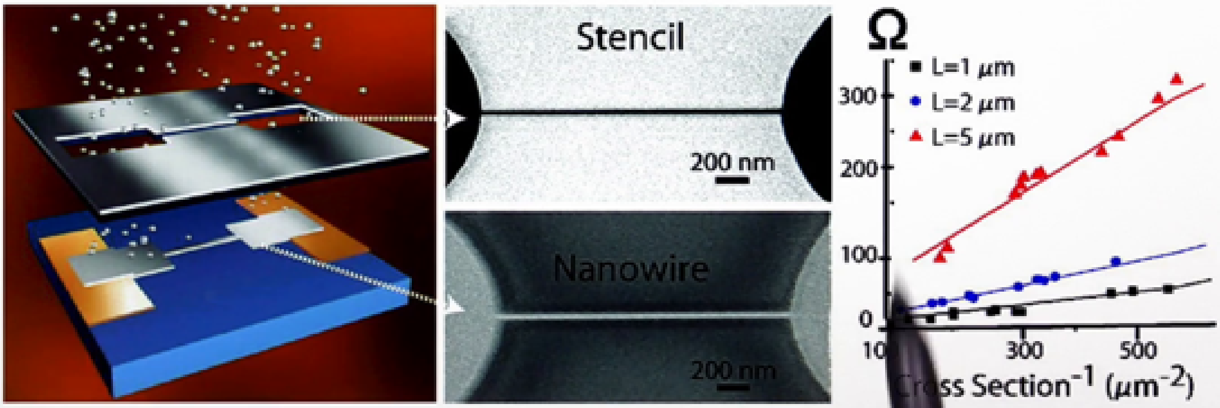
notes

summary

10m 57s

Stencil lithography nanowire fabrication

EPFL



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O. Vazquez et al. Nano Lett., 2008, 8 (11), pp 3675–3682

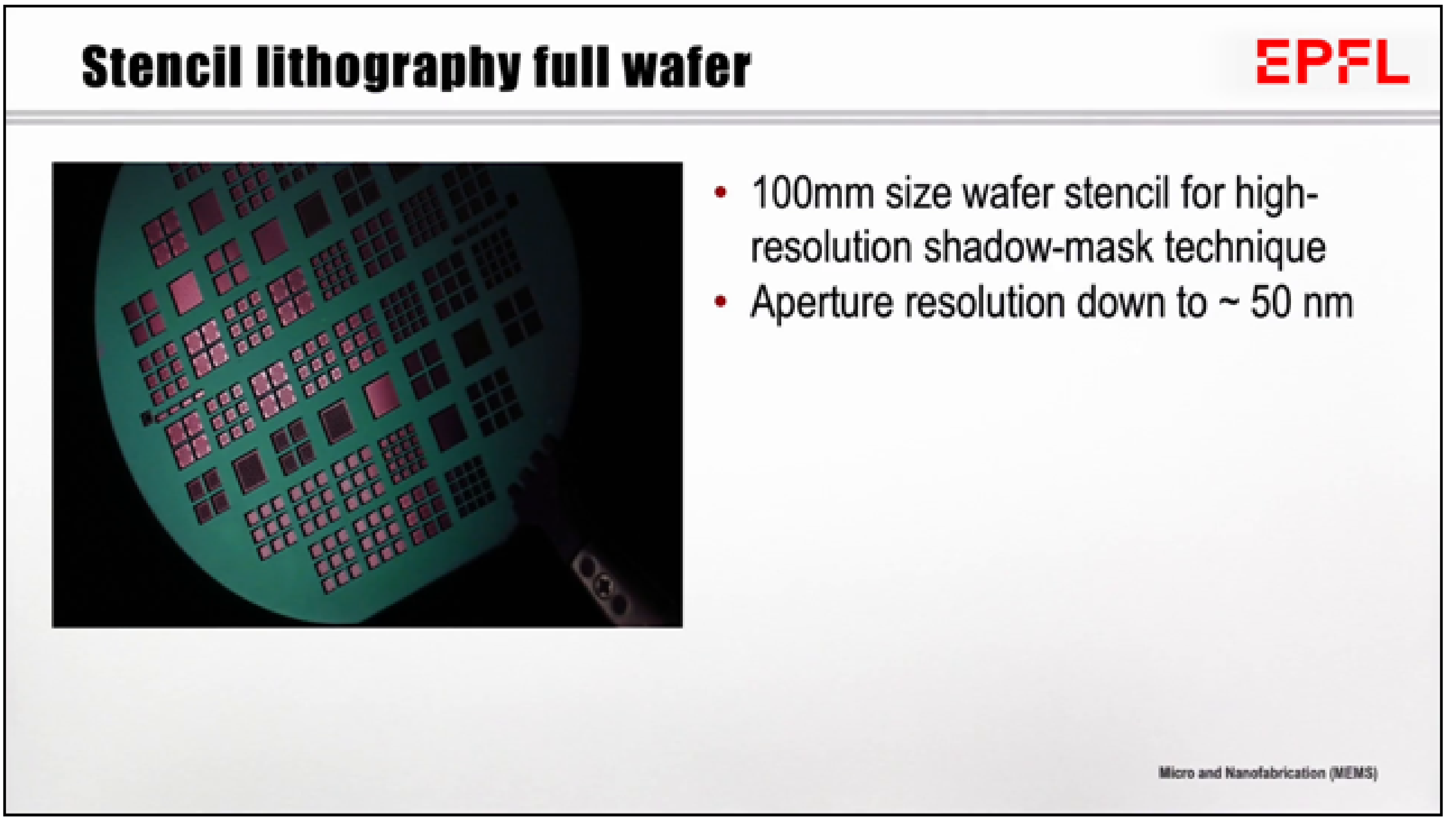
Micro and Nanofabrication (MEMS)

Stencil lithography is a convenient way to directly fabricate nano wires and their contact pads. For this, a so-called "dog bone geometry" is often used as shown here on the left side. PVD of a conducting thin film material directly creates the nano wire without any additional process steps such as developing and baking. Thus reducing the risk of contamination, which may affect the electronic transfer property in the nano structure. It does allow studying new materials for this type of devices without the need for electron beam lithography for the final step. Here on this photo we can see an SEM of a stencil with the nanowire slit and the two openings for the contact pad and the corresponding metallic nano wire, shown here with the bigger contact pads that can then be interfaced with some probe systems.

notes

summary

11m 13s

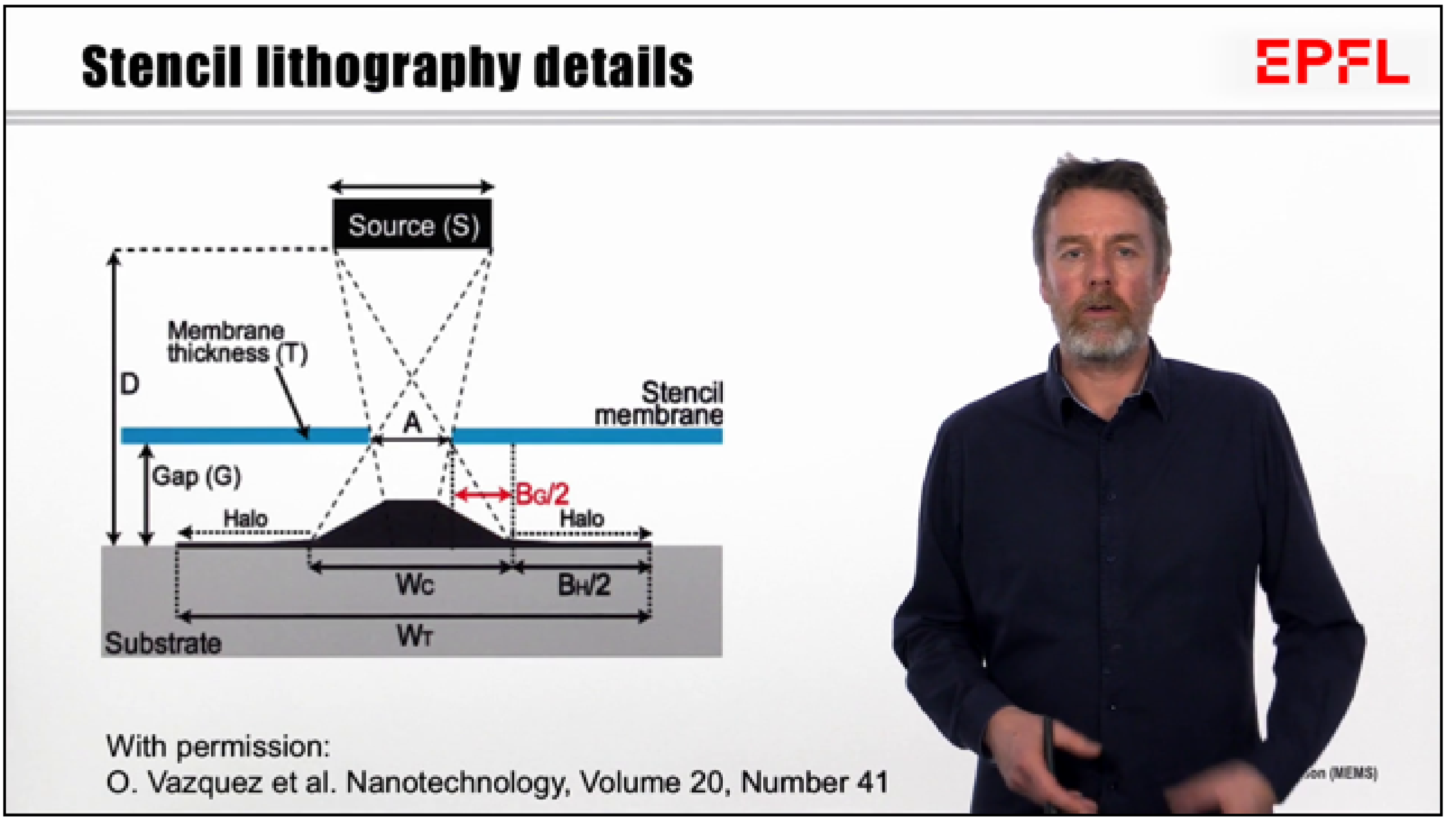


And here is a typical resistivity curve of a metallic nanowire as a function of the cross section, anti-length.

notes

summary

12m 13s

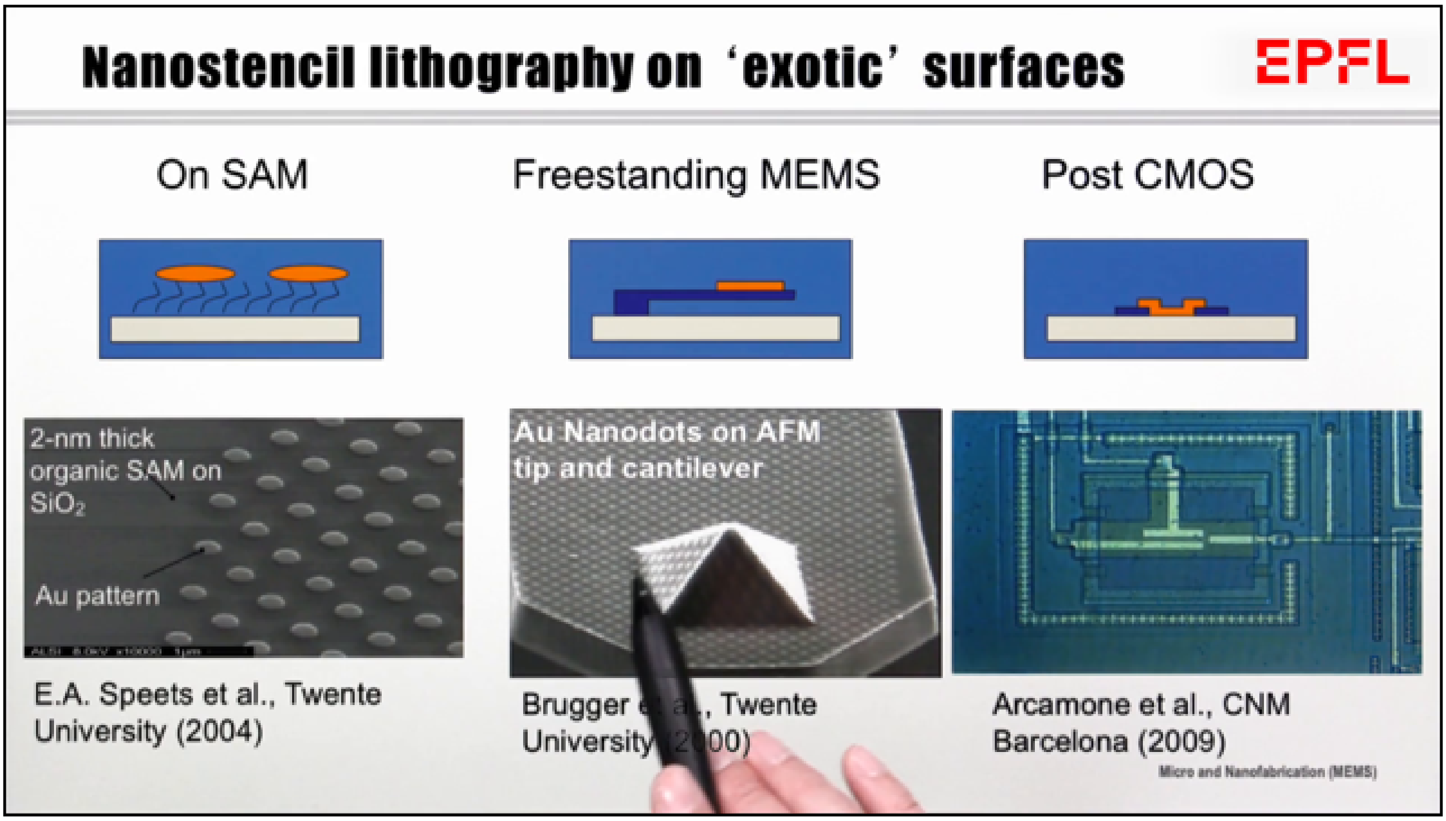


Stencils are fabricated by UV or e-beam lithography and aperture etching in a very thin silicon-nitrite membrane. Shown here, in red-ish. This image shows a 100mm sized wafer stencil containing hundreds and thousands of micro nano apertures. Such stencils can be reused many times. Challenges are the stencil's mechanical robustness, aperture clogging, and membrane stress issues, as well as alignment overlay. Please have a look at the accompanying references for more details.

notes

summary

12m 24s

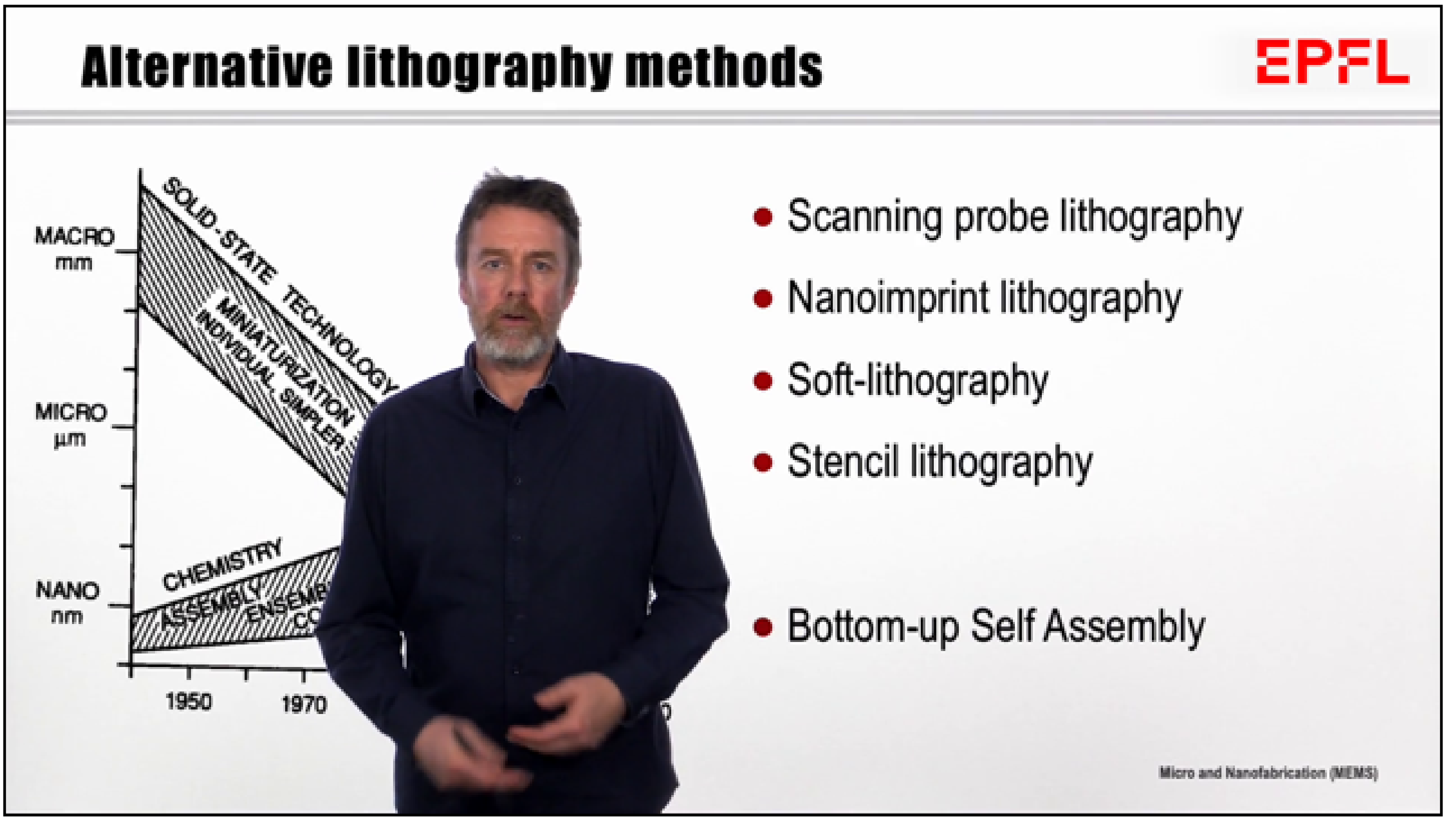


For creating small structures with sharp edges, the best deposition method is the physical vapor deposition technique, which has a long mean free path, such as thermal, or e-beam evaporation which occurs, as we remember, in high vacuum. This figure shows the geometry during the stencil lithography with the dimensions and locations of the source, the stencil apertures, shown here, and the substrate. Assuming line of sight deposition, straight lines, one can predict very precisely the pattern as a function of the various parameters. Another contribution to the pattern widening is not only geometry, but also the surface diffusion of the arriving thermal atoms. From this observation it becomes obvious that highest resolution can be achieved by placing the stencil very close to the substrate, and by placing the emission source as far away as possible. Stencil lithography is not meant to replace conventional lithography, but it has some attractive assets for particular cases, as summarized here. In all these cases, normal lithography in fact is not possible. The left image shows how sub micrometer gold dots can be deposited directly on organic, self-assembled monolayers on a SiO2 substrate, which is an important layer for organic electronic devices. These are the gold dots directly on the SAM patterned through the openings of a stencil. The middle example shows nano structures directly deposited on freestanding MEMS cantilevers which is otherwise difficult, if not impossible, to pattern because resist coating on a freestanding mechanical device is hard to realize or impossible to make. Here, one can see gold nano dots deposited on an AFM cantilever and the AFM tip.

notes

summary

12m 59s



The right example shows stencil nano structures that are directly and locally deposited onto a CMOS circuit without the need for resist chemistry and temperature steps. This allows for post-processing highly sophisticated CMOS circuitry by locally adding metallic or other material nano structures. This concludes this chapter on alternative and emerging lithography. We have seen direct writing using scanning probes and the replication using soft stamps, nano imprint stamps and vacuum stencils. Please note that all these methods are so-called "top down patterning". They are approaching the length scale of resolution in the order of 10 nanometers to overlap with so-called "bottom-up self assembly" where molecules and nano particles are using natural forces for creating ordered structures.

notes

summary

15m 15s