Course material

Course:

Micro and Nanofabrication (MEMS)

Video:

4.6 Lithography 3

Concepts (extracted from automatically generated subtitles):

Limit of resolution. Details of uv lithography. Uv light. Different mask. High resolution. Exposure dose of uv light. Minimum feature size. Important part. Phase shift mask. Most widespread lithography technique. Large wafers. Only difference. Numerical aperture. Best resolution. Chrome mask.

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

to video

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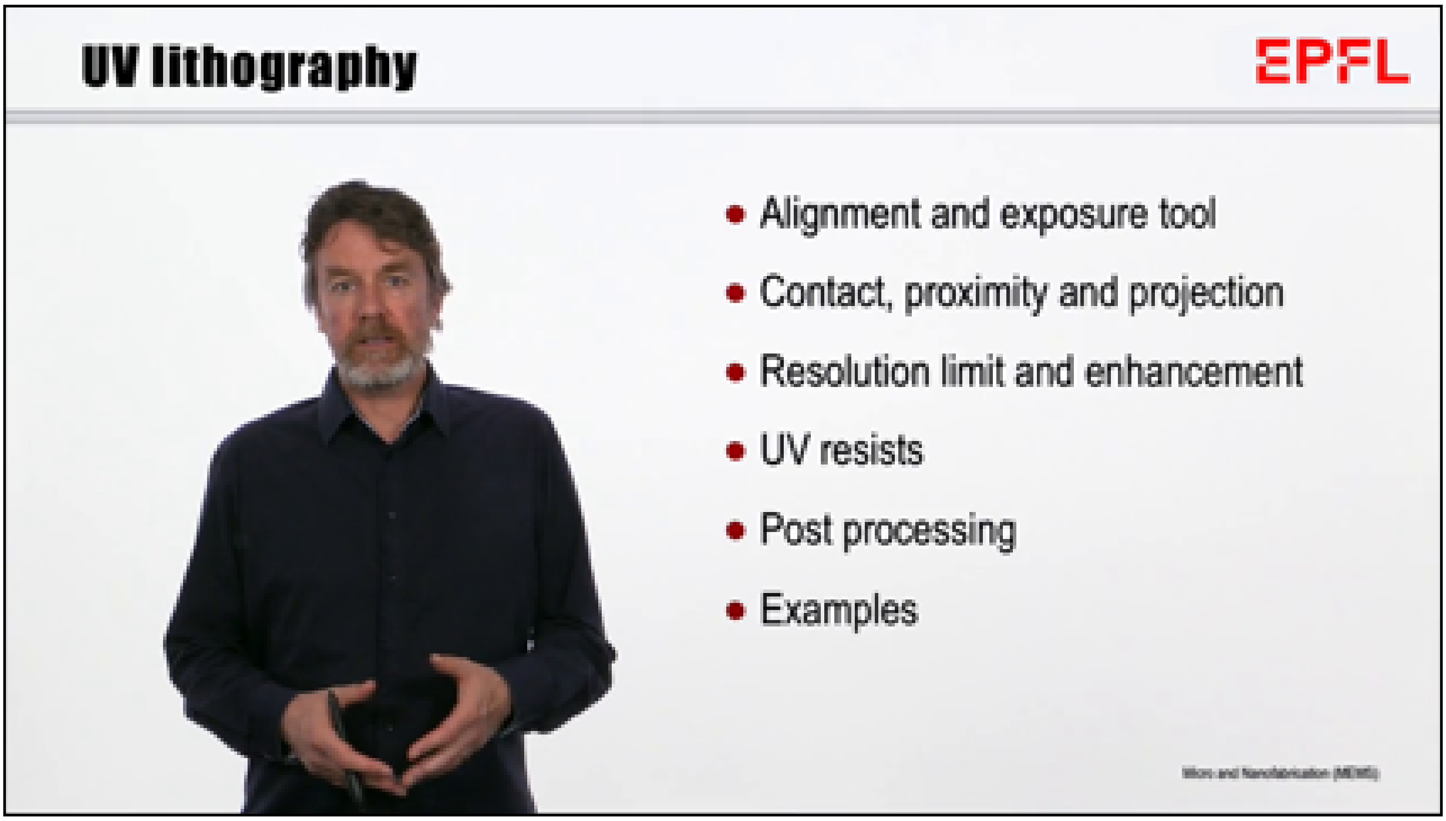
notes

summary

0m 0s

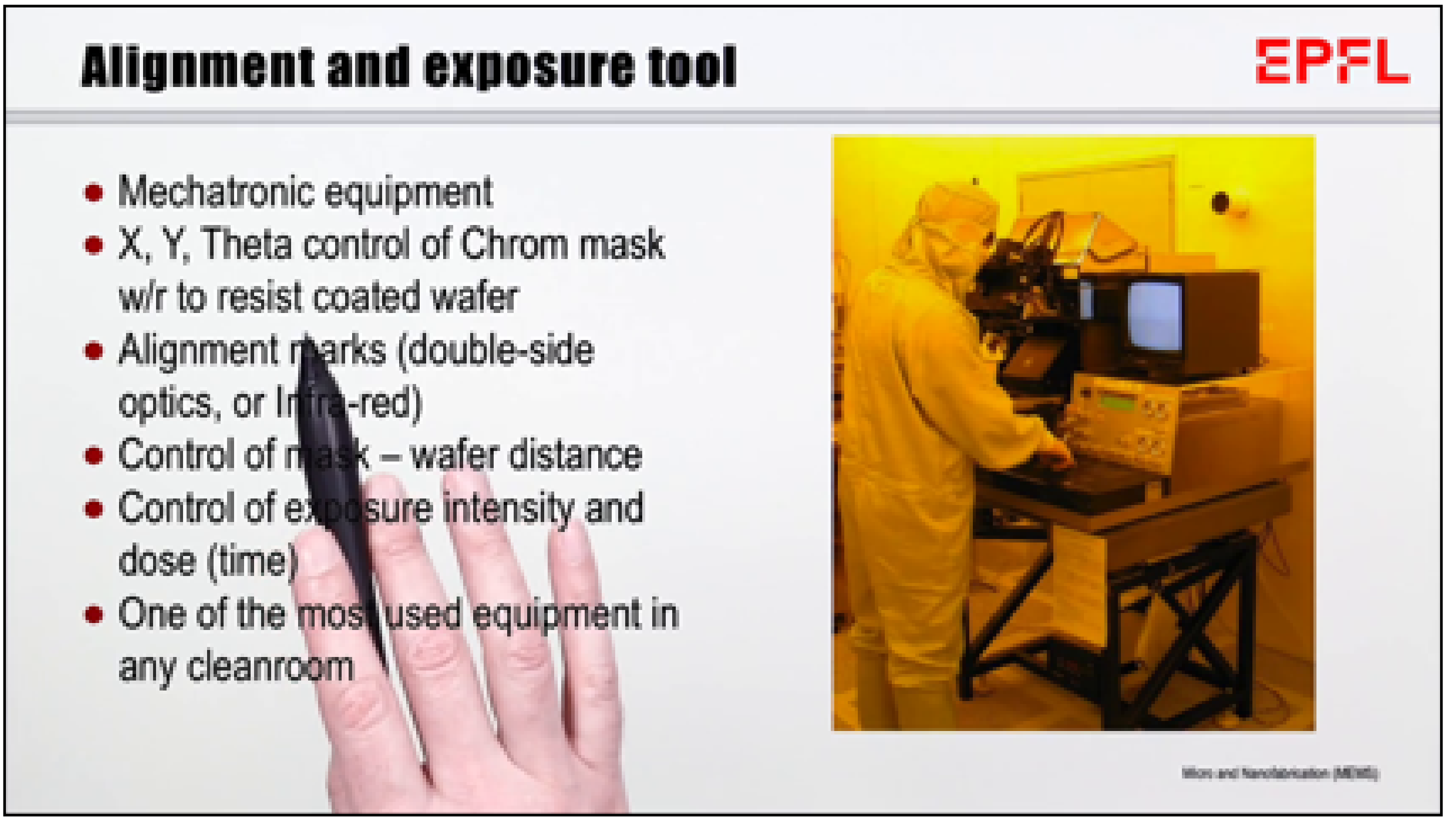


This lesson will now focus

notes

summary

0m 1s

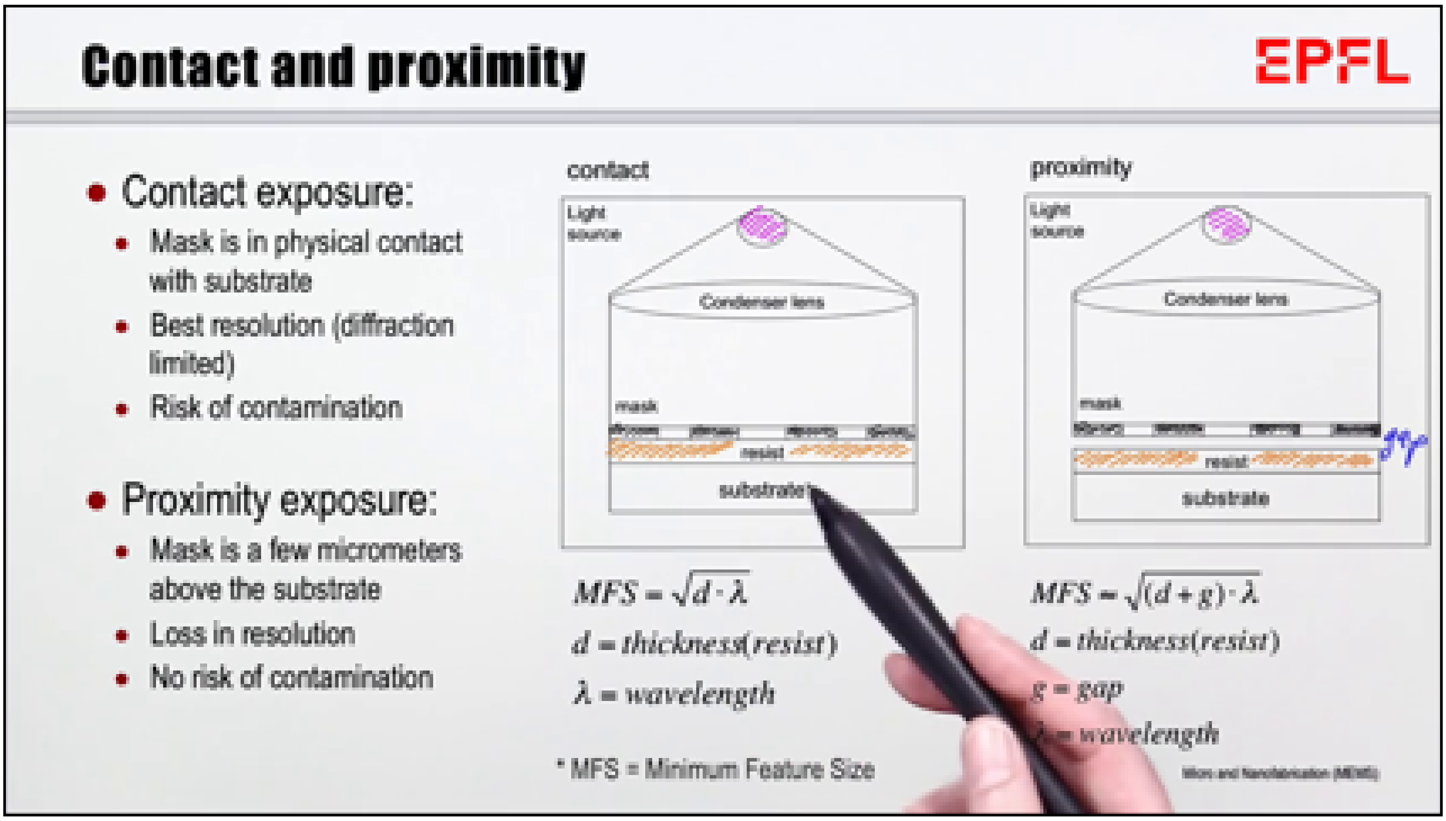


on the details of UV lithography which is the most widespread lithography technique in microfabrication. It uses UV light as exposure which allows patterning devices at the micrometer scale and on large wafers in a few seconds. I will talk about the tool that allows us to align wafers to masks and to control the exposure dose of UV light. Then I will show the three different mask based illumination systems which are the contact, proximity and projection. Then I will recall the limit of resolution and what can be done to enhance it. I show some typical UV resists along with their post processing capabilities and will conclude with some examples. In the previous lesson we have seen how to write the Chrome mask by direct laser writer. We are now using such a mask for the UV lithography. For this purpose we rely on a so called mask aligner shown here, which is a mechatronic equipment that allows the positioning of the wafer with respect to the mask. By means of alignment marks on both the mask and the wafer one can use the microscope and X, Y, Theta stages to align

notes

summary

0m 5s

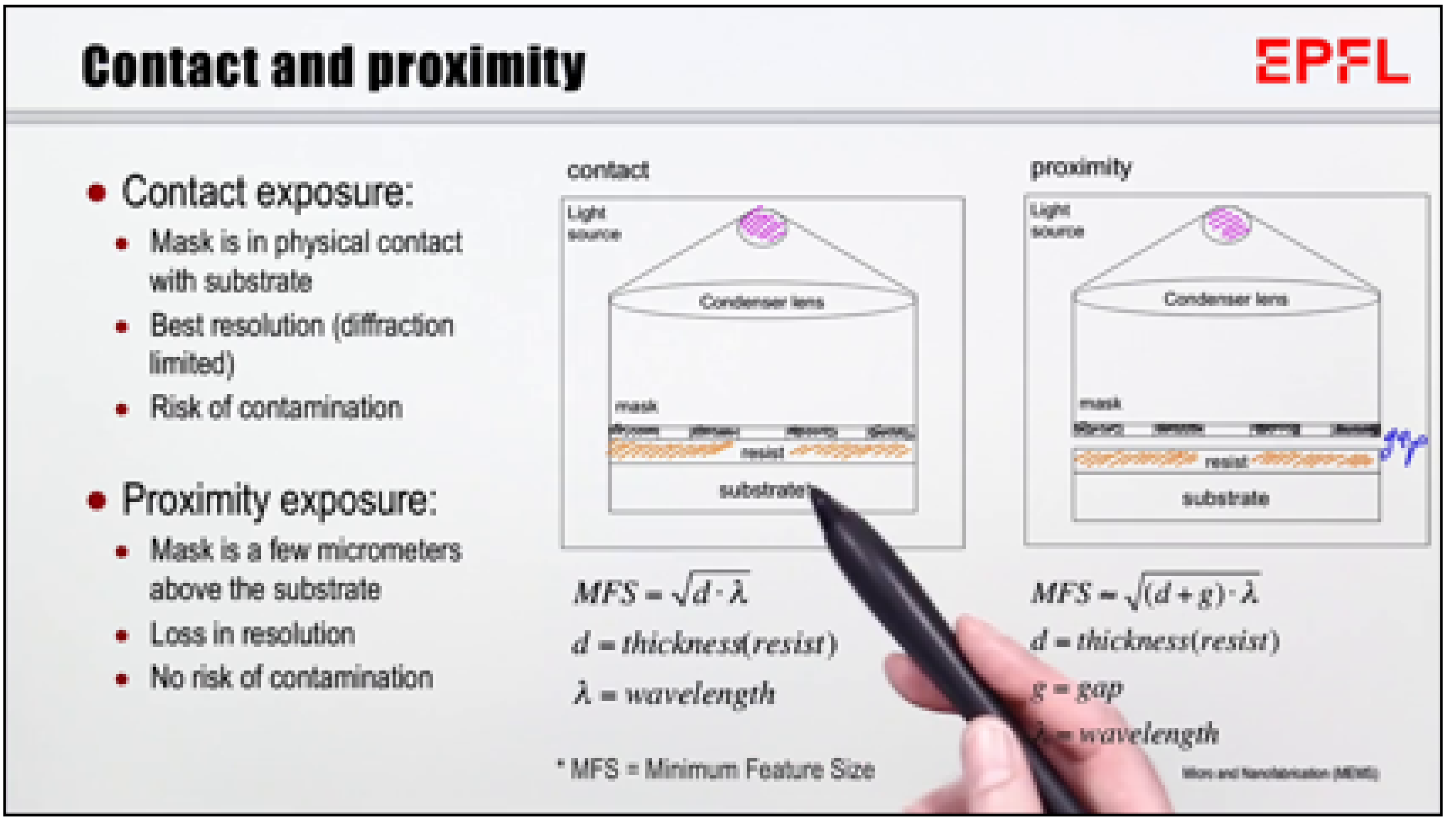


for multiple layer fabrication. This can be done in UV systems at a resolution of about one micrometer. Some tools also allow for back-side alignment which is important for MEMS processing when micromachining of both side of the wafer is needed. The tool allows furthermore controlling the distance between the mask and the wafer for either contact or proximity printing. It then allows for controlling the exposure dose and lamp intensity which will ultimately define the dose on the resist. It is needless to say that such equipment is one of the most used in any clean room around the world. The picture here shows the UV mask aligner in our clean room in the yellow light for the lithography section. Two modes of exposure exist for the one to one mask UV lithography, contact and proximity. The only difference between the two modes in fact is that there's either no gap between the mask and the resist or a well-controlled gap drawn here between the mask and the resist. This gap is in the order of a couple of micrometers. Contact exposure yields the best resolution but it may suffer from issues such as mask contamination mask sticking and substrate damage. The minimum feature size called MFS that one can estimate for contact exposure can be expressed roughly by the expression shown here which is thickness d, the wavelength of the light being used, in the square root of the product of the two. To avoid these problems mentioned here in contact mode one can lift the mask a little bit from the wafer and then perform the exposure in this so-called proximity mode. In this case we lose resolution and the minimum feature size can be expressed now by this equation as before, wherever you have to add the gap that has been introduced between the resist and the mask. Again, d is the thickness of the resist

notes

summary

1m 14s



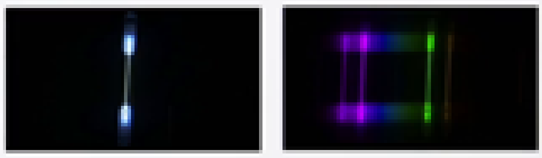
the gap (g) and the wavelength of the light source. If one requires high resolution in the order of one micrometer then one chooses the contact mode.

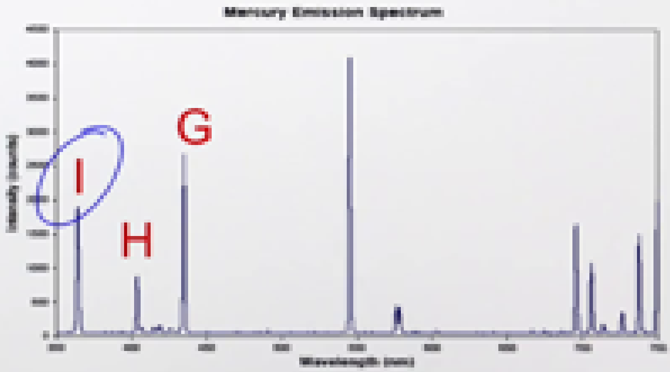
notes

summary

Exposure wavelength and light sources

Wavelength [nm]	Source	Range
436	Hg arc lamp	G-line
405	Hg arc lamp	H-line
365	Hg arc lamp	I-line
248	Hg/Xe arc lamp, KrF excimer laser	Deep UV (DUV)
193	ArF excimer laser	DUV
157	F2 laser	Vacuum UV (VUV)
~ 10	Laser-produces plasma sources	Extreme UV (EUV)
~ 1	X-ray tube, syncrotonon	X-Ray





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If one is happy with the 5 or 10 micrometer resolution one can relax the conditions and work in the proximity mode which preserves the masks and the resist better. One important part in the UV exposure tool is the light source. In fact it is the source that emits the energy of the radiation to expose the resists. We can see here a table that gives an overview of different light sources and what physically is actually behind the light emission, starting from the macro lamp with the different lines and wavelengths. You'll also see the sources for the deep UV, Extreme UV and X-ray lithography. Deep UVs are the industry standard for CMOS whereas EUV and X-ray are future options. Here you can see the light coming out from a Mercury Arc lamp and then separating the radiation into its spectral distribution, we can see the different colors with the, I, H and G lines respectively. For most microfabrication one uses the well-known I line at 365 nanometers.

notes

summary

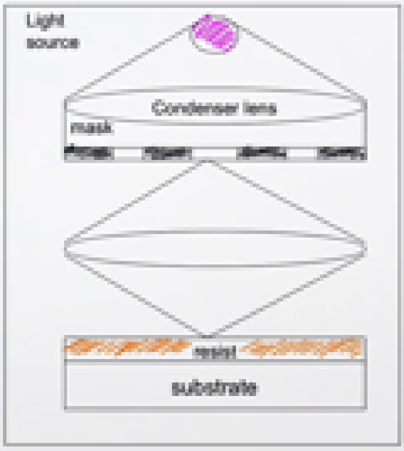
3m 37s

Projection lithography

EPFL

- Mainly used today for IC industry
- Picture of the mask is projected
- No contact
- No deterioration
- Excellent resolution (reduction e.g. 4x, 5x)
- Reduction of errors
- Stepper, x-y movement, from field to field

projection



Rayleigh criterion says: MFS=0.61*λ/NA

In microlithography: $MFS=k_1*\lambda/NA$
k_1=technology cte (0.5-0.9)
Non-ideal behavior of equipment
Lens error
Resist processing, shape, etc.

$$MFS = \sqrt{d \cdot \lambda}$$
$$d = thickness(resist)$$
$$\lambda = wavelength$$

* MFS = Minimum Feature Size
NA = Numerical Aperture

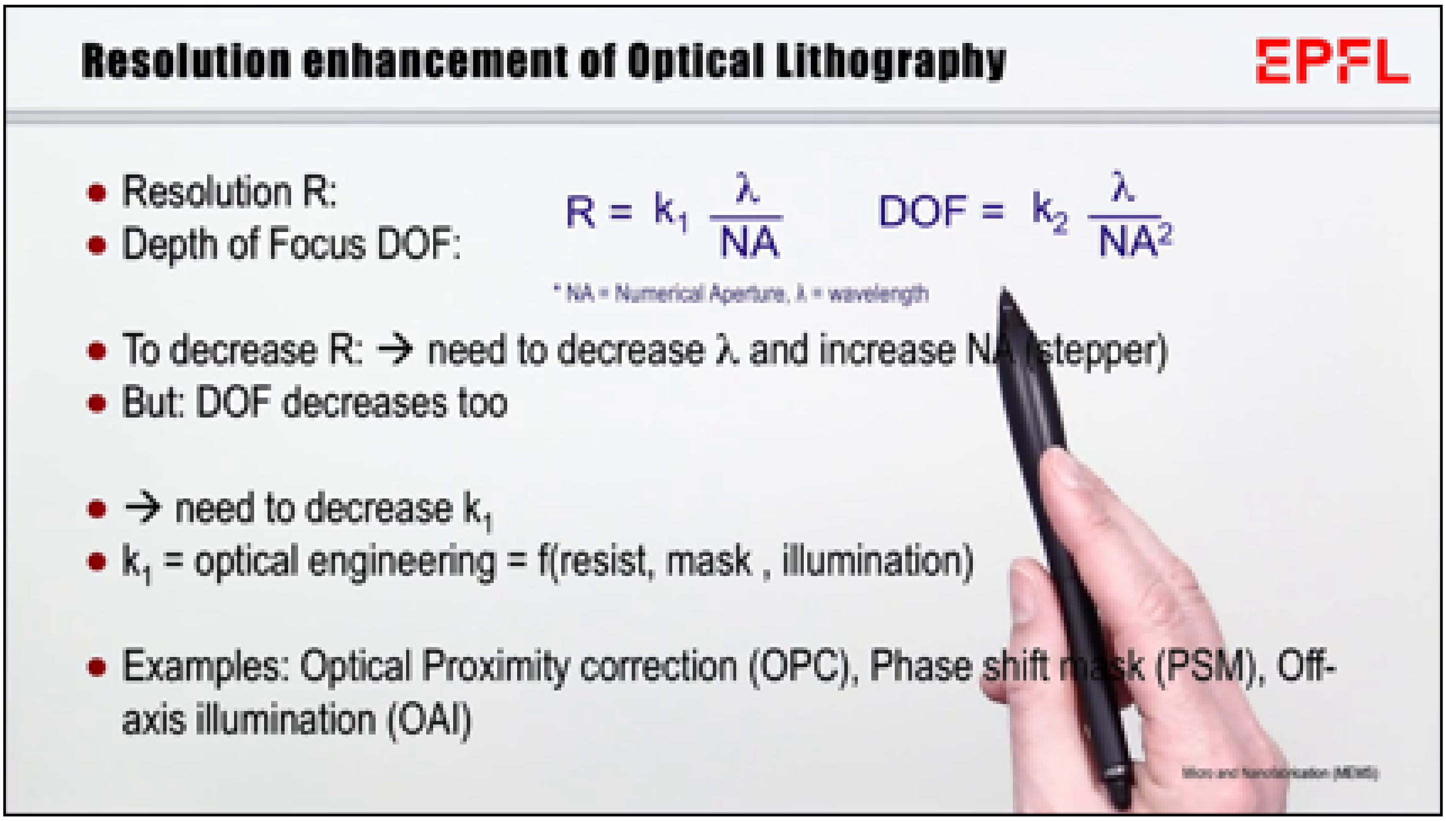
Micro and Nanofabrication (MEMS)

Another important class

notes

summary

4m 49s

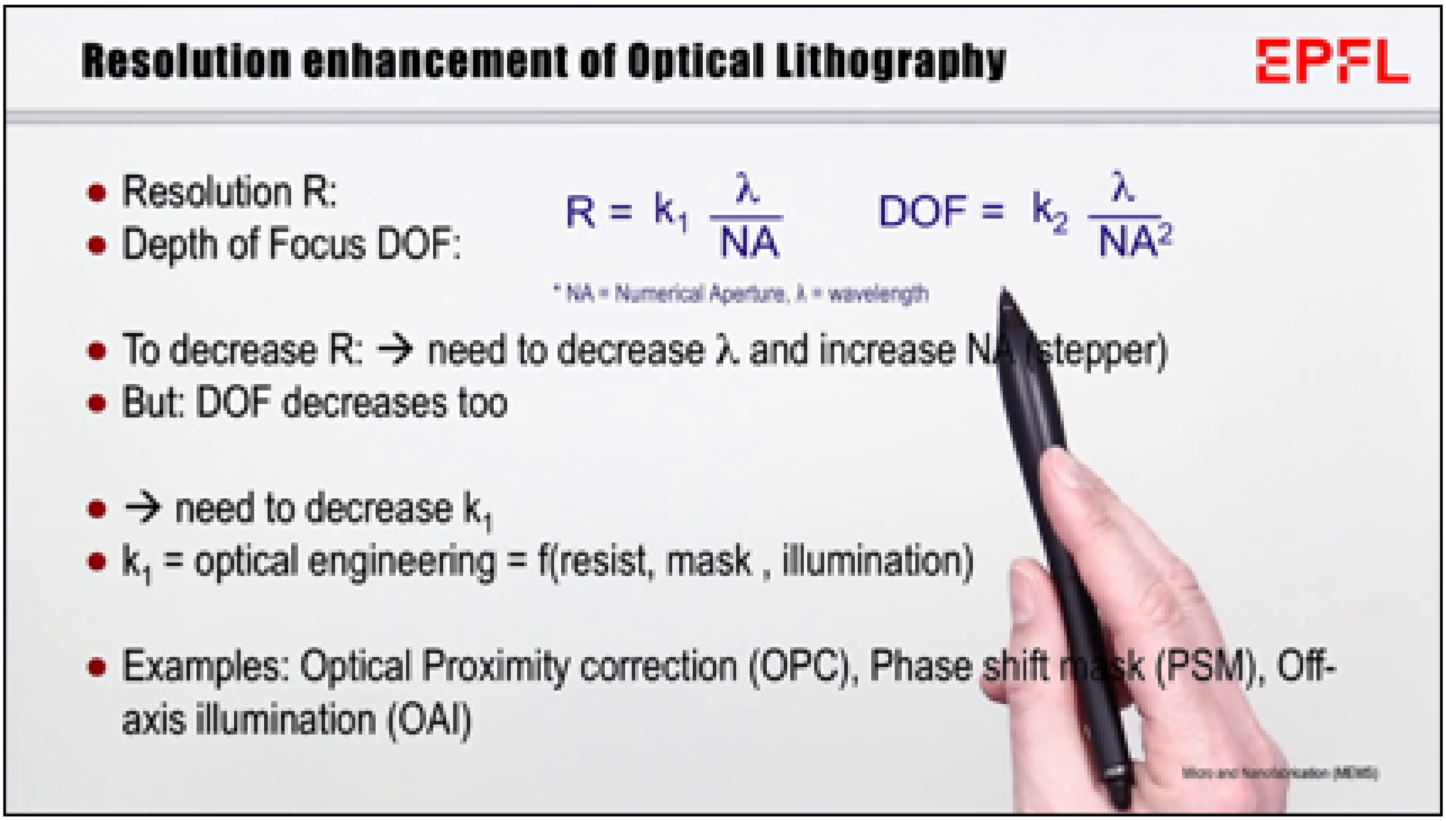


of UV lithography is using projection of a mask via an optical magnification system, 4 or 5X times on to the resist. This is the main technique for deep UV and high end semi-conductor systems and reaching clearly sub 20-nanometer resolution. So here, the picture of the mask is projected by an optical system onto the resist. There's no contact at all when there's no risk of mask deterioration. They are very expensive in fact. The reduction effect not only allows for excellent resolution but also reduces any error in the mask by the same factor. On the down side one cannot expose the entire wafer one to one as shown before but has to take a step and repeat the procedure a couple of times per wafer. The resolution estimate for the minimal feature size is shown here. At this point of the state of the art, the resolution is not anymore given by the pure optical defraction limit as there are additional technological parameters named K1 or later we see also K2 that help enhancing the resolution. These K factors are linked to the non-linear resist chemistry from design optimization, phase shift mask, double exposure, etc., etc. In optical lithography it is not only the resolution that is important but also the depth of focus, DOF, shown here. Why is that? It is because the resist has a non-zero thickness and to expose a sharp image at high resolution for the entire resist thickness we need to have a large DOF. Resolution and DOF are closely linked together by the wavelength, numerical aperture, and then the technological parameters K1 and K2. So we see for example that if we aim to decrease R to get higher resolution we need to decrease the wavelength, lambda and increase numerical aperture in our optical stepper system but then DOF decreases too which is not good. The only way to optimize R

notes

summary

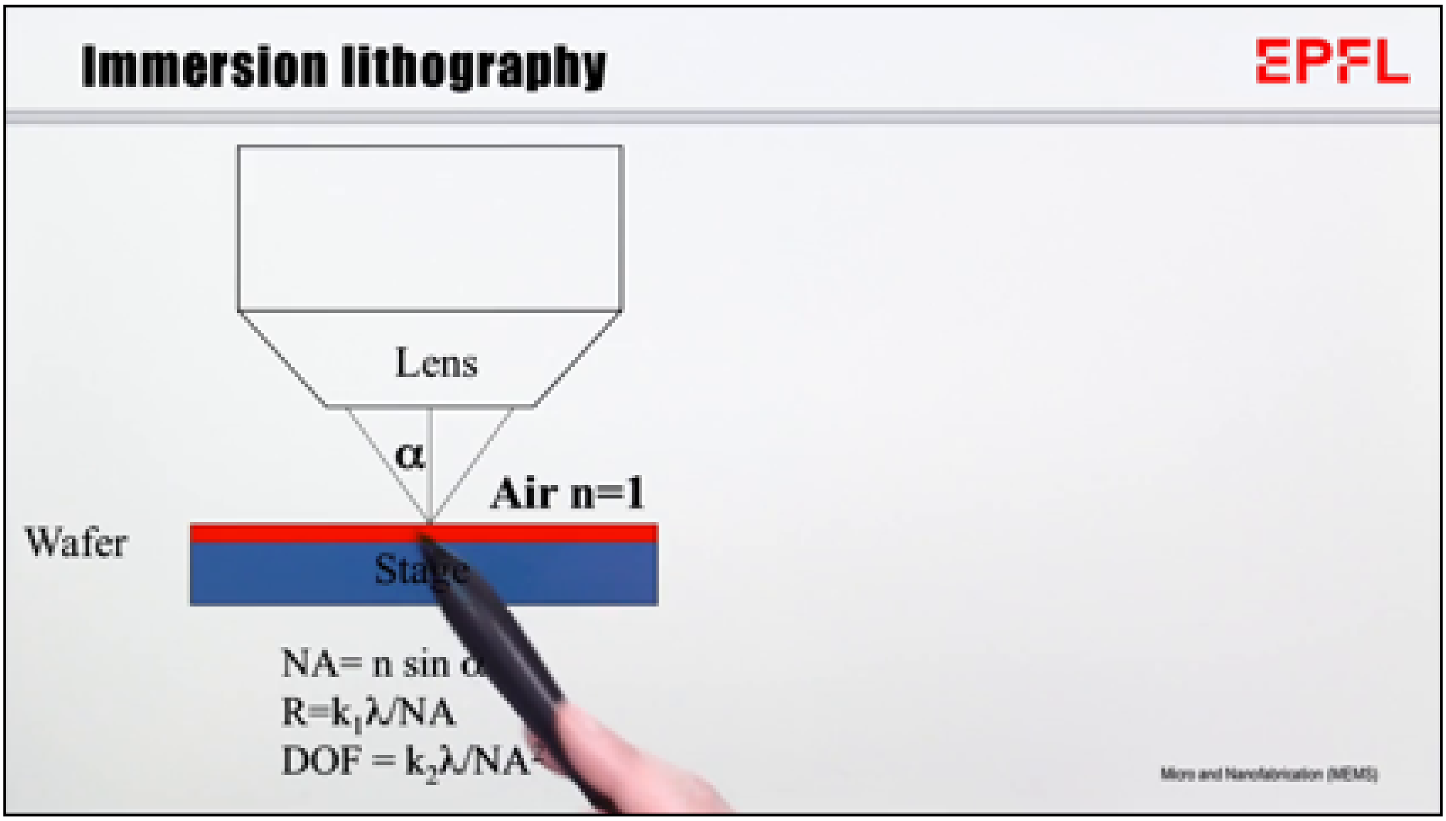
4m 51s



and DOF simultaneously

notes

summary

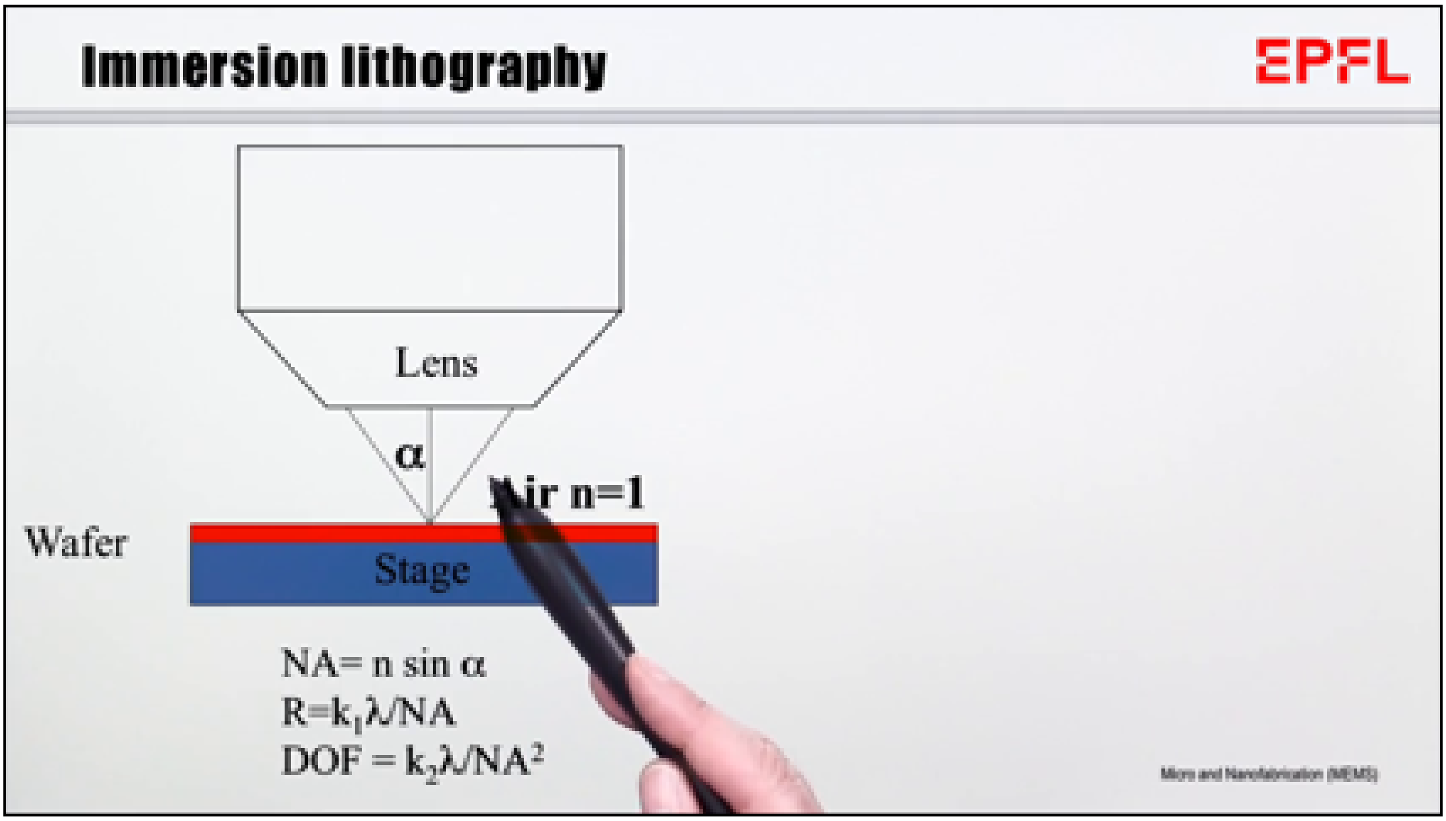


is to work on these parameters K1 and K2. I will show a couple of examples. Normal masks are binary, Glass and Chrome to create transparent and opaque portions. We have seen the modulation transfer function of such a system just before. Phase shift masks are shown here, they are masks that transmit light with the phase shift at some strategic positions in the mask. To this end, we either remove (like shown here) or add some dielectric materials such as quartz, SiO_2 or similar. By creating 180 degree phase shift between two adjacent transparent parts, we create a destructive interference in the E-field of the radiation and thus improve the intensity curve shown here. This allows for creating a sharper image in the resist and ultimately to reach higher resolution. This image shows the end length between the exposure optics and the wafer with the photoresist.

notes

summary

7m 13s



It shows the numerical aperture, NA, and how it is defined

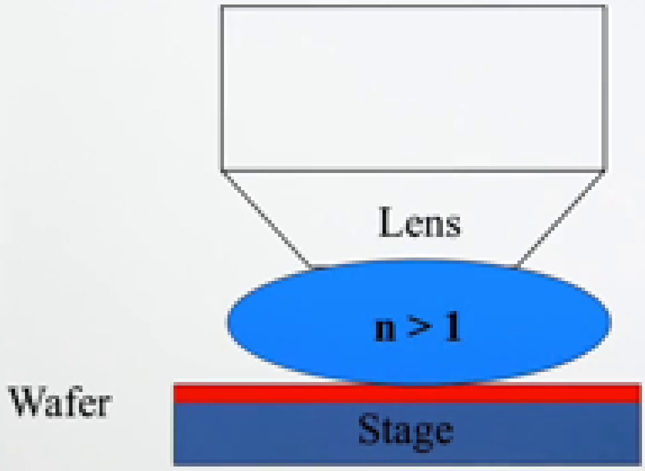
notes

summary

8m 25s

Immersion lithography

EPFL



	Medium	n	λ/n
193 nm dry	Air	1.0	193 nm
193 nm immersion	H_2O	1.44	134 nm
157 nm dry	N_2	1.0	157 nm
157 nm immersion	PFPE	1.37	115 nm

$NA = n \sin \alpha$

$R = k_1 \lambda / NA$

$DOF = k_2 \lambda / NA^2$

$R = k_1 (\lambda / n) / \sin \alpha$

$DOF = k_2 n \lambda / NA^2$

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as the sine alpha times the index of refraction of the medium and the related resolution and DOF values. Immersion lithography is a photo lithography resolution enhancement technique for manufacturing integrated circuits, ICs, that replaces the usual air gap between the final lens and the wafer surface with the liquid medium that has a refractive index greater than one. The resolution is increased by a factor equal to the refractive index of the liquid. Current immersion lithography tools used highly purified water or oil for this liquid, achieving feature sizes needed in current semiconductor manufacturing. In fact, we can see by changing the refractive index one gets another equivalent factor here in the resolution and DOF equation which gives an equivalent shift in the wavelength as a function of the index of refraction.

notes

summary

8m 28s