Course material

Course:

Micro and Nanofabrication (MEMS)

Video:

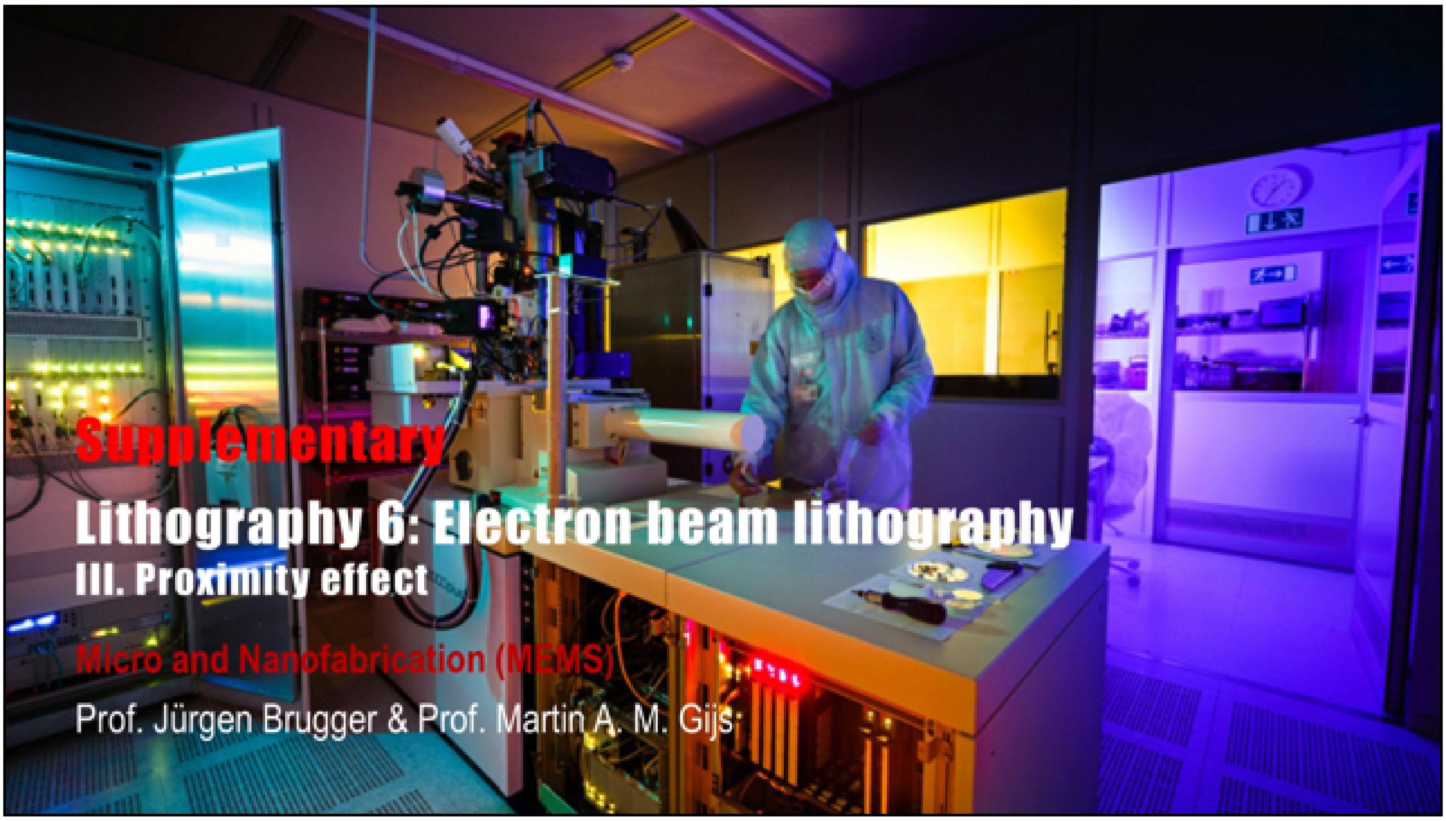
4.14 Lithography 6, Electron beam lithography, III Proximity effect

Concepts (extracted from automatically generated subtitles):

Last parameter eta. Uniform background dose. Large patterns. More detailed look. Proximity effects. Simple dose scaling. Proximity effect corrections. Back scattering range. Base of these corrections. Dose. Pattern density. Effective dose. Gaussian accounts. Alpha parameter. Point spread function.

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

to video

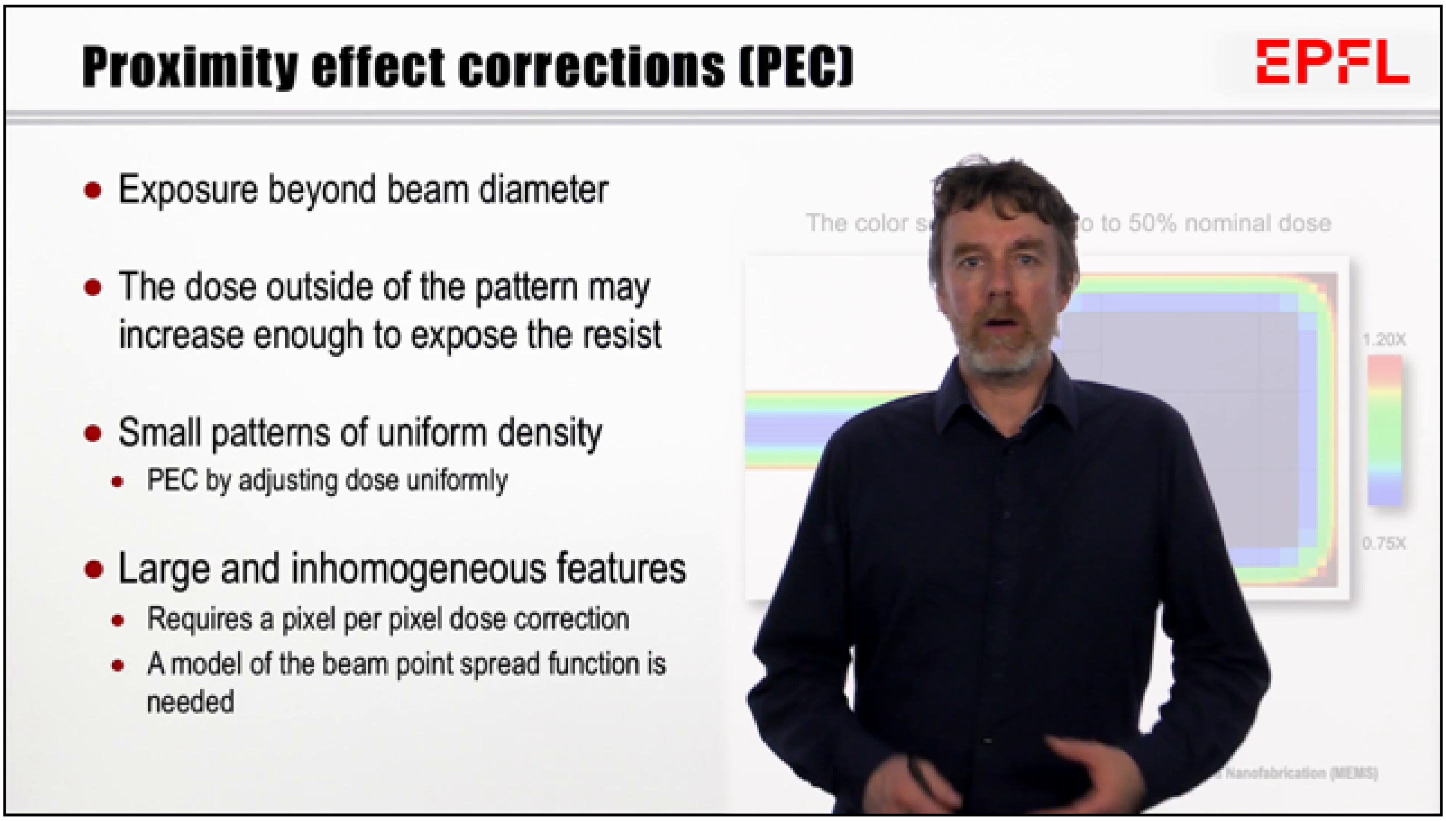


...

notes

summary

0m 0s

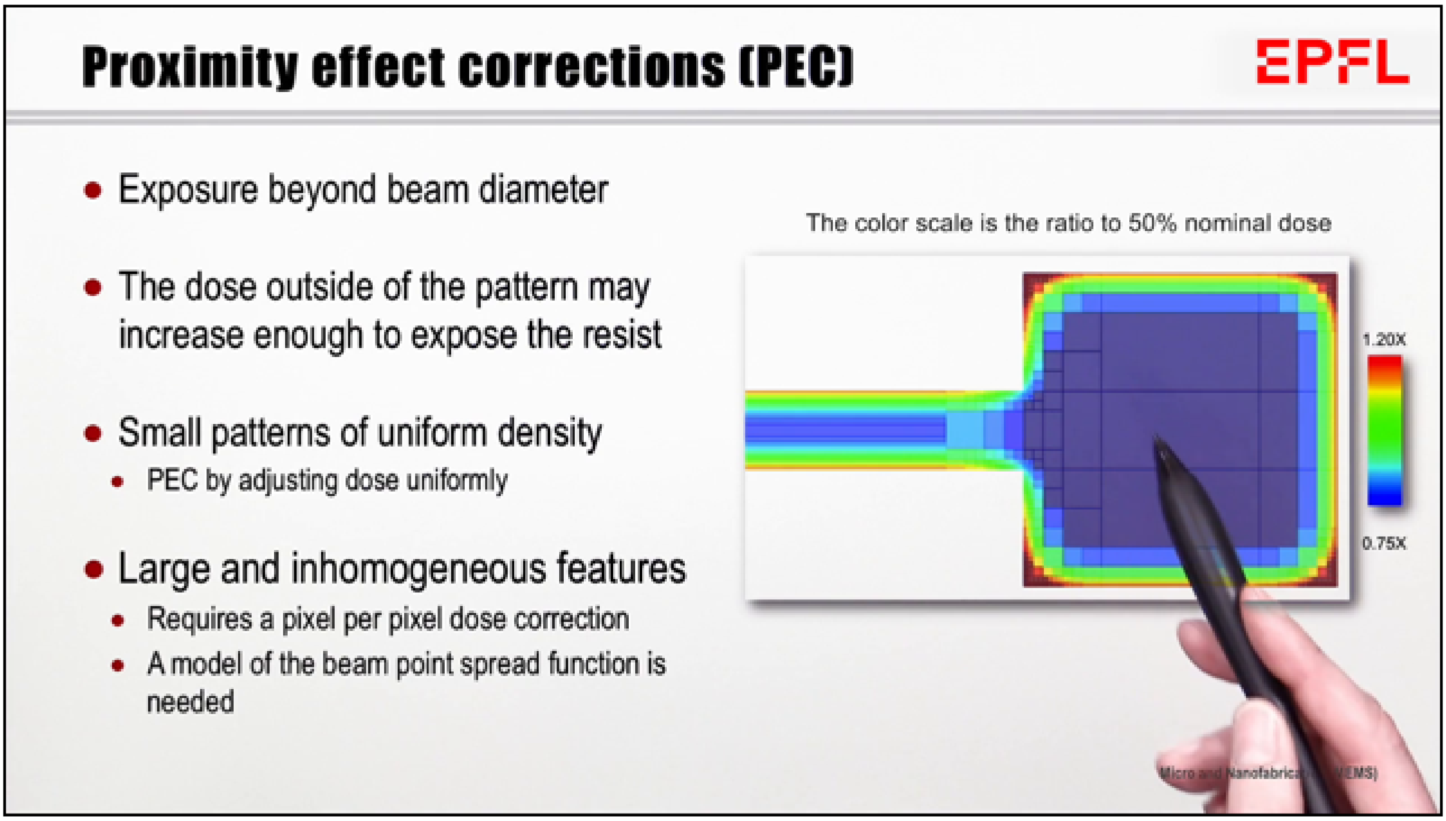


We will now have a more detailed look at the proximity effects that

notes

summary

0m 1s



are at the heart of the electron beam lithography. As exposure occurs beyond the beam diameter and the impact point, the dose outside of the intended area may be sufficient to expose the resist. If the patterns are significantly smaller than the back scattering range, and uniform in density, this will result in a uniform background dose. Therefore, a simple dose scaling is applied to correct for the unwanted proximity effect. For large patterns, or complex geometries, this is more complicated. As seen in the image on the right, for a large pad in the order of 500 µm size and an associated connecting wire of 100µm width, the dose is locally adjusted by proximity effect corrections. One can see for example that the dose in the edges must

notes

summary

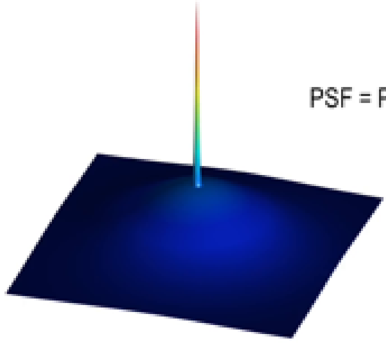
0m 5s

Proximity effect corrections (PEC)

- Input parameters: beam model
  - Double Gaussian approximation: forward and backscattering
    - α: forward scattering parameter
      - Lowered with higher acceleration voltage
      - Dependent on resist thickness
    - β: backscattering parameter
      - Reduced with low Z substrate
      - Increased with higher acceleration voltage
    - η: forward/backscattered energy ratio

$$I(r) = \frac{1}{\pi(1+\eta)}\left(\frac{1}{\alpha^2}e^{-\frac{r^2}{\alpha^2}} + \frac{\eta}{\beta^2}e^{-\frac{r^2}{\beta^2}}\right)$$

Forward scattering | Backscattering



PSF = Point Spread Function

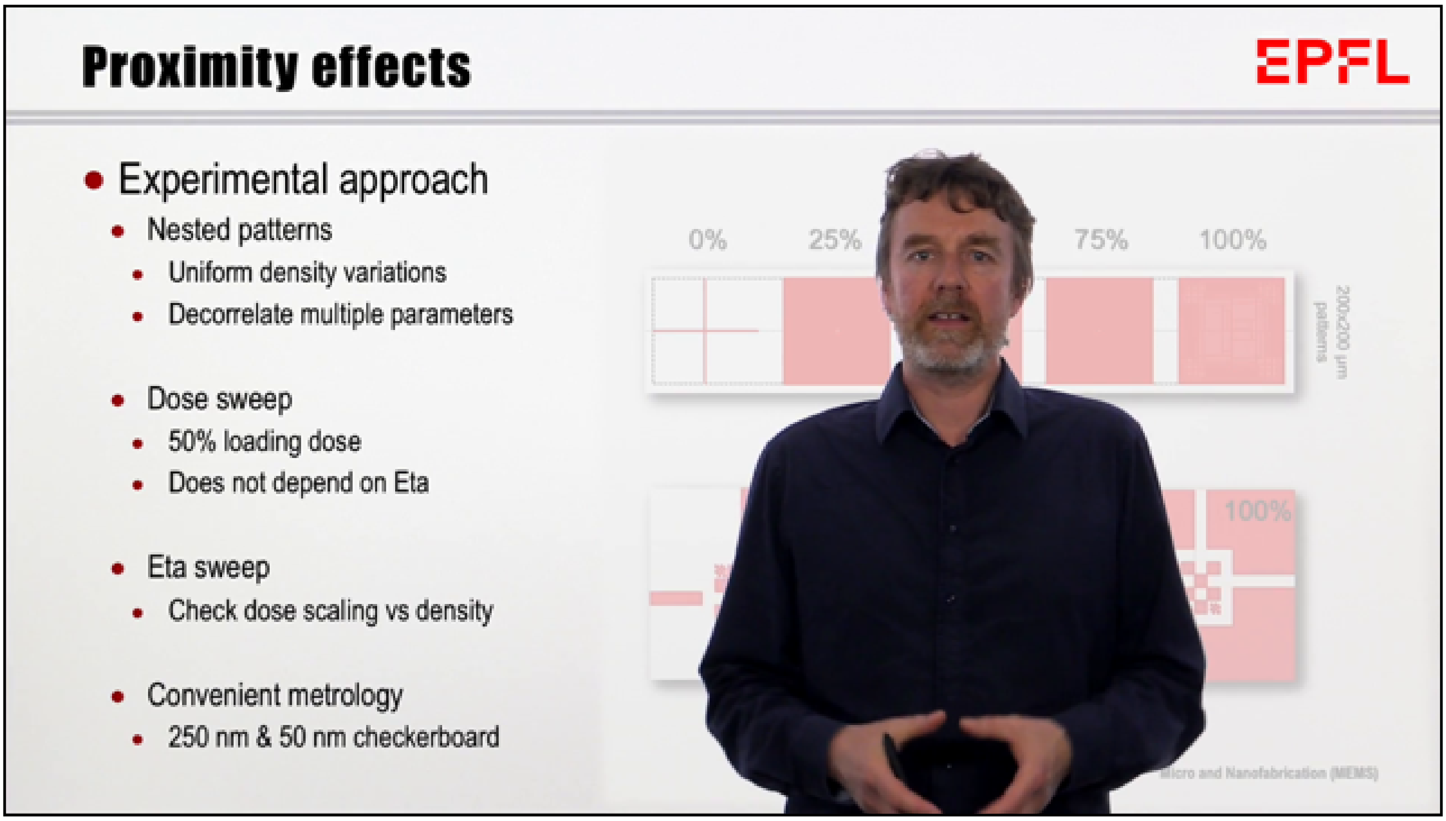
Micro and Nanofabrication (MEMS)

be increased compared to the dose at the center of the square. Red is more dose, blue is less dose. The base of these corrections relies on the modeling of energy distribution away from the beam impact point, which is commonly referred to as the point spread function or PSF. As seen previously, two main effects are responsible for energy distribution in the substrate: forward and backward scattering. The simplest, yet efficient model to approximate the point spread function is therefore a double Gaussian. One Gaussian accounts for forward scattering and depends on the alpha parameter mostly affected by acceleration voltage, and resist thickness. The second Gaussian is defined by beta that accounts for the back scattering that heavily depends on the atomic mass Z of the substrate and acceleration voltage. A last parameter eta modulates the ratio between forward and backward scattering: if eta = 0, this means that there is no back scattering, whereas if eta = 1, it allows for equal weight of both Gaussians in the point spread function. Eta is here, and here.

notes

summary

1m 1s

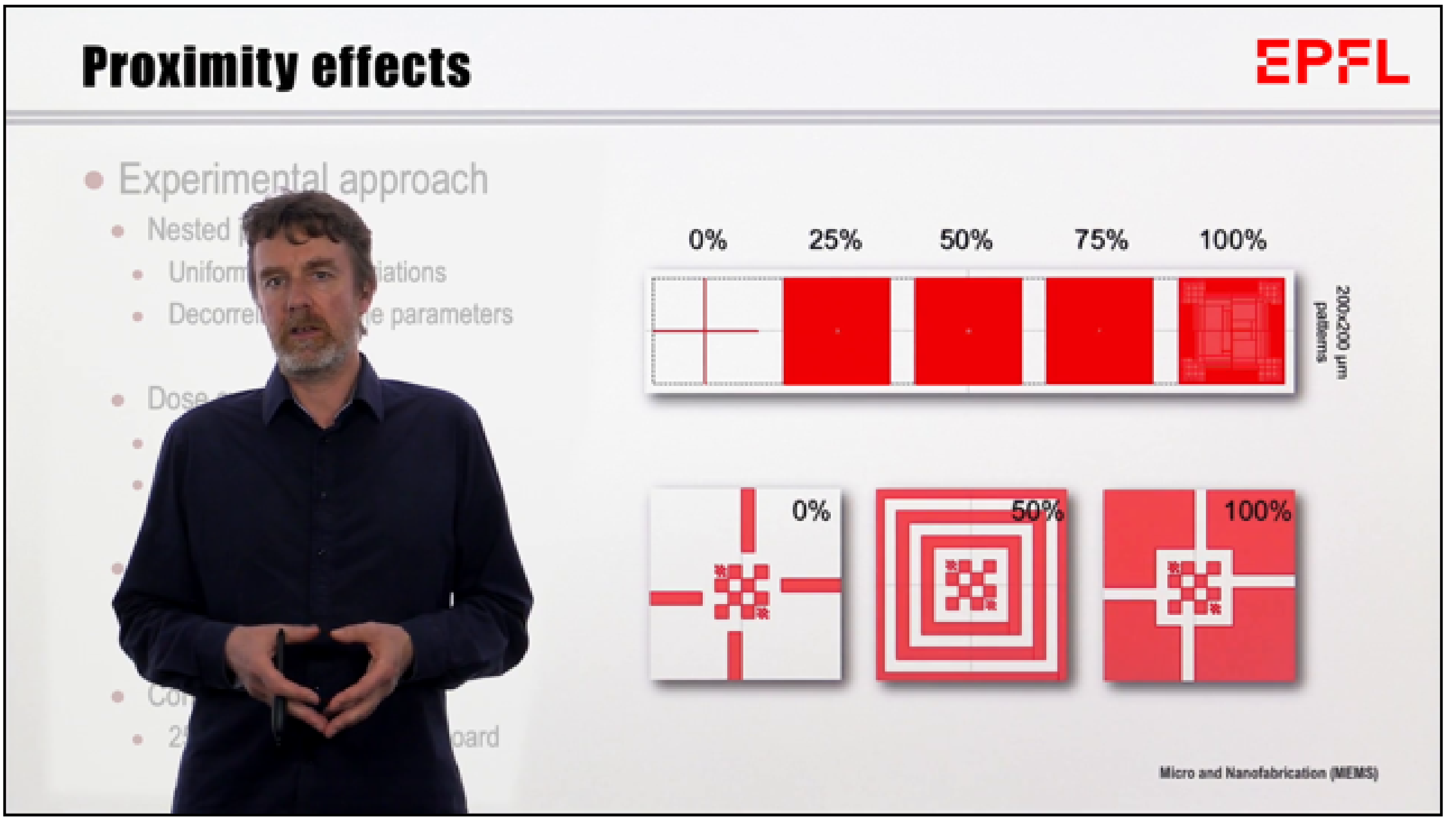


The 3D plot of a double Gaussian system shows well, the sharp center peak here and the broad background distribution of the back scattered electrons.

notes

summary

2m 13s

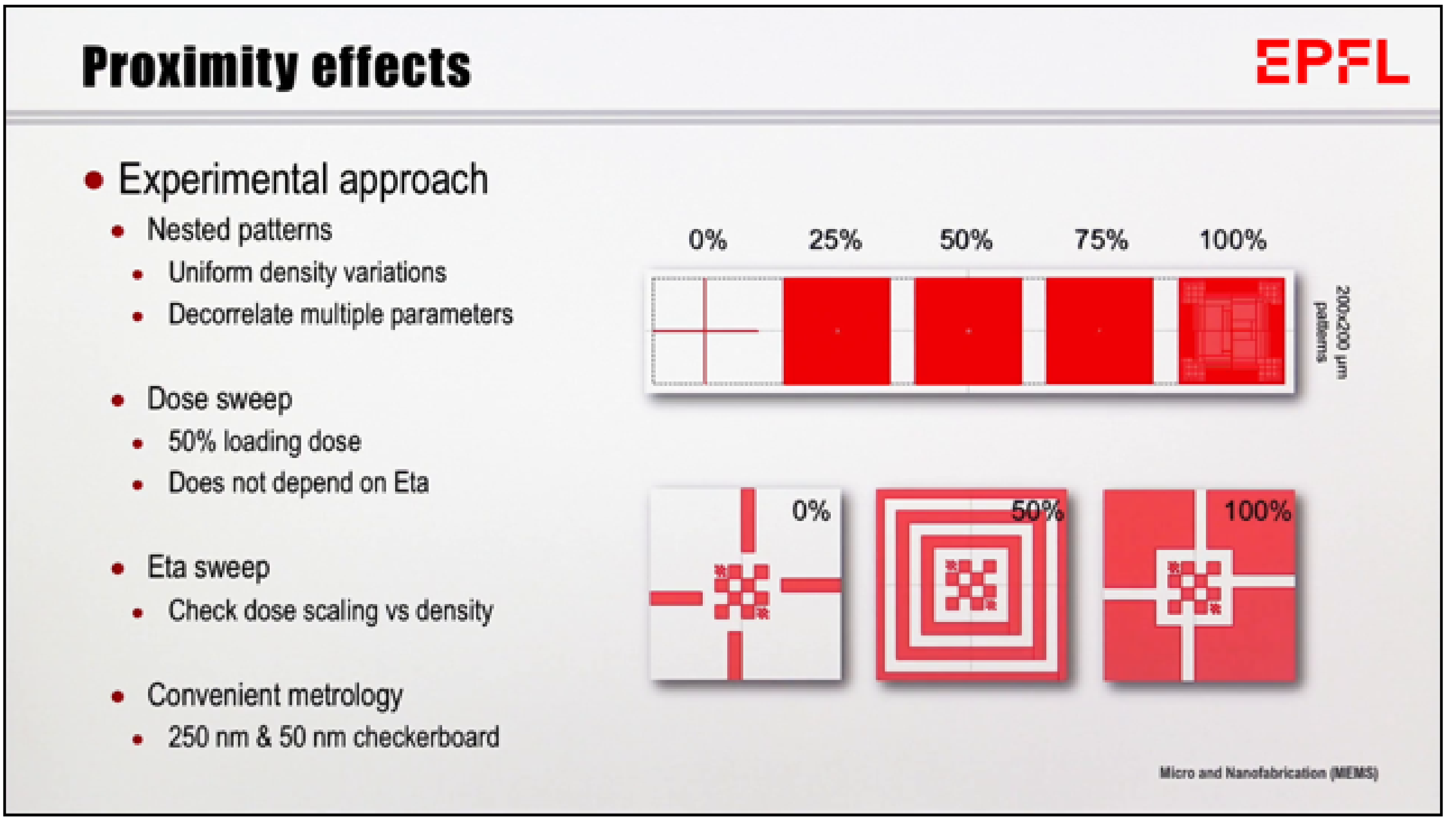


If one can determine experimentally the alpha, beta and eta parameters, one can compute the effective dose delivered at each shot location, taking into account the background exposure from the neighboring pixels. Once this computation is done, the proximity effect correction consists in scaling the dose per pixel to provide a uniform, effective energy delivered on the substrate, regardless of pattern density. In practice, we choose that the 50% density patterns have the nominal base dose and are not scaled, whereas isolated features are corrected to receive a higher dose, while the patterns denser that 50% receive a lower dose. In order to obtain the proper point spread function for double Gaussian approximation, that will allow for the proximity effect corrections, nested structures of different densities are written to isolate the various parameters. While alpha is typically affecting the short range and is difficult

notes

summary

2m 24s

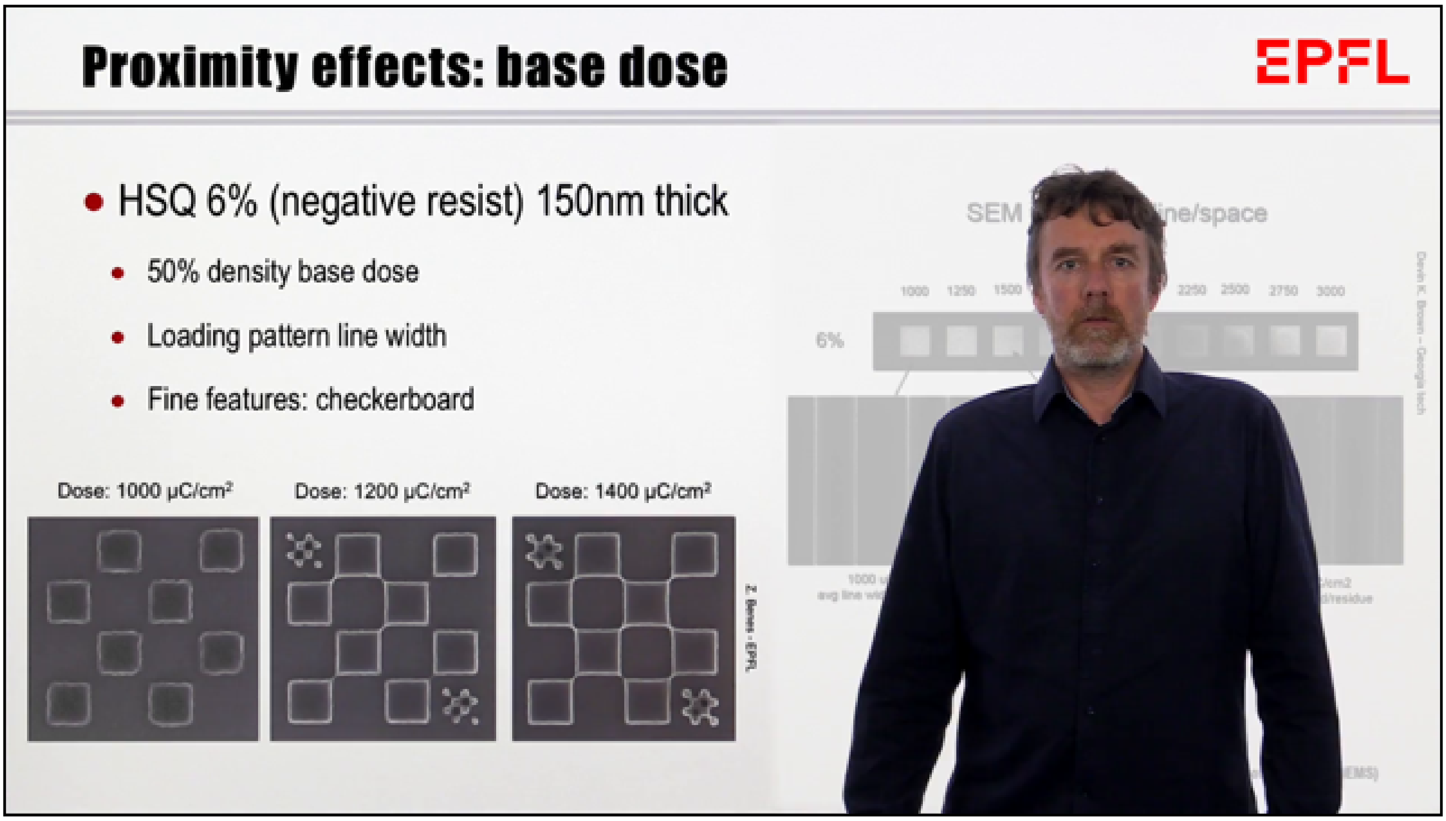


to measure, it is in the range of 10 nm to 20 nm at most, beta and eta are more easily determined experimentally. Using standard substrates such as silicon or silicon dioxide on silicon, large amounts of experimental values for beta are available. Different methods allow determining beta experimentally. Here we will focus on eta, because it largely depends on the resist type and can therefore vary widely. The test patterns used our checkerboards, like shown here, the 250 nm squares and 50 nm squares, that provide a good basis for the measurement of critical dimensions. They are surrounded by periodic patterns of varying density with an extent greater than the back scattering range in order to reproduce different background conditions. So this checkerboard is surrounded by zero patterns around, this one is completely filled 100% with writing area and this is a 50% writing area coverage around the checkerboard test pattern. Knowing alpha and beta from literature, the user will run software

notes

summary

3m 25s

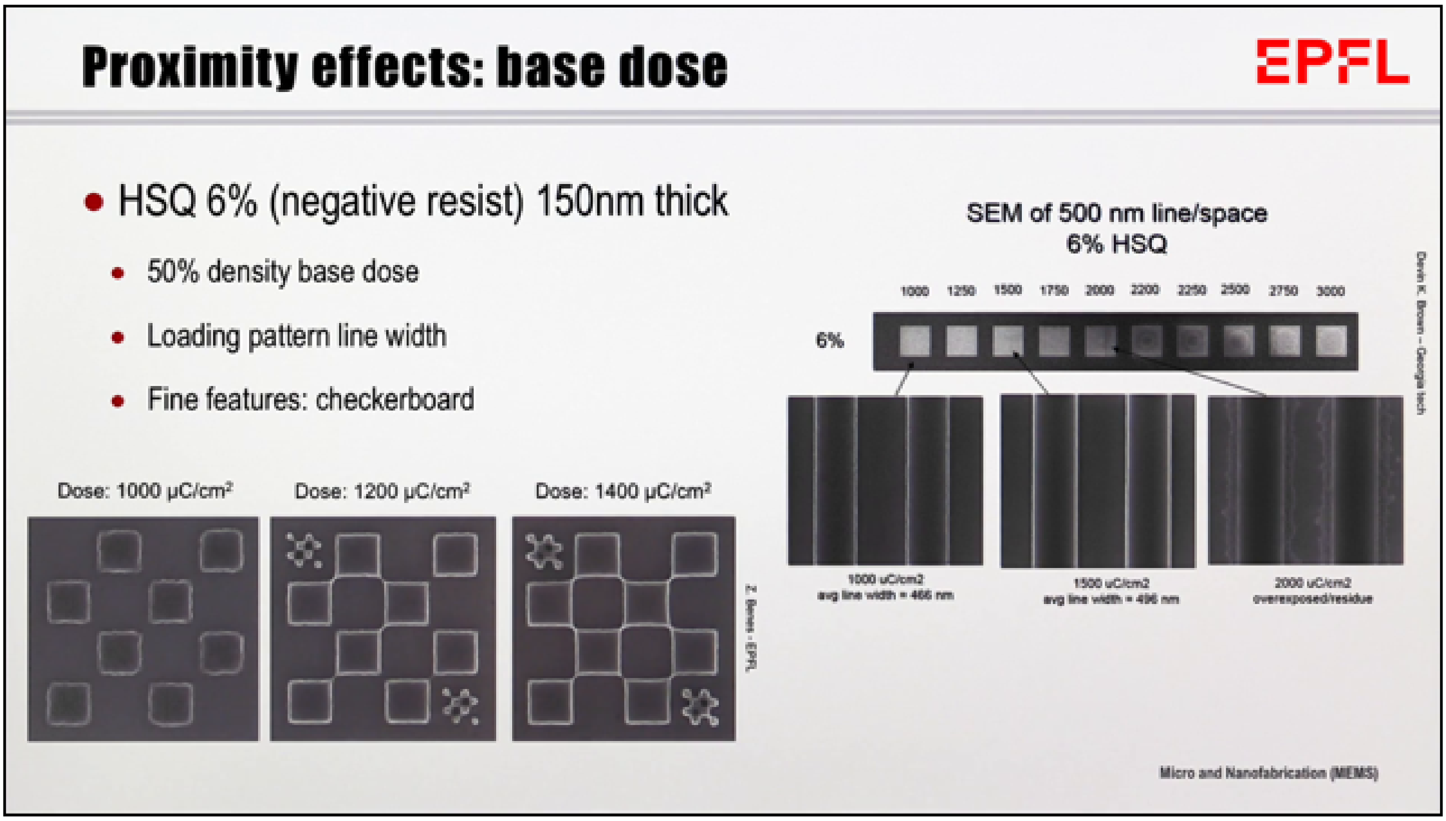


proximity effect corrections on these patterns for a wide range of eta and will write the patterns for different doses to perform metrology and identify optical proximity effect correction conditions.

notes

summary

4m 37s

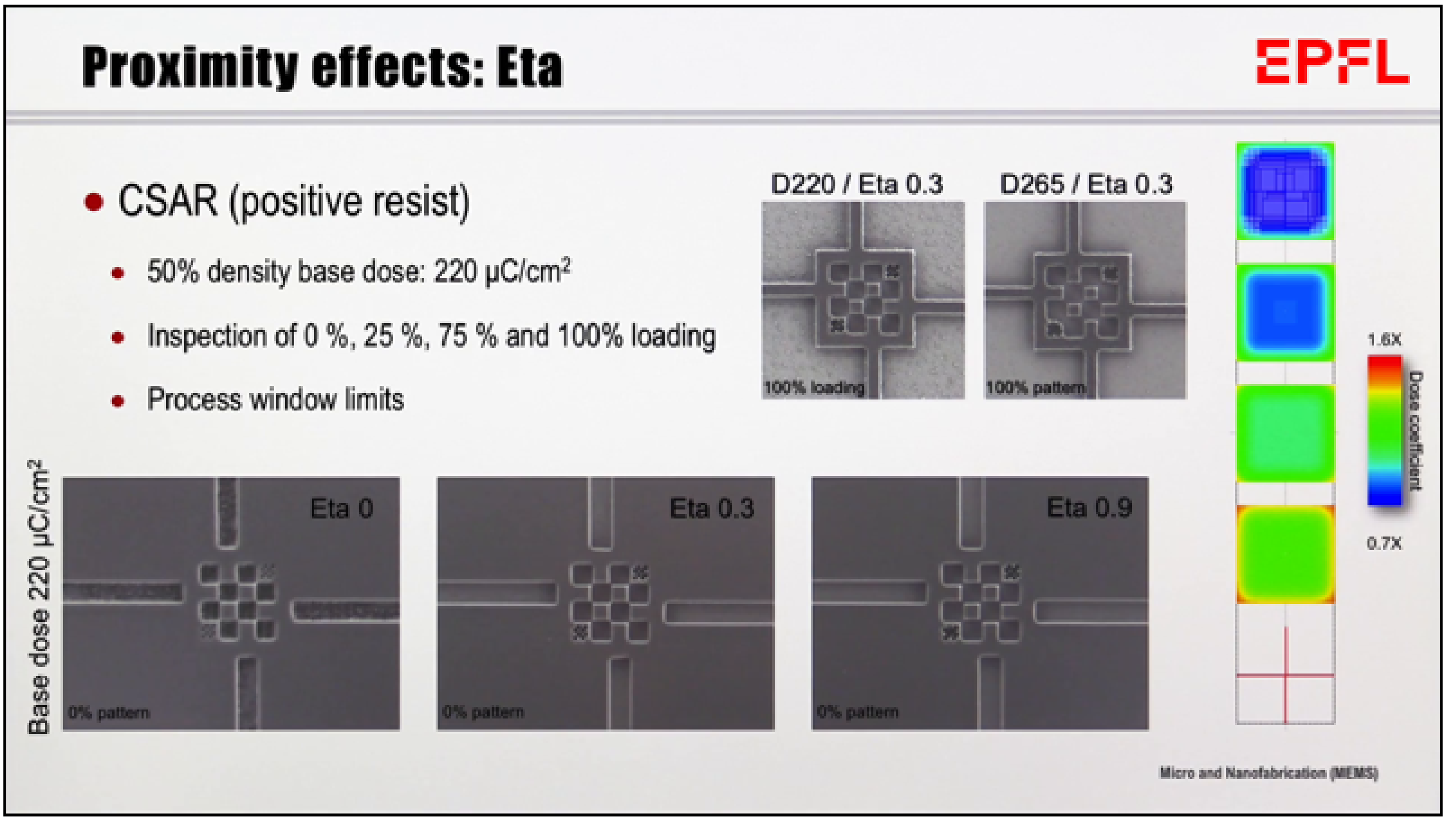


At 50% density, the effective dose in the central pattern region is not affected by the choice of either. In fact, when performing proximity effect corrections the dose is augmented or reduced for lower or higher densities only. The 50% pattern shown on the previous slide will therefore be used to determine our base dose. Three levels of features allow for the assessment of the base dose: the dimensions of the loading lines, as well as the checkerboards with a square edge length of 250 nm and 50 nm, like shown here. Let's now look at some real examples using HSQ resist. First, looking at the image at the top right, here the base dose is determined by measuring the line width of the 50% density pattern. When underexposed, 1000 µC/cm^2, the lines are narrow whereas when overexposed, residues of line broadening are observed. If looking at the central checkerboard one can see that when underexposed, the small checkerboard is absent and gradually appears and widens with the increasing dose. It is important to note that our double Gaussian model is an approximation for the electron distribution during exposure. Additionally, development may be affected by feature size and aspect ratio, and that due to the finite contrast and process latitude of the resist, the perfect critical dimension at all scales may be hard to reach. This is already apparent for the checkerboard pattern between dose 1200 and 1400. At the lower dose, the apertures in the fine checkerboard are well defined, whereas the blanks in the large checkerboard are too large.

notes

summary

4m 51s



For the higher dose, the apertures in the large checkerboard are reduced, although still too large, but the fine checkerboard is already showing signs of overexposure. Additionally, we only tune the dose of the written areas but cannot physically apply a negative dose in the non written areas that suffer from background exposure. In a way, we are here limited to a dose leveling rather than a true correction. Once the base dose is extracted from the 50% density patterns, the eta parameter may be investigated. Let's now have a look at this for CSAR, a positive resist with a base dose of 220 µC/cm^2. Inspecting the 0% loading, one can see that at eta=0 the feature is still full of undeveloped resist, like shown here. At eta=0. hence, there is no compensation to boost the dose for the low density pattern and the resist is therefore underexposed. As eta is increased, a back scattering contribution is assumed and the dose in low density areas slowly rises. At eta=0.3, the fine checkerboard is very well defined, you can see here. By increasing eta further to 0.9, we can see the collapse of the fine checkerboard and the separation of the large 250 nm squares, slightly overexposed. On the right you can see how the dose correction is applied for the different patterns and associated density. It is interesting to know that if you look at the 100% loading pattern, the eta=0.3 at 220 base dose provides good results on the checkerboard. But the large area written around shows a lot of remaining resist scum. Increasing the dose further clears the large areas but the fine patterns are distorted. This is again another illustration of process window limitations. Proximity effect corrections should preferably be performed taking into account the actual density of the target patterns and shape corrections, or bias may be used to further correct the exposure.

notes

summary

6m 49s