Course material

Course:

Micro and Nanofabrication (MEMS)

Video:

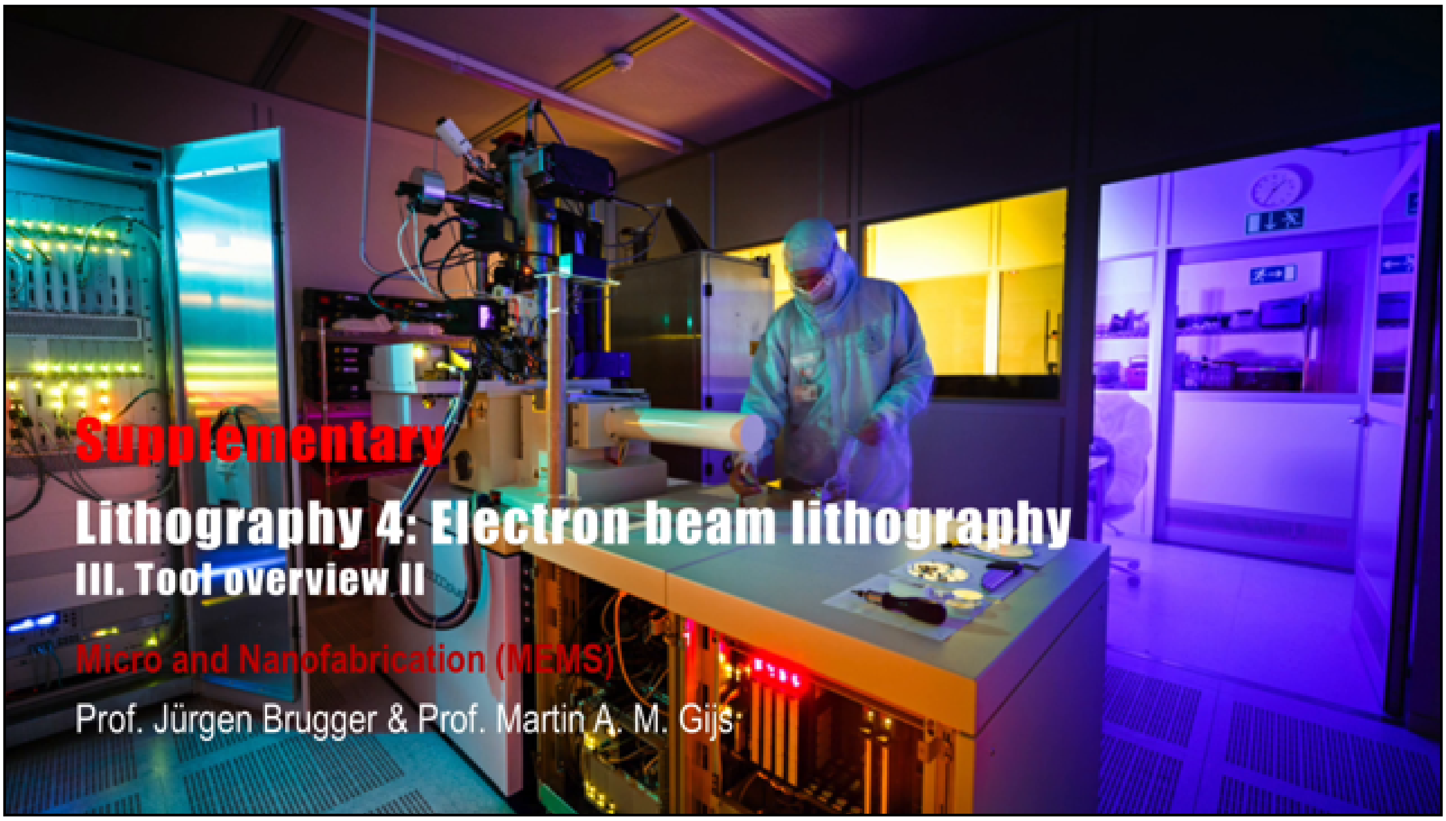
4.10 Lithography 4, Electron beam lithography, III Tool overview II

Concepts (extracted from automatically generated subtitles):

Beam diameter. Number of aberrations. Electron gun choice. Electron beam diameter. Probe current. Chromatic aberrations. Solid angle. Optical microscopy. Electron beam. Types of aberrations. Large impact. Current diameter relations. Different gun types. Acceleration voltages. Spherical aberrations.

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

to video



...

notes

summary

0m 0s

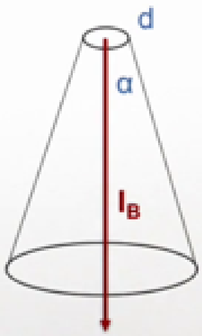
EBL: electron gun brightness

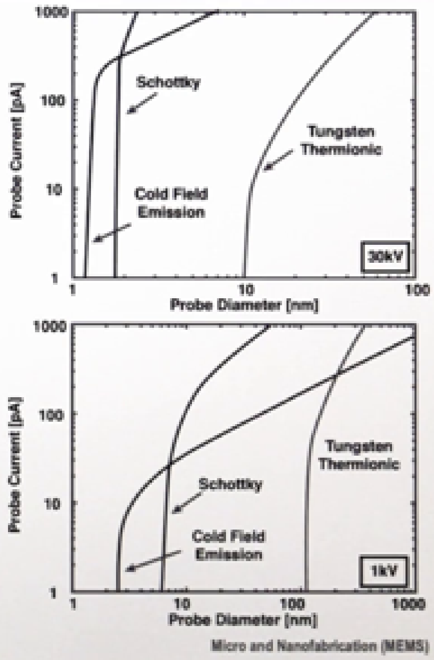
EPFL

- Probe size depends on
  - Gun type
  - Acceleration voltage
  - Extraction current
- Gun brightness β
- EBL writing speed: varying beam properties for different features

$$\beta = \frac{beam\ current}{area \cdot solid\ angle}$$

$$\beta = \frac{4\, I_B}{\pi^2\, d^2 \alpha^2}$$



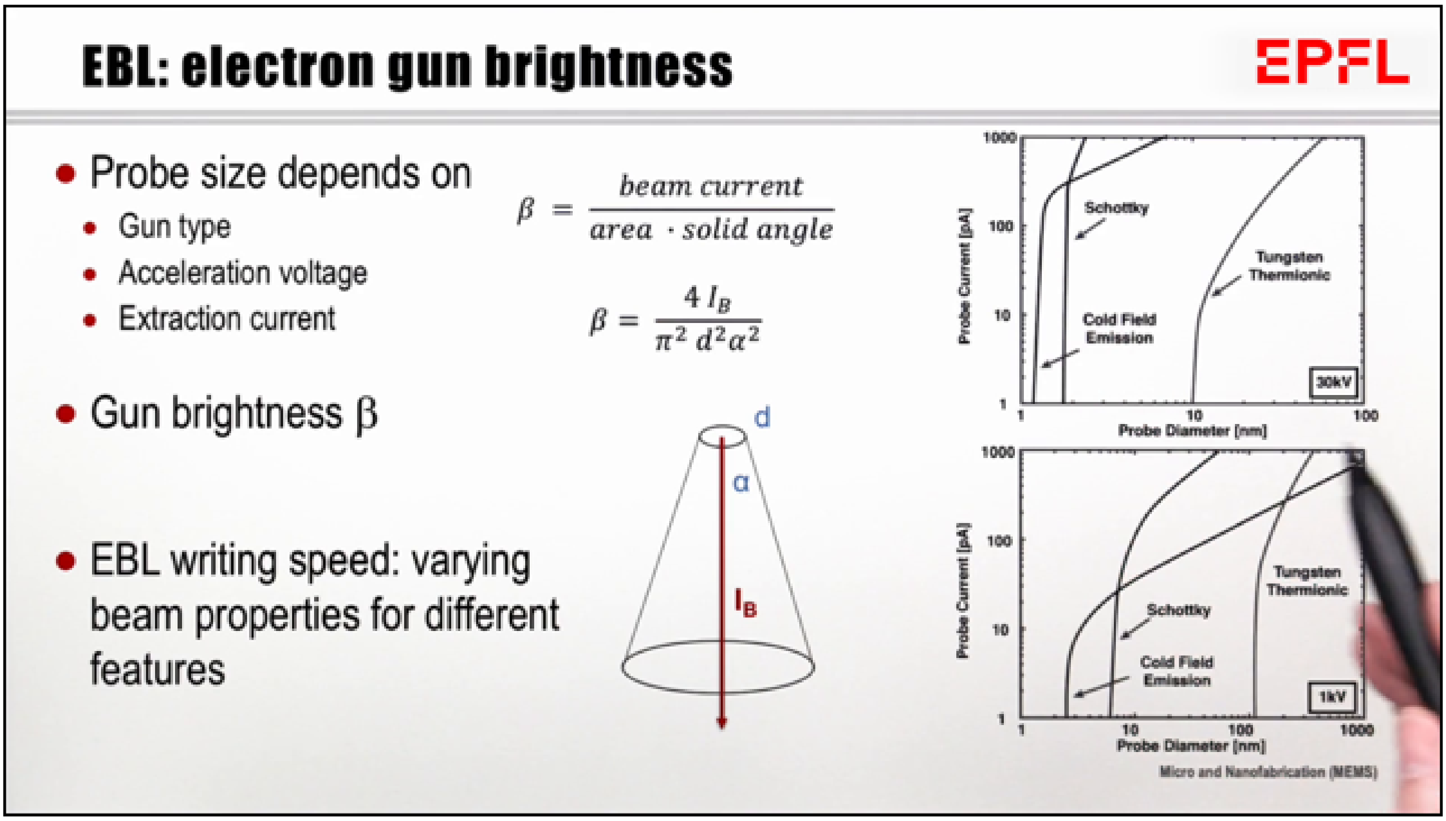


The electron gun choice has a large impact on the beam diameter.

notes

summary

0m 1s

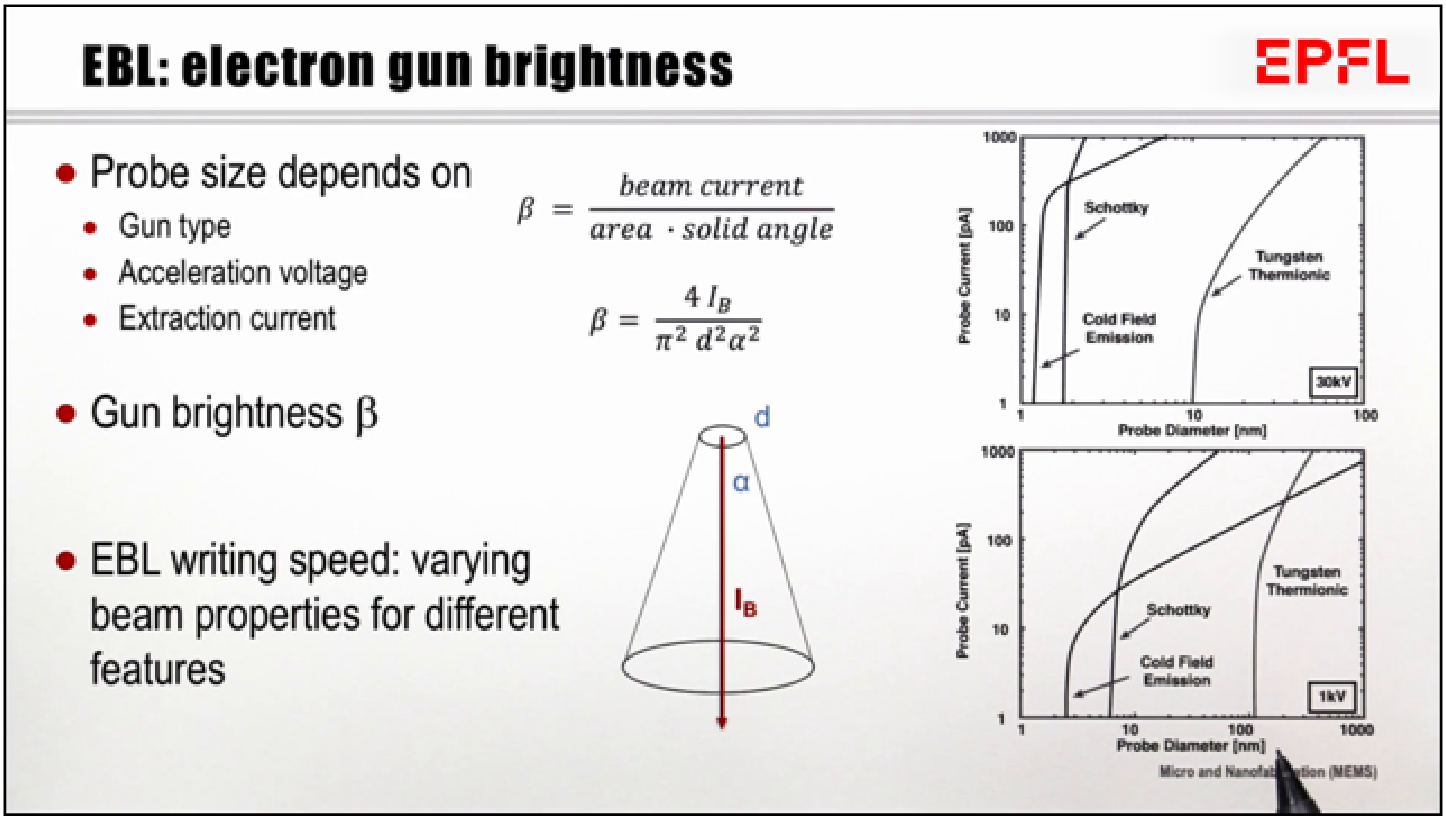


that is also called "probe diameter". As can be seen on the graphs here on the right, different gun types are compared where the probe current

notes

summary

0m 5s

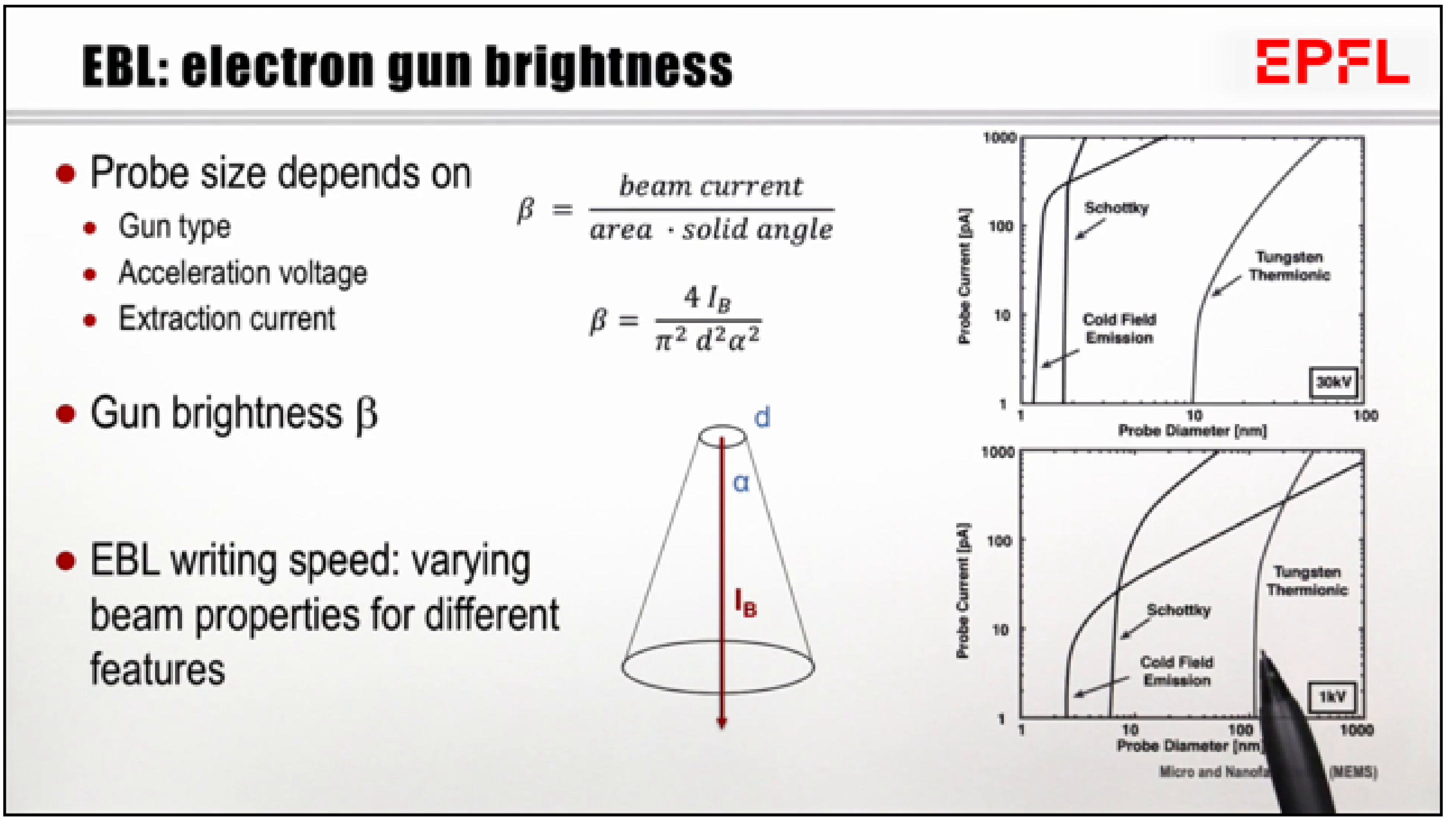


is displayed as a function of the probe diameter for two acceleration voltages, 30 kV here, and 1 kV down here. In EBL, one typically employs currents from a few hundred pico amps range, to several tens of hundreds of nano amps. As seen in the graphs, at these current values,

notes

summary

0m 22s

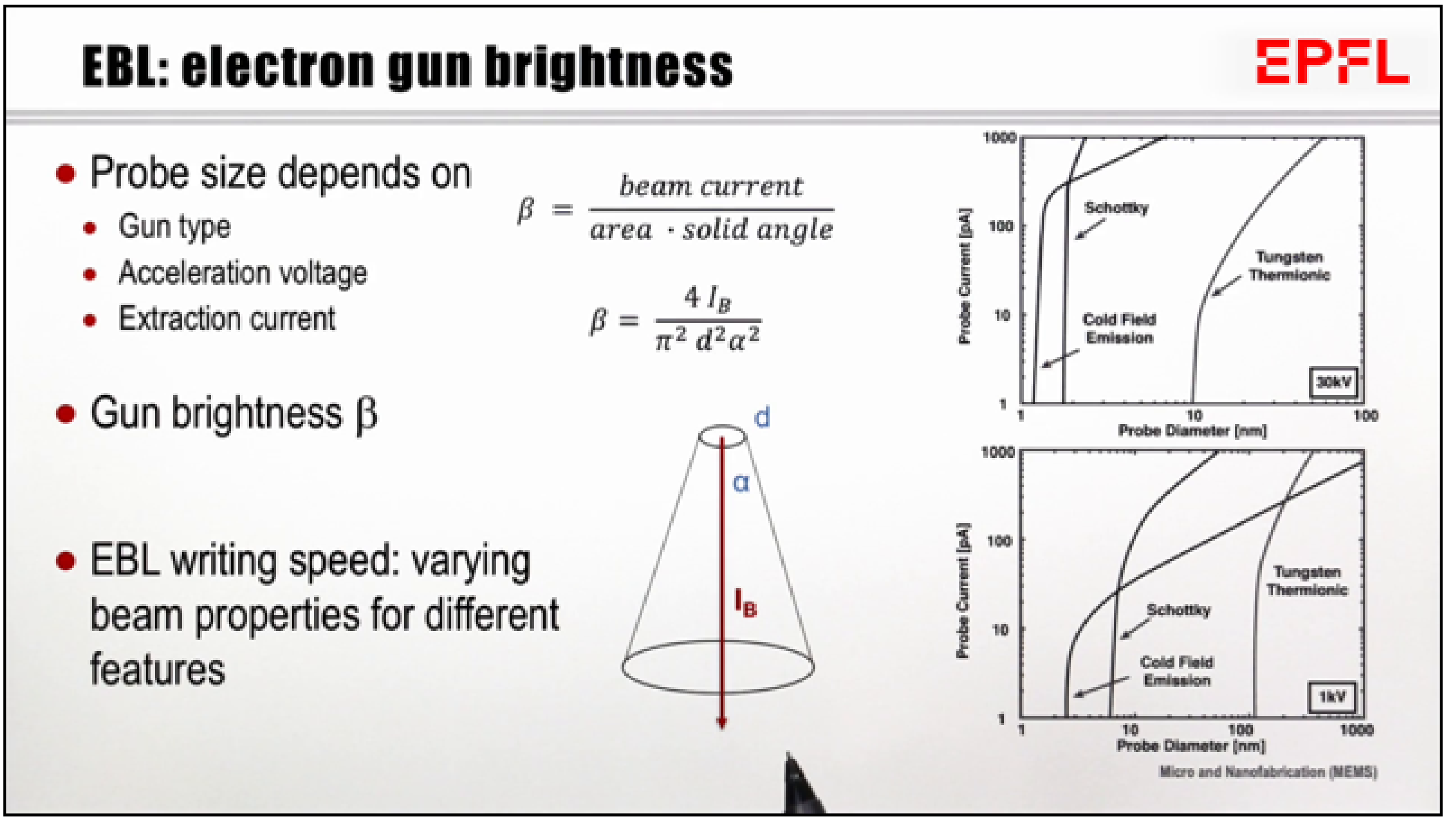


the electron beam diameter undergoes large changes: from a few nanometers to several tens of nanometers. You can also see that these current diameter relations are not linear and they vary largely from one gun type to the other.

notes

summary

0m 45s



Therefore, a good metric to compare gun types, is needed and introducing the concept of brightness or beta. It is defined as how much current is emitted per unit solid angle, per unit area of the emitting surface, described in this drawing here.

notes

summary

1m 2s

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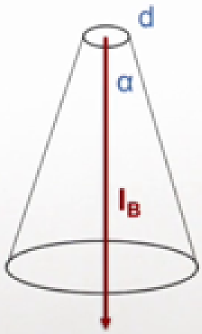
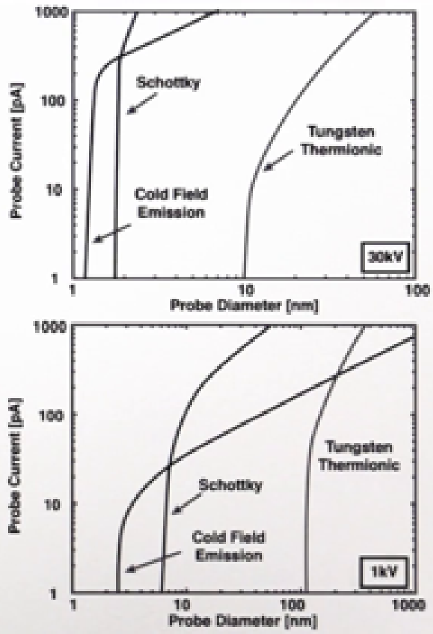
$$\beta = \frac{4\, I_B}{\pi^2\, d^2 \alpha^2}$$





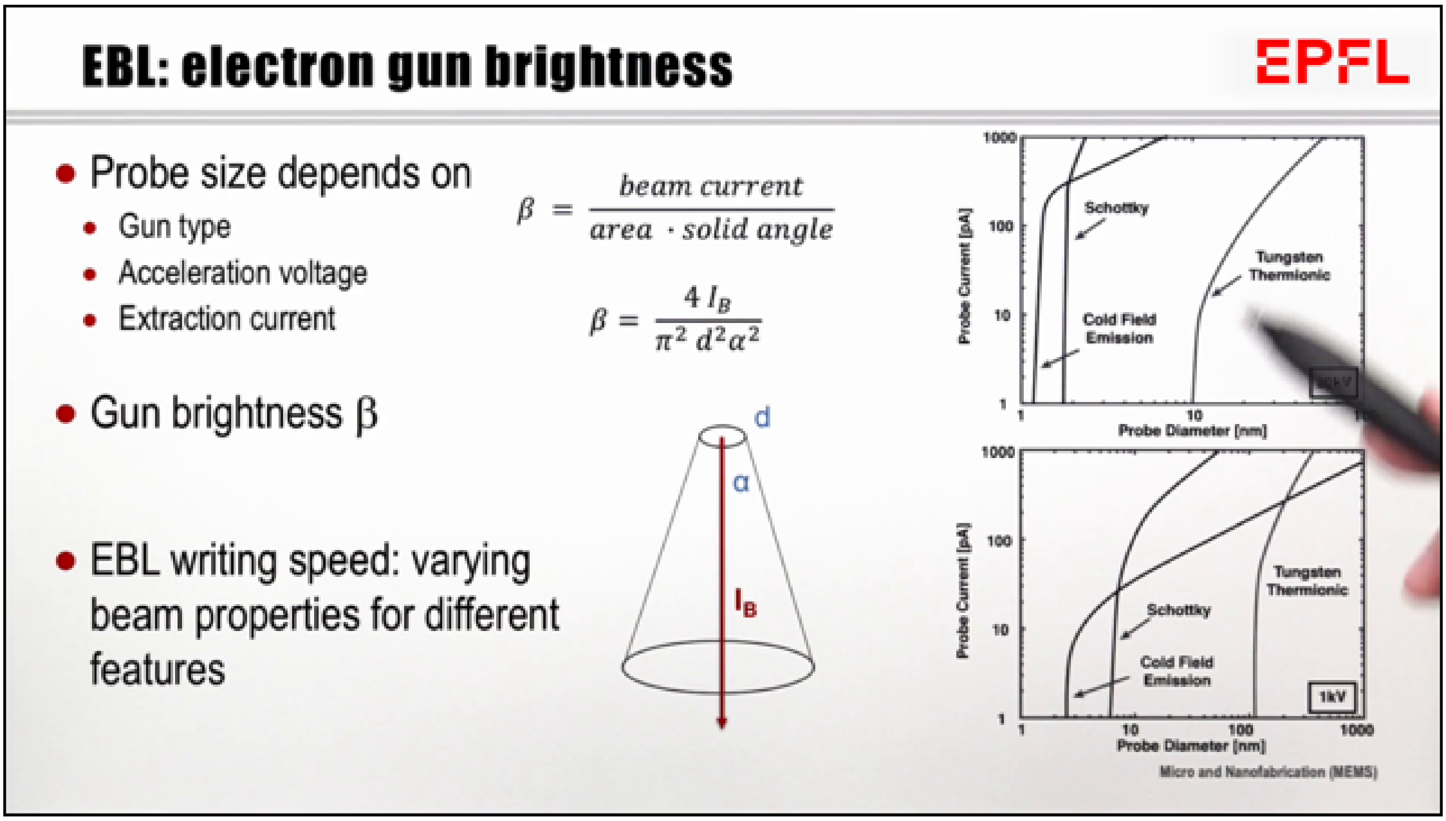
Micro and Nanofabrication (MEMS)

This should be compared at equivalent acceleration voltages and takes into account beam current diameter and the incident angle on the sample.

notes

summary

1m 25s

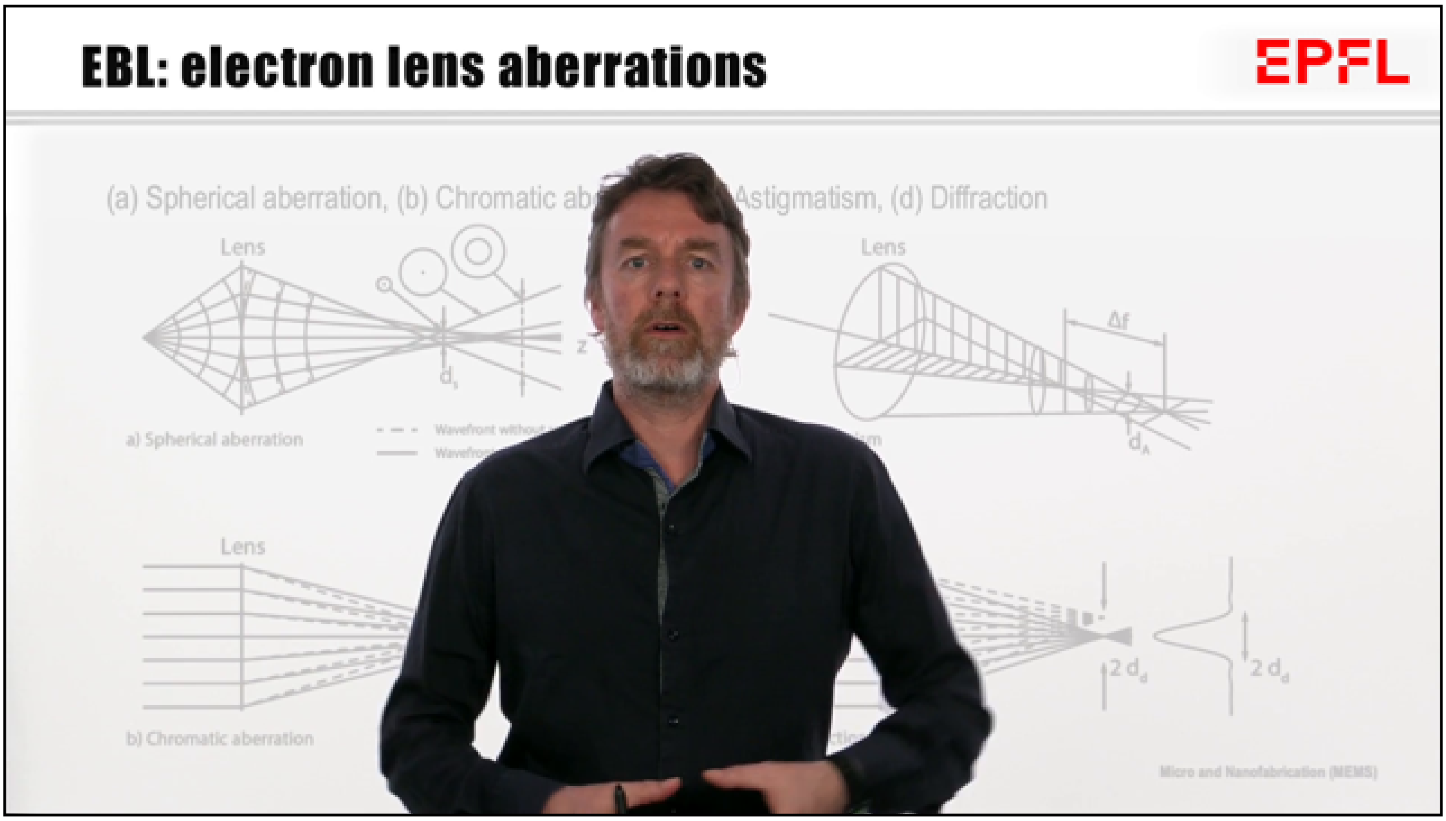


For example, thermionic emitters may have very high beam currents, shown here,

notes

summary

1m 35s



but very low brightness, due to their large spot size. It is additionally important to be able to tune the electron beam so that one can write large features with a large beam and then use low currents to write the finer features. Like in optical microscopy, a number of aberrations limit

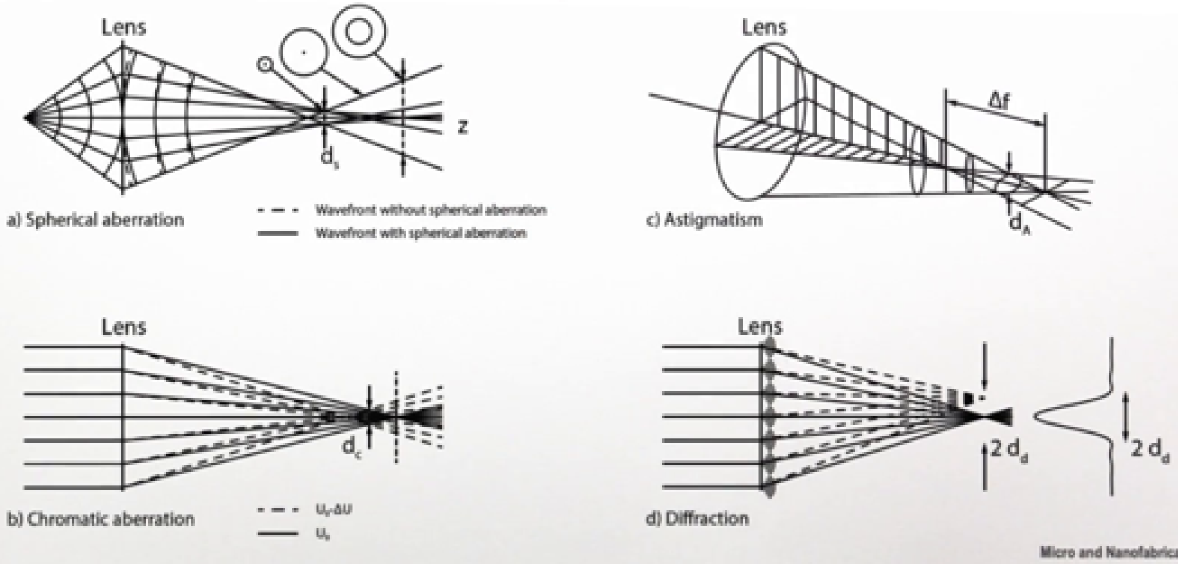
notes

summary

1m 41s

EBL: electron lens aberrations

(a) Spherical aberration, (b) Chromatic aberration, (c) Astigmatism, (d) Diffraction



Micro and Nanofabrication (MEMS)

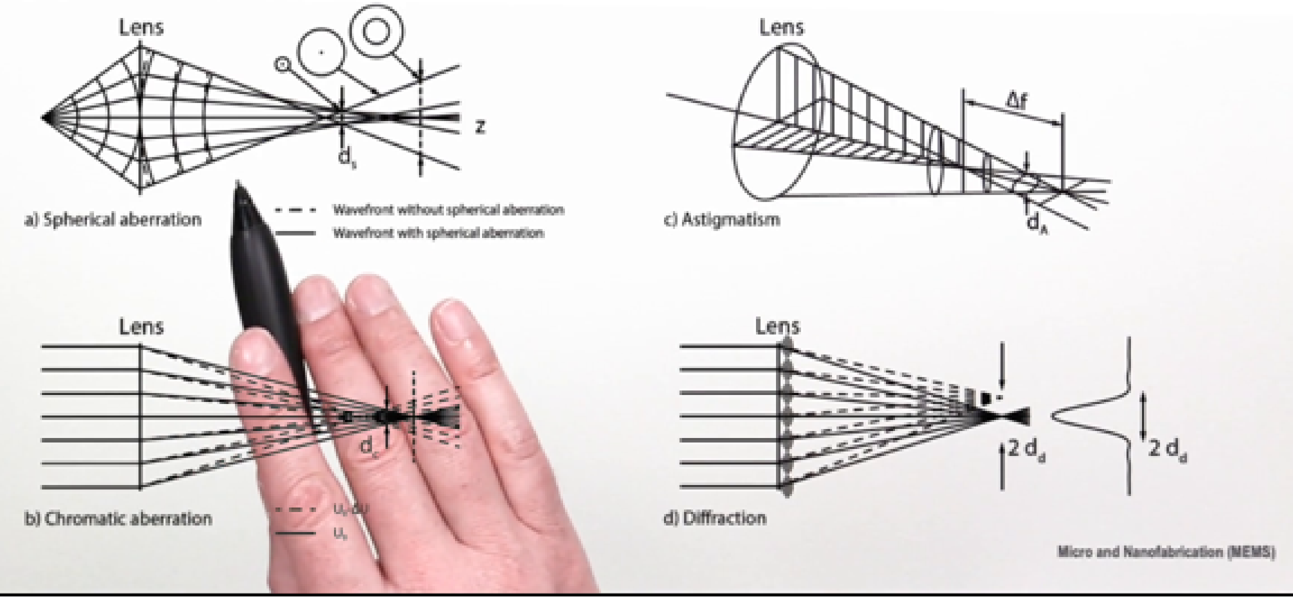
the ultimate resolution of the electron probe. There are 4 types of aberrations listed here from A to D.

notes

summary

2m 1s

EBL: electron lens aberrations



Spherical aberrations (a) are the result of an inhomogeneous focusing property,

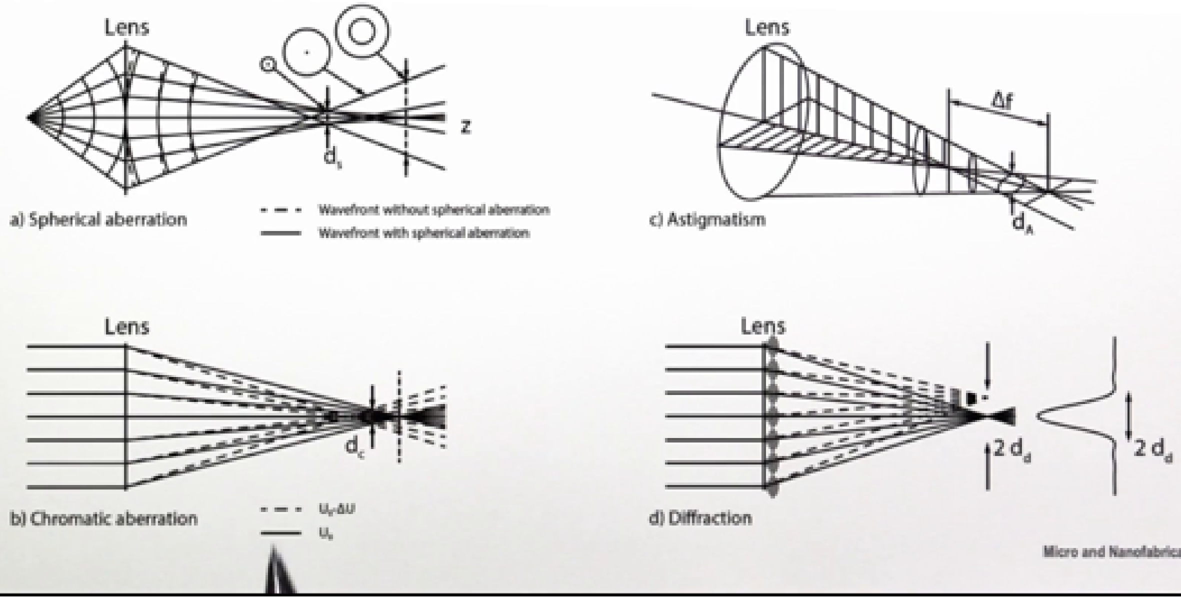
notes

summary

2m 9s

EBL: electron lens aberrations

(a) Spherical aberration, (b) Chromatic aberration, (c) Astigmatism, (d) Diffraction



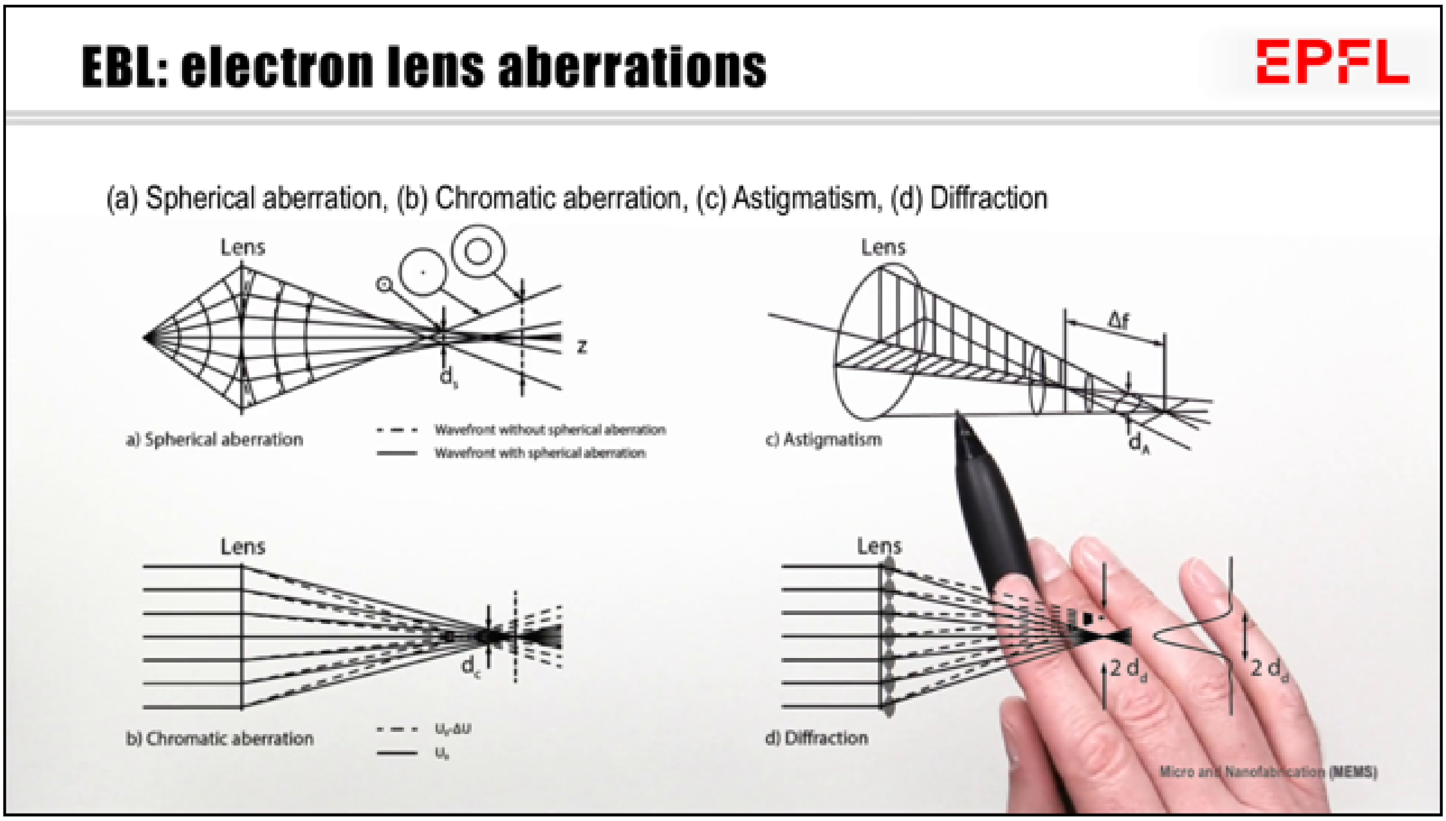
Micro and Nanofabrication (MEMS)

for electrons travelling on or off the axis. Chromatic aberrations (b) are the result of varying focus for electrons of different energy. Both of these aberrations can be minimized

notes

summary

2m 14s



by reducing the convergence angle of the system so that electrons are confined to the center of the lenses, at the cost of greatly reduced beam current. Astigmatism (c) occurs when the electrons sense a non consistent magnetic field as they spiral around the optical x, which arises from construction errors.

notes

summary

2m 27s

EBL: effective beam diameter

EPFL

Effective beam diameter

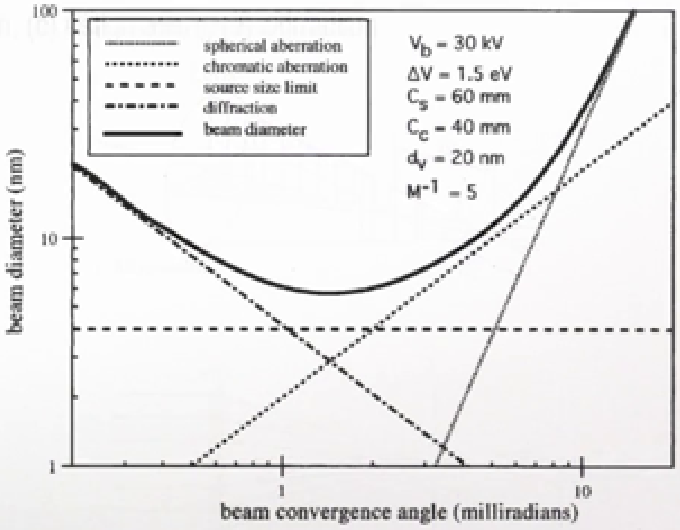
$$d = \sqrt{d_g^2 + d_s^2 + d_c^2 + d_d^2}$$

d_v: virtual source diameter
M (>1): demagnification $\quad d_g = \dfrac{d_v}{M}$

Spherical aberration $\quad d_s = \dfrac{1}{2} C_s \alpha^3$

Chromatic aberration $\quad d_c = C_c \alpha \dfrac{\Delta V}{V}$

Diffraction $\quad d_d = 0.61 \dfrac{\lambda}{\alpha}, \lambda = \dfrac{1.2}{\sqrt{V}} nm$



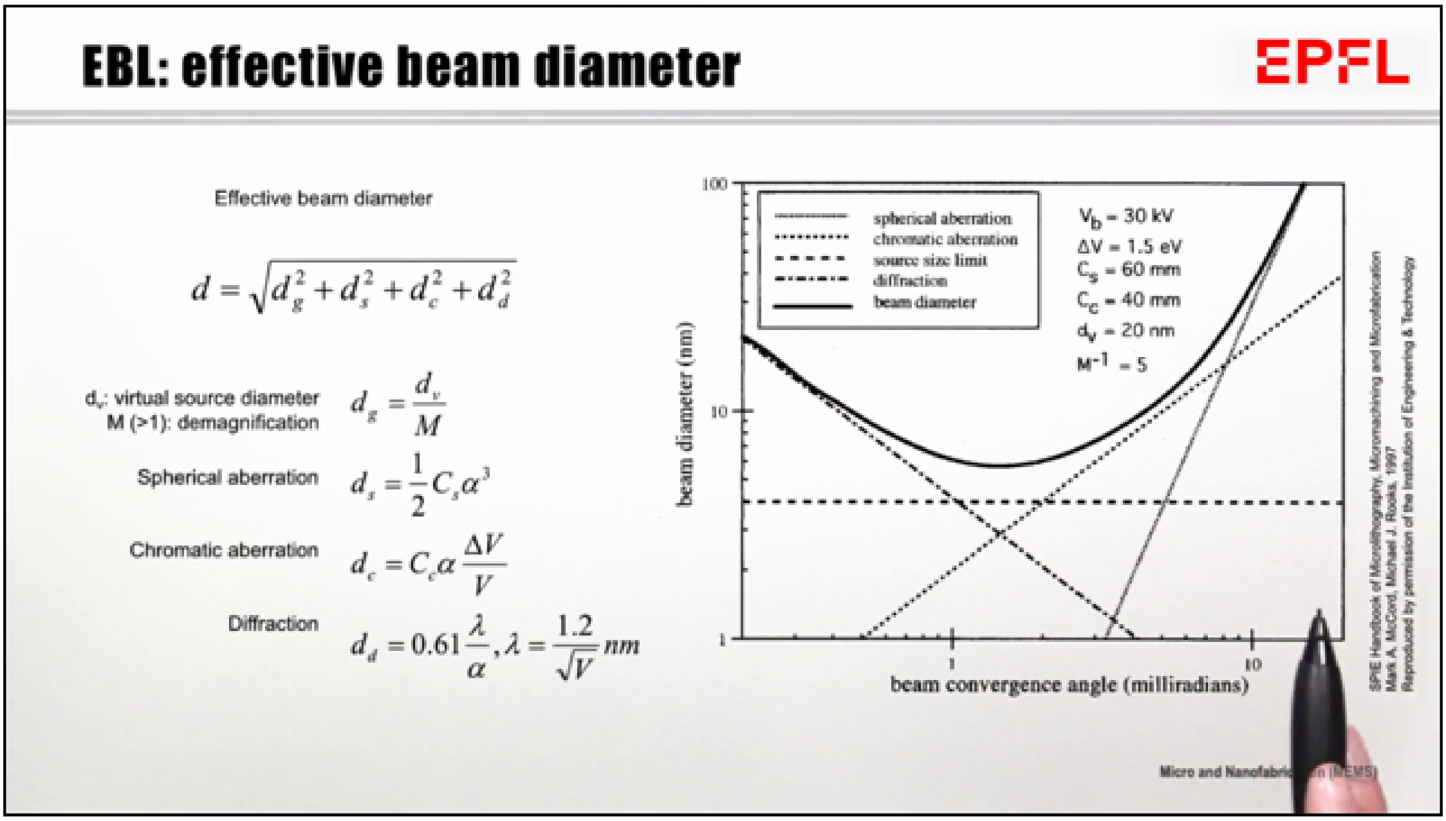
Micro and Nanofabrication (MEMS)

The result is a non symmetric beam cross-section. At low energies and with convergence angles, altered diffractions (d) may play a significant role, shown here.

notes

summary

2m 49s



The understanding of aberrations is essential to reach mininal effective beam diameters that enable high patterning resolutions. As you can see here on the graph on the right side,

notes

summary

3m 1s

EBL: effective beam diameter

EPFL

Effective beam diameter

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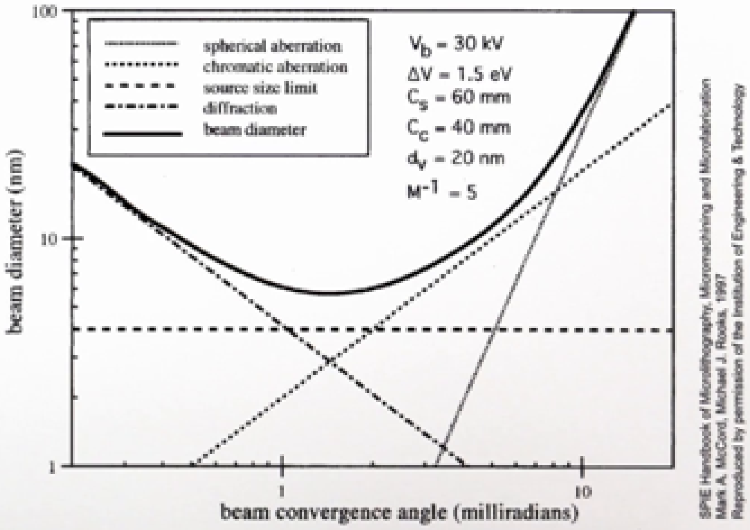
Diffraction $\quad d_d = 0.61 \frac{\lambda}{\alpha}, \lambda = \frac{1.2}{\sqrt{V}} nm$



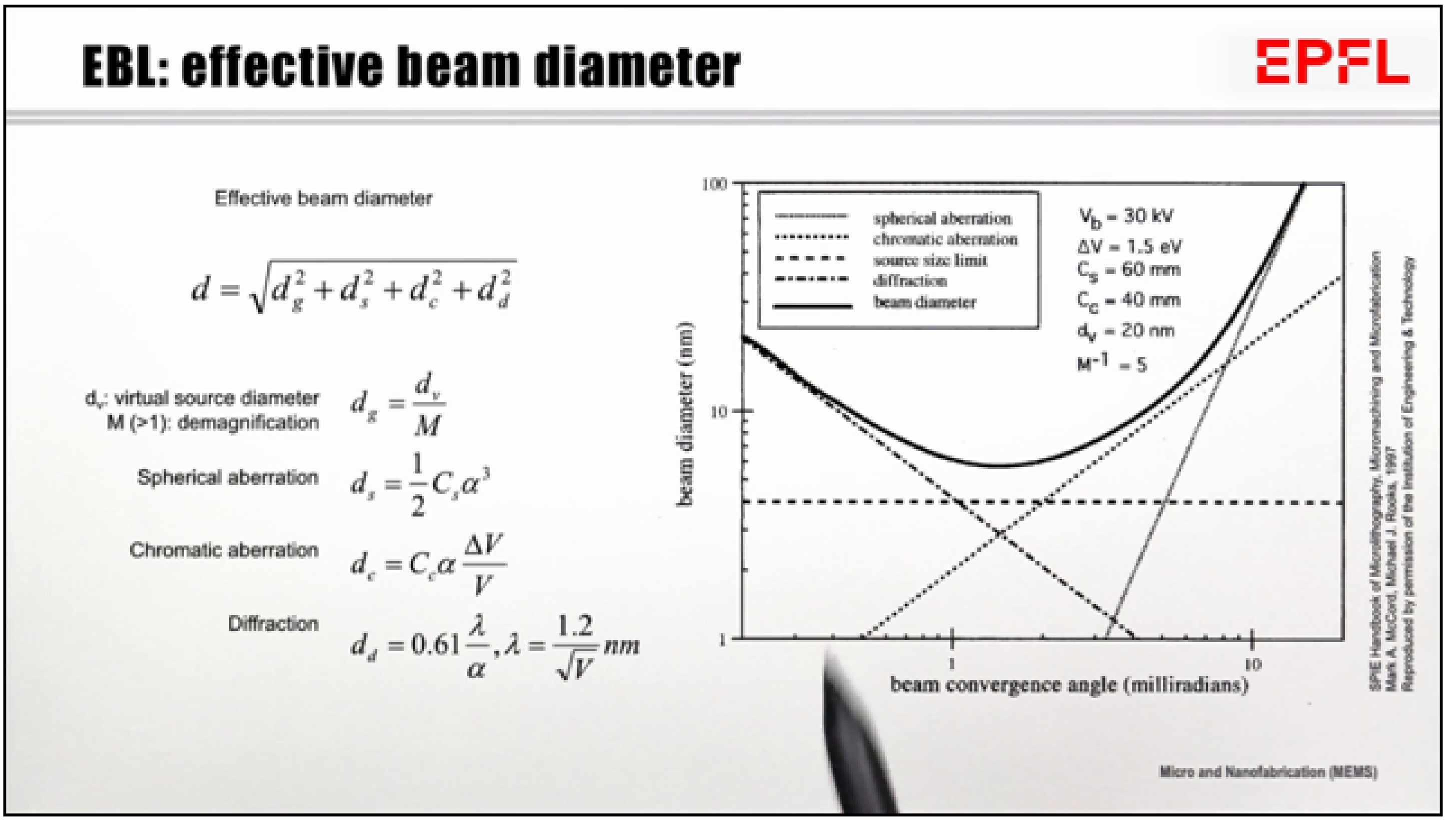
Micro and Nanofabrication (MEMS)

all the aberrations mentioned previously must be taken into account at once, also in relation with the beam convergence angle. In practice, the effective beam diameter

notes

summary

3m 12s

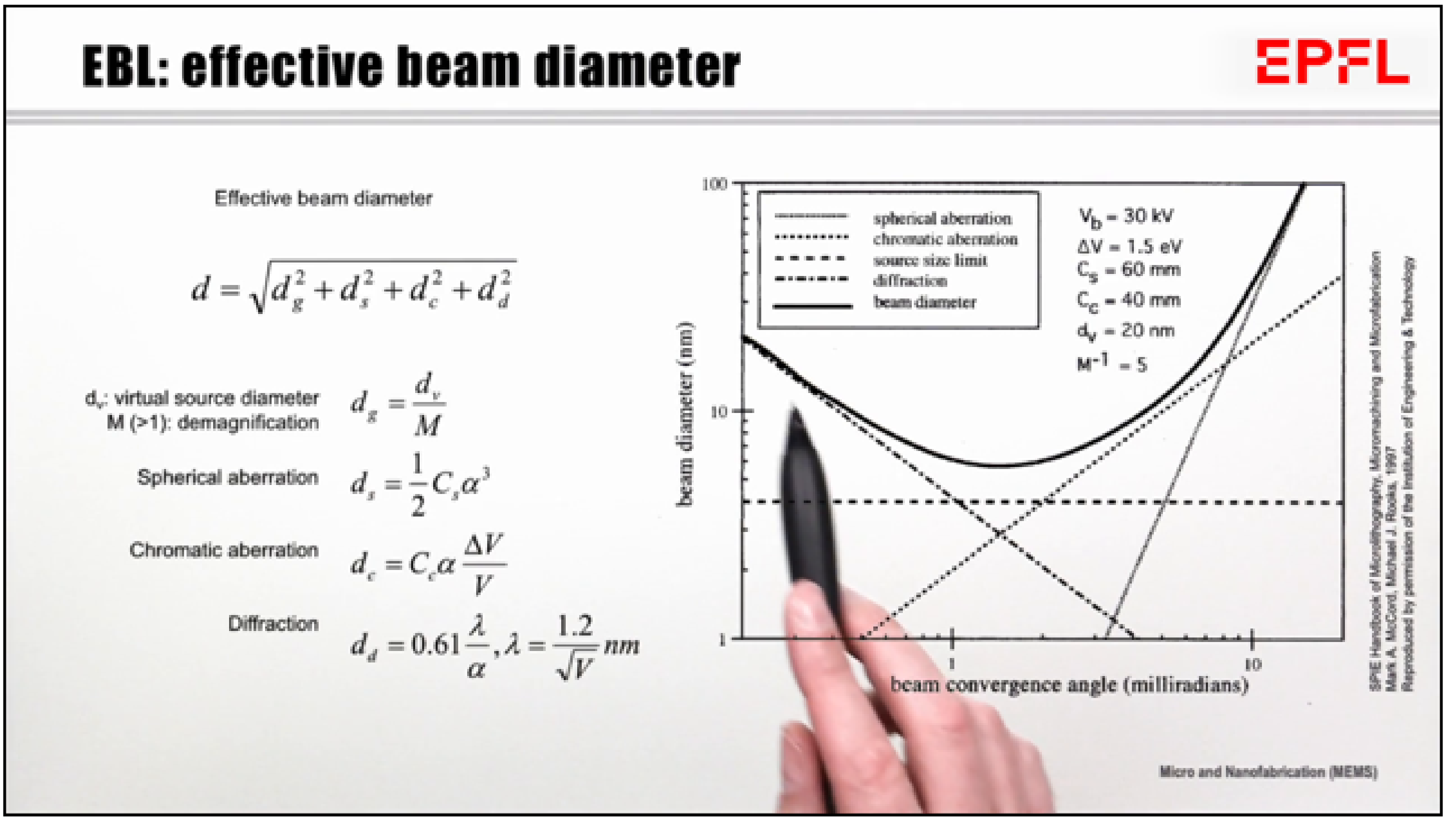


is indeed expressed by the square root of each contribution squared and summed. Whereas the virtual source size limit does not depend on the beam convergence angle, this line here. Chromatic and spherical aberrations obviously increase with greater convergence angle.

notes

summary

3m 25s



This relation is inverted for diffraction.

notes

summary

3m 49s

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EPFL

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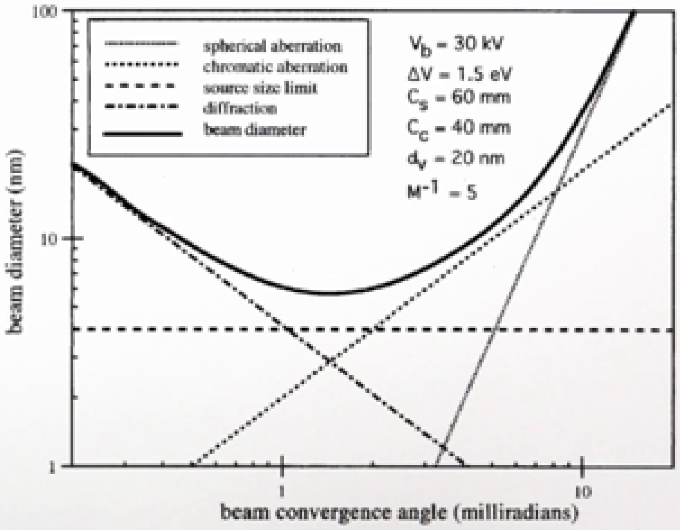


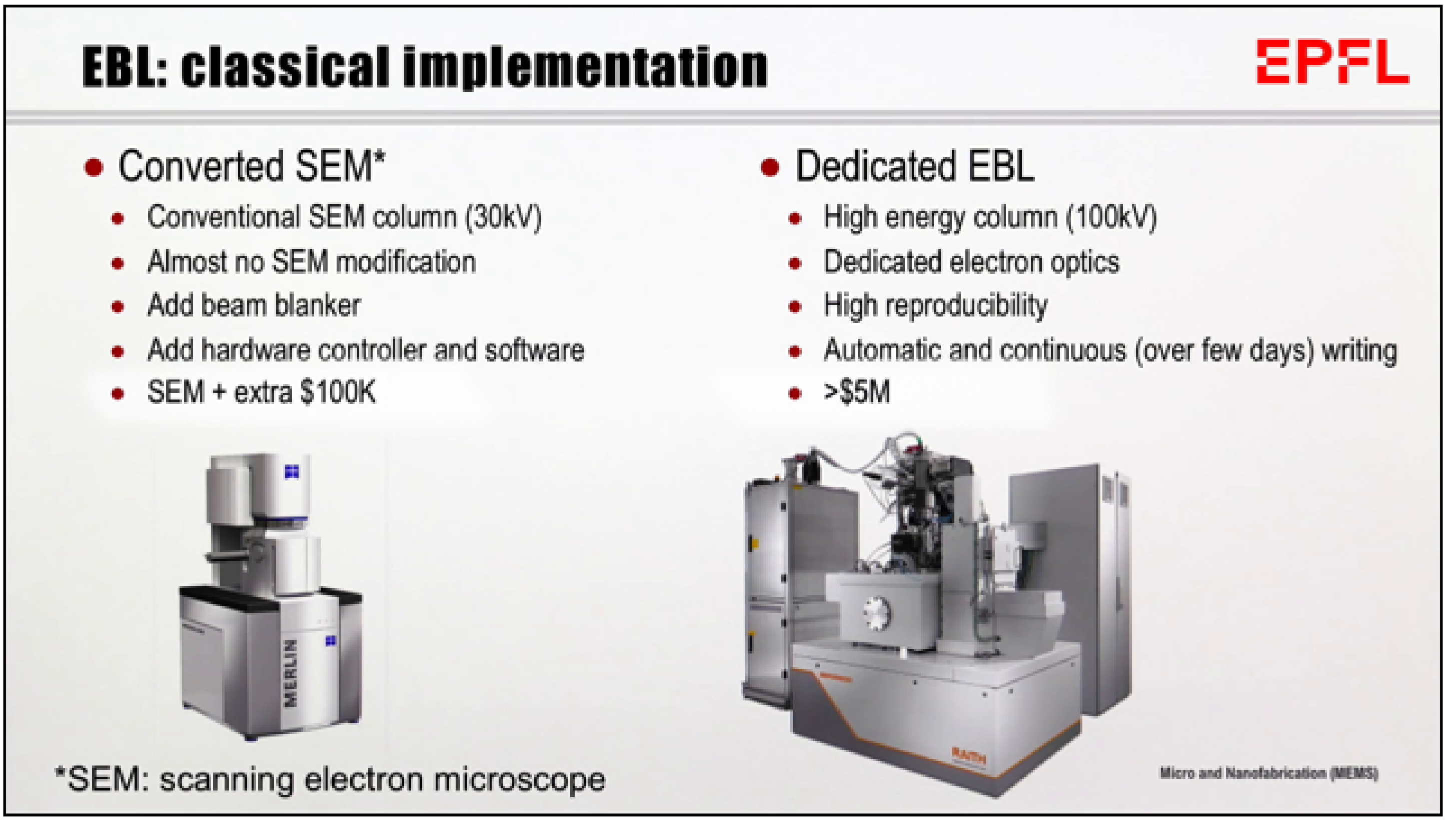
Micro and Nanofabrication (MEMS)

Reaching an optimal work configuration requires the optimization of all contributions rather than seeking the individual minimization. Notably, and in relation to the previous slides, each aberration and contribution to the final beam diameter are subject to additional parameters

notes

summary

3m 50s



other than the beam convergence angle and may be optimized in part independently by the instrument design or choice of acceleration voltage. Electron beam lithography tools for research can be configured in 2 ways: one is to convert a scanning electron microscope SEM, here on the left side, as a scanning electron microscope already includes the main elements required to perform lithography. The only component that needs to be added is the pattern generator. It consists of a beam blanker to switch on and off the beam, as it raster scans the sample, as well as a computer control. These low cost EBL systems are typically using acceleration voltages of 30 kV and they do not benefit from the advantages of a dedicated EBL column in terms of speed and stability. So, dedicated EBL tools operate at a higher voltage, up to 100 kV, and allow for high throughput and stability. They have higher costs of several millions of euros - but they are essential and needed for mask writing in deep UV masks and nano-science research.

notes

summary

4m 13s