Course material

Course:

## Micro and Nanofabrication (MEMS)

Video:

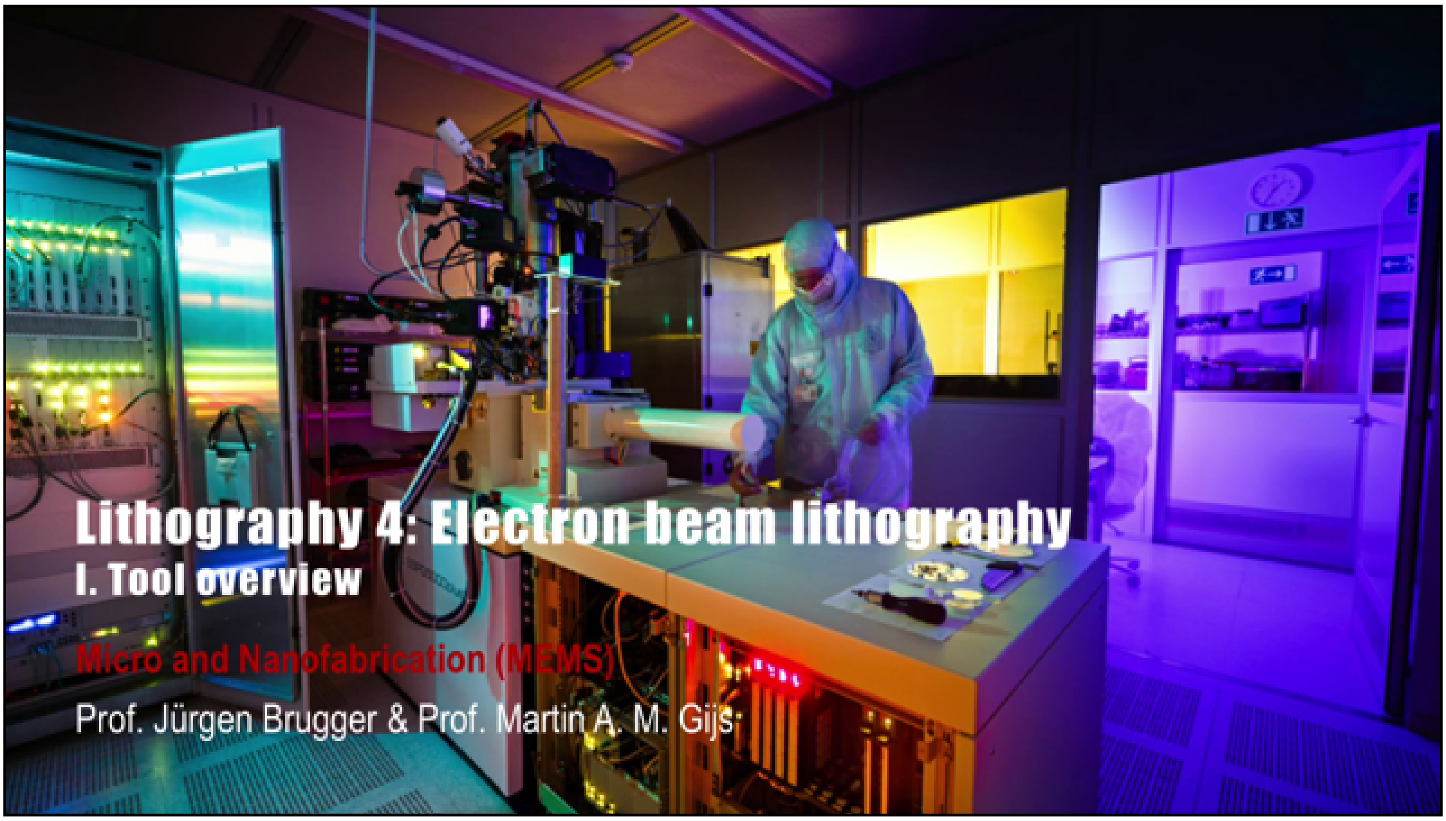
## 4.8 Lithography 4, Electron beam lithography, I Tool overview

Concepts (extracted from automatically generated subtitles):

**Field emitters. Electron gun. E-beam litho. General concepts of lithography. Different vacuum levels. Original high resolution mask. Kv acceleration voltage. Zirconium oxide. E-beam litho tool. Main components. Schottky field. Work function. Uv lithography techniques. Electrons. Source contamination.**

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

to video

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notes

summary

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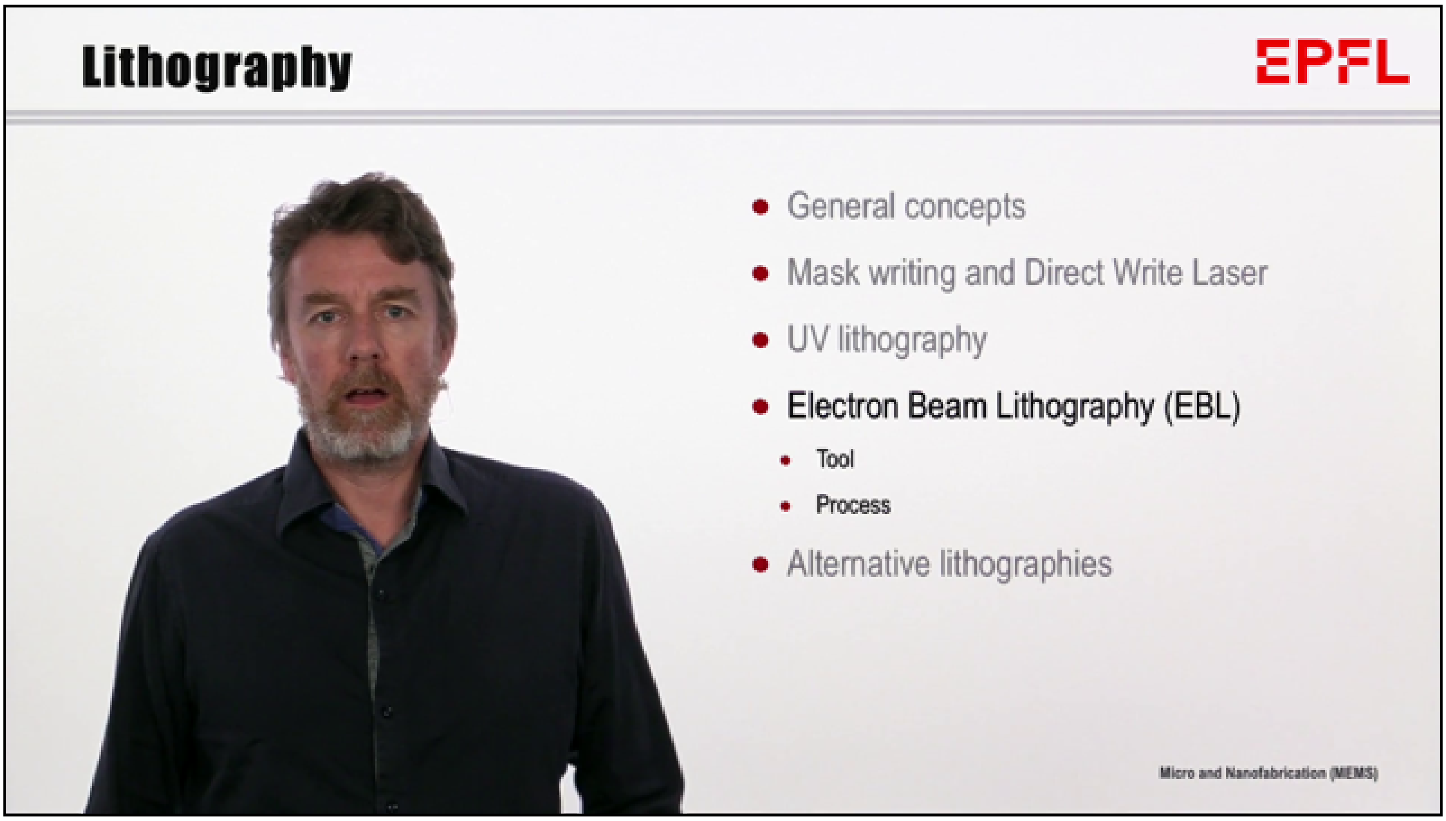


After the introduction to the general concepts of lithography,

notes

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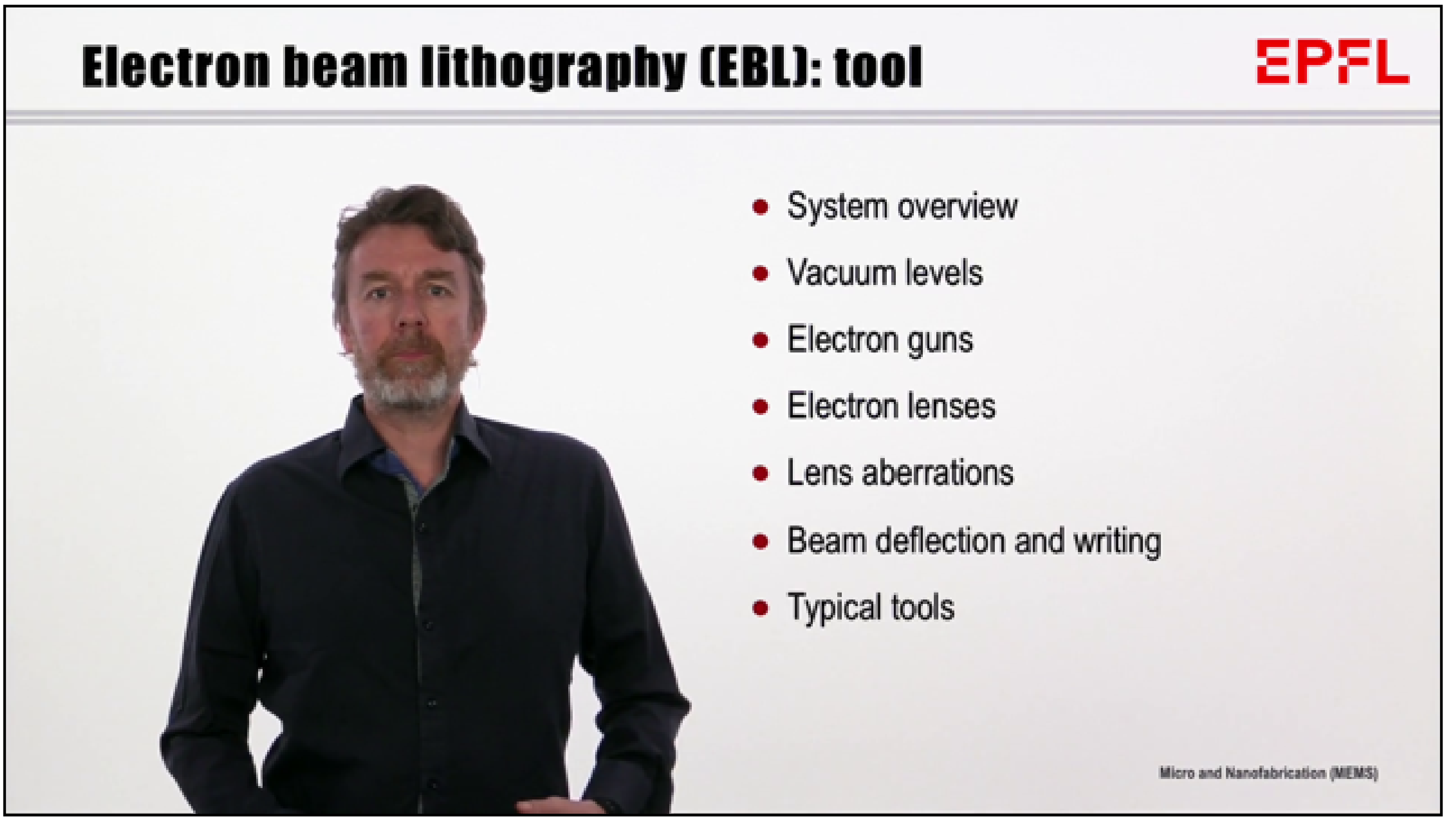


and the details on mask writing and UV lithography techniques, I will now focus in this lesson on Electron Beam Lithography, E-Beam Litho or EBL. It allows for pattern resolution down to 5 nanometer level. This is important for many devices in nano-science and nano-technology. This lecture will first describe the equipment and then detail e-beam litho specific process steps.

notes

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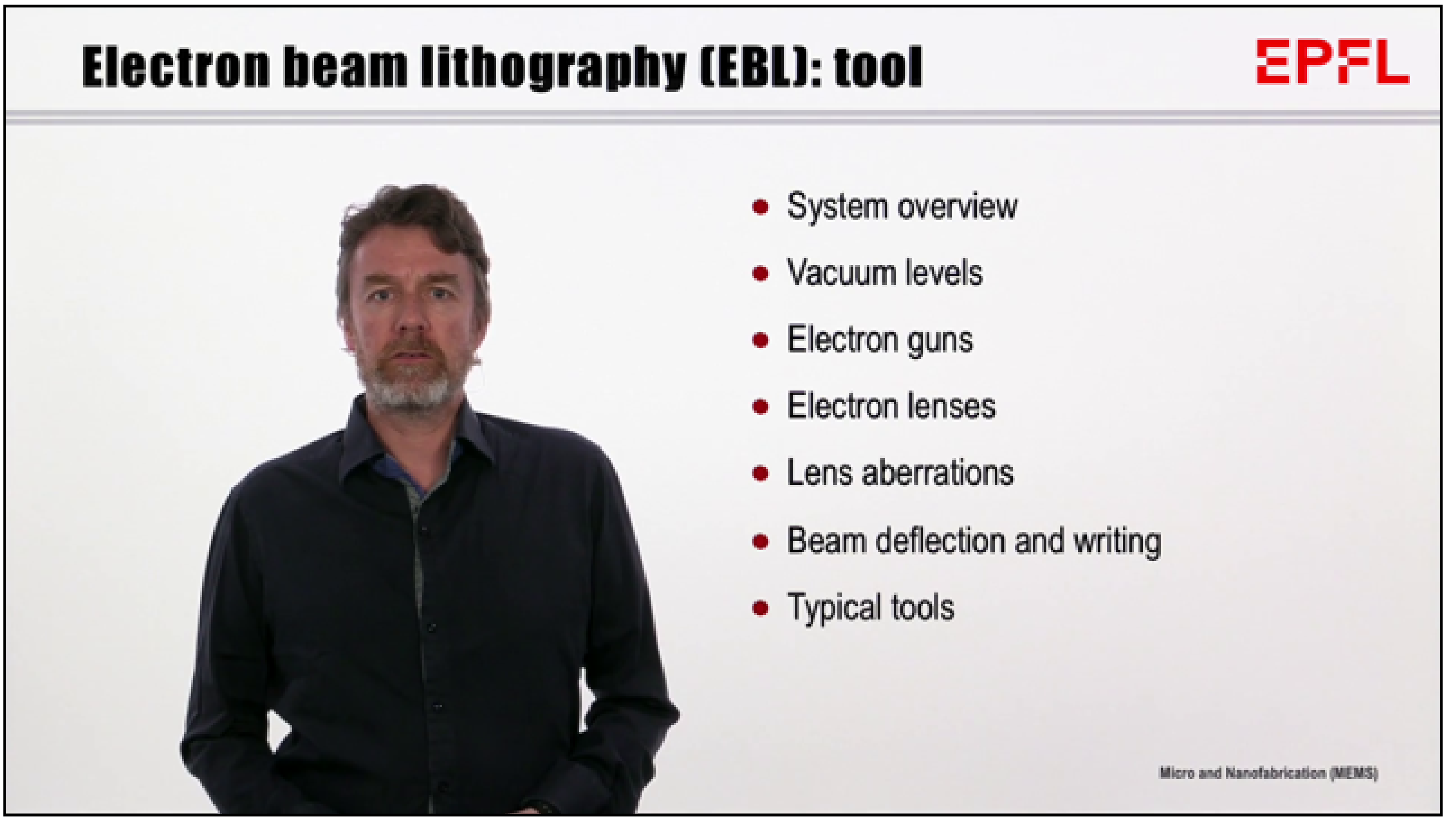


This chapter will thus show details on the e-beam litho tool, like the one you saw on the cover slide of this lesson. I will first introduce the main components that are required for an EBL system, starting from the different vacuum levels,

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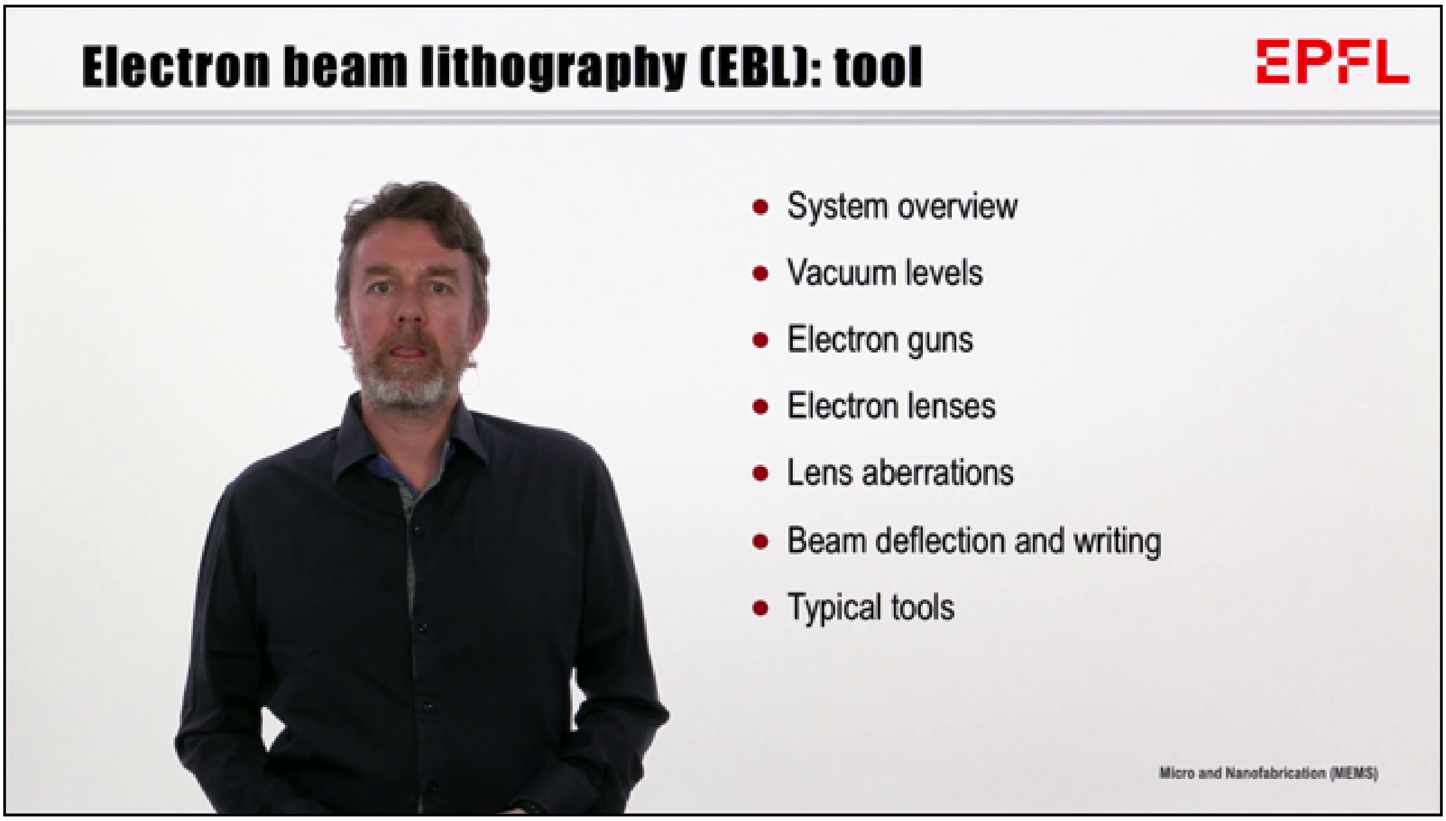



show how electrons are emitted by the electron gun,

notes

summary

0m 49s

# EBL: basic concepts

EPFL

- Why use electrons instead of photons?
  - Overcome the optical diffraction limit $\sim \lambda/2$
  - Electron wavelength, De Broglie equation

| kV | 1 | 10 | 100 |
|---|---|---|---|
| nm | 0.038 | 0.012 | 0.0038 |

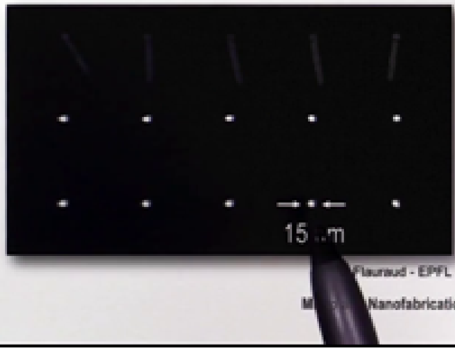
$$\lambda_e = \frac{h}{p}$$

  - sub-20 nm features feasible
  - Writing tool for UV/DUV masks
- What are the «cons»?
  - Expensive
  - Slow when compared to projection lithography systems

SEM image of two layer lithography with negative resist (HSQ)


V. Flauraud - EPFL

Negative resist (HSQ) pillars 15 nm diameter, 150nm height




V. Flauraud - EPFL

how the electrons are then focused into a probe by lenses and also mention the imperfections called aberrations. Then I will describe how the electrons are deflected and controlled over the sample to write into the resist, and I will wrap this lesson up with some example tools. E-beam lithography is motivated by the possibility to overcome the optical diffraction limit. As we have seen, resolution in optical projection systems is limited to about lambda over 2. Of course, industrial Deep UV lithography has developed many process tricks to push the resolution of optical lithography down to a deep sub hundred nanometer scale. But these methods can be extremely costly and complex while they still require an original high resolution mask. Instead of photons, we are now considering electrons which are charged elementary particles. Electrons can also be described as a wave with a corresponding wavelength, even by the De Broglie equation that depends on their velocity. The equivalent wavelength of an electron, is given by the Planck constant over the momentum of the electron. So we have a look at some numbers. At 1 kV acceleration voltage, the wavelength of the electron is in the order of 0.038 nanometer, much smaller than an Angstrom. At 10 kV, it gets even smaller below 0.1 Angstrom, and for 1 kV we have already 0.0038 nanometer wavelengths. Typically e-beam is performed between 30 and 100 kV. The effective wavelength of the electron that is accelerated in an e-beam lithography tool is in the order of a few picometers. But unfortunately, the resolution limit using electrons in an EBL lithography tool is not given by its wave properties, but rather by other effects such as beam focusing, electron scattering, and charging and can reach down to a sub 10 nanometer scale in good cases. The main disadvantage of e-beam lithography is the low throughput because it is using a single electron beam to

notes

summary

0m 51s

# EBL: basic concepts

EPFL

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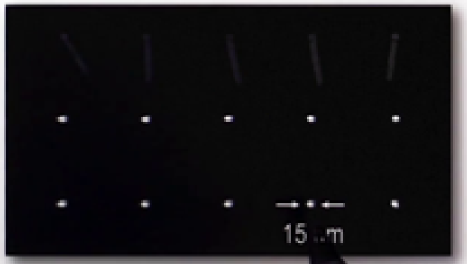
SEM image of two layer lithography with negative resist (HSQ)


V. Flauraud - EPFL

Negative resist (HSQ) pillars 15 nm diameter, 150nm height



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Nanofabrication (MEMS)

write, and therefore, there are high fabrication costs. Here on the right side you see two nice example images. Here is an SEM image of two layers of HSQ, which is a negative e-beam resist. The scale bar here is 1 micrometer, so these are lines in the order of a couple of hundred nanometers wide, with a varying pitch to check their resolution and alignment capability. This SEM image shows a high resolution and high aspect ratio HSQ resist pattern, which is 15 nanometers in diameter,

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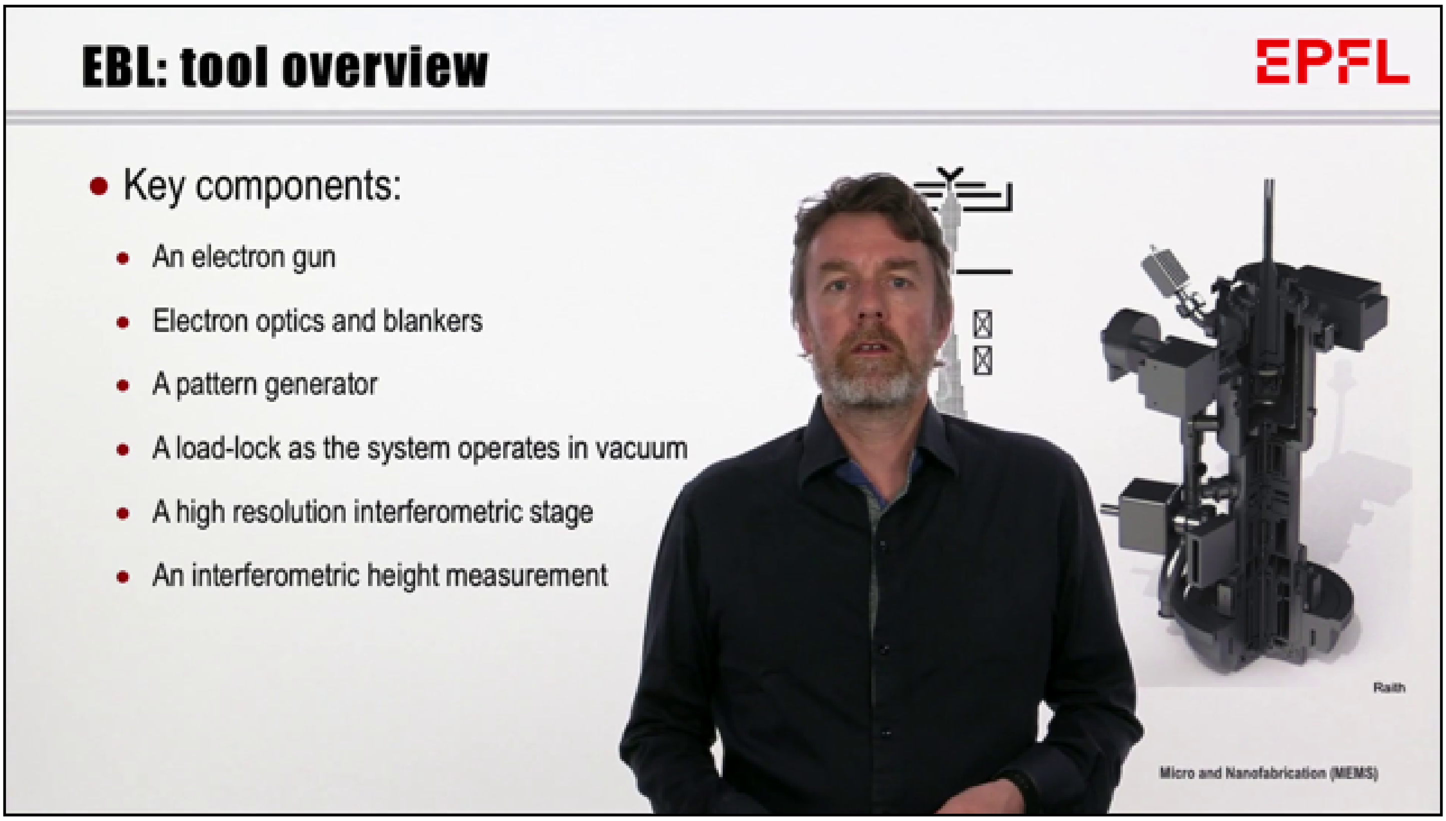


and 150 nanometers in height. These white spots here are the pillars seen from the top. Whereas these ones are pillars that have collapsed during the last drying process. It shows their width and high aspect ratio of the pillar.

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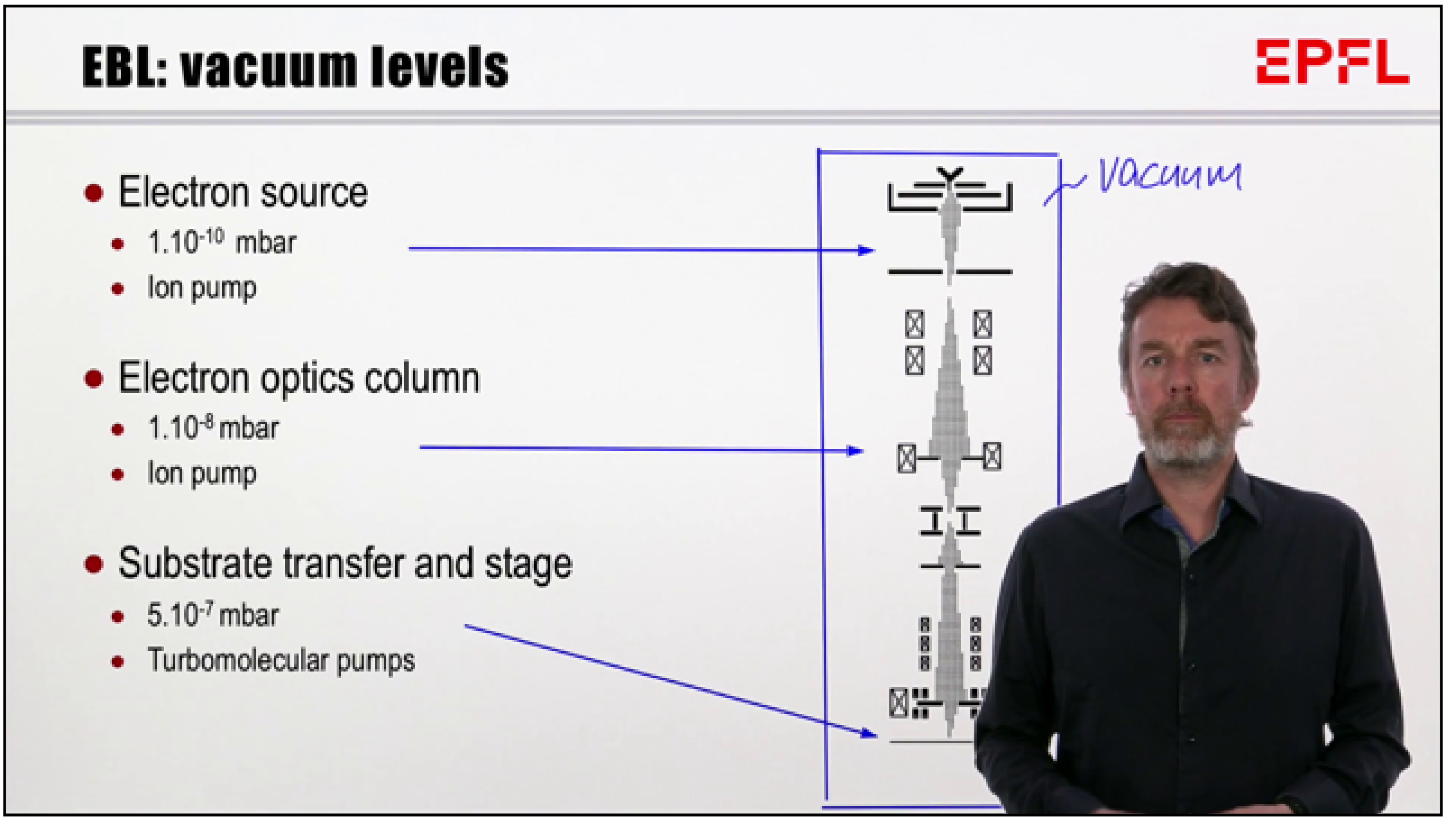


The key ability of an e-beam lithography system is to focus a beam of electrons into a few nanometer range, and then to directly write with electrons in the resist a relative displacement of beam and substrate. EBL is therefore a direct write serial technique, similar to laser writing that we discussed earlier for the mask making in UV lithography. The electrons are first extracted from the gun, and then accelerated towards a series of electron lenses that will focus and correct aberrations in order to obtain the smallest and brightest possible electron beam. Additional features include beam blankers, and beam deflectors. The resist coated wafer is placed on a stage, whose position can be controlled by optical interferometers. The user interacts with a column indirectly via exposure software that controls the hardware's so-called "pedal generator". Samples are loaded and unloaded into a system via a vacuum load lock, not shown on this slide. E-beam lithography requires a high vacuum chamber so that electrons can freely travel from the gun to the wafer. The e-beam column is built inside a vacuum system, like shown here. Different vacuum levels are required for the different parts of the electron column. High vacuum is required at the electron gun region to avoid source contamination by residual gas molecules. Further down in the column, the vacuum requirement becomes less stringent. Ionic pumps are required for the gun and the optics. At the sample level, turbo pumps are typically sufficient. So how can we have different vacuum levels in one chamber? The electron optic section of the EBL tool is almost entirely separated from the sample stage, except for a small aperture called a "differential pumping aperture", which is large enough to let the electrons down the column, but which is small enough to maintain a differential pressure. Note that the high vacuum air does not get sucked through holes like in a domestic vacuum

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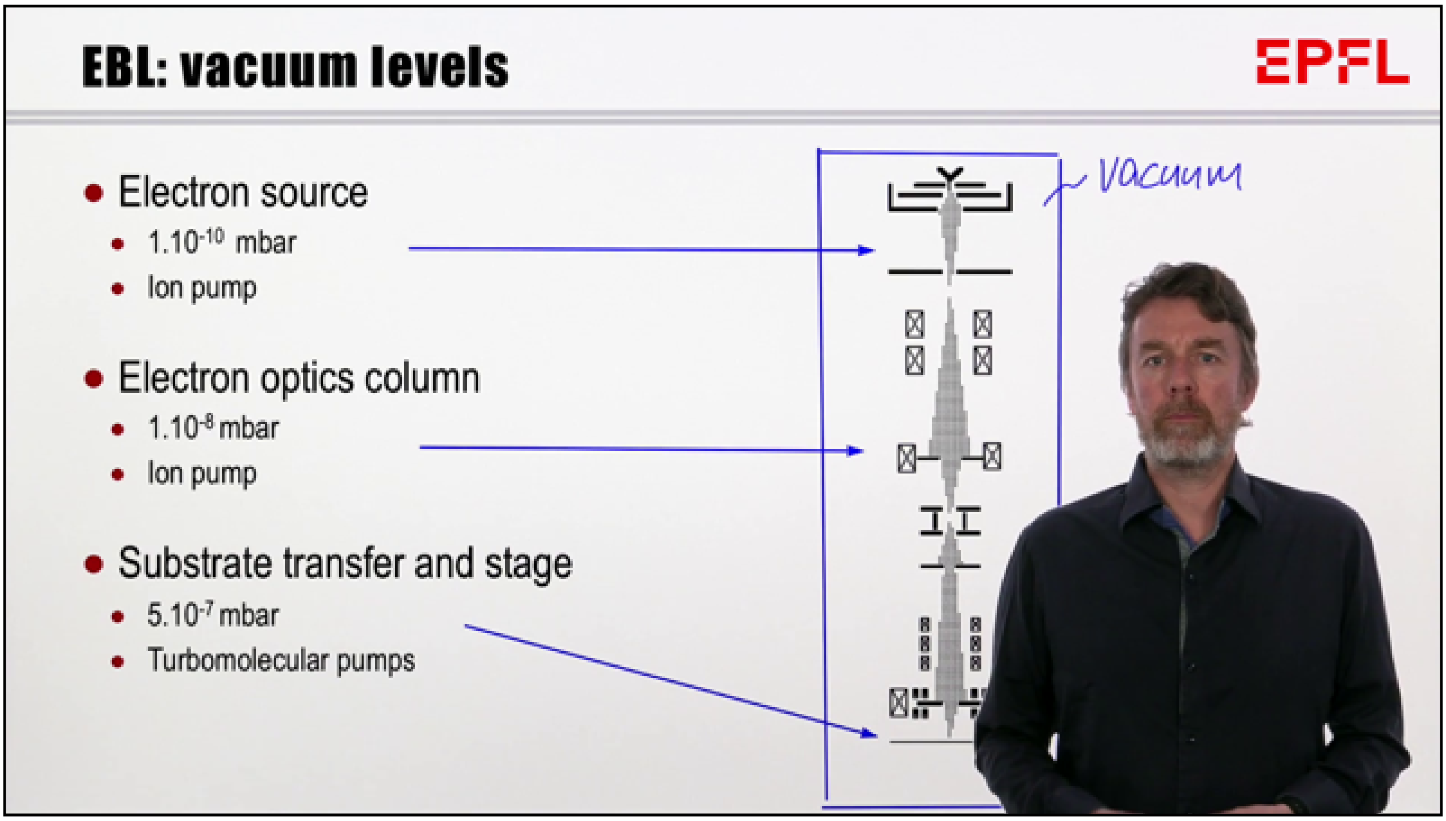
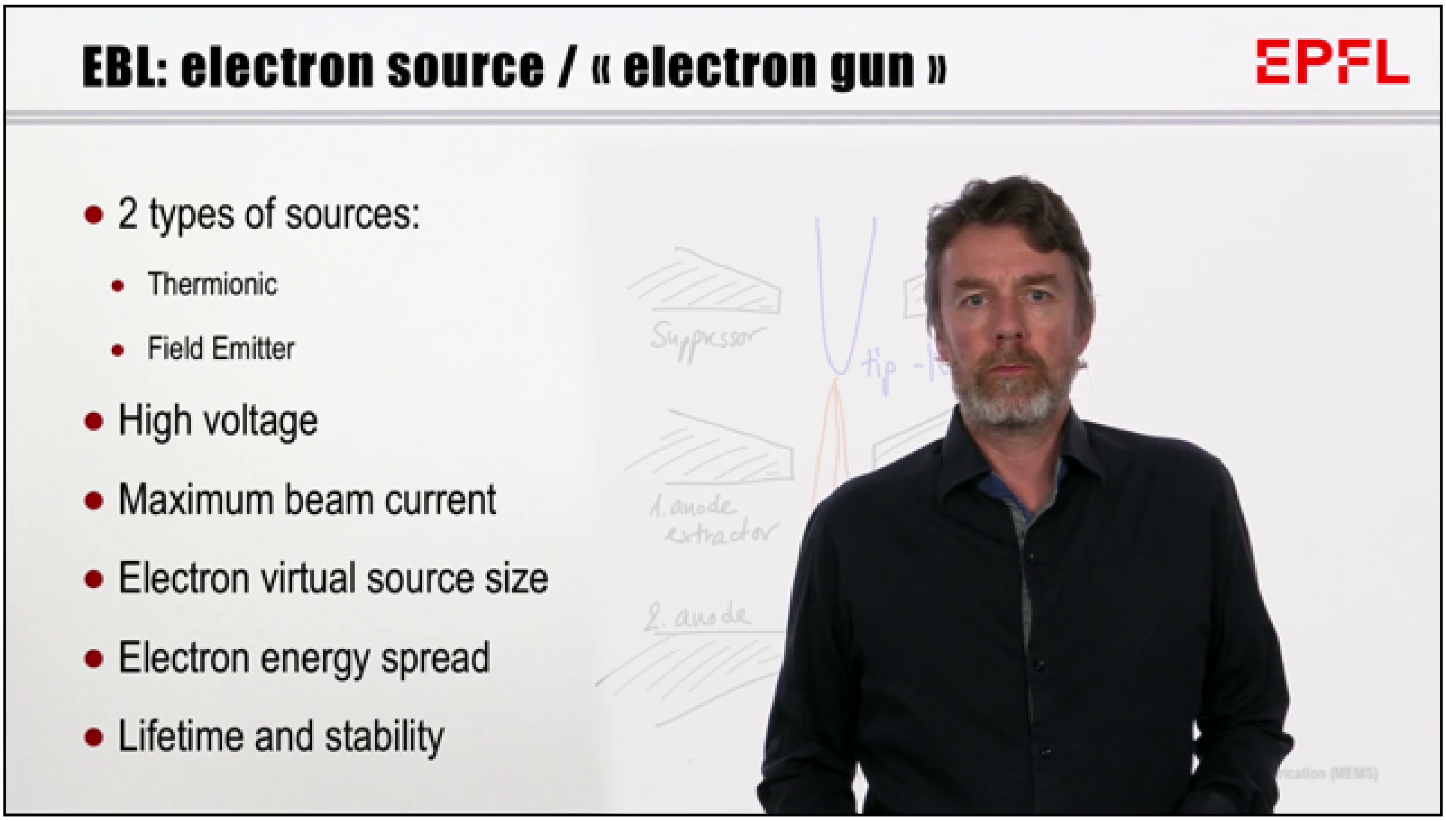



cleaner, because the mean free path of air atoms at low pressure can be many meters, so that they never bump into each other.

notes

summary




They just bounce around the chamber and rarely pass through the small aperture. In this way, it is possible to have a poor vacuum in the sample stage region, say 10^-7 mbar, but a high vacuum, 10^-8 mbar or better, in the gun, an electron optics part of the column.

notes

summary

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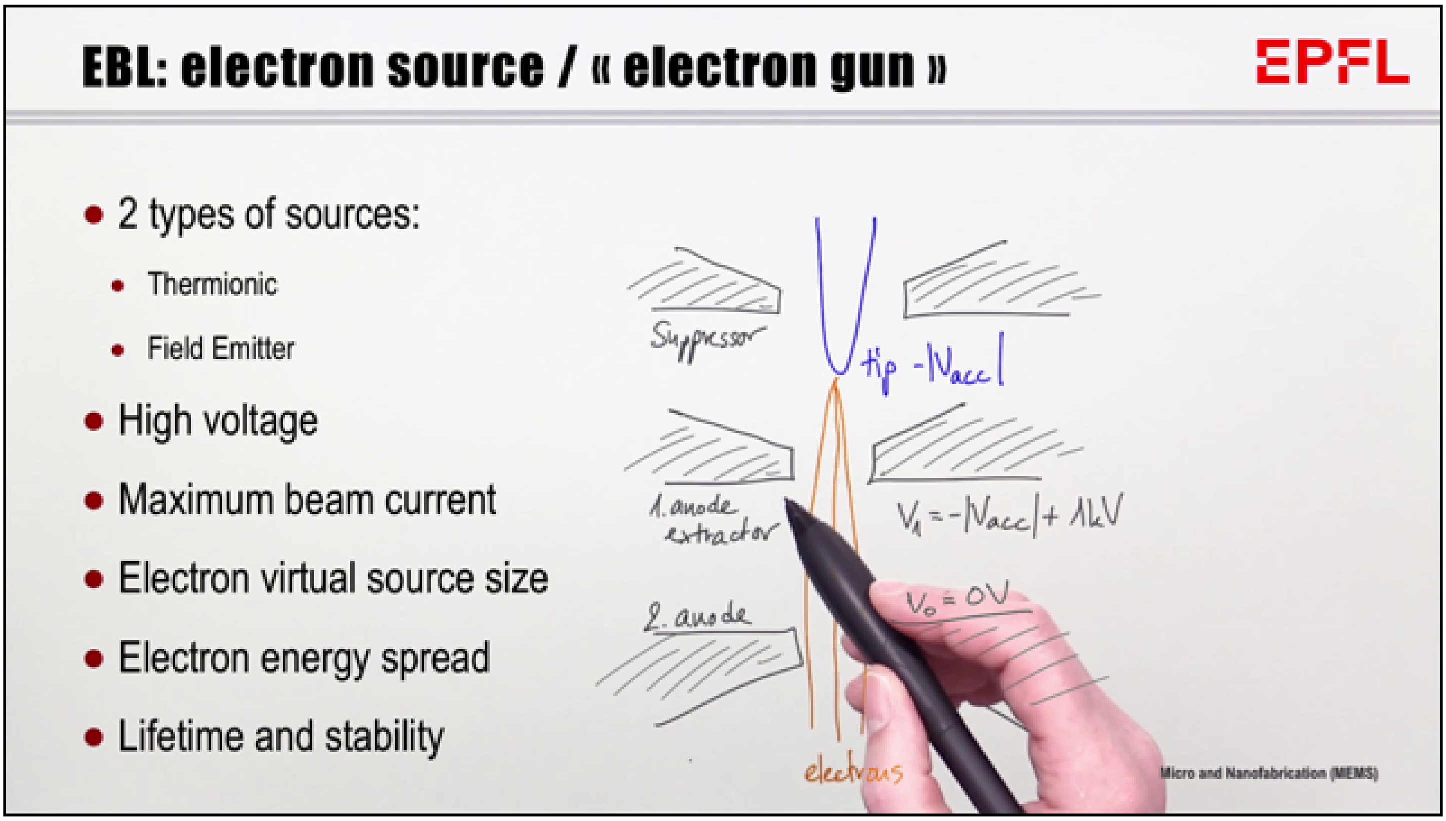
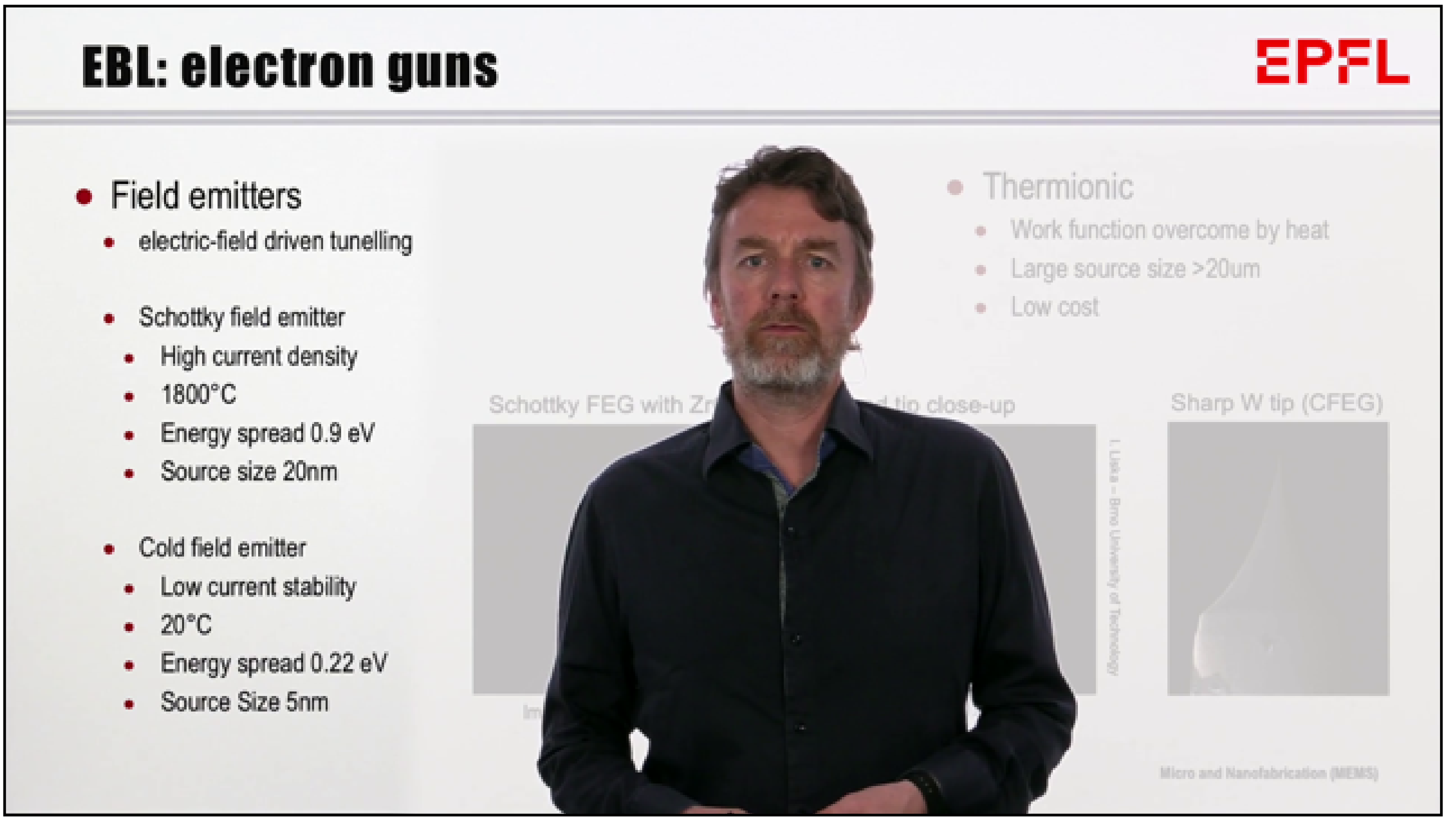



So lets now have a look at the electron source, also called gun. Different options exist to emit electrons from a metal source into a vacuum. One variation is to use thermionic sources, where the source is heated to overcome the work function to bring electrons into the vacuum. Another way is to use the so-called "field emitters", where high electric potential is applied to the sharp tip. In e-beam lithography, the electron source must combine the two following properties: first, ideally it is monochromatic to reduce chromatic aberrations; second, it has a high brightness and a current stability. Field emitters fulfill these requirements much better than thermionic sources. So, lets see how a field emitter electron gun looks like. So the cathode, the tip, is at the negative potential with respect to the first anode, which is the extractor, in order to create a high field to extract the electrons from the tip.

notes

summary

6m 49s




Between the extractor and the second anode, the electrons are further accelerated. The main function of the suppressor, up here, is to limit electron emission to the end of the tip. This helps to reduce the effective source size and improves resolution. The potential of the suppressor is negative, relative to the tip. Typically, Schottky field emitting guns are used, which are thermal field emitting sources. In such FEG, a single crystal tungsten tip is coated with zirconium oxide, which has the unusual property of increasing in electrical conductivity at high temperature. Zirconium oxide allows lowering the work function compared to tungsten alone. Compared to cold field emitting guns, these guns are less bright but deliver stable high currents and are less demanding in operation. The cathode for field emitter systems is typically a single crystal sharpened tungsten wire. This allows for virtual source diameters of a few tens of nanometers for Schottky emitters, all the way down to 5 nanometers for cold field emitting guns. Schottky field emitters are ideal for e-beam lithography due to the excellent current stability, which is below 1% probe noise versus up to 10% for cold field emitting guns. They have low current drift, below 1% versus over 5% for cold field emitting guns. And thermionic emitters are typically not used in e-beam lithography due to their large source diameter, energy spread and limited lifetime. The electric field on the tip of a Schottky field emitter is applied to decrease the material working function. For this reason, such field emitters are coated with low working function materials such as zirconium dioxide. Even if the Schottky field emitter is a thermionic emitter, the brightness and the current density are compared with that of a cold field emitter. Here we can see two images of a Schottky field emitting gun. On the left, the zirconium oxide reservoir is nicely seen below the tip. In the central

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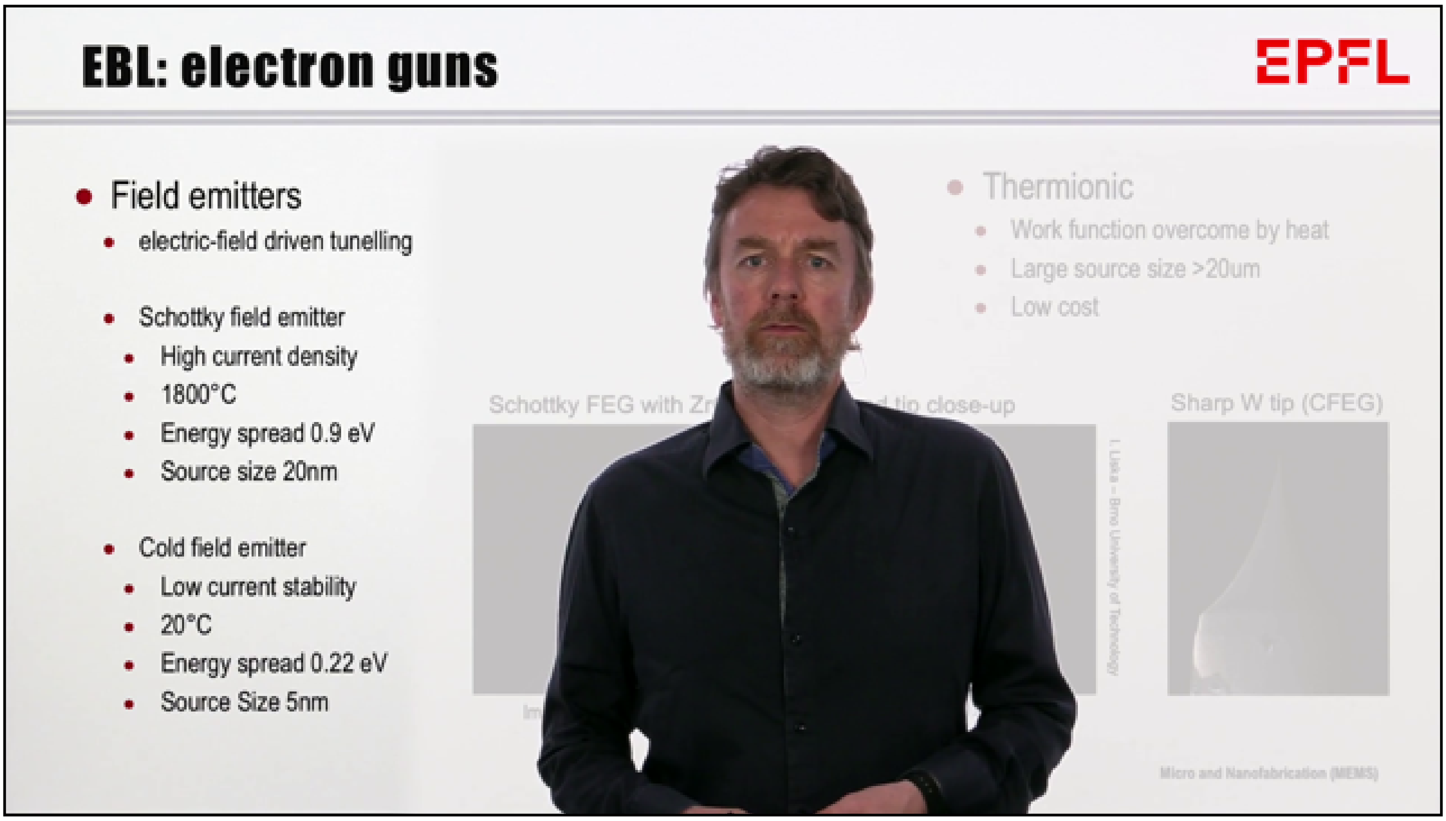


image, one can identify the crystalline planes of the tungsten tip in the Schottky emitter and for cold field emitting guns, here on the right side, the tip is sharpened to about 100 nanometers. In high electric fields the electrons are thus extracted directly from the tip.

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