EPFL

Course material

Course:

Micro and Nanofabrication (MEMS)

Video:

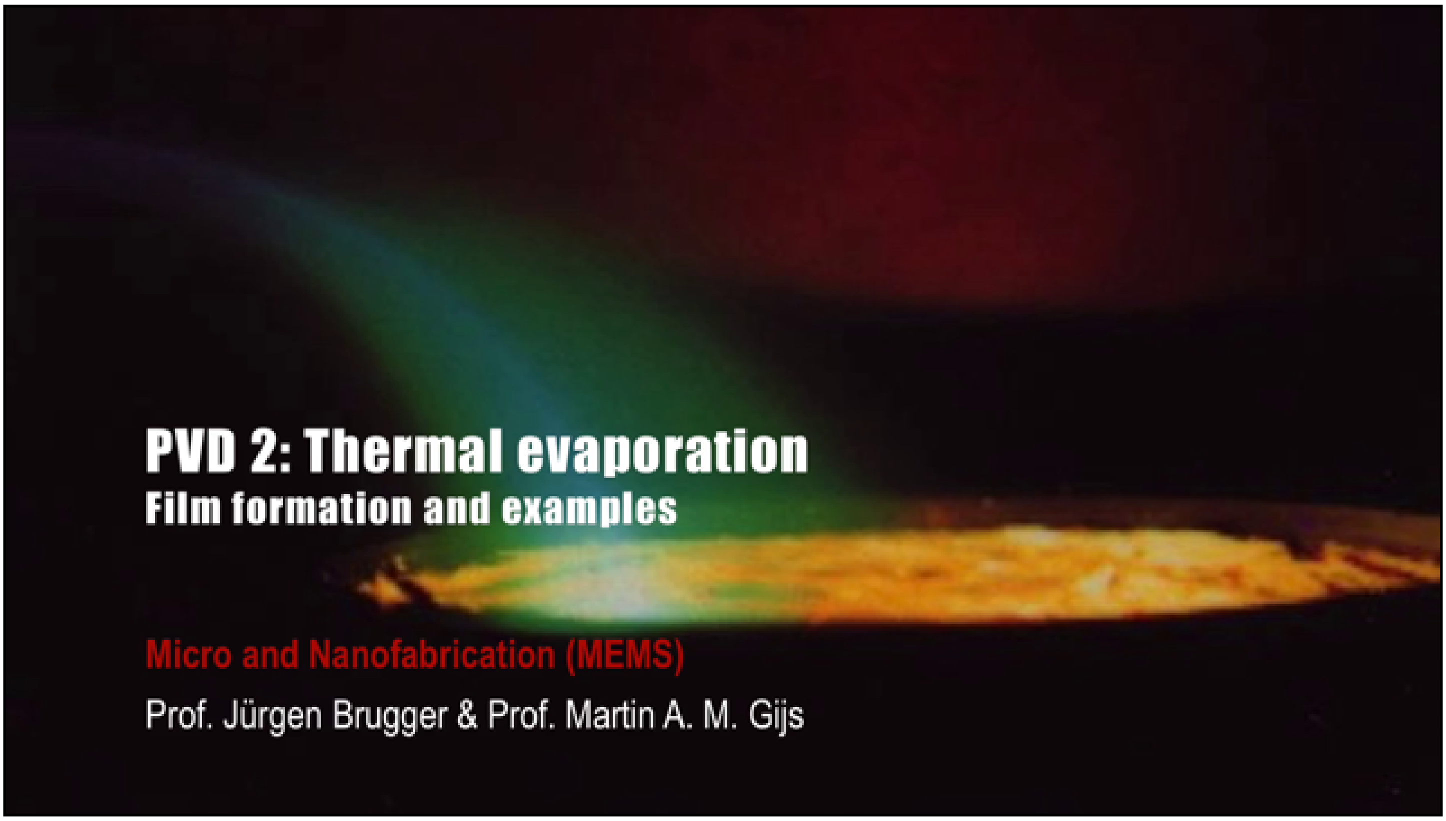
3.2 PVD2, Thermal evaporation

Concepts (extracted from automatically generated subtitles):

Off-axis position of the wafer. Amount of material. So-called lift-off technique. Surface features. Details of these equipment aspects. Film forms. Important case. Layer of photoresist. Lift-off. Thin film. Stencil lithography. Live demonstration of a lift-off step. Temperature of the substrate. Planetary systems. Basic configuration of a thermal evaporator.

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

to video

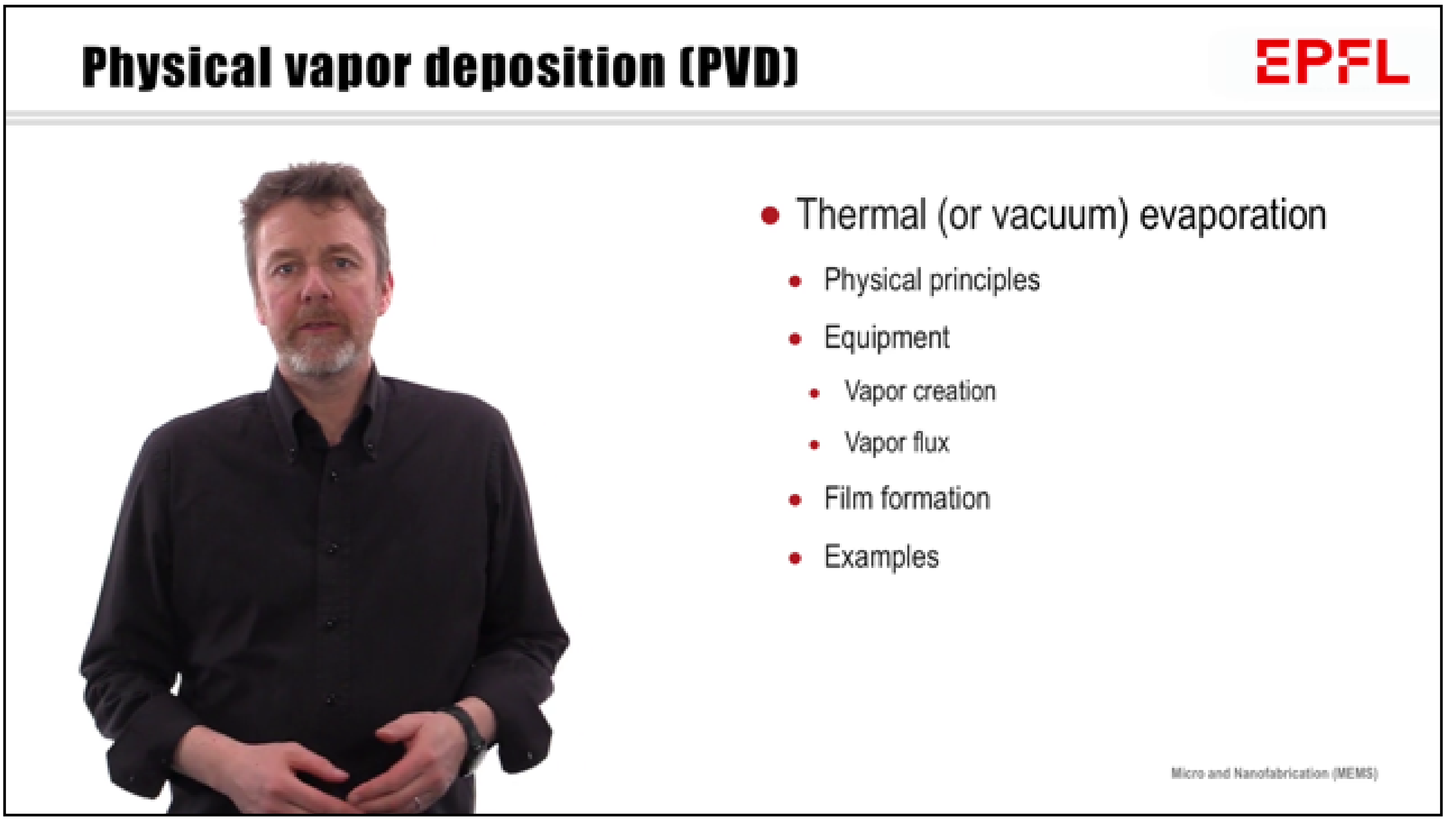


...

notes

summary

0m 0s

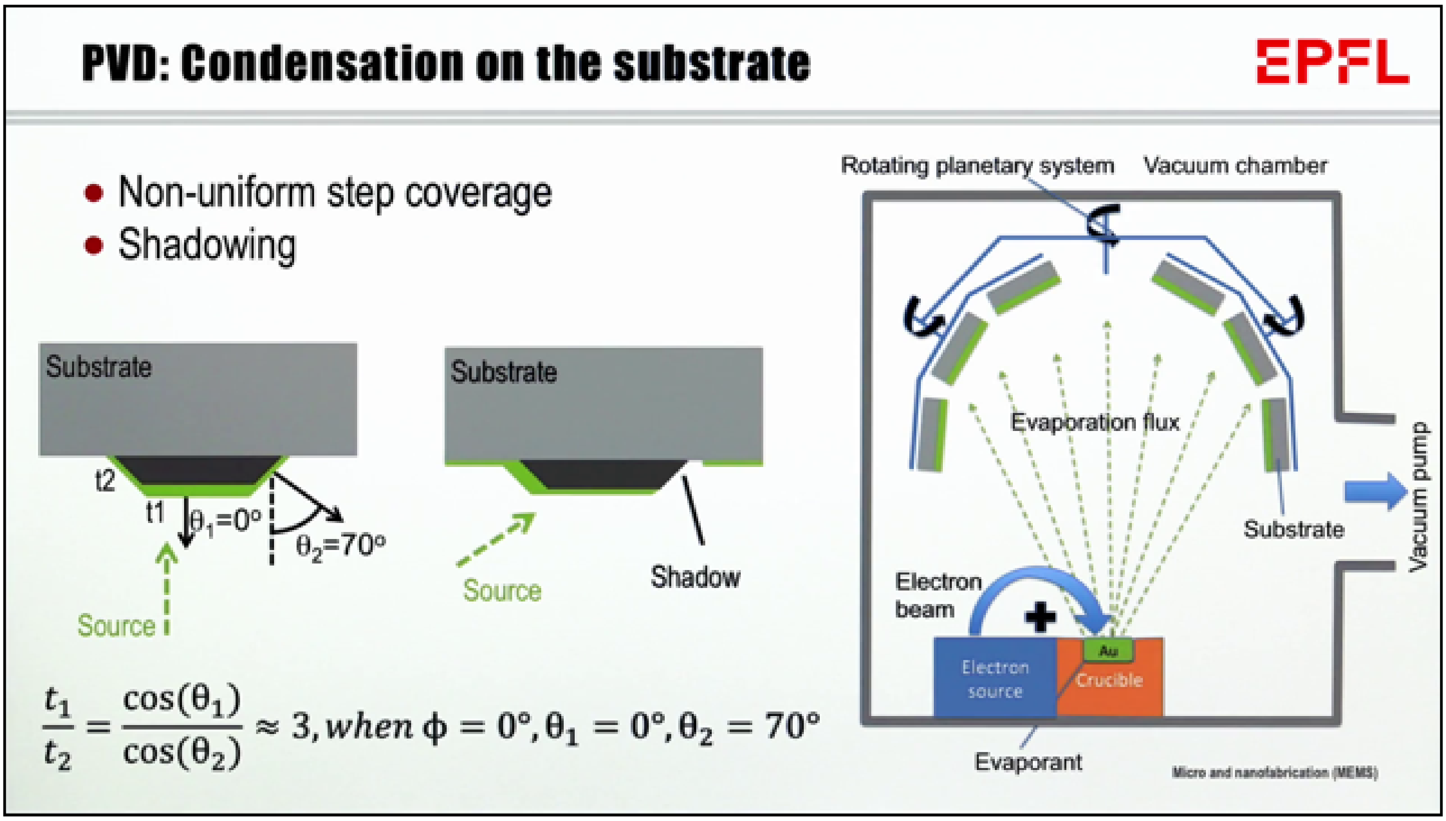


Now let's have a look in detail how the film forms on the surface.

notes

summary

0m 1s

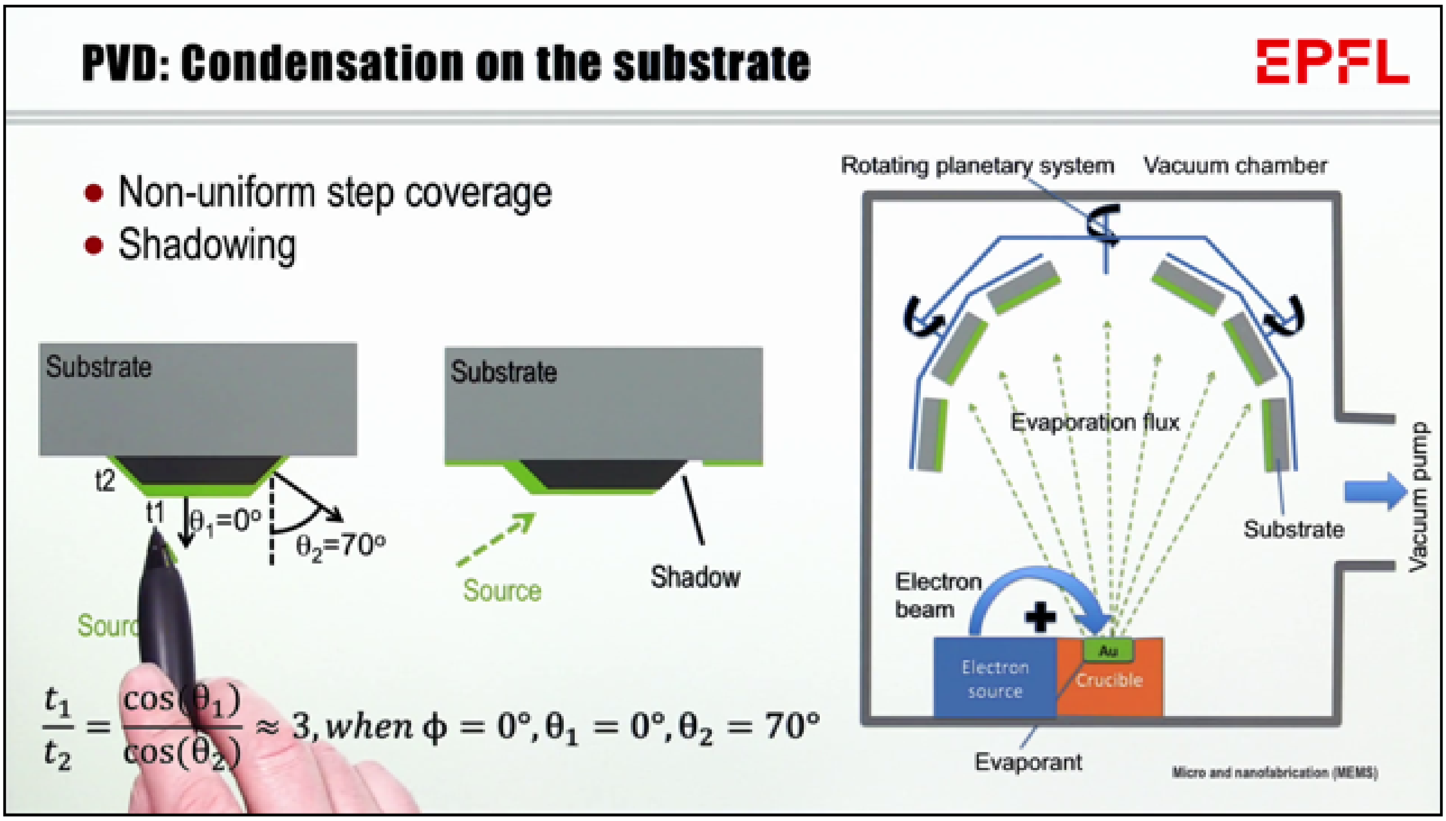


As mentioned before, the long mean free path allows for very directional flux of evaporant. This has an effect for surfaces that are not perfectly flat as often encountered in MEMS and microfabrication with 3D surface features.

notes

summary

0m 5s

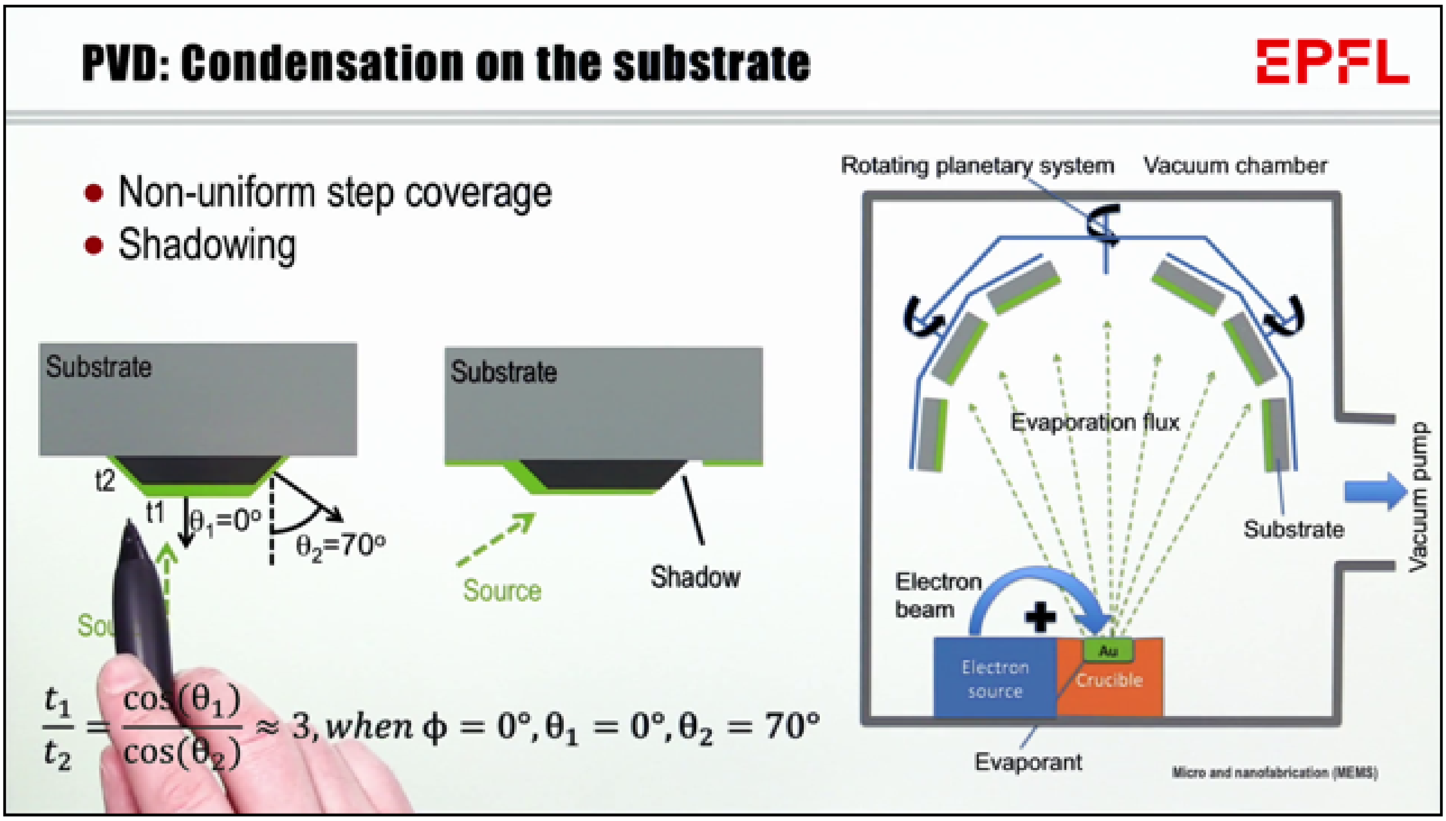


The left image shows a situation for a tapered surface structure in grey , that has to be coated by the thin film in green with the source coming from the bottom. Now, by simple geometrical consideration, one can already see that on the flat part, that is facing the source, we obtain the target of thickness t1,

notes

summary

0m 24s

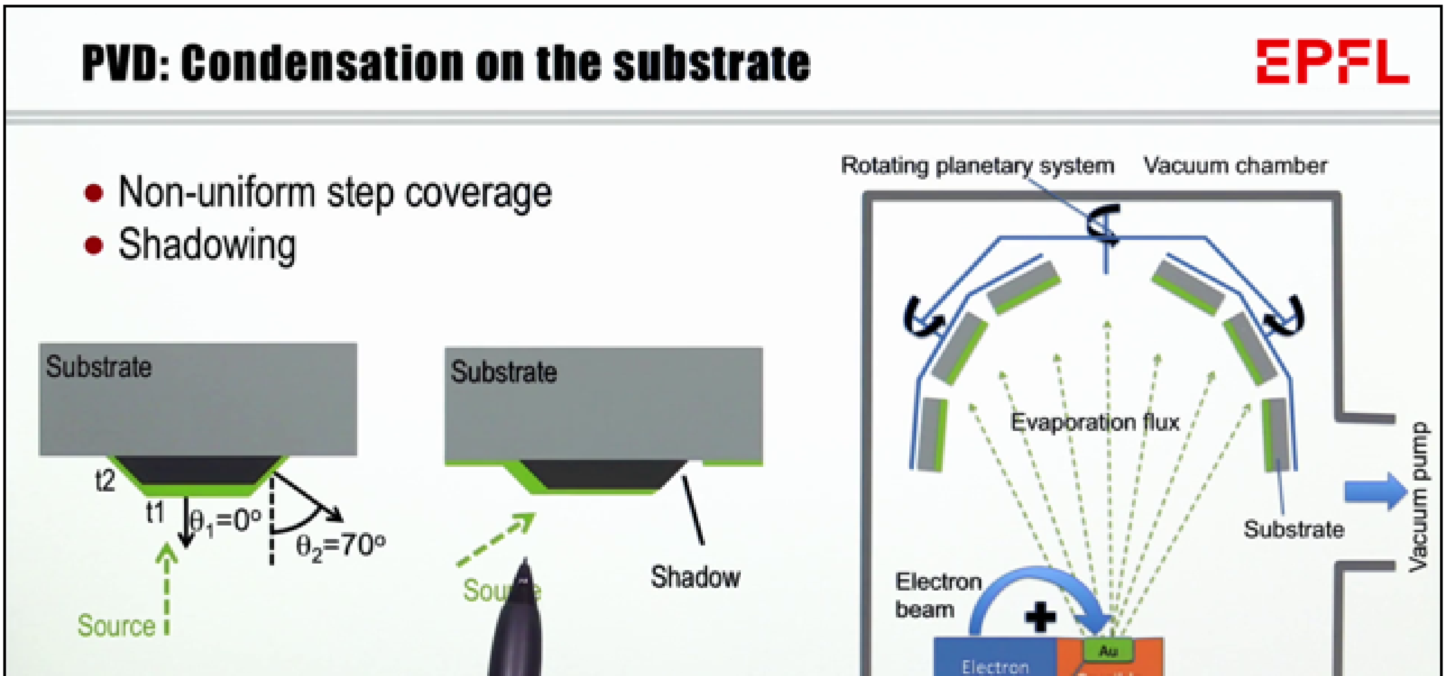


whereas on the sloped part of the structure,

notes

summary

0m 48s



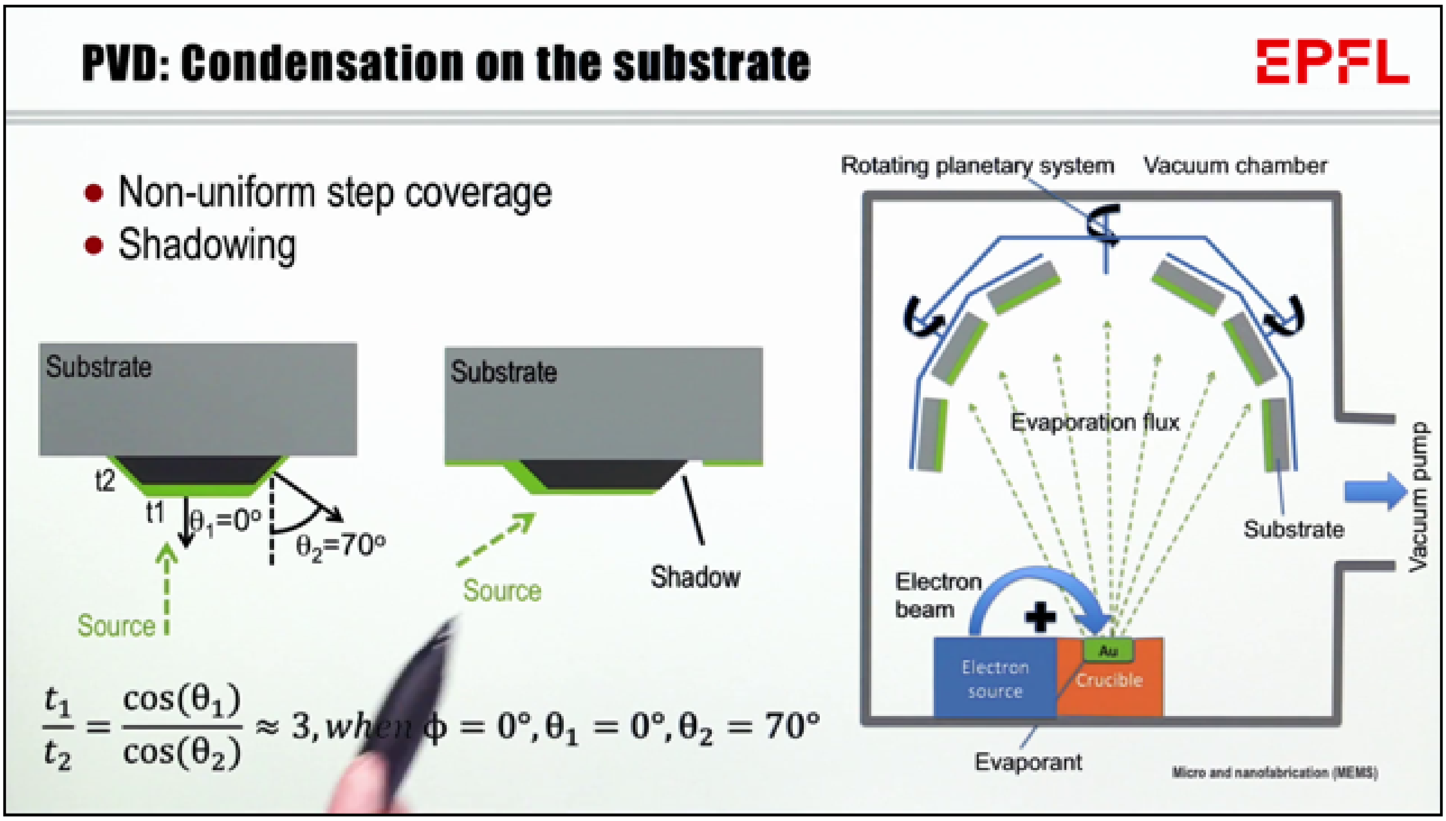
$$\frac{t_1}{t_2} = \frac{\cos(\theta_1)}{\cos(\theta_2)} \approx 3, when\ \phi = 0°, \theta_1 = 0°, \theta_2 = 70°$$

we have a thickness of only about one third of the target thickness in the case of an angle of 70 degrees like shown here. This can be calculated simply by geometrical considerations.

notes

summary

0m 56s



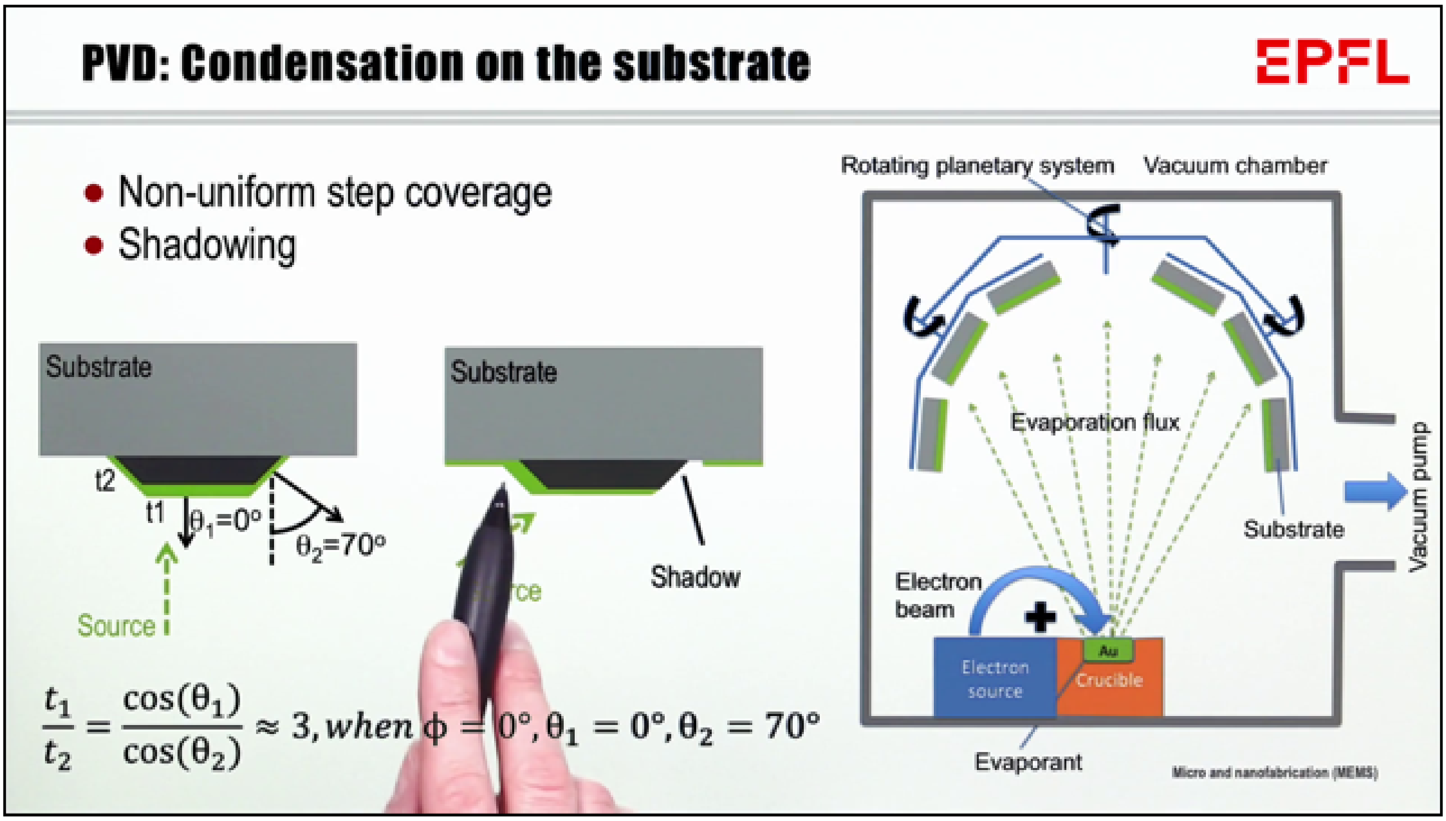
$$\frac{t_1}{t_2} = \frac{\cos(\theta_1)}{\cos(\theta_2)} \approx 3, when\ \phi = 0°, \theta_1 = 0°, \theta_2 = 70°$$

Another important case is the off-axis position of the wafer, which we always have in this sort of arrangement,

notes

summary

1m 13s

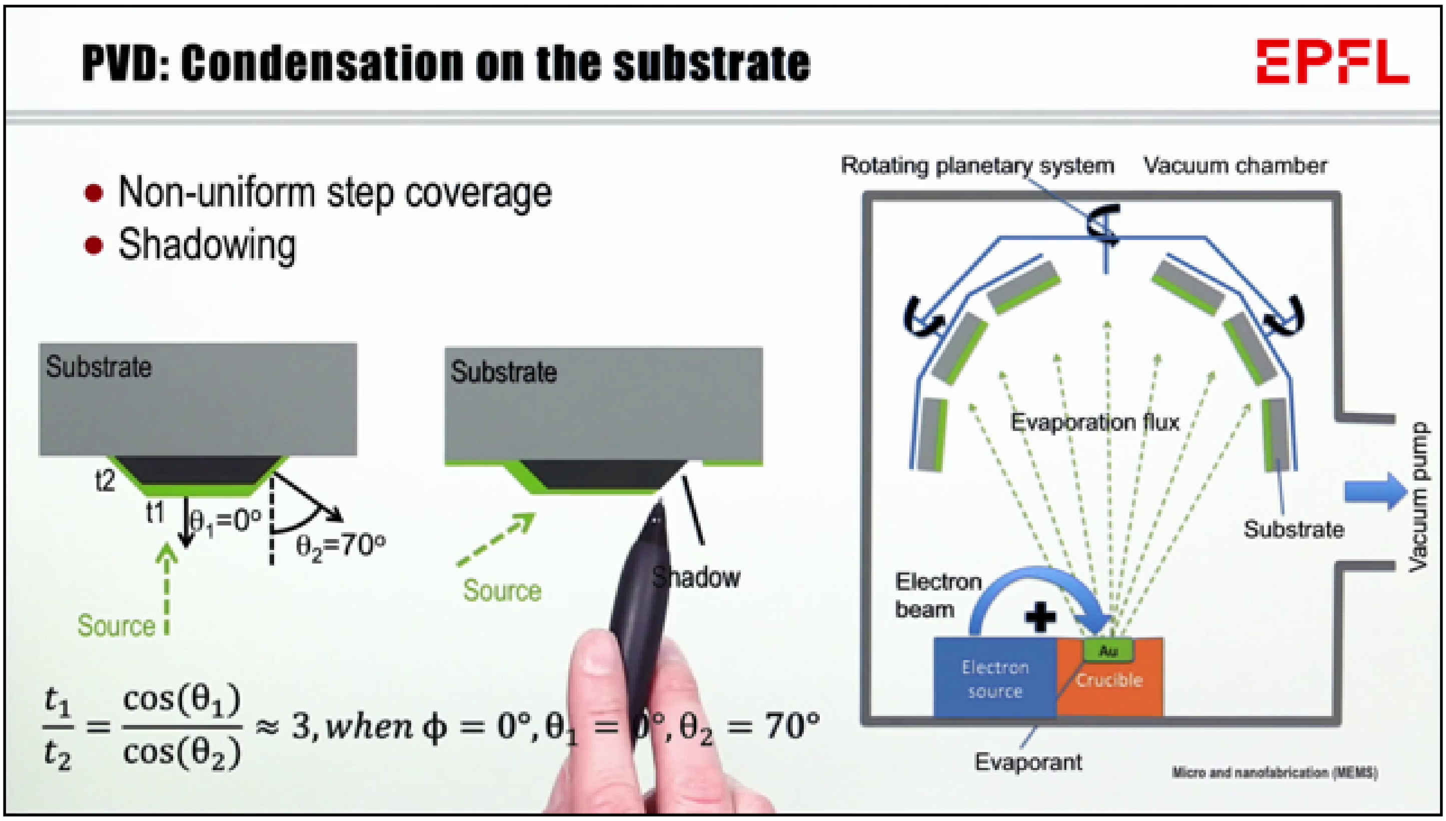


is that if we have surface features we can create a shadow effect because of the directionality of the beam. which can not deposit on the lee side of this structure. Consequently, there is a much thicker film deposited

notes

summary

1m 23s

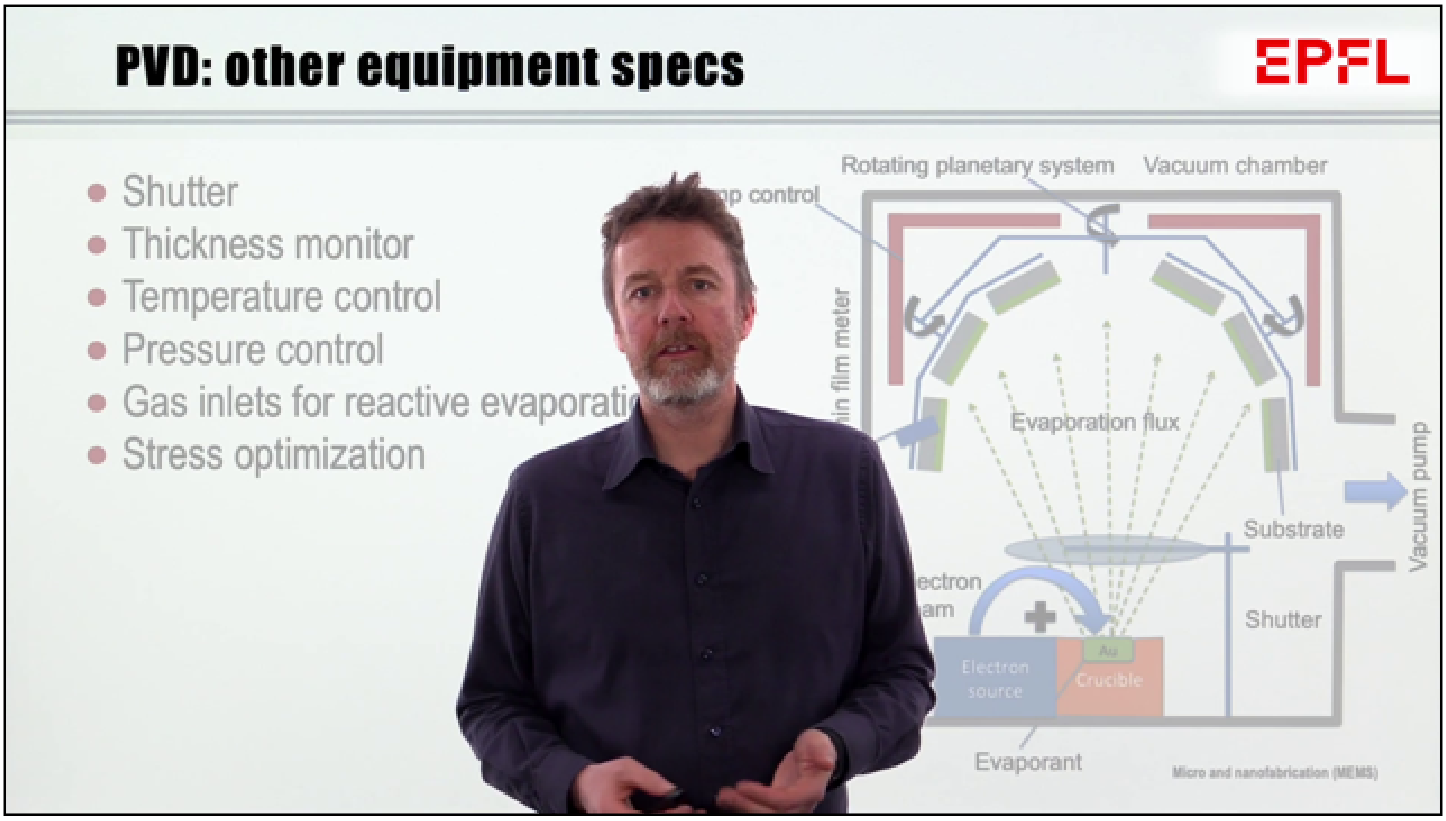


on the slope, facing the source, than on the slopes that are under an angle to the source

notes

summary

1m 37s

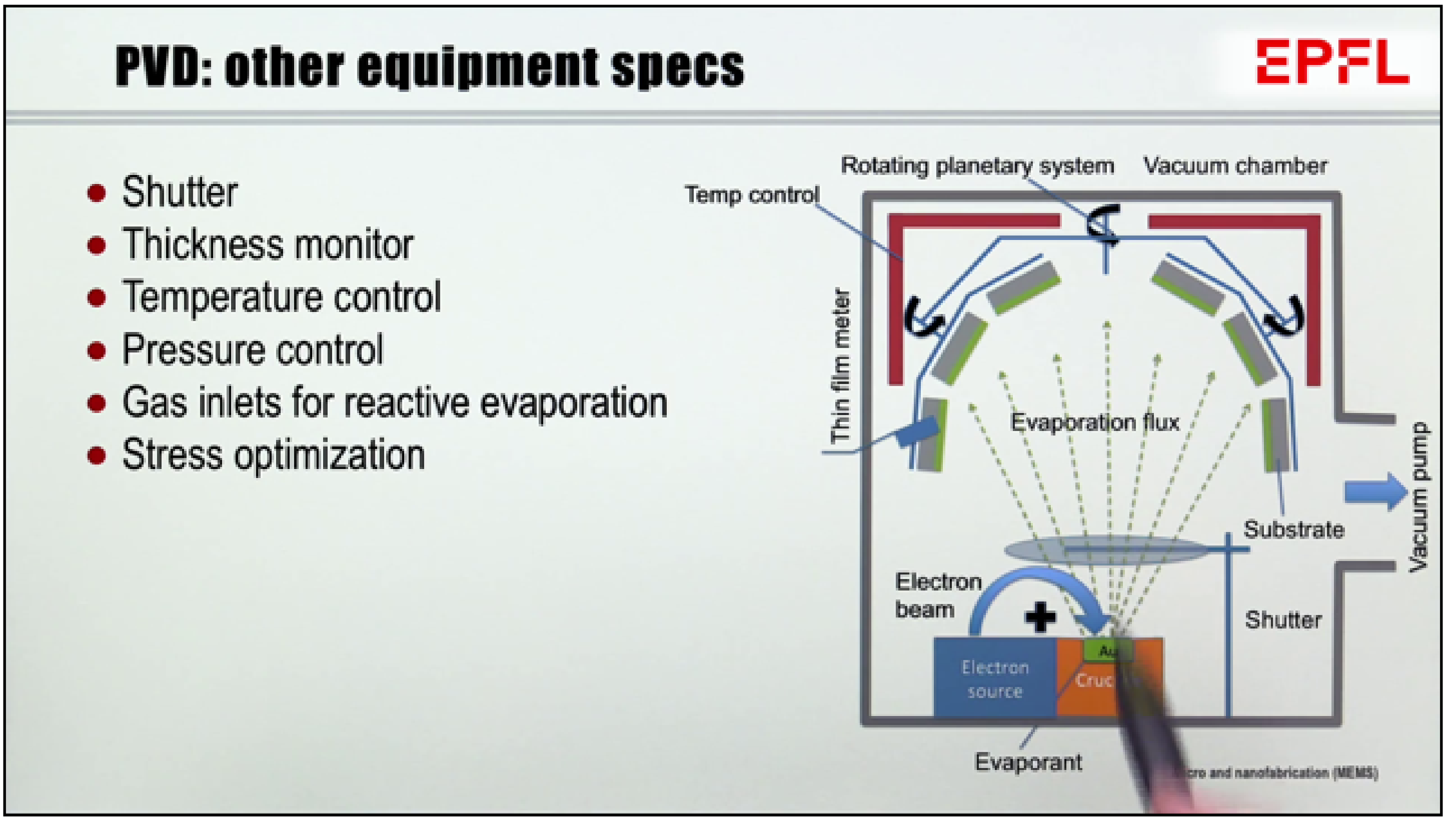


or actually invisible to the source. To overcome this important drawback, modern evaporator tools are equipped with rotating planetary systems as shown here which repositions the wafers during the evaporation and cancels the aforementioned effects. Thus, every wafer in the planetary system receives the exact same amount of material under various angles which yields a well controlled film thickness across a wafer's surface, and from wafer to wafer in a batch.

notes

summary

1m 45s



In addition to the basic configuration of a thermal evaporator, there are some other features that have been incorporated for better control and monitoring. One of them is the mechanical shutter shown here that blocks the flux between the crucible

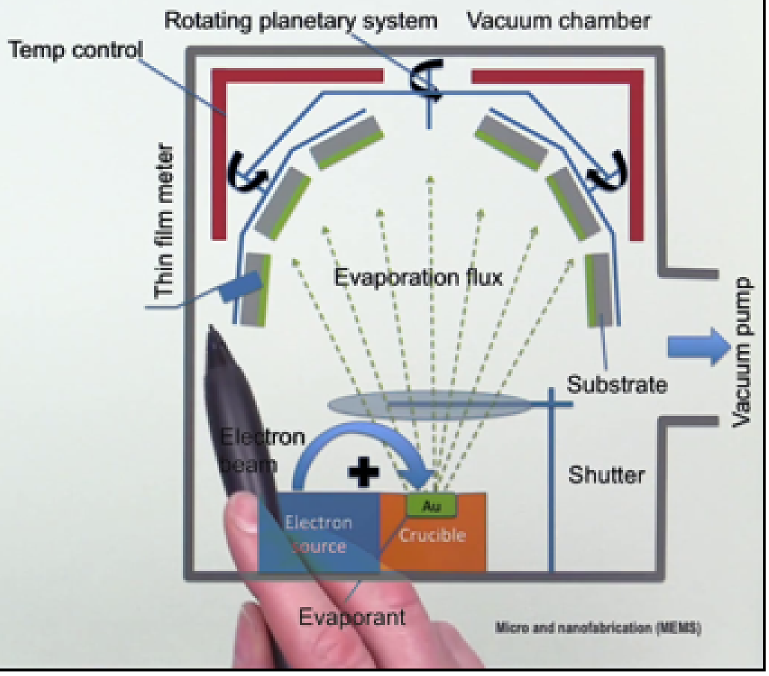
notes

summary

2m 22s

PVD: other equipment specs

- Shutter
- Thickness monitor
- Temperature control
- Pressure control
- Gas inlets for reactive evaporation
- Stress optimization

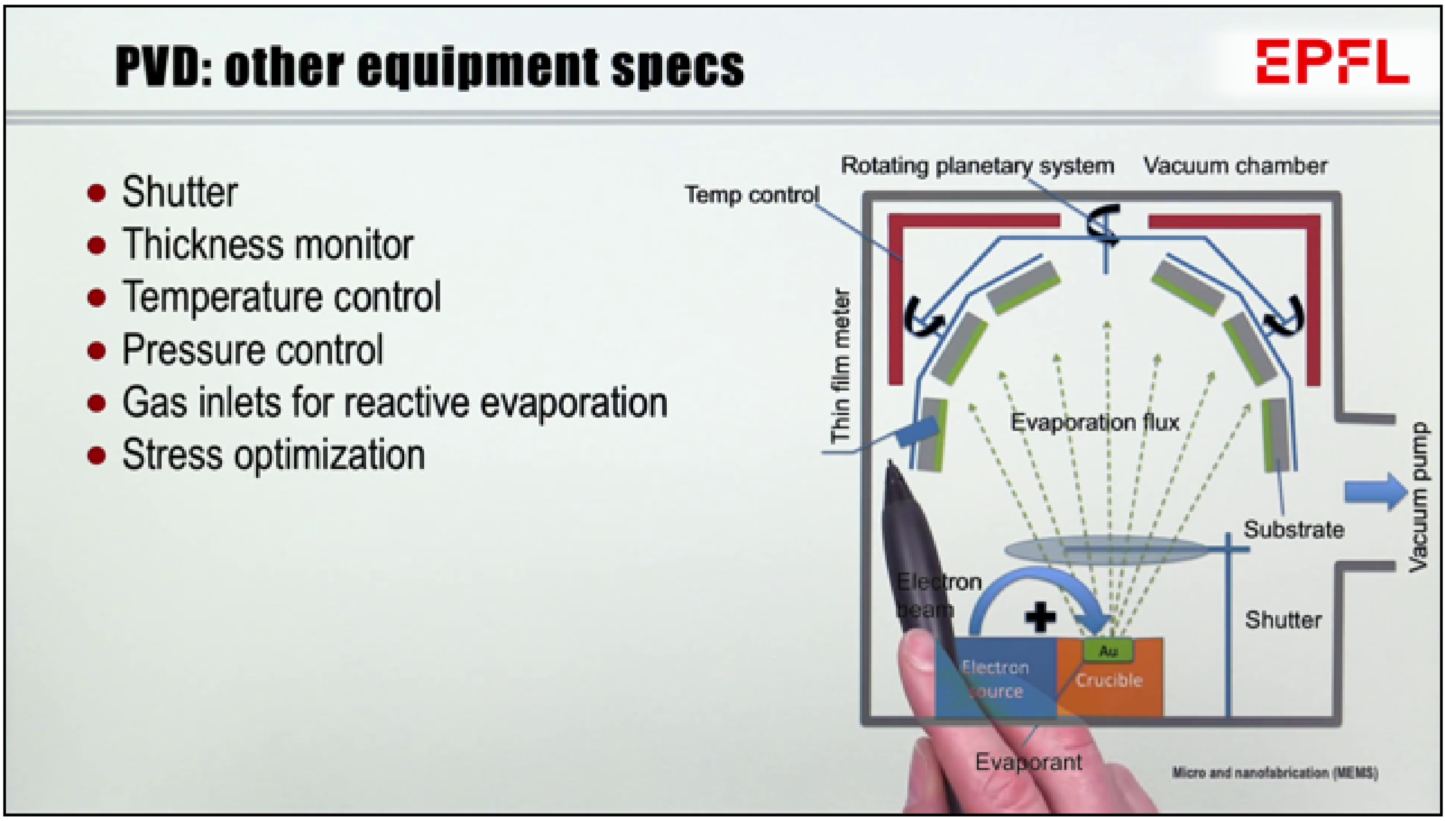


and the wafers and allows for very precise timing of the deposition. It's much more precise than switching on and off the heat source

notes

summary

2m 37s

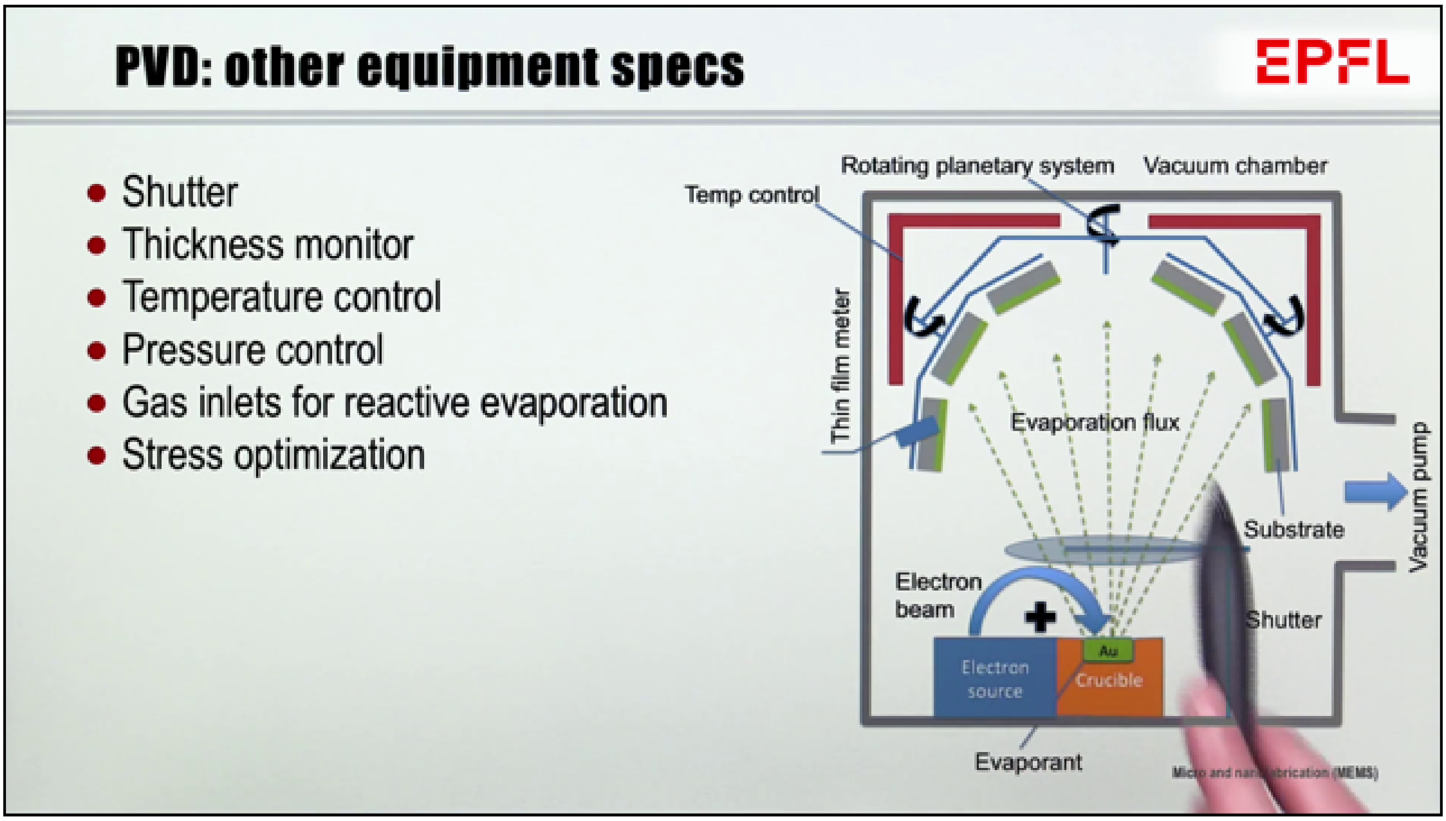


Another important feature is the thin film monitor,

notes

summary

2m 49s

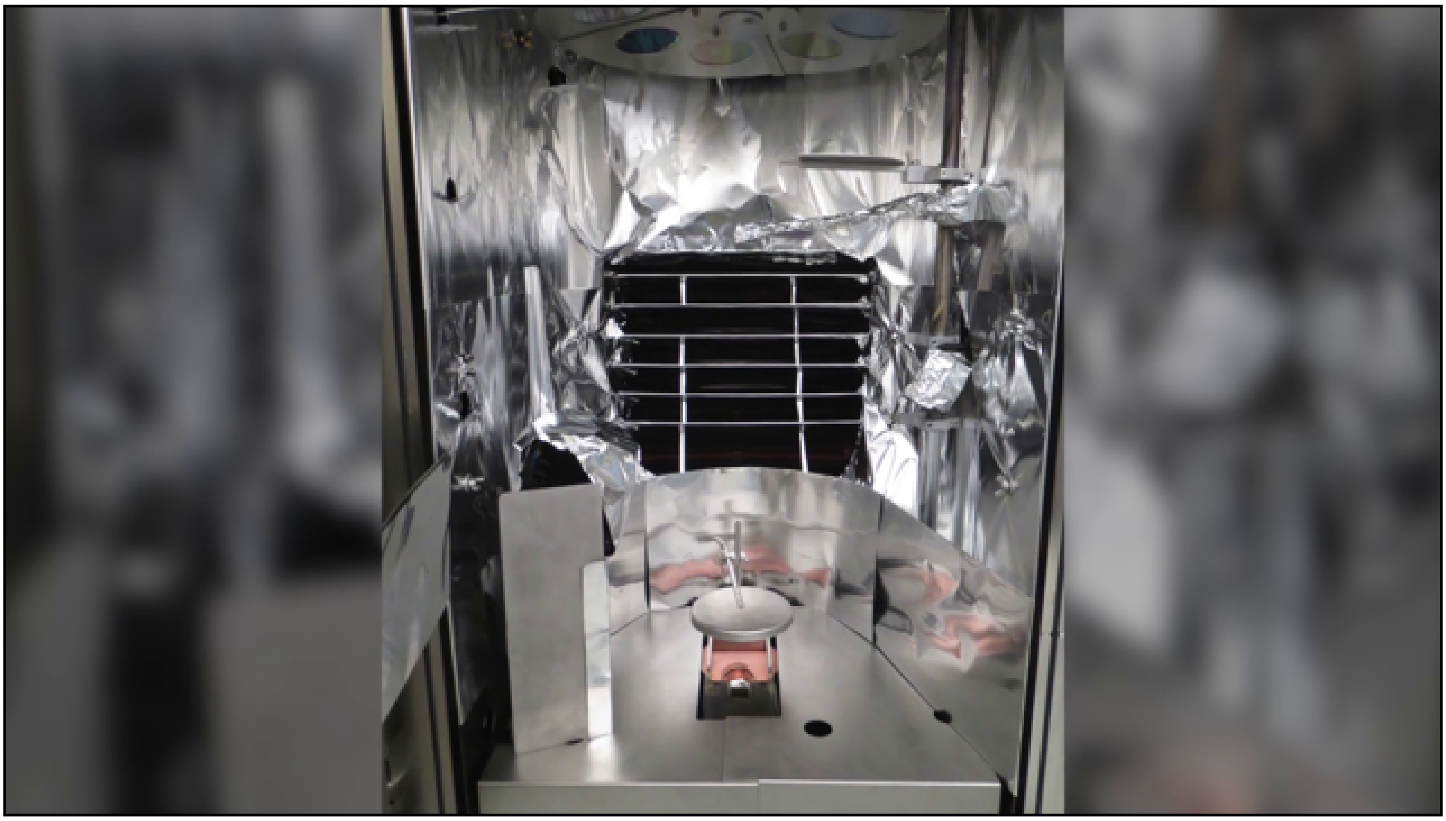


typically a quartz crystal microbalance that measures the added mass which can then be used to deduce the thickness that has been added on each of the wafer. We can furthermore control the temperature of the substrate either by cooling or heating which has an important influence on the film morphology as the thin film grows.

notes

summary

2m 50s

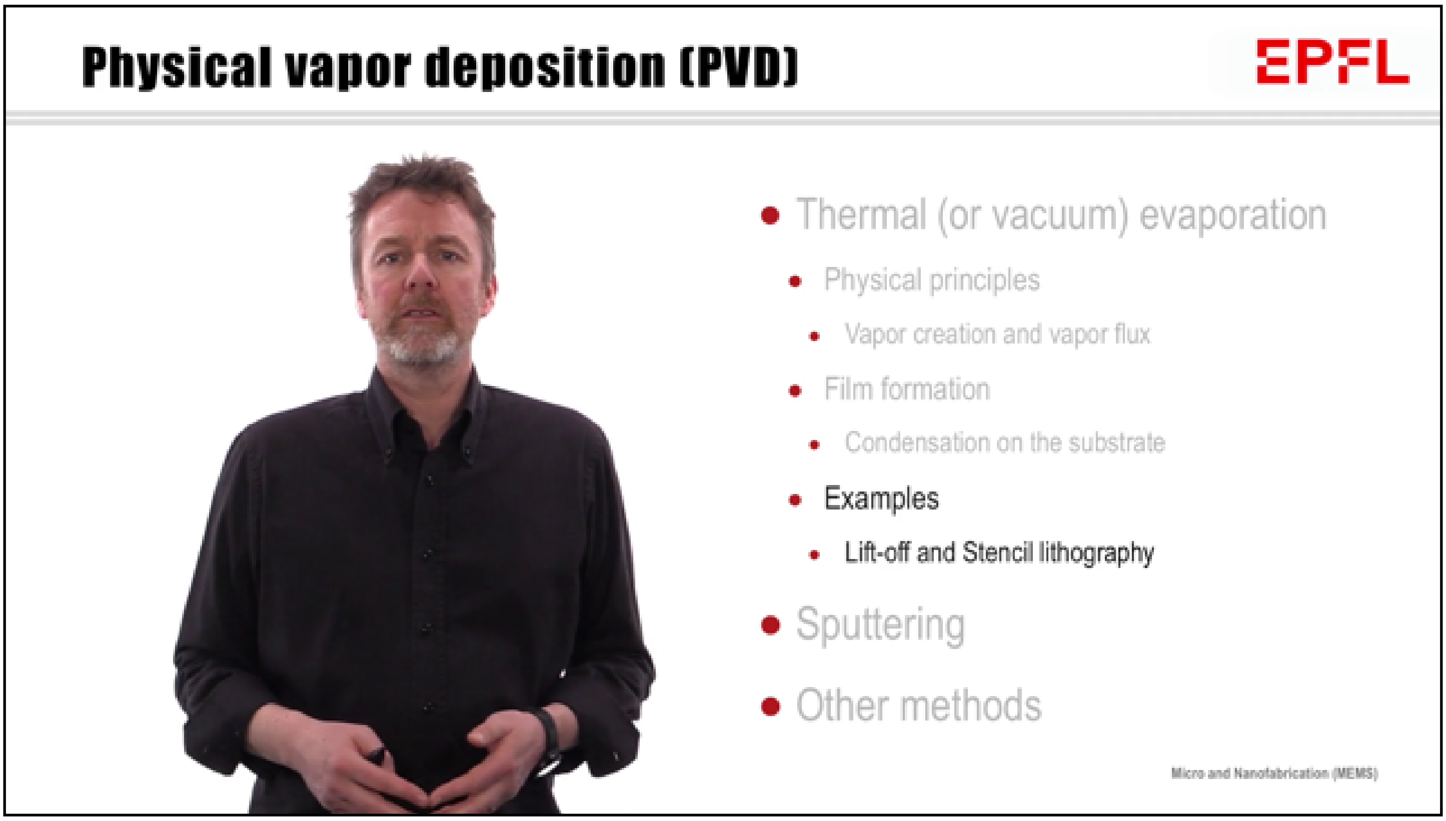


Further, we can always control the pressure in the chamber and also inlet some specific gases for reactive evaporation. All these features have an influence on the stress of the thin-film as it grows on the surface and can be optimized if one knows how they influence the growth mechanism. Here on this photograph, you can see the inside of one of our clean room thermal evaporators. On the bottom you can see the crucible with the mechanic shutter, and on top,

notes

summary

3m 13s



you can see the wafer holder system that holds a couple of wafers for thin film coating. And here you can see a close up photograph of the crucible area with the mechanical shutters. More details of these equipment aspects will be shown later in a dedicated video taken in our clean room. So now that we have seen the basic principles

notes

summary

3m 49s

PVD: particular example LIFT-OFF

1. Photoresist patterning (Slope!)
2. PVD with shadow effect (directional)
3. Photoresist stripping

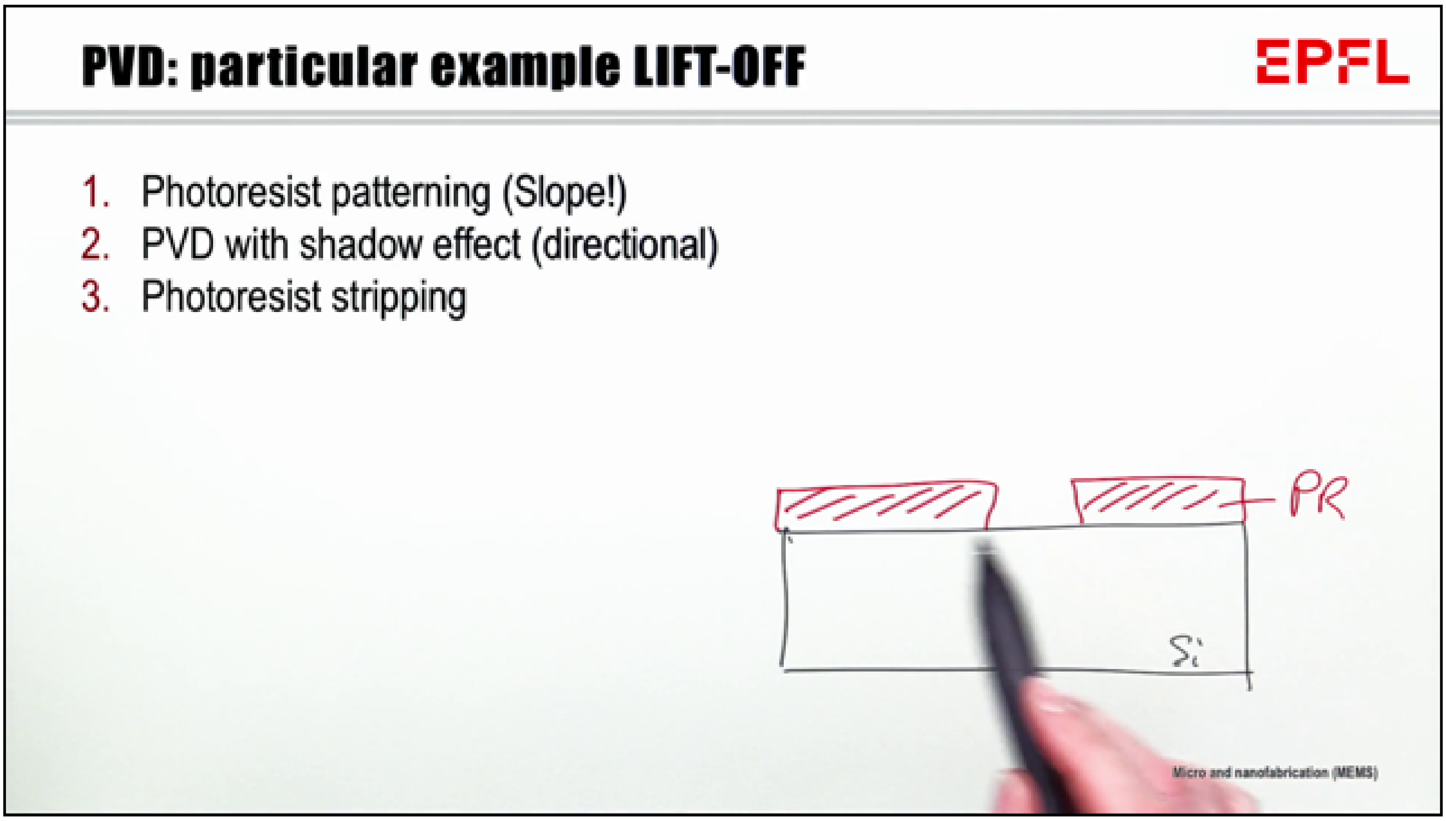
Micro and nanofabrication (MEMS)

and equipment aspects of thermal evaporation, let's have a look at some characteristic examples. I want to show you in particular the so-called lift-off technique and then stencil lithography. They both rely and benefit from the long mean free path and shadowing effect that we can obtain in thermal PVD.

notes

summary

4m 11s

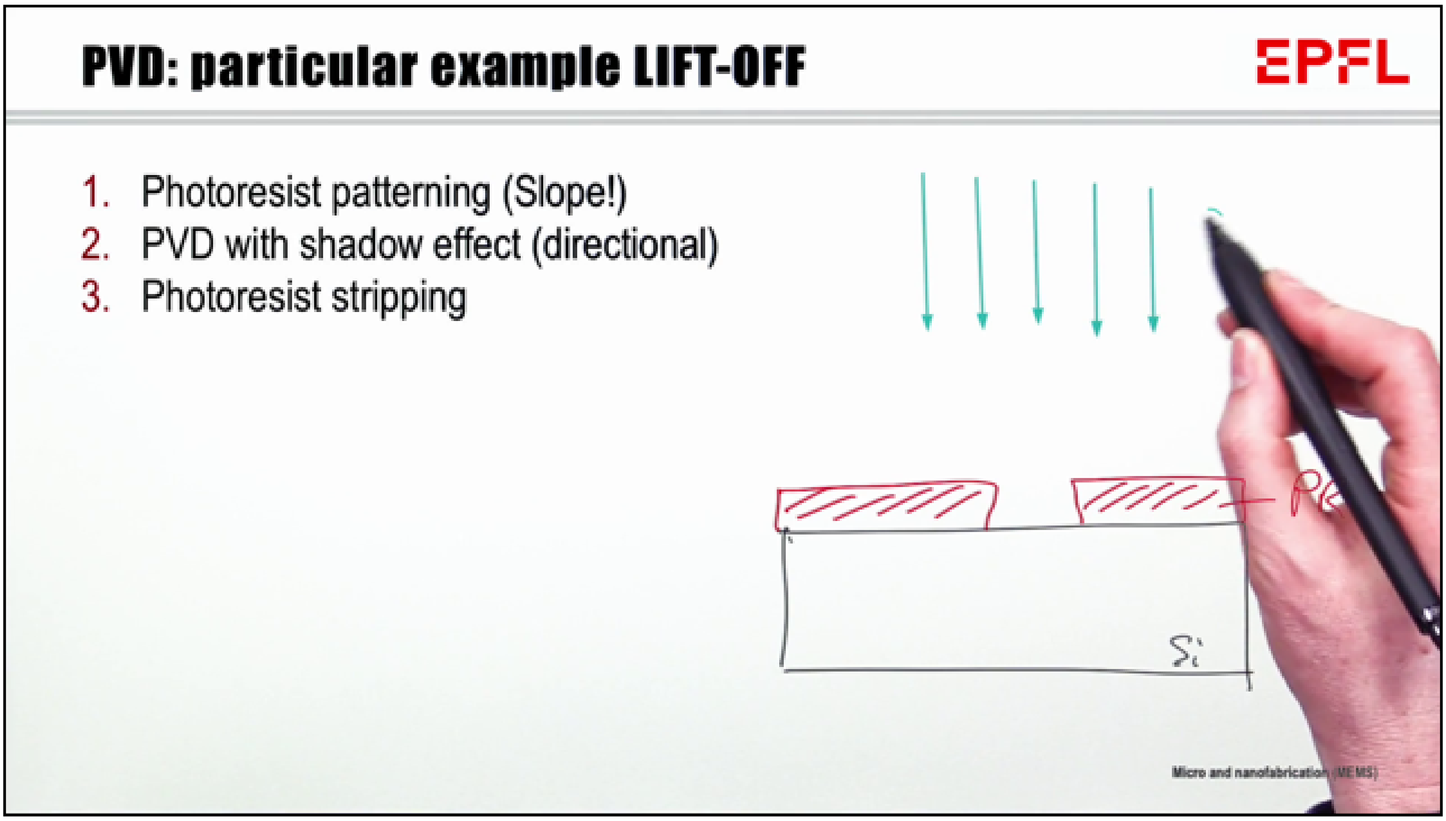


Let's have a look at the lift-off which is a particular example where thermal evaporation PVD is very useful. Lift-off is done typically on a substrate like shown here, like a silicon wafer that has been coated with a layer of photoresist and patterned by lithography,

notes

summary

4m 31s

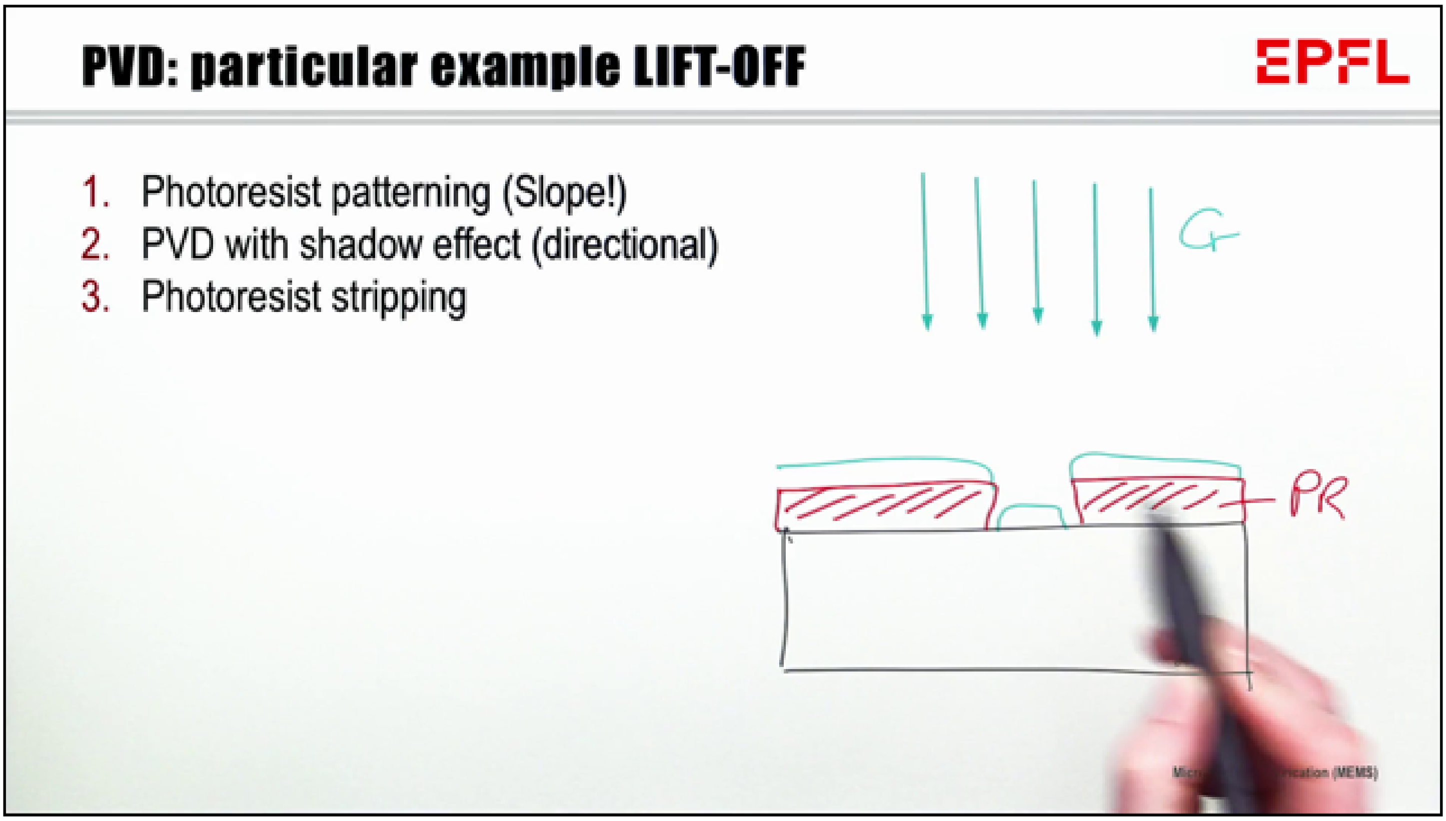


it is a photoresist layer that has an opening by lithography and development and now we come with the source that is far a way, that emits chromium

notes

summary

4m 56s

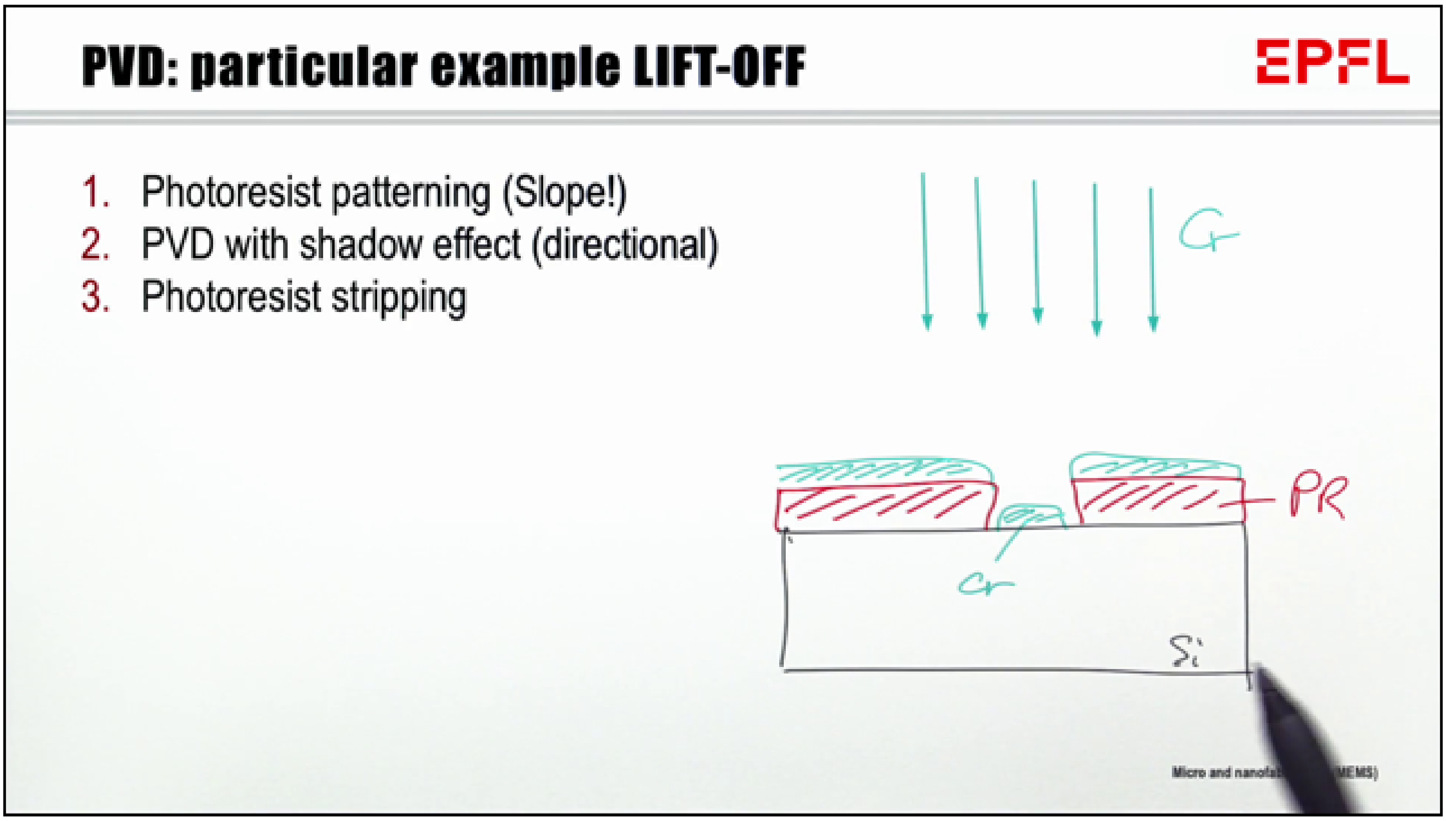


as material in a vacuum chamber, which deposits now all over the surface

notes

summary

5m 13s

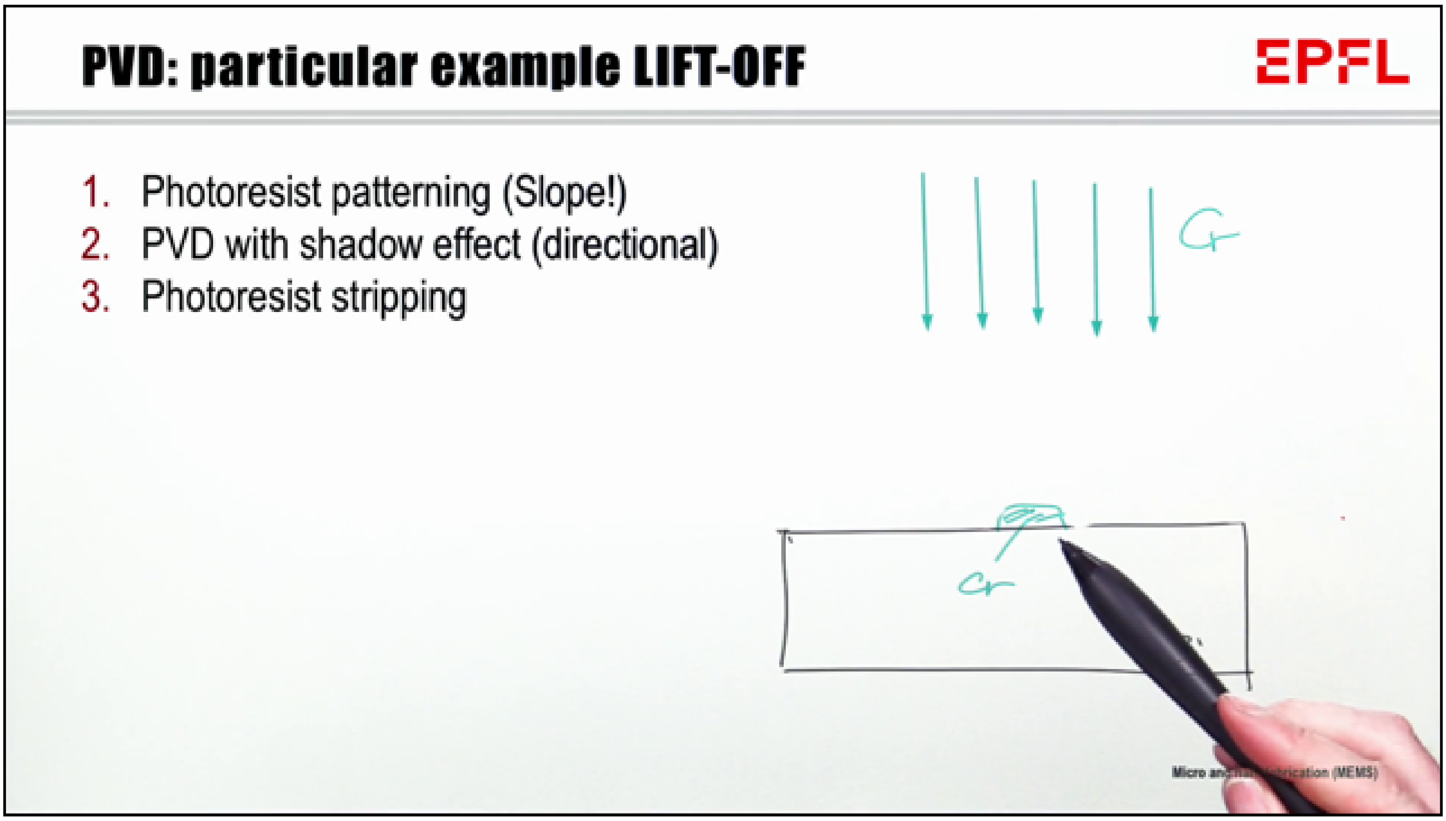


and forms a film which has more or less this shape Where this is chrome. You notice now that the photoresist was designed to have a certain sloped angle which prevents that the directional flux of material creates a bridge from the part of the film that is on the photoresist and part that is directly on the substrate.

notes

summary

5m 21s

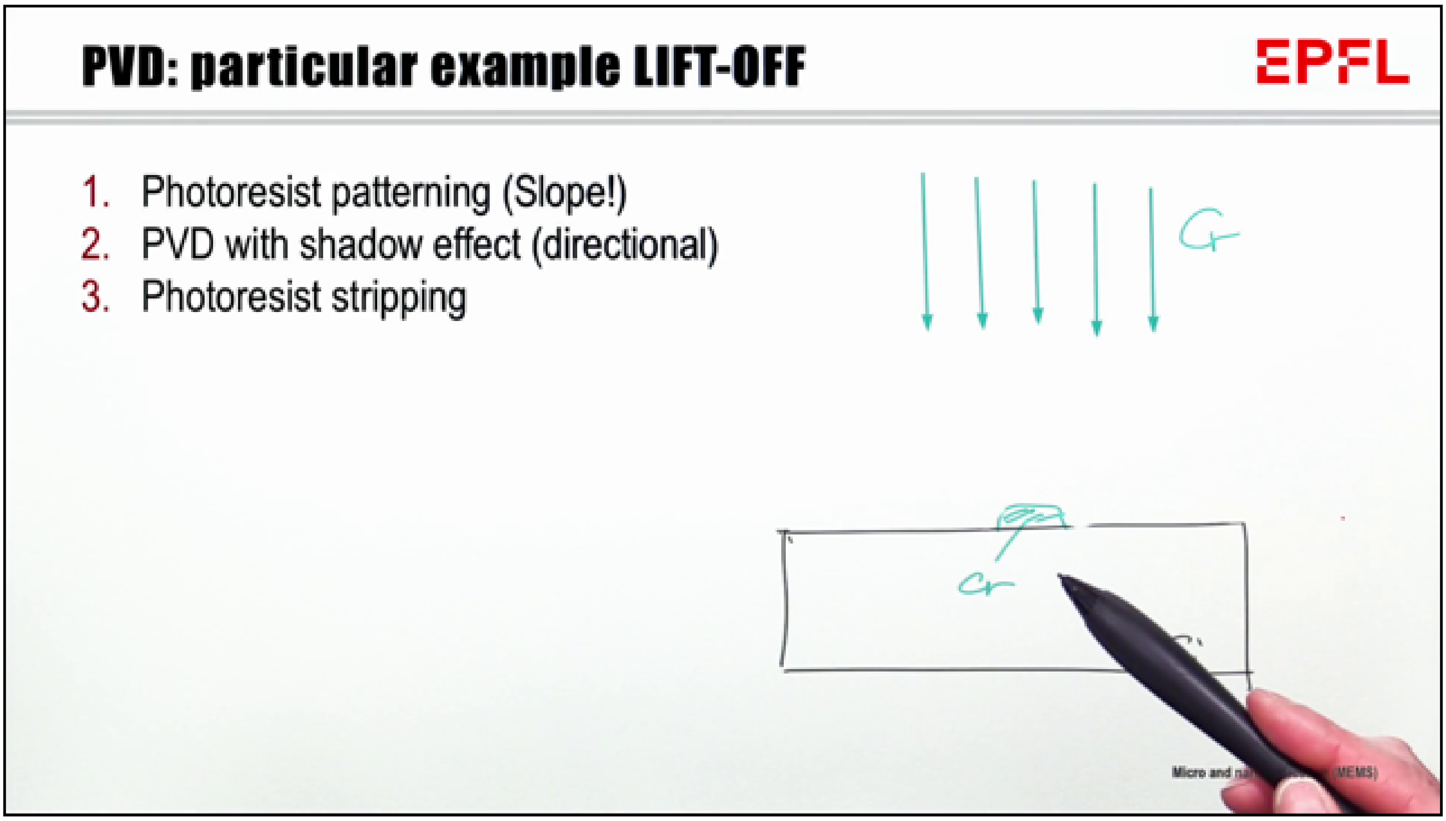


Now the actual lift-off is then the stripping of the photoresist, which is a liquid, a solvent, that can penetrate through the openings and start to remove the photoresist from this part and removes everything that is also on top of it. And the same on this side. Which leaves us at the end...

notes

summary

5m 44s

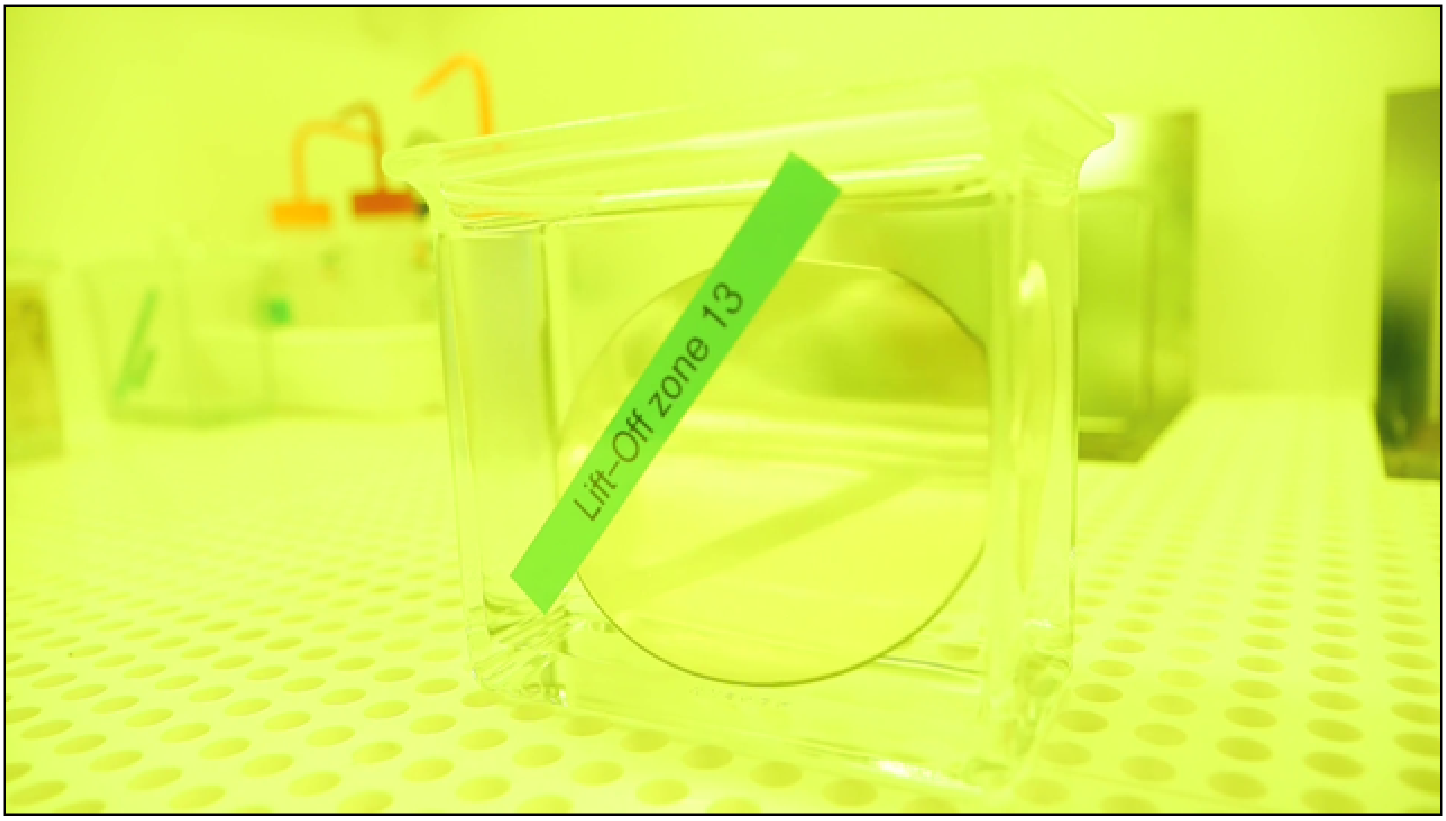


the chrome pattern that we want and this chrome pattern now has been made simply by one lithography and deposition without the need for etching.

notes

summary

6m 11s

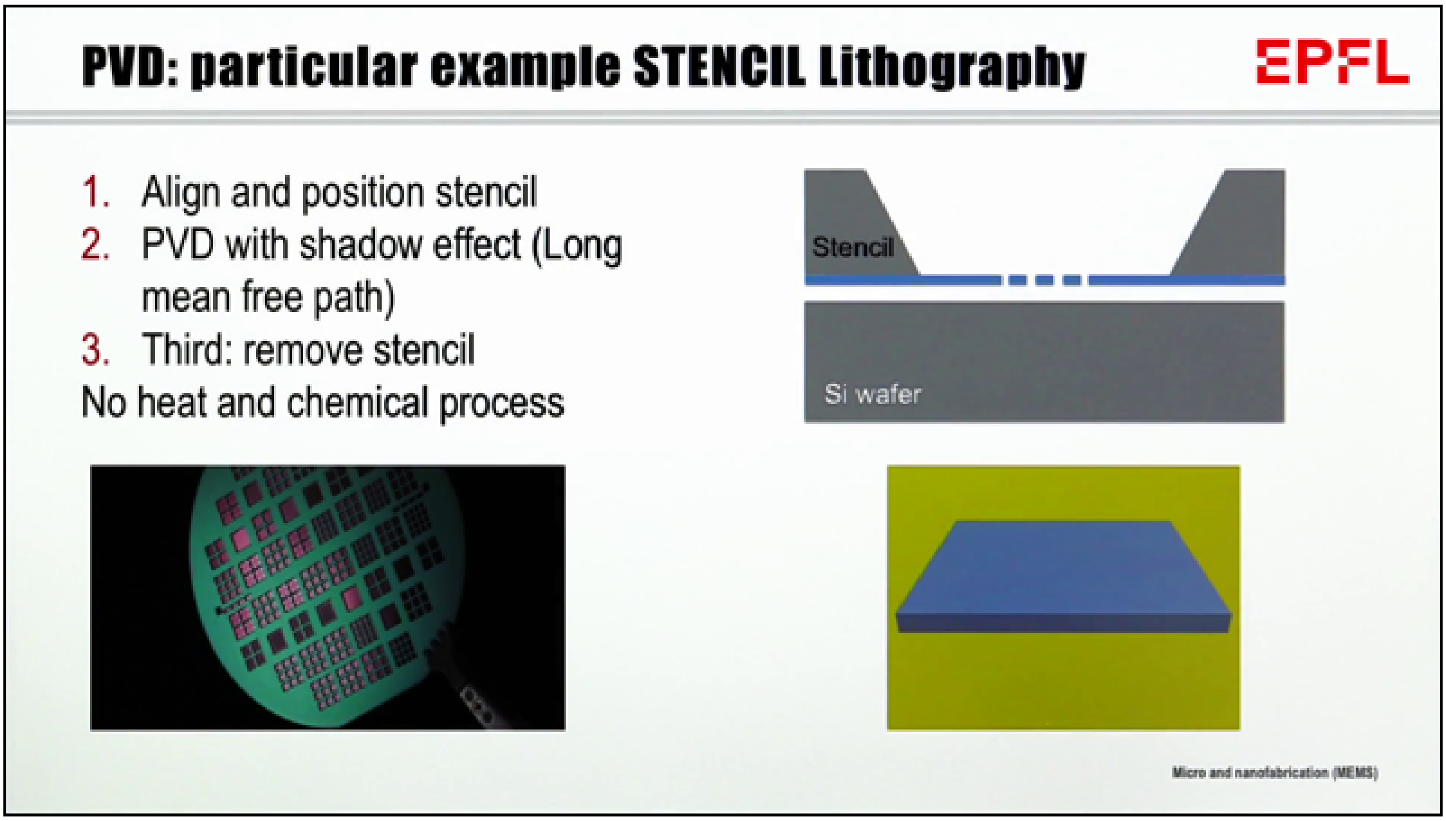


Some materials are indeed very difficult to etch so the lift-off is a very convenient way to create micro and nano patterns by this technique. Here you can a live demonstration of a lift-off step in our clean room.

notes

summary

6m 20s

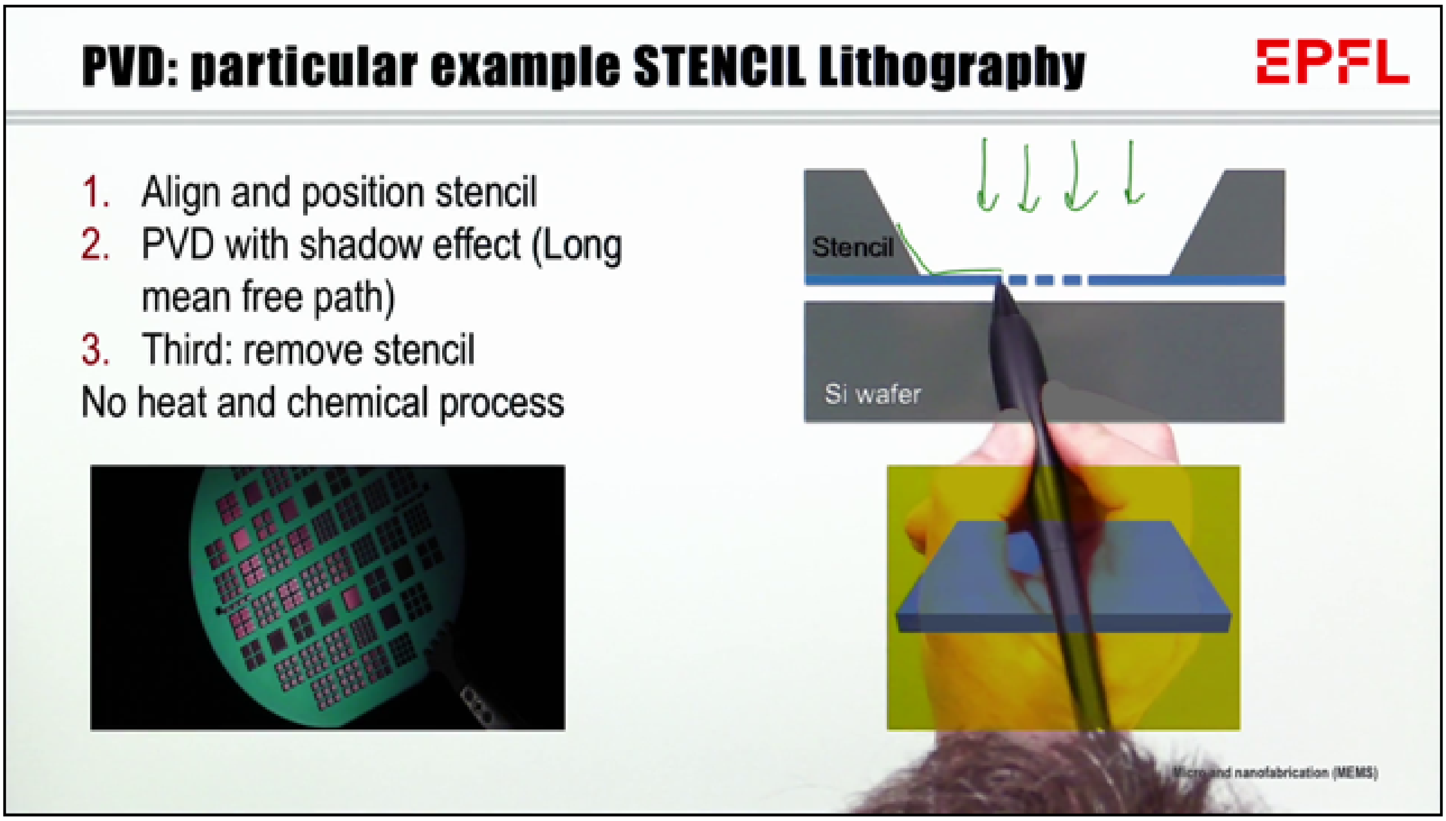


A glass wafer has previously been patterned with a photoresist and then coated by PVD evaporation with a thin film of chrome. When placing the wafer in a solvent, for example, Acetone, that photoresist dissolves after some time and also removes the metal layer on top of it. This lift-off process takes a few seconds depending on the materials involved and the dimensions. It helps to mechanically move the wafer in the bath. Also ultrasound can be applied in some cases . In this step, the appearance of the patterned metal structures become visible. At the end, the glass substrate is rinsed with the solvent to remove remaining residues on the surface, then rinsed in DI water and finally dried for further use.

notes

summary

6m 37s

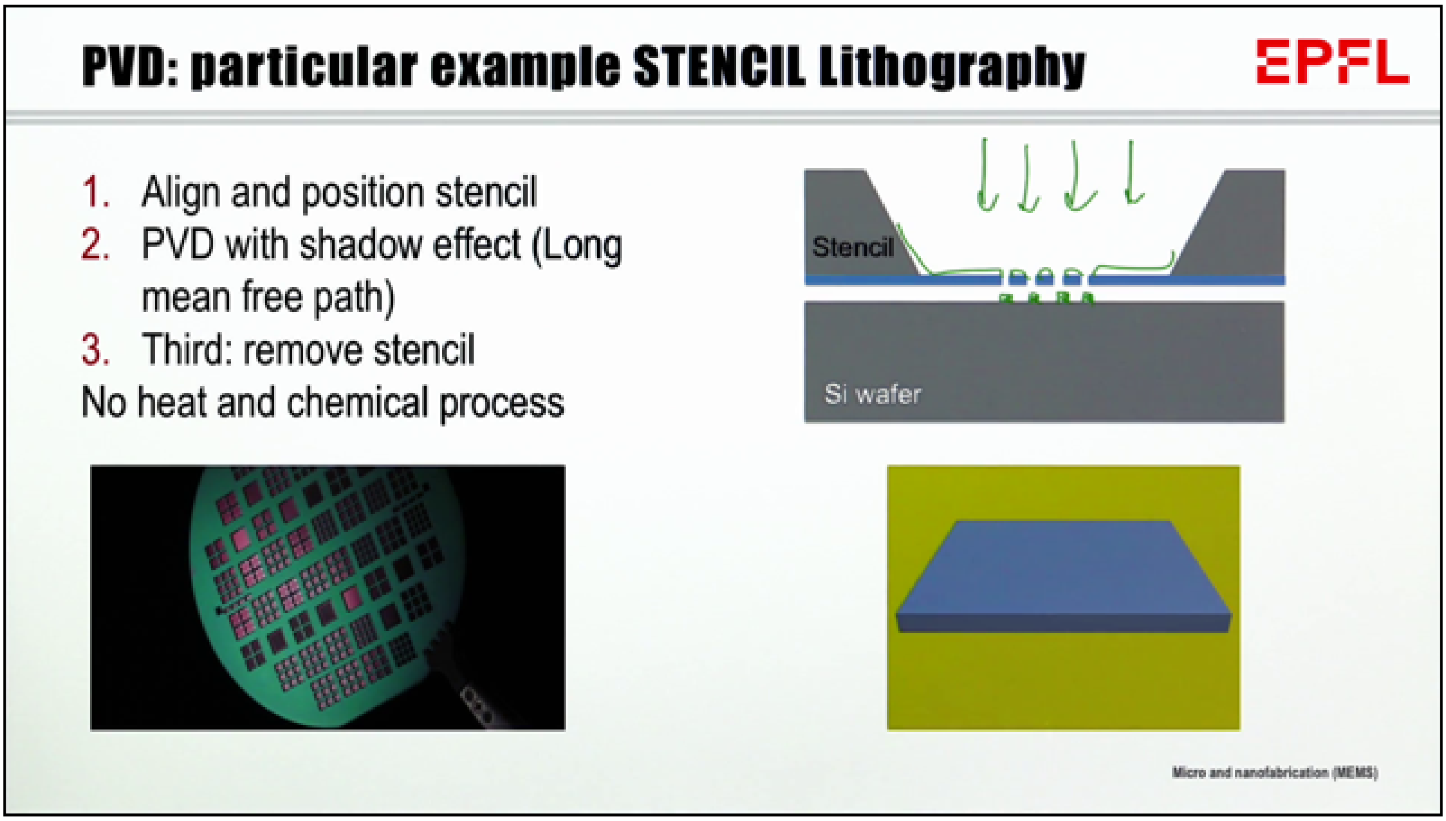


The second example that benefits from the long mean free path and the shadow effect in PVD is stencil Lithography which is shown here where a very thin membrane with apertures is approached close to the surface to be coated and then when we get material evaporated with a very directional flux,

notes

summary

7m 24s

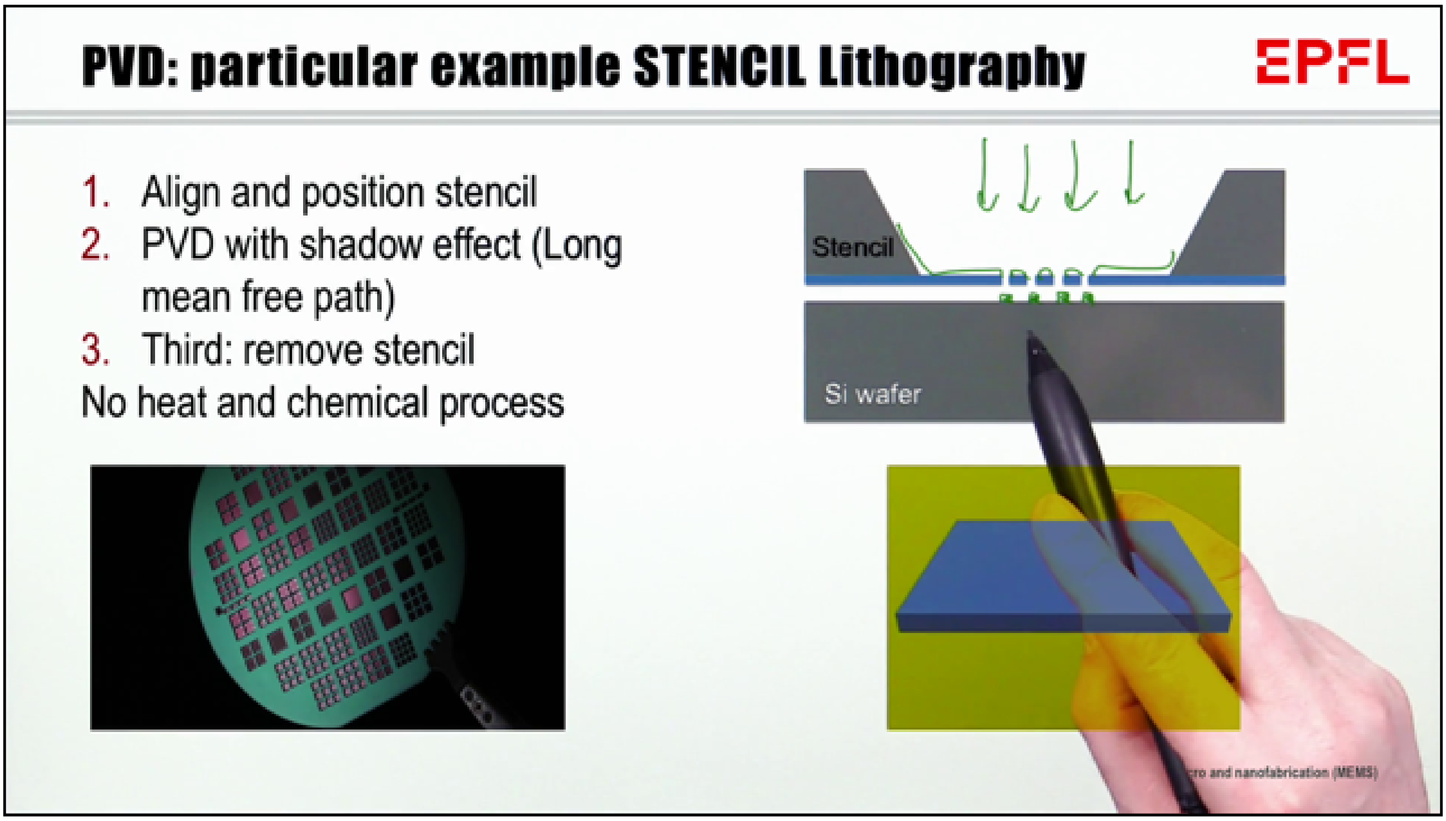


there is the deposition of the material on the stencil but also through the apertures on the substrate like shown here.

notes

summary

7m 49s

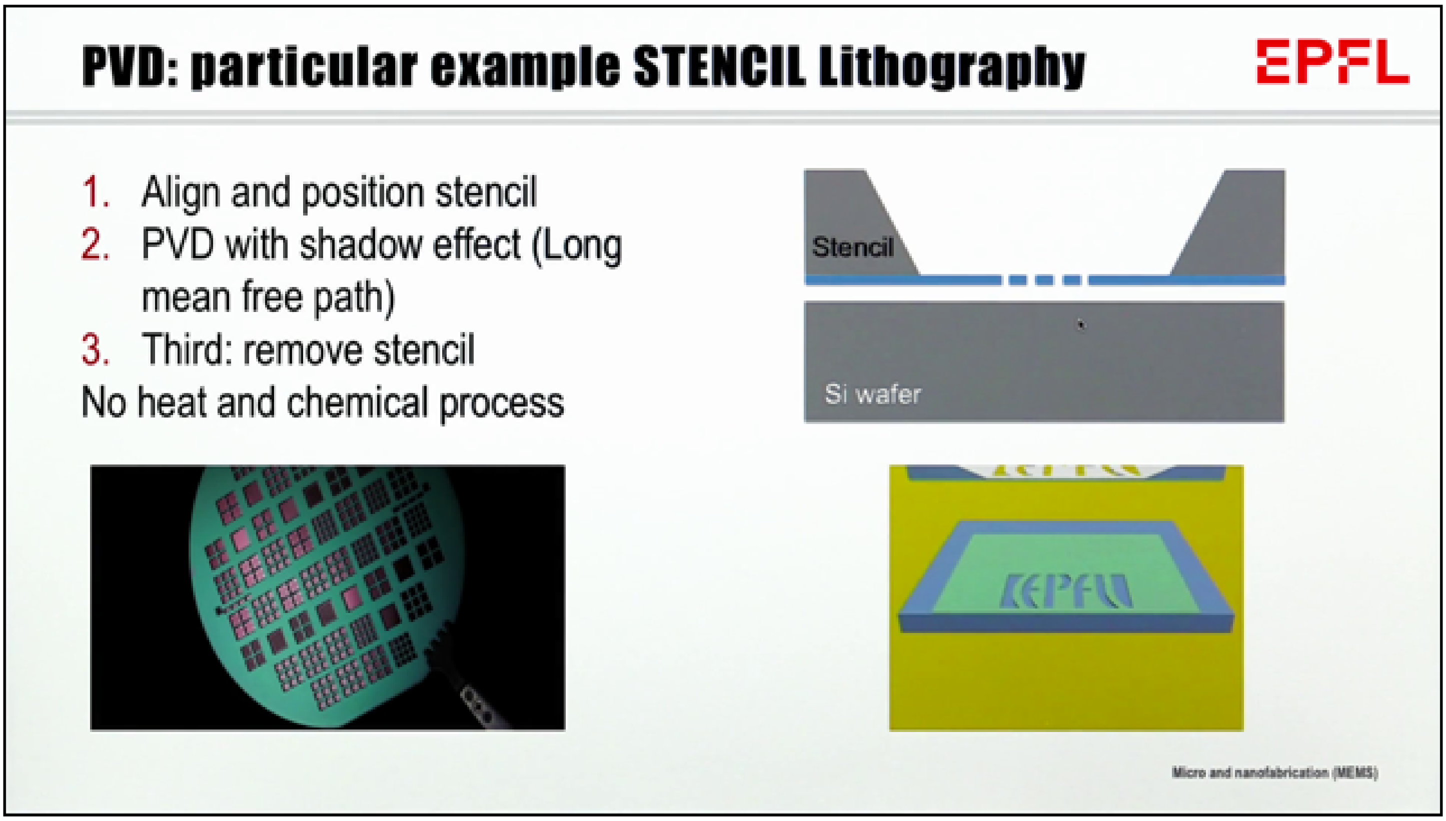


The third step would then be to remove the stencil simply mechanically and the surface features

notes

summary

7m 58s



are created without any further heat or chemical processes which makes this technique very suitable for patterning fragile substrates.

notes

summary

8m 7s

Evaporation setup details

EPFL

- Leybold Optics LAB 600H
  - 1 x e-beam, 6 pockets
  - 1 x resistive heating
  - 1 x ion source for IAD + cleaning
  - Ag, Al, Au, Cr, Ge, In, Mo, Ni, NiFe, Nb, Pd, Pt, Ta, Ti, Y, Al_2O_3, ITO, La_2O_3, MgO, SiO_2, Ti_2O_3, Ti_3O_5, Y_2O_3, ZrO_2, MgF_2
  - 4 and 6 inches wafers
  - Large source-substrate (1010 [mm]) distance for lift-off
  - Deposition from RT to 200 [ºC] (heaters)
  - Cryopump to reach high vacuum of 10^{-6} to 10^{-7} [Torr]
  - Quartz-crystal deposition rate monitor

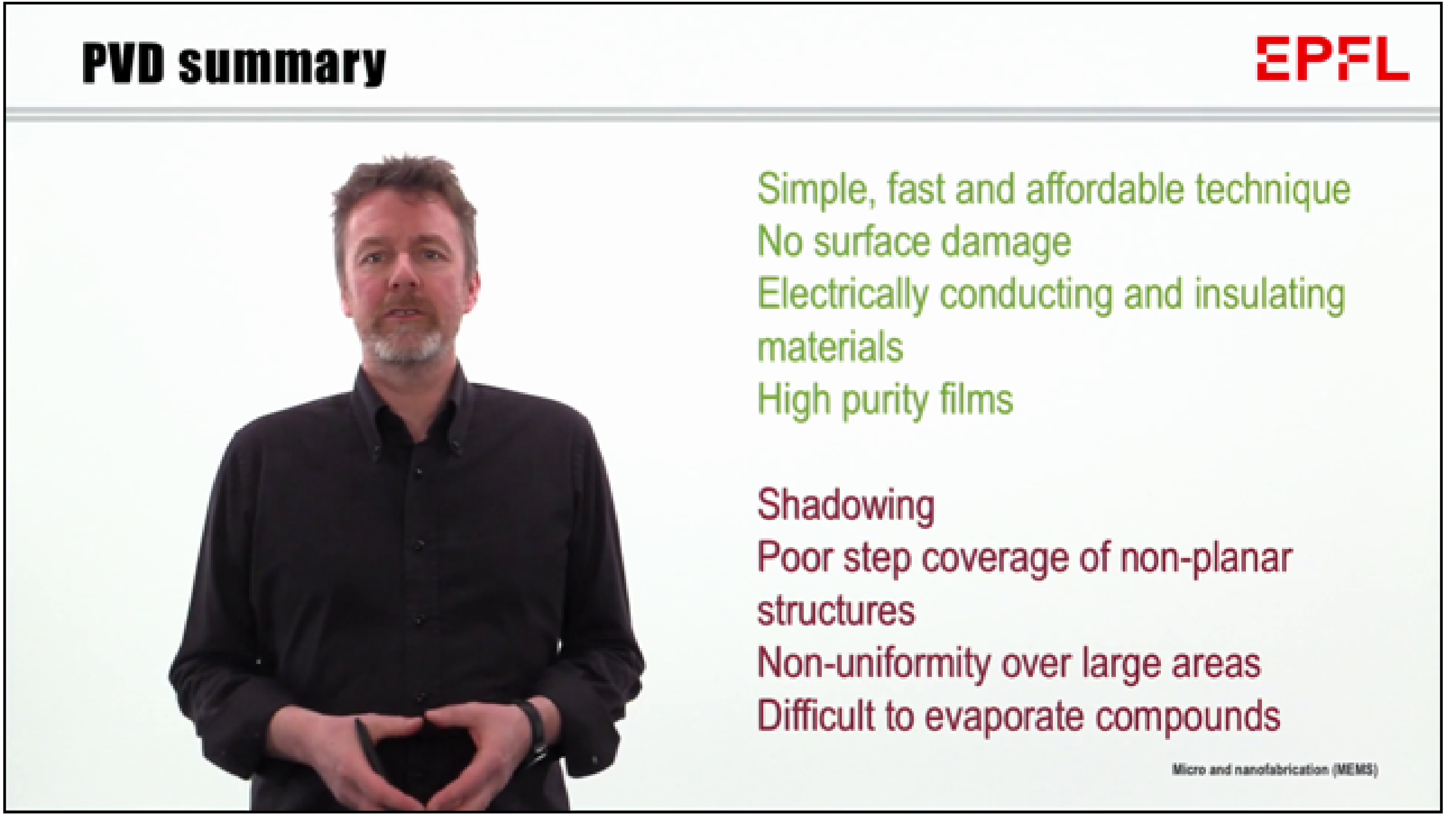
Micro and nanofabrication (MEMS)

In the animation, you can see now how the, material is deposited through the stencil on the surface leaving their features and the second step here also shows that this stencil technique can be used for local etching. Here you see photos of our clean room equipment from thermal evaporation. One the left side is shown the front panel with a loading port and the control panel. On the right photo you see how the equipment looks from the back side with all the connections for pumps, heat sources, monitors, et cetera. A sophisticated equipment like this has many features as you can see here, an e-beam source with the pockets for various materials, resistive heating, then here is a list of possible materials that can be evaporated in such an equipment, it can hold four and six inches wafers.

notes

summary

8m 17s



It has a very large distance between the source and the substrate, more than one meter and you remember this is important for the directionality and shadow, and which is therefore very good for lift-off, it can deposit from room temperatures to 200 degrees, and it has a very strong pump to reach a vacuum in the order 10 to -6, 10 to -7 Torr. And it has the before mentioned quartz, crystal deposition rate monitor. This concludes this part of the PVD lesson on thermal evaporation. You have seen that it is a fast and simple technique to coat a wafer with a thin material film. There is no surface damage, it is done in a high vacuum which yields high purity films. No atoms from the atmosphere are incorporated into the film. Limitations come from the shadowing poor step coverage of high aspect ratio structures, non uniformity over large areas and the difficulty to evaporate compounds because of their decomposition or phase change at high temperature. So let's now have a look in the clean room how such an equipment is operated in details. In the next lesson, I will explain to you how sputtering can be used to form a thin-material film.

notes

summary

9m 13s