Course material

Course:

Micro and Nanofabrication (MEMS)

Video:

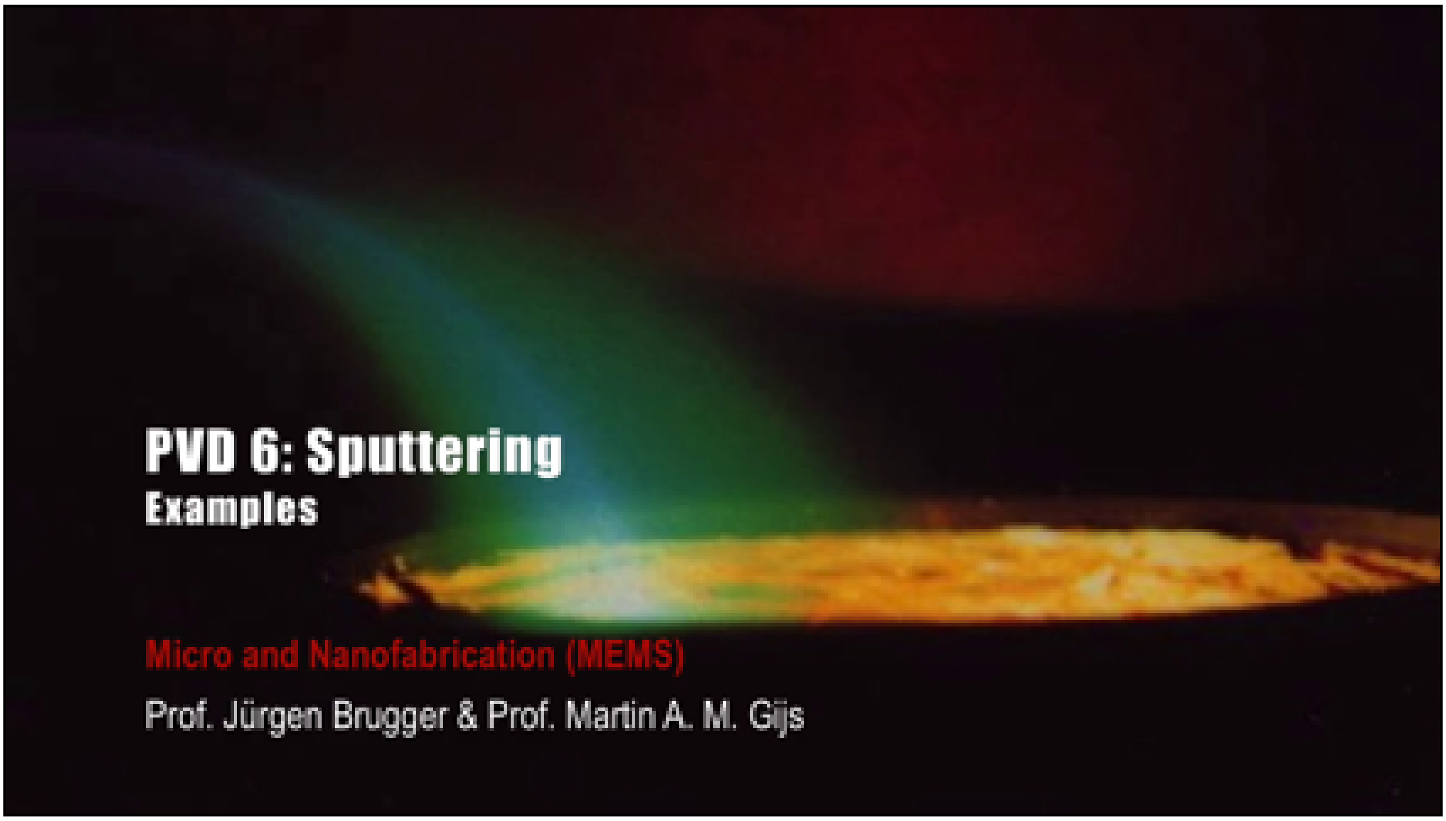
3.9 PVD6, Sputtering

Concepts (extracted from automatically generated subtitles):

Crystalline silicon. Film growth. Crystalline silicon layer. Mass sensors. Fabrication of transparent conductive oxide films. Basic principles of sputtering. So-called tco. Photovoltaic solar cells. Couple of relevant examples. Final stoichiometry of the deposited film. Vacuum deposition chamber. Absorbing material. Oxide aluminum tco layer. Electrical signal. Micro-fabrication processes.

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

to video



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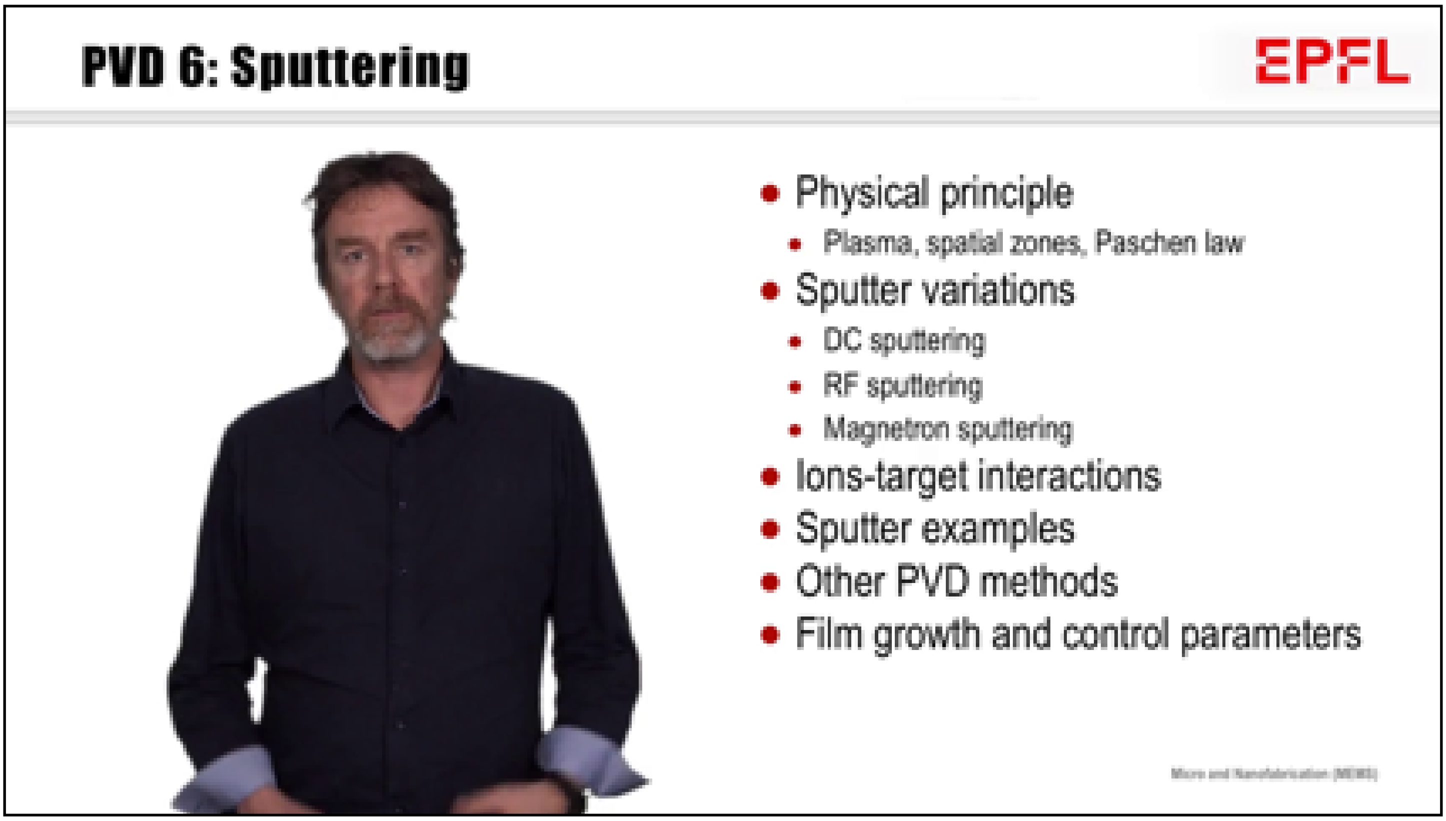
notes

summary

0m 0s

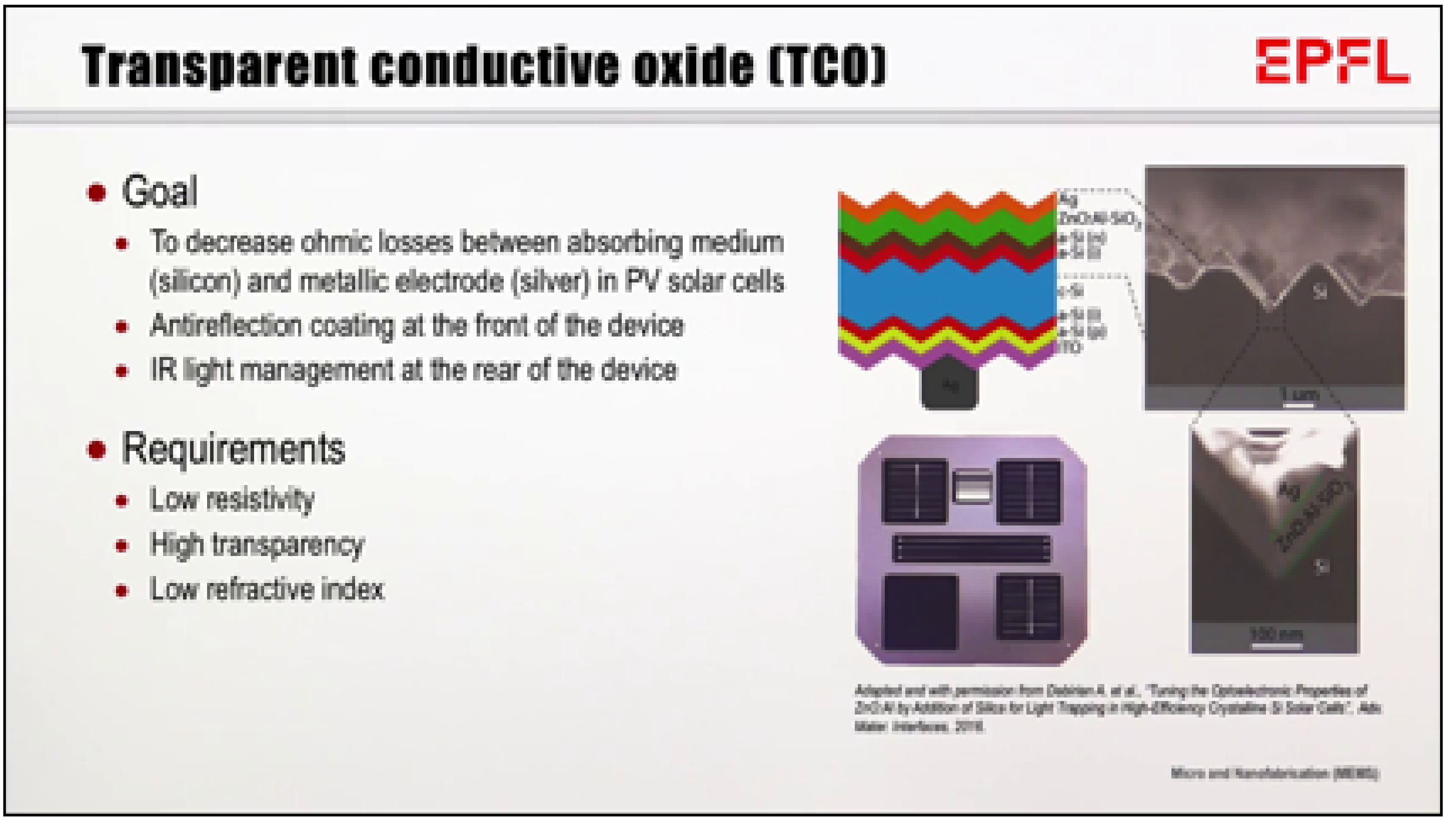


After having seen the basic principles

notes

summary

0m 1s

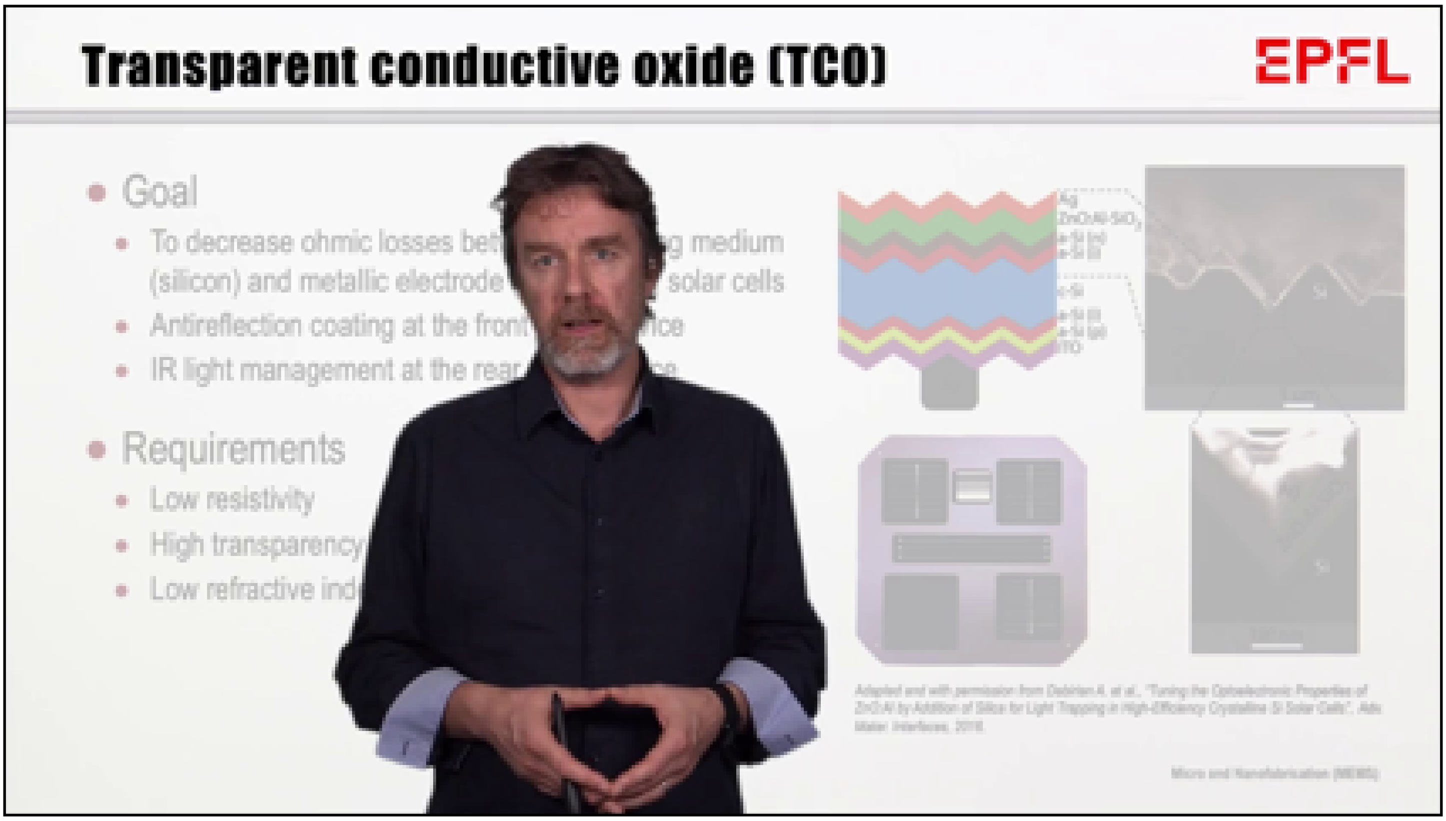


of sputtering and details on the film growth, let's now present a couple of relevant examples where sputtered films are used in MEMs. At the end of this lesson I will also show some details of the sputtering setup and take you into the clean room to see the real tools at work. At first, application where

notes

summary

0m 5s

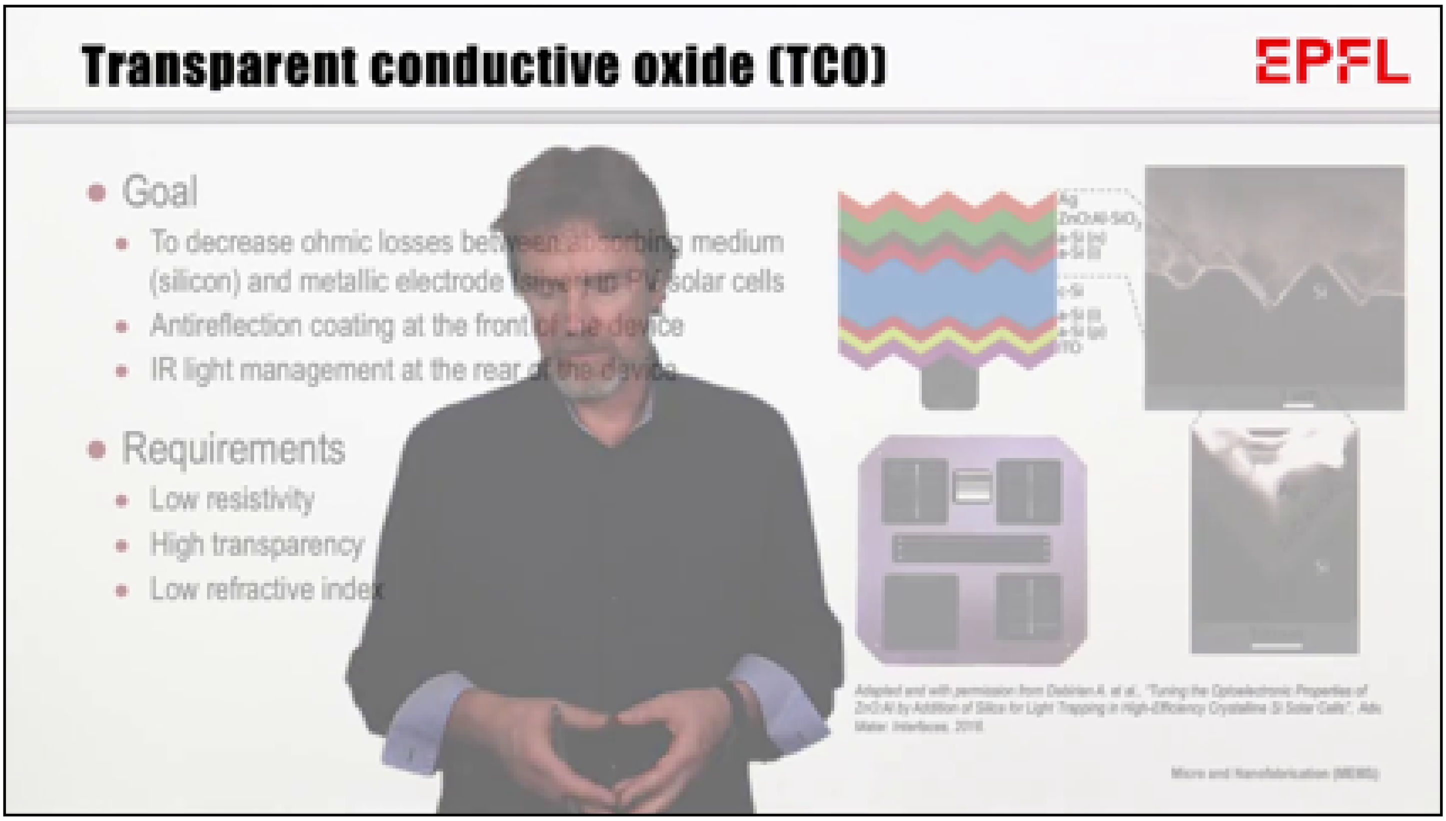


sputtering is advantageous is the fabrication of transparent conductive oxide films for photovoltaic solar cells (PV). A photovoltaic solar cell is a device which transforms light into an electrical current. In most common solar cells, the absorbing material is made of crystalline silicon contacted with metallic electrodes. Incoming photons are absorbed in the crystalline silicon layer and generate electron-hole pairs. These electron-hole pairs are then extracted through the electrodes. Although a simple cell made of silicon directly contacted with metallic electrodes could work, its efficiency would be very low because of ohmic losses in the silicon metal junction and because of the surface recombination of electron-hole pairs. To improve the efficiency of crystalline silicon solar cells, amorphous silicon

notes

summary

0m 26s

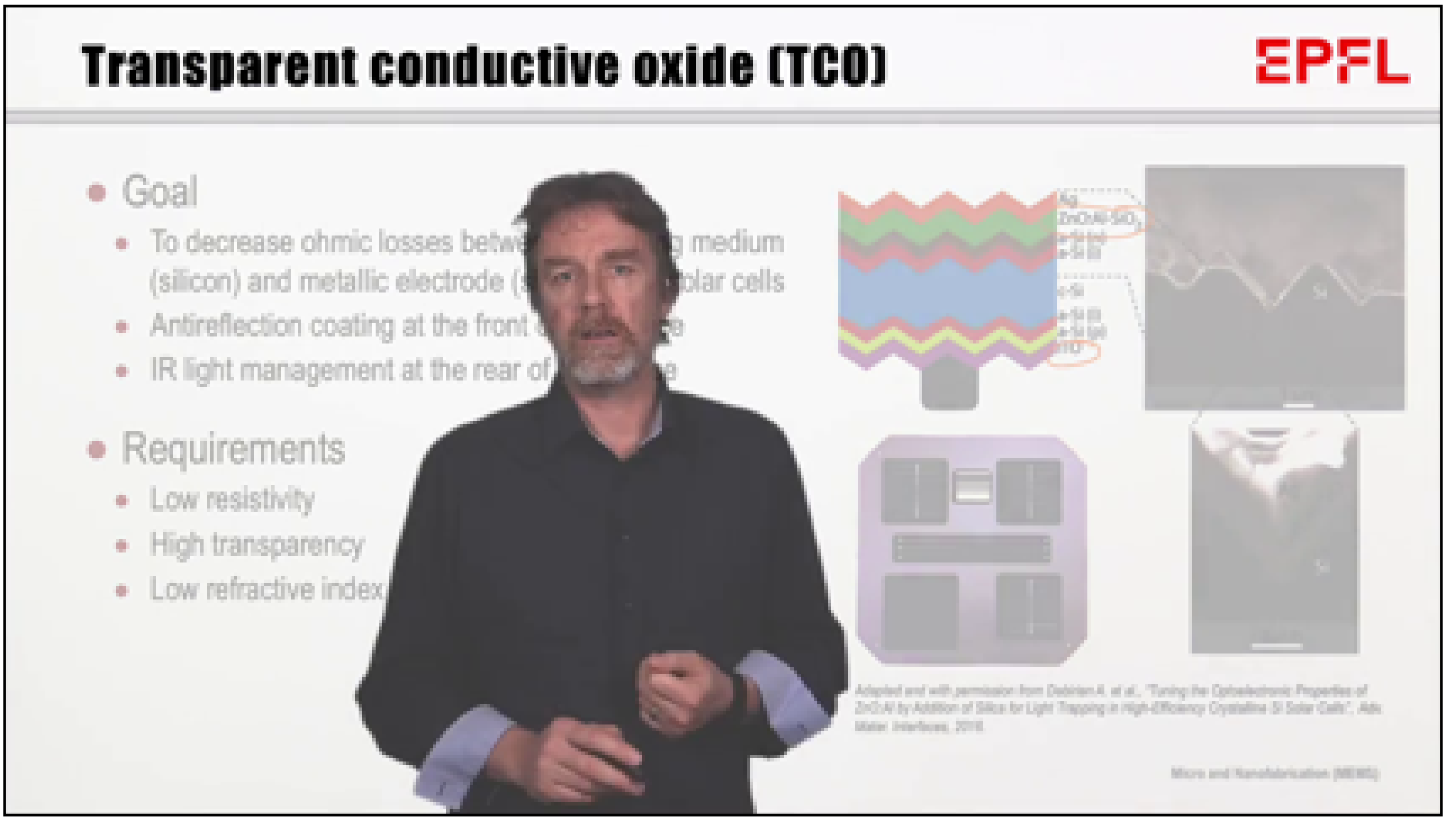


or alpha silicon and transparent conductive oxide so-called TCO are added in between the active crystalline silicon area and the metallic electrodes, in silver. As shown here in the right side of the slide.

notes

summary

1m 25s



In this specific example, two different TCO are considered. First, the indium tin oxide or ITO is added at the front side of the device where the light comes in. And the second a zinc oxide aluminum silicon dioxide alloy, shown here, is added at the rear of the device.

notes

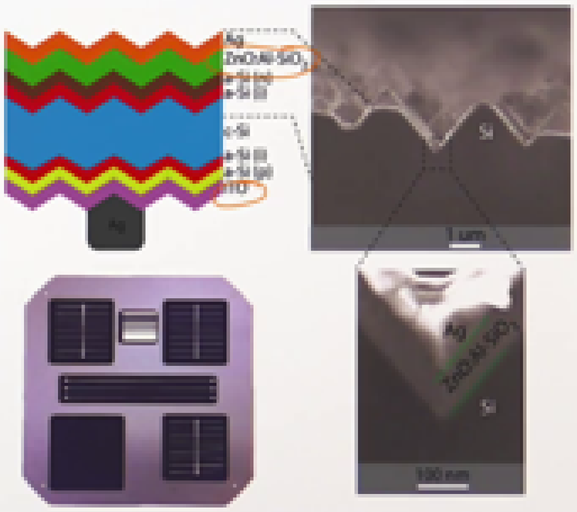
summary

1m 40s

Transparent conductive oxide (TCO)

EPFL

- **Goal**
  - To decrease ohmic losses between absorbing medium (silicon) and metallic electrode (silver) in PV solar cells
  - Antireflection coating at the front of the device
  - IR light management at the rear of the device
- **Requirements**
  - Low resistivity
  - High transparency
  - Low refractive index



Adapted and with permission from Dabirian A. et al., "Tuning the Optoelectronic Properties of ZnO:Al by Addition of Silica for Light Trapping in High-Efficiency Crystalline Si Solar Cells", Adv. Mater. Interfaces, 2016.

Micro and Nanofabrication (MEMS)

The first call of the TCO in the photovoltaic solar cells is to decrease ohmic losses between the electrode and the absorbing medium. However, TCO also functions as anti-reflection coatings at the front of the solar cell, as well as for infrared light absorption management at the rear of the cells. In order to fabricate cells with the highest efficiency as possible, TCO layers must have low resistivity, high transparency, and a low refractive index. To satisfy all these three requirements at the same time it is not that straightforward

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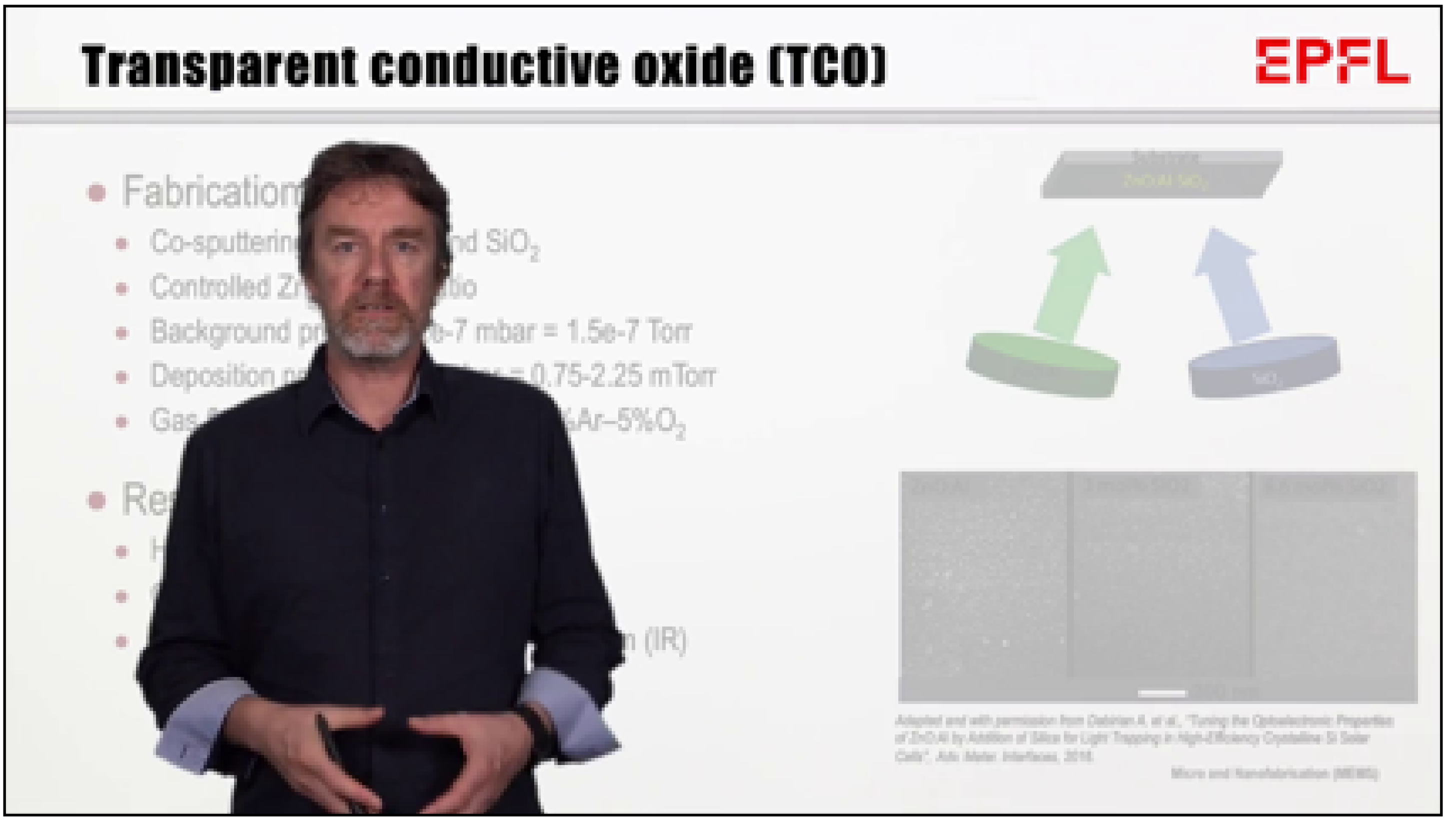
summary

2m 7s

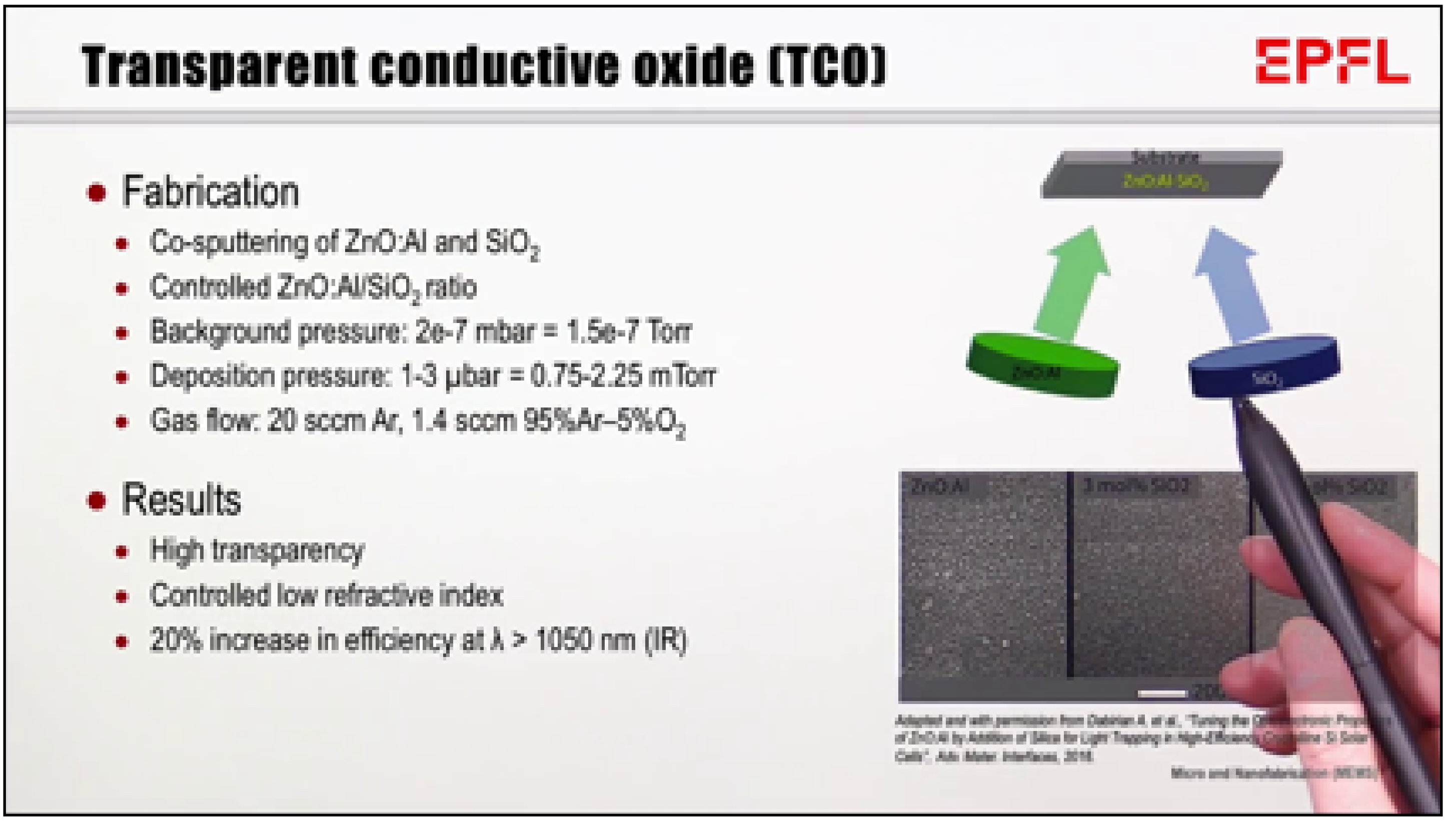


by using standard thin film materials. One way to succeed to match all of these properties is, for instance, to add SiO2 to zinc oxide aluminum TCO layer On the right side of the slide, we can see a TCO layer made of zinc oxide aluminum SiO2 in between the silicon absorbing medium and the silver rear electrode. Like shown here. Silicon, the TCO and the silver layer This sputtered composite layer allowed for tuning the optoelectronic properties and for improving the PV efficiency. Let's see in the next slide how this film is actually made.

notes

summary

2m 49s



To deposit a zinc oxide aluminum SiO2 layer cool sputtering of zinc oxide aluminum and SiO2 is performed. As shown here,

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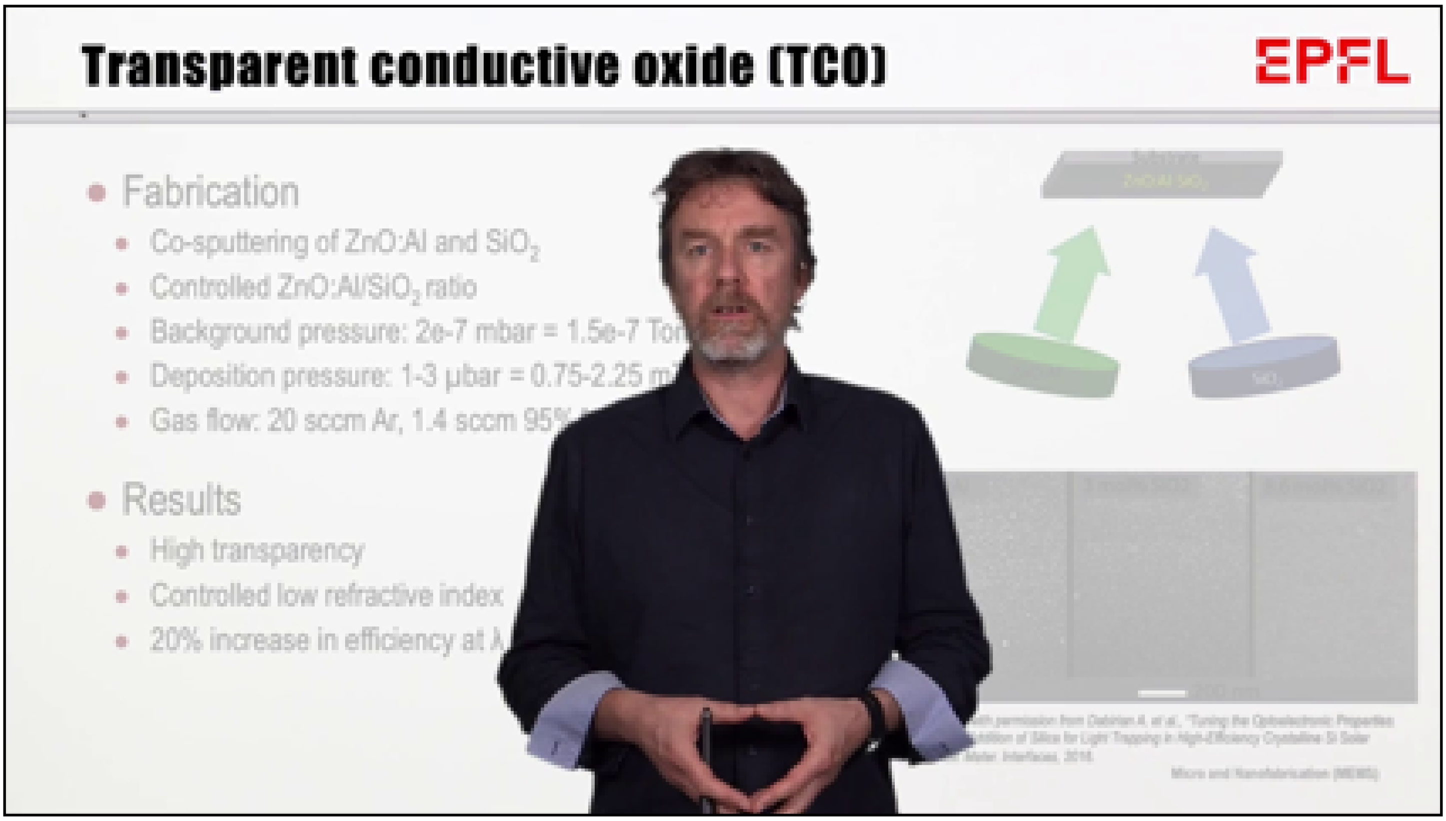
summary

3m 32s

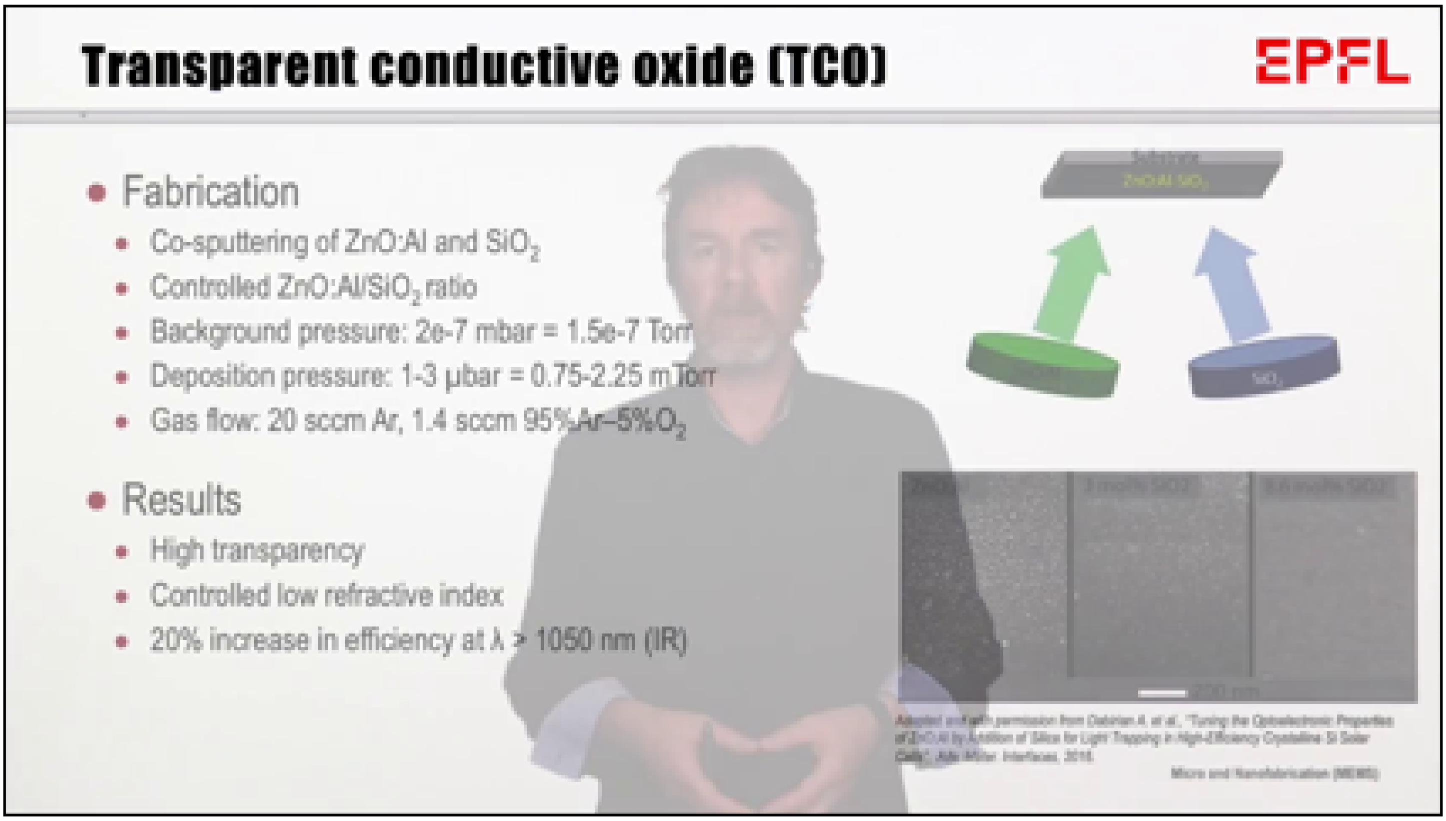


two targets are used within the same vacuum deposition chamber. Tuning the voltage on each target enables to change the zinc oxide aluminum SiO2 ratio into film. Formed here on the substrate. And thereby to adjust the film microstructure and refractive index. The more SiO2 we add, the less crystalline becomes the material and the lower is the refractive index. In this concrete example, sputtering enables the deposition of two compounds at the same time and thereby tuning the final stoichiometry of the deposited film. Such a performance is impossible to achieve

notes

summary

3m 41s

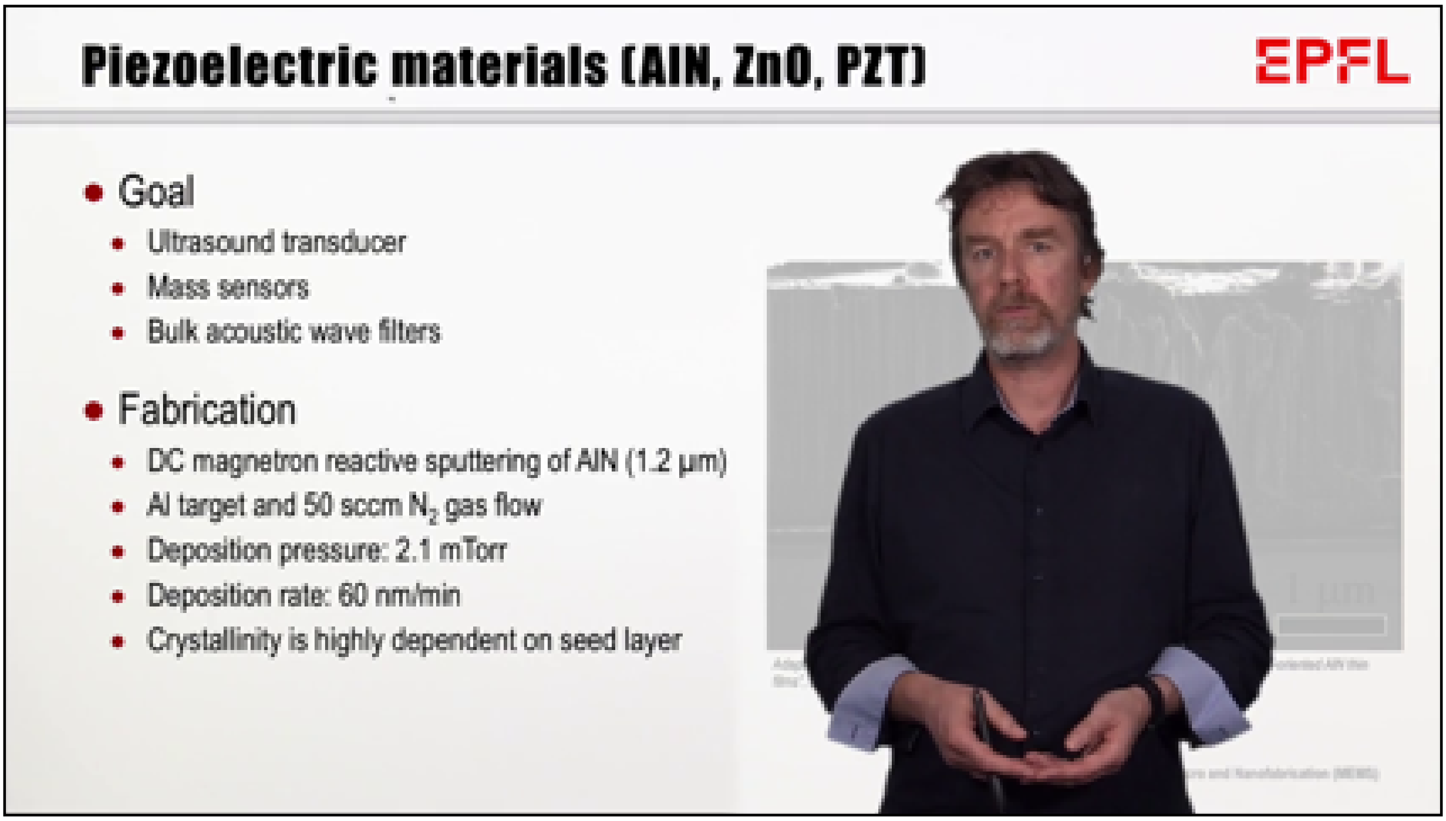


with thermal evaporation. The fabricated films exhibit high transparency and low refractive index.

notes

summary

4m 25s

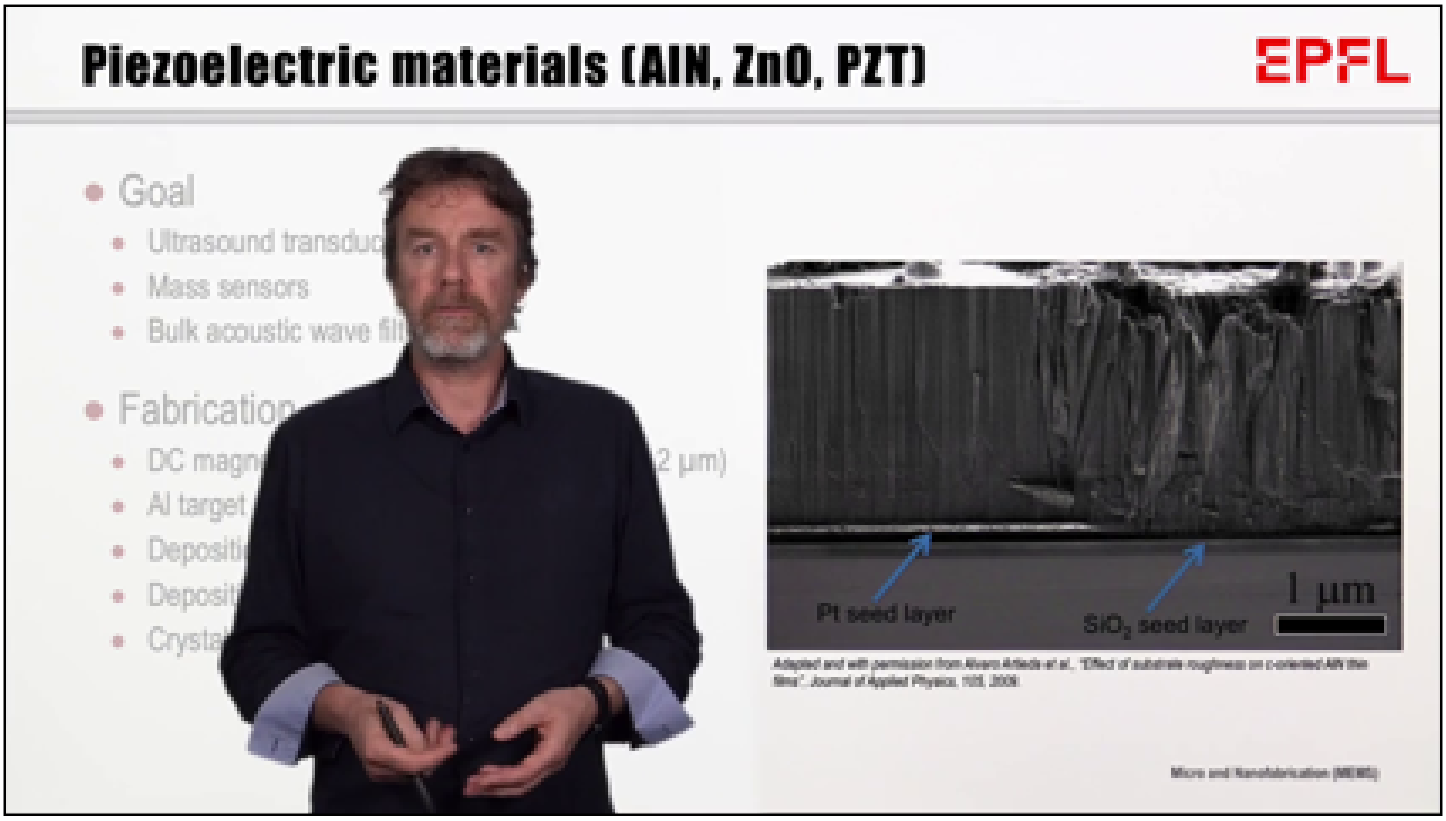


Three different coatings are shown here. First, on the left, the zinc oxide aluminum film without addition of SiO2. And then with increasing SiO2 concentration. It shows that the texture is changing towards less grainy morphology. At the same time, the solar cell efficiency increases by 20% in the infrared when using the zinc oxide aluminum SiO2 TCO layer at the rear of the device, instead of a standard zinc oxide aluminum layer. For further details please have a look at this cited paper. Our second thin film example of interest is based on piezoelectric materials, that are often deposited by reactive sputtering. Piezoelectric materials are very important and used in many MEMs devices such as ultrasound transducers, that means these devices convert a pressure wave into an electrical signal. Or mass sensors, where the mass change induces a resonance frequency shift. And bulk acoustic wave filters. For this latter application, suspended piezoelectric microstructures are sandwiched between electrodes. When an incoming electrical signal which matches the mechanical resonance frequency of one of the microstructures is applied to the input electrodes, the device enters into a mechanical resonance and an electrical signal is transmitted to the output electrode.

notes

summary

4m 32s



Typically, bulk acoustic wave filters are made of aluminum nitrate; because of the excellent electroacoustic properties of this material and its chemical compatibility with micro-fabrication processes. The quality of the filter is determined by the piezoelectric film crystal structure. Reactive sputtering with an aluminum target in a nitrogen atmosphere is used to deposit the aluminum nitrate film. As it is the only deposition method which allows for high film quality below 500° C. However, the film crystal structure

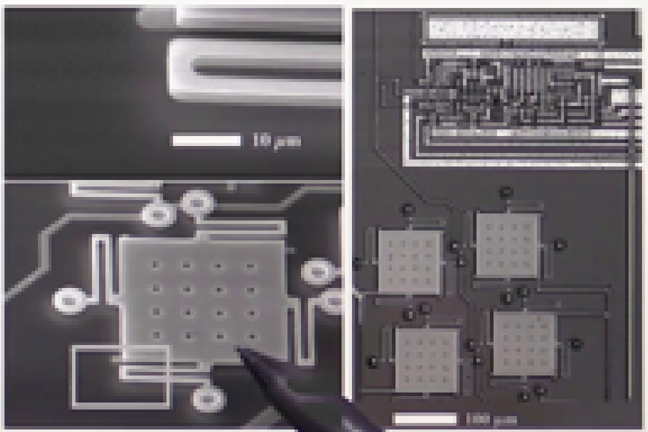
notes

summary

6m 2s

Low temperature (350 °C) sputtered silicon

- Goal
  - Silicon surface micromachined MEMS
  - CMOS compatible
  - Organic sacrificial layer compatible
- Fabrication
  - Sputtering of Si (2 μm)
  - Pressure & power tuning to control stress (<100 MPa)
  - 350 °C annealing
  - Background pressure: 1e-7 Torr
  - Deposition pressure: 8 to 14 mTorr
  - Deposition rate: 19-37 nm/min



Honer et al., "Integration of sputtered ... structures with pre-fabricated CMOS circuitry", Sensors and Actuators A: Phys...

notes

summary

6m 37s

Low temperature (350 °C) sputtered silicon

EPFL

- Goal
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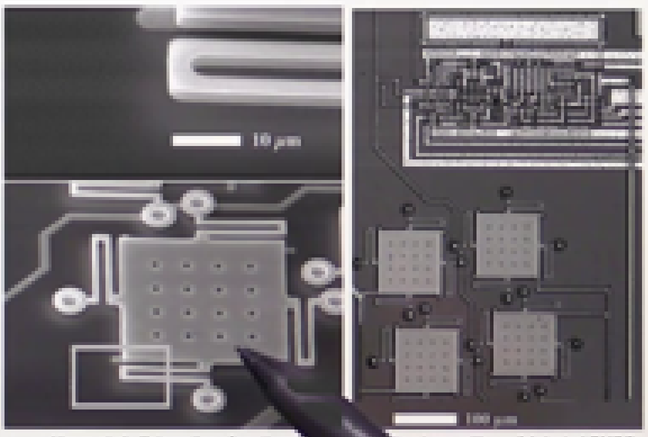
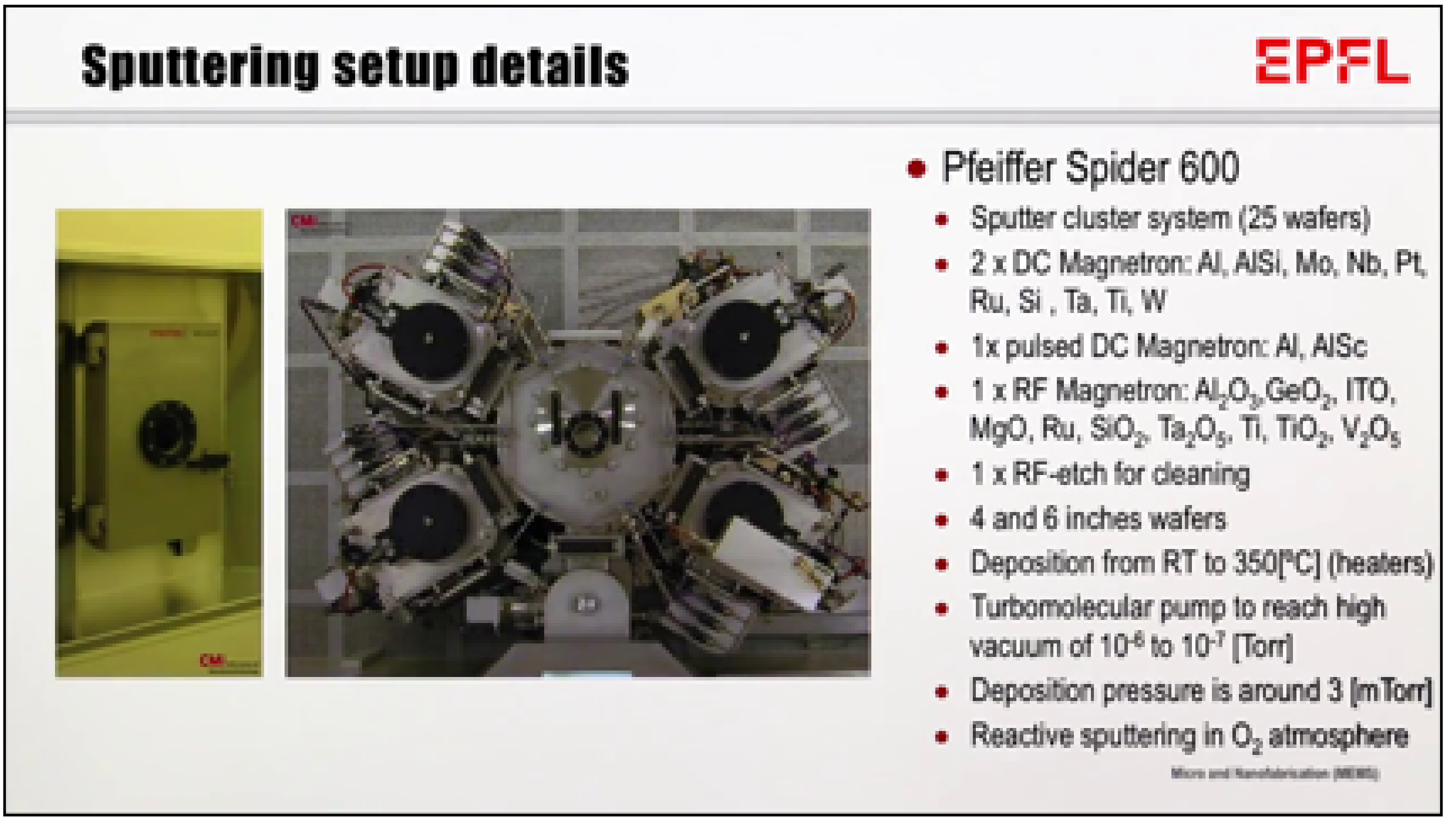


Tuning the pressure and power of the sputtering process, and performing a post-annealing at 350° C, allows depositing up to 2 μm thick silicon films with residual stresses lower than 100 MPa. In addition to be CMOS-compatible, such a process can also be performed on a polymeric or organic sacrificial layer. As a result, suspended silicon structures can be fabricated on top of CMOS circuitry using a dry relief process in oxygen plasma to remove the sacrificial layer. This process is much simpler than the usual SiO_2 sacrificial layer using HF, wet release, and critical point drying process. An example of a sputtered silicon microstructure suspended with 4 springs next to its CMOS circuitry is shown here. The silicon plates, shown here in the magnification,

notes

summary



is electrostatically actuated and its deflection is quantified measuring the change of capacitance with a dedicated on-chip CMOS amplifier. Like, shown here. And like it is nowadays integrated in many state of the art commercial MEMs. Here is an example of a cluster sputtering tool from our clean room. A load-lock system. Here. Enables to load the wafers into the tool, without venting the deposition chambers themselves. This way pumping time is shorter and there is less contamination of the deposition chambers with gaseous atmospheric components. A robotic arm, located in the central chamber, automatically moves the wafer from load-lock, here, into one of the 4 deposition chambers. Shown here. Each chamber has a different target of material, which enables serial deposition of multiple materials without venting the sample in between each deposition. This is an advantage when the deposited material are very sensitive to native oxides, for instance. To conclude this chapter about sputtering, let's now have a look how such a system really works in reality. So let's come together in the clean room.

notes

summary

10m 13s