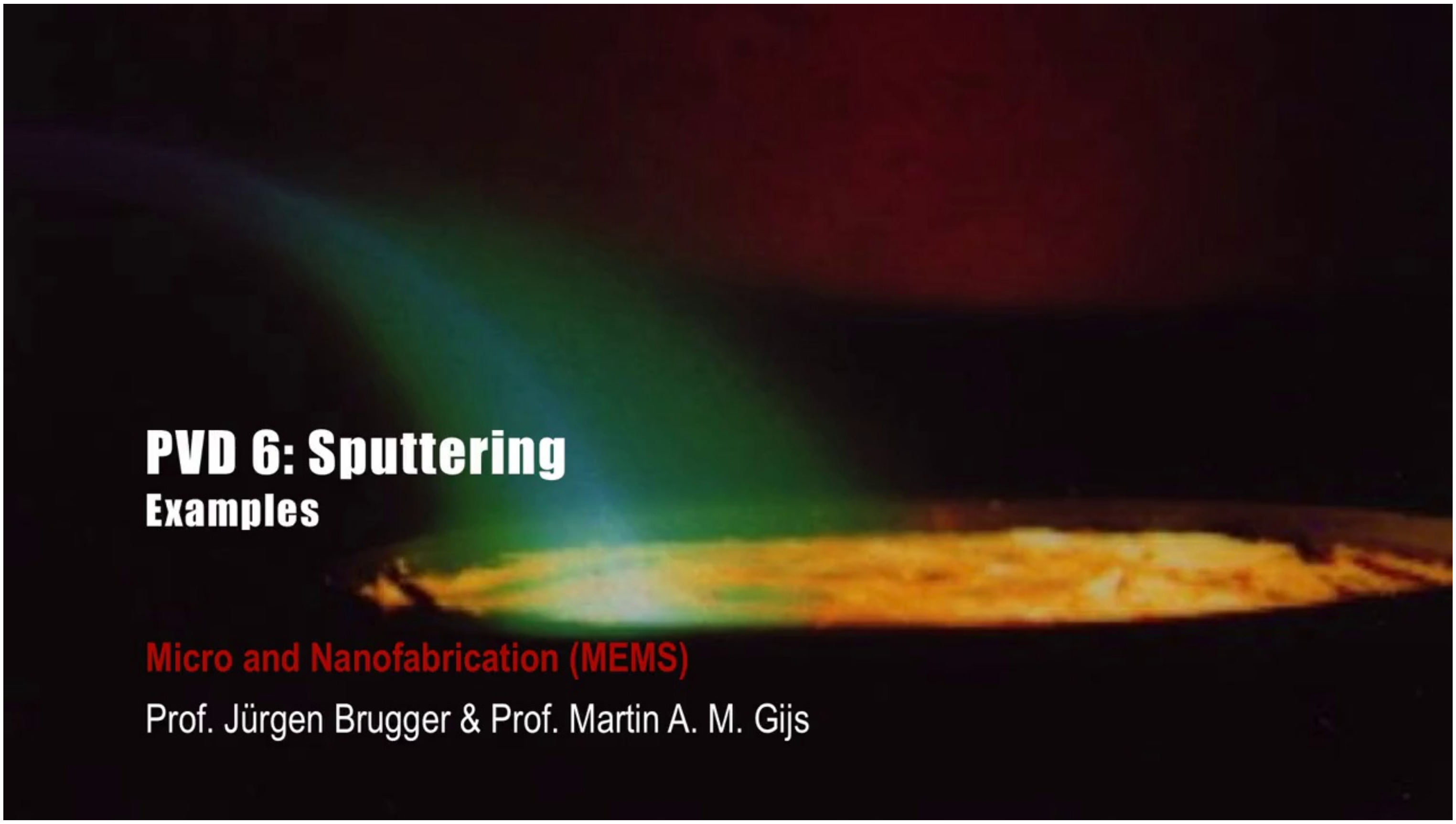


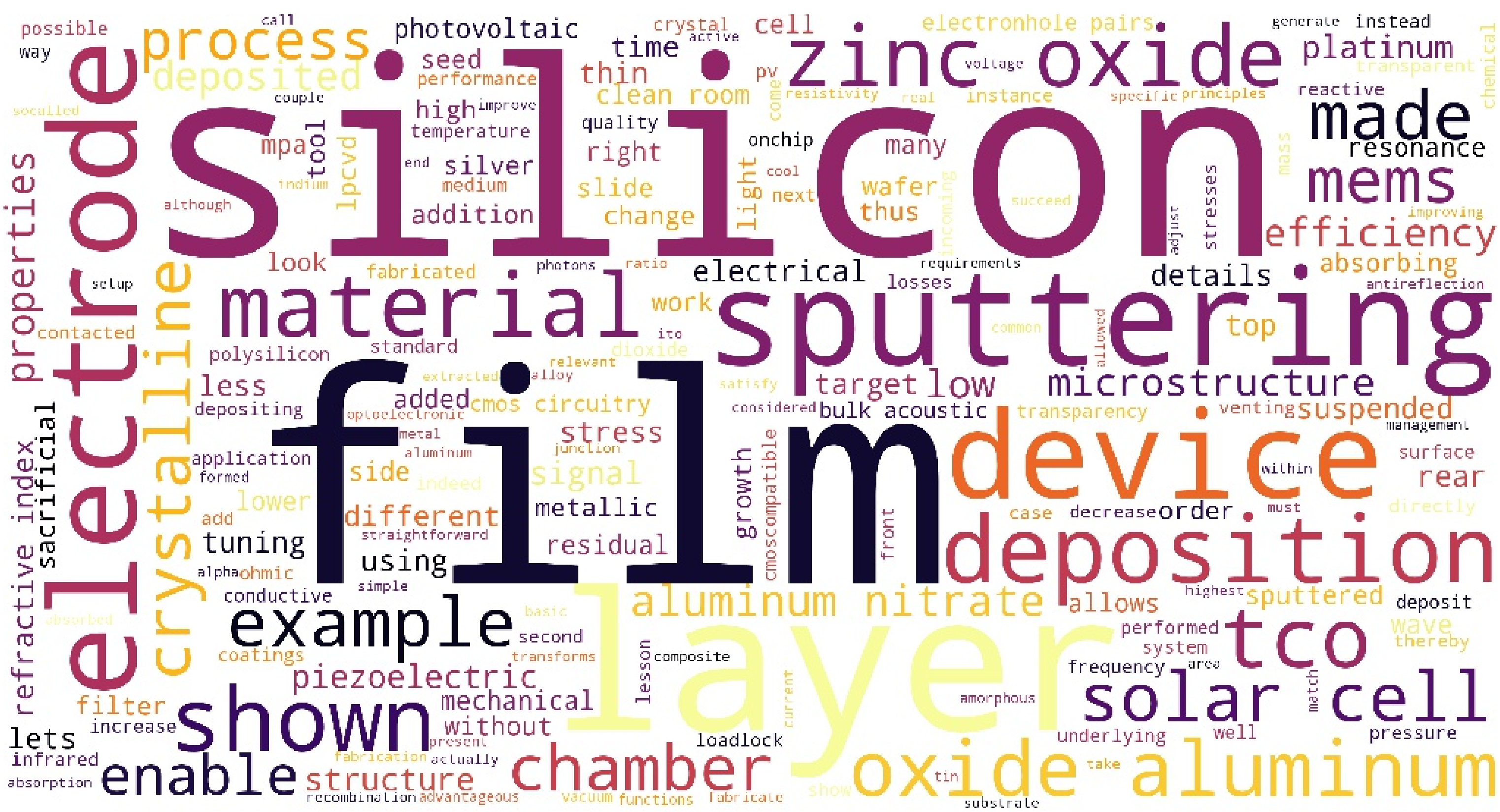


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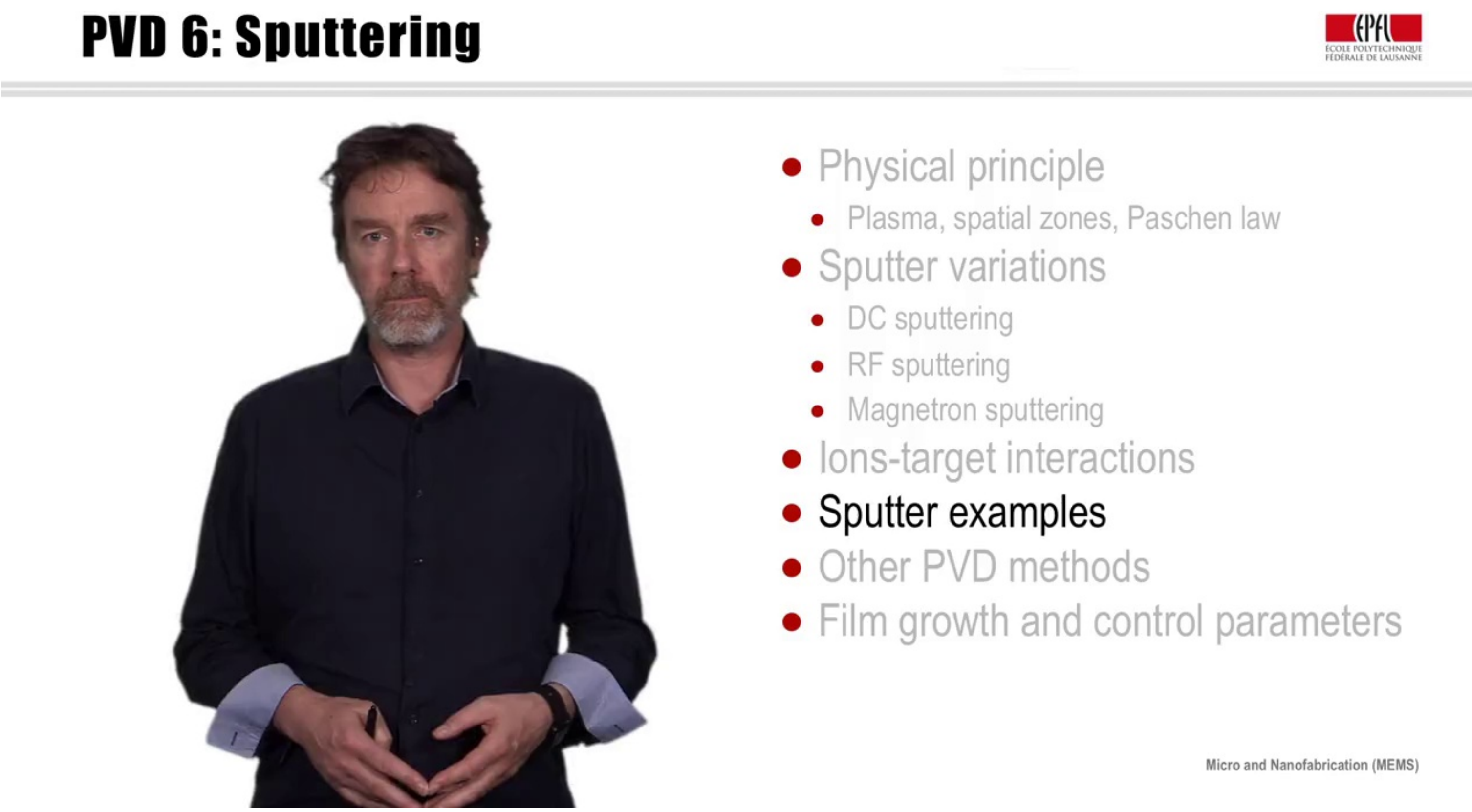
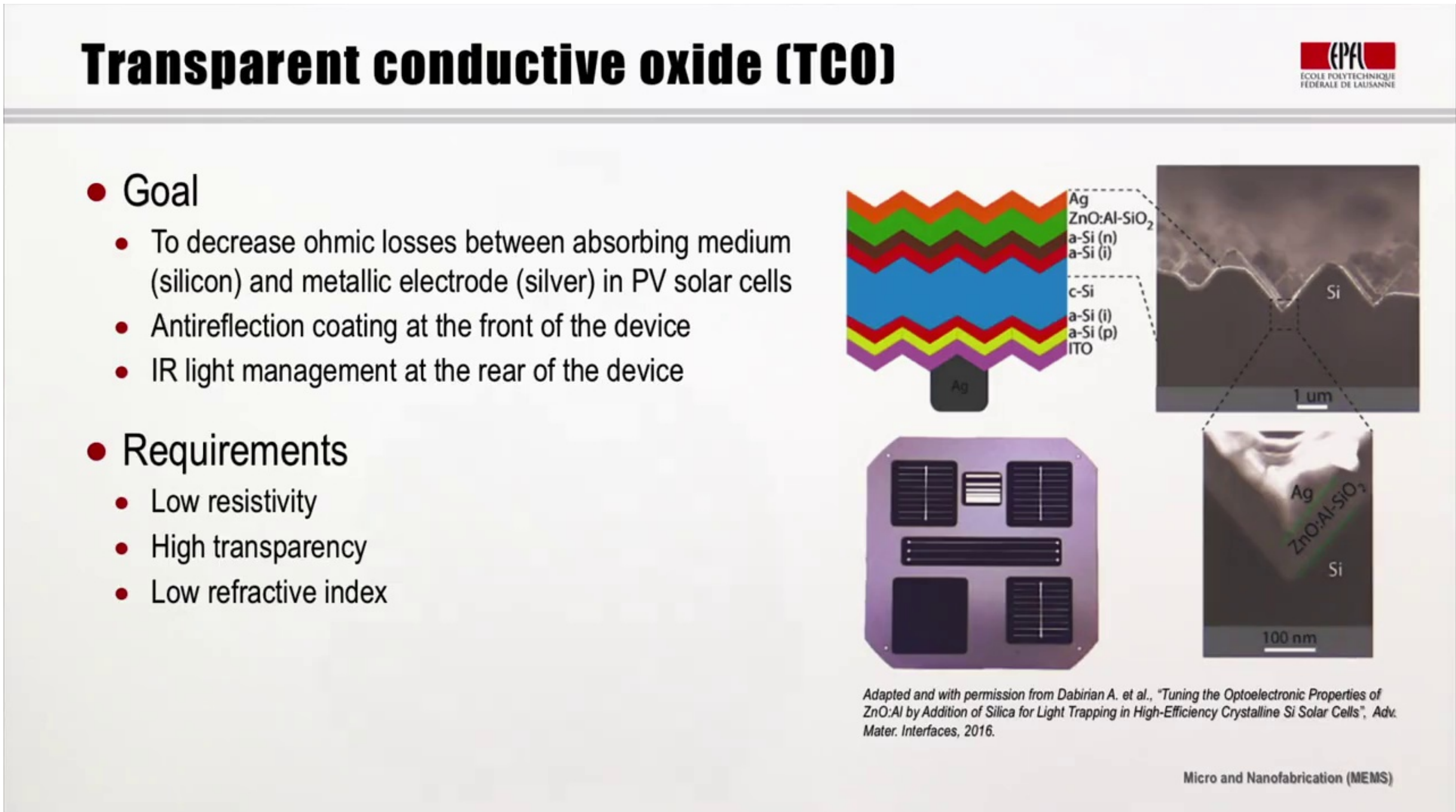
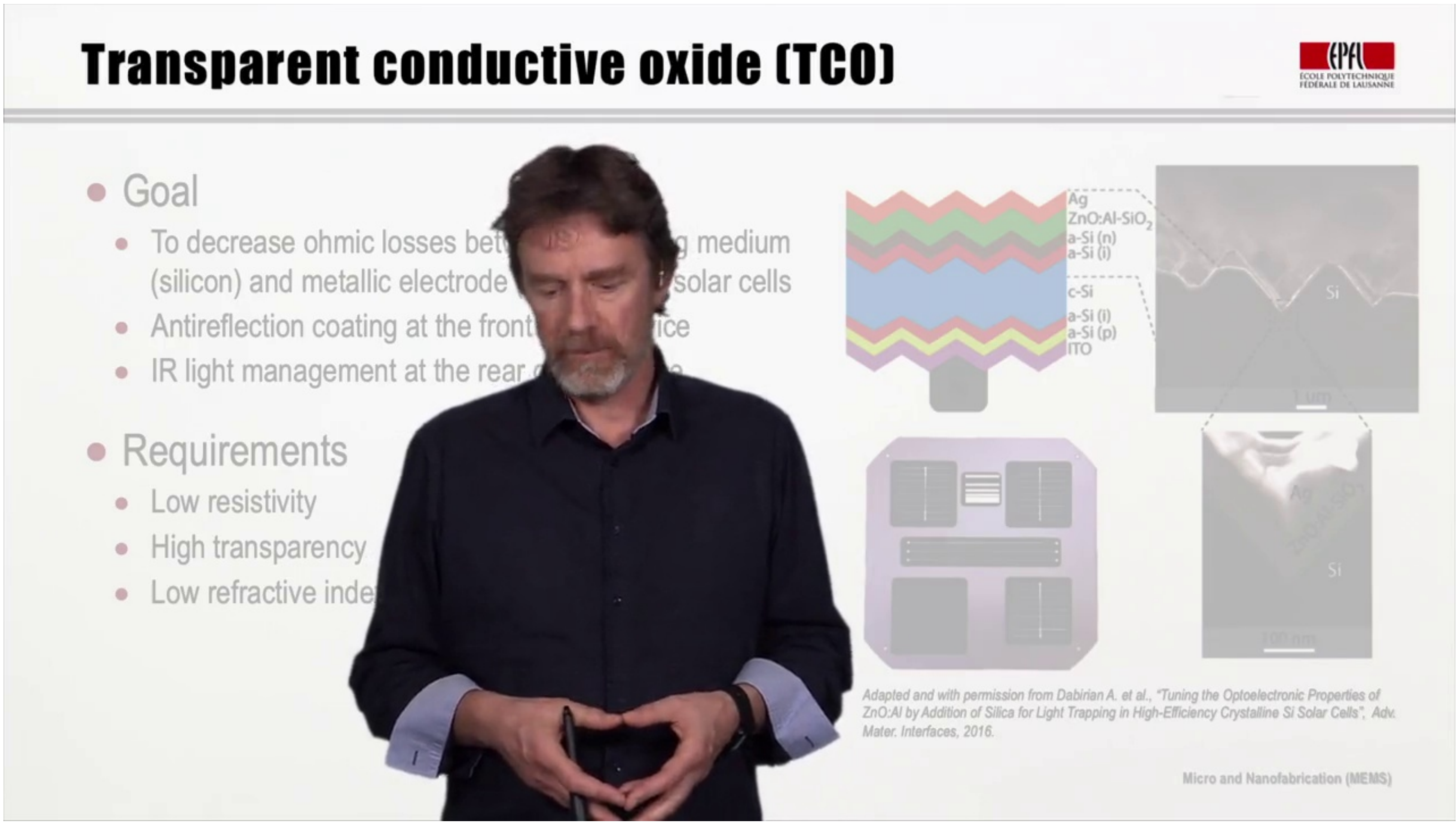


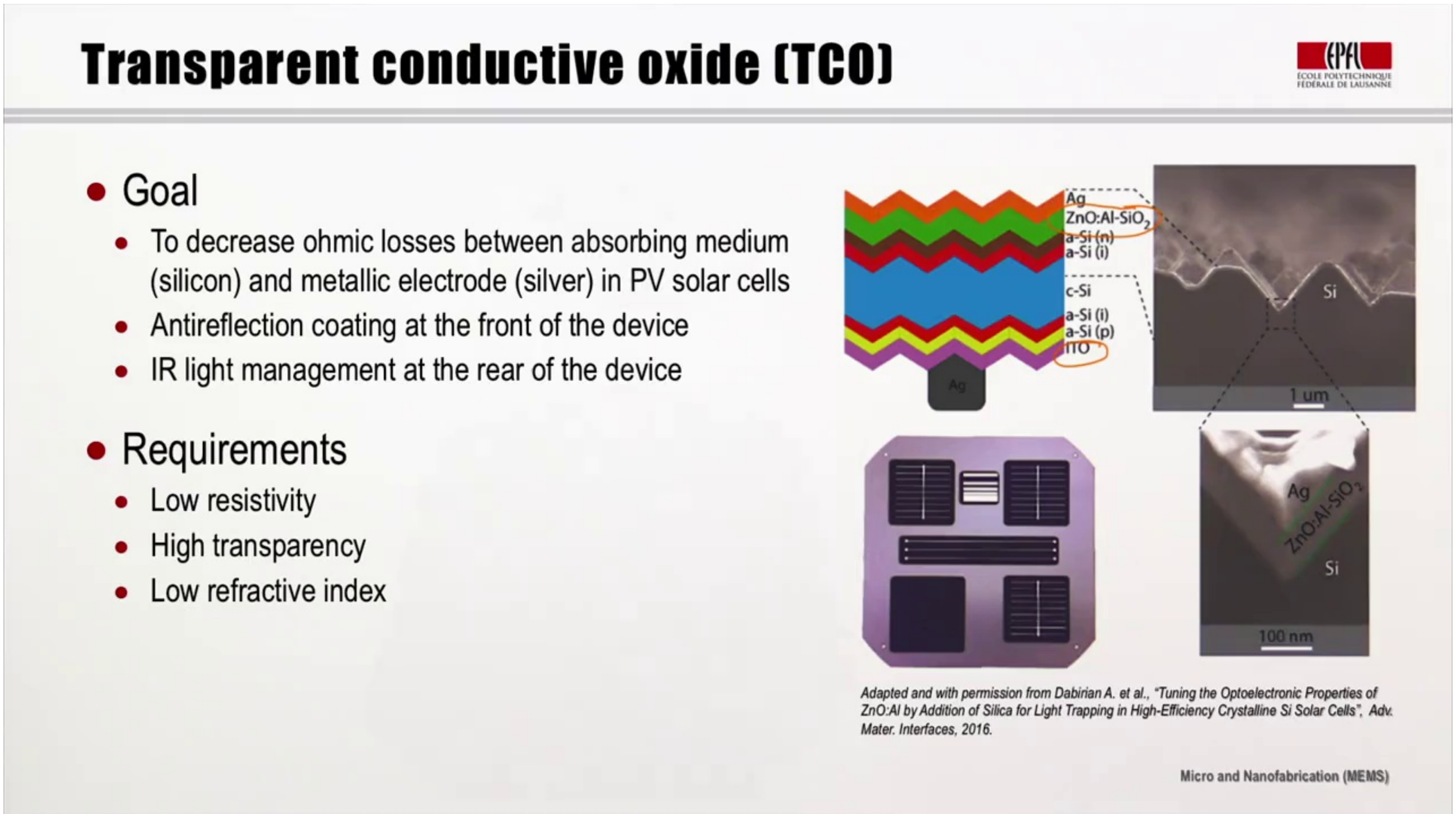

After having seen the basic principles of sputtering and details on the film growth, let's now present a couple of relevant examples where sputtered films are used in MEMs. At the end of this lesson I will also show some details of the sputtering setup and take you into the clean room to see the real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



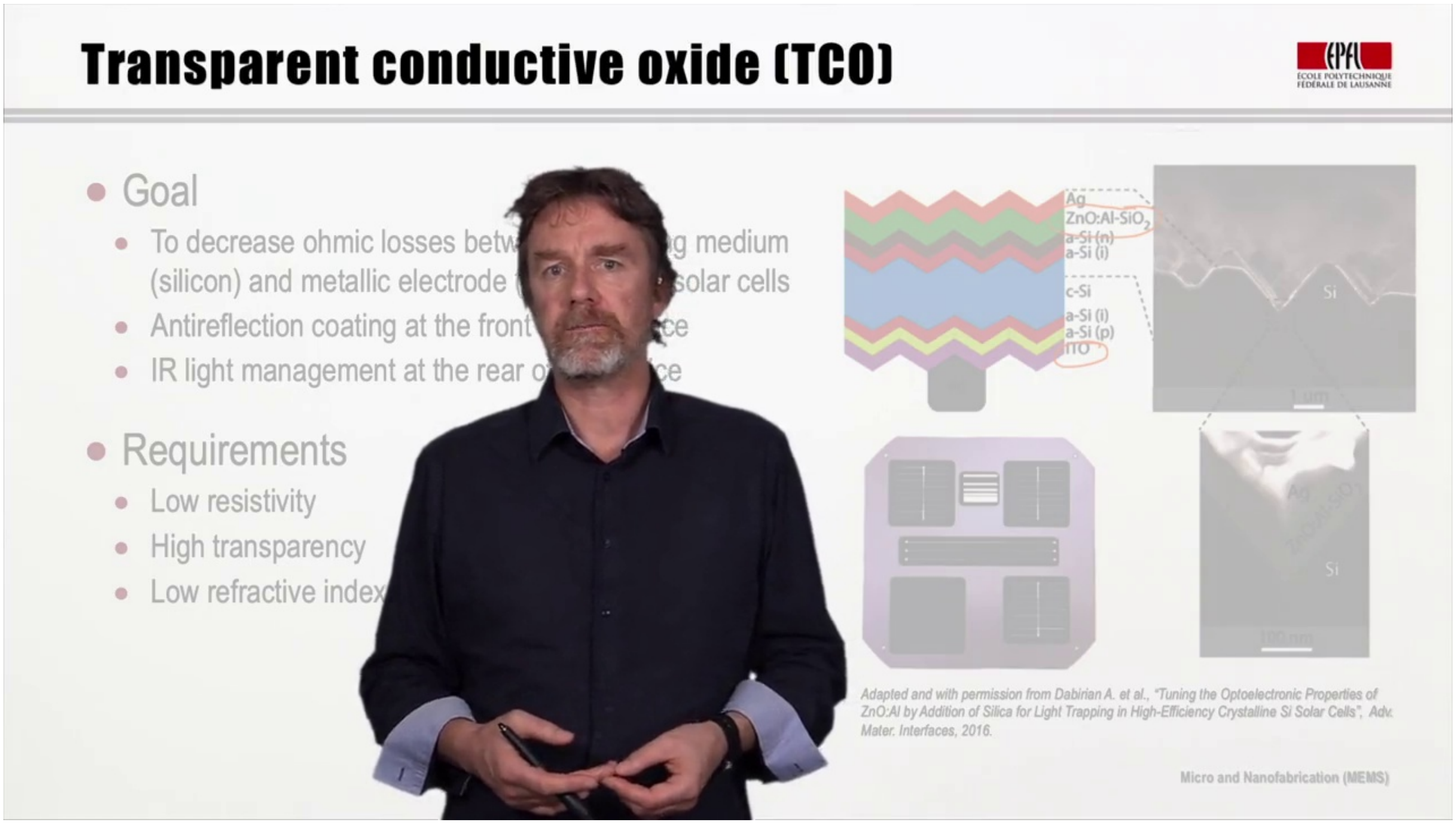

At first, application where sputtering is advantageous is the fabrication of transparent conductive oxide films for photovoltaic solar cells (PV). A photovoltaic solar cell is a device which transforms light into an electrical current. In most common solar cells, the absorbing material is made of crystalline 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.



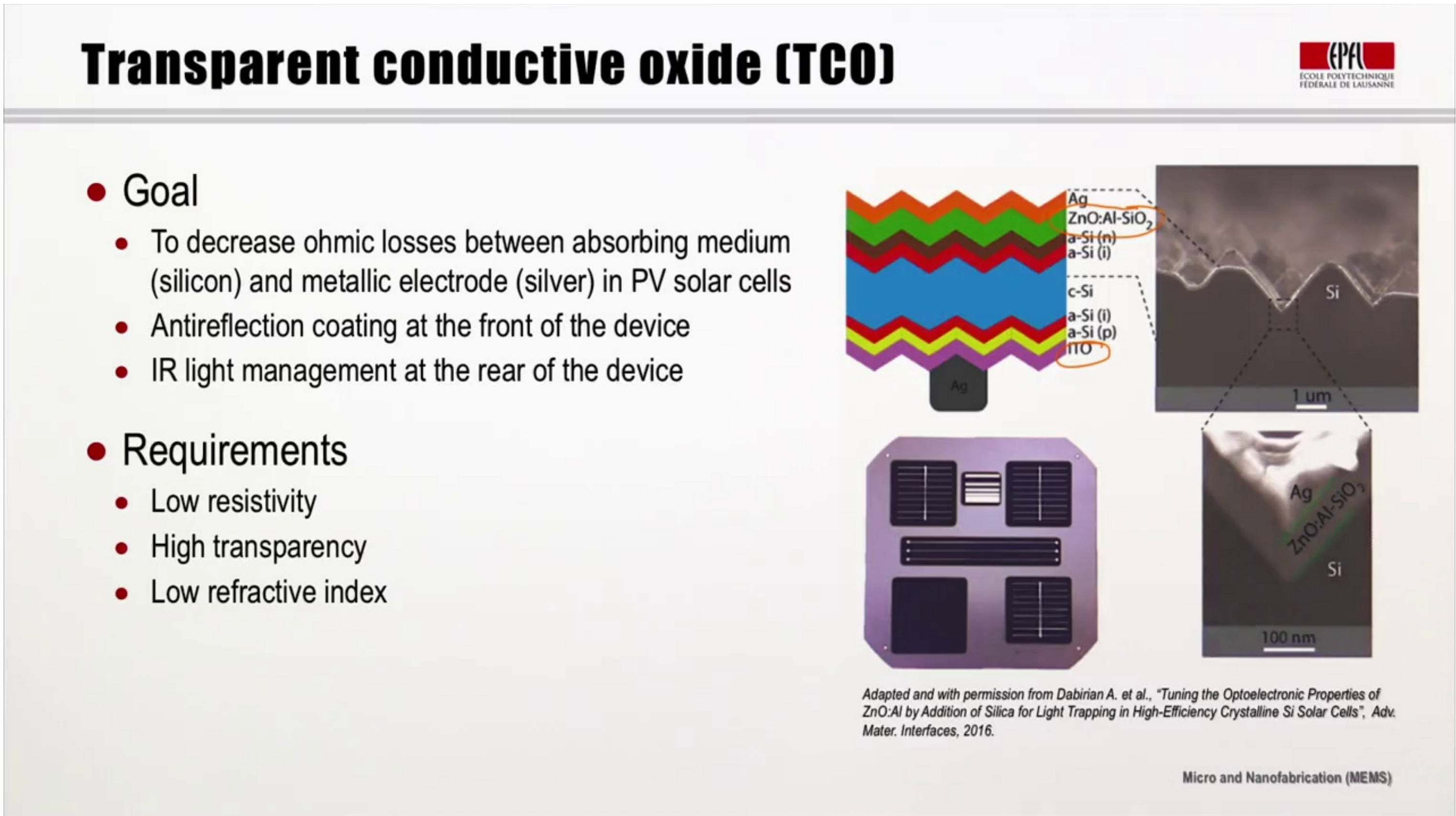

To improve the efficiency of crystalline silicon solar cells, amorphous silicon or alpha silicon and transparent conductive oxide so-called TCO are added in between the active crystalline silicon area and the metallic electrodes, in silver. As shown here in the right side of the slide.



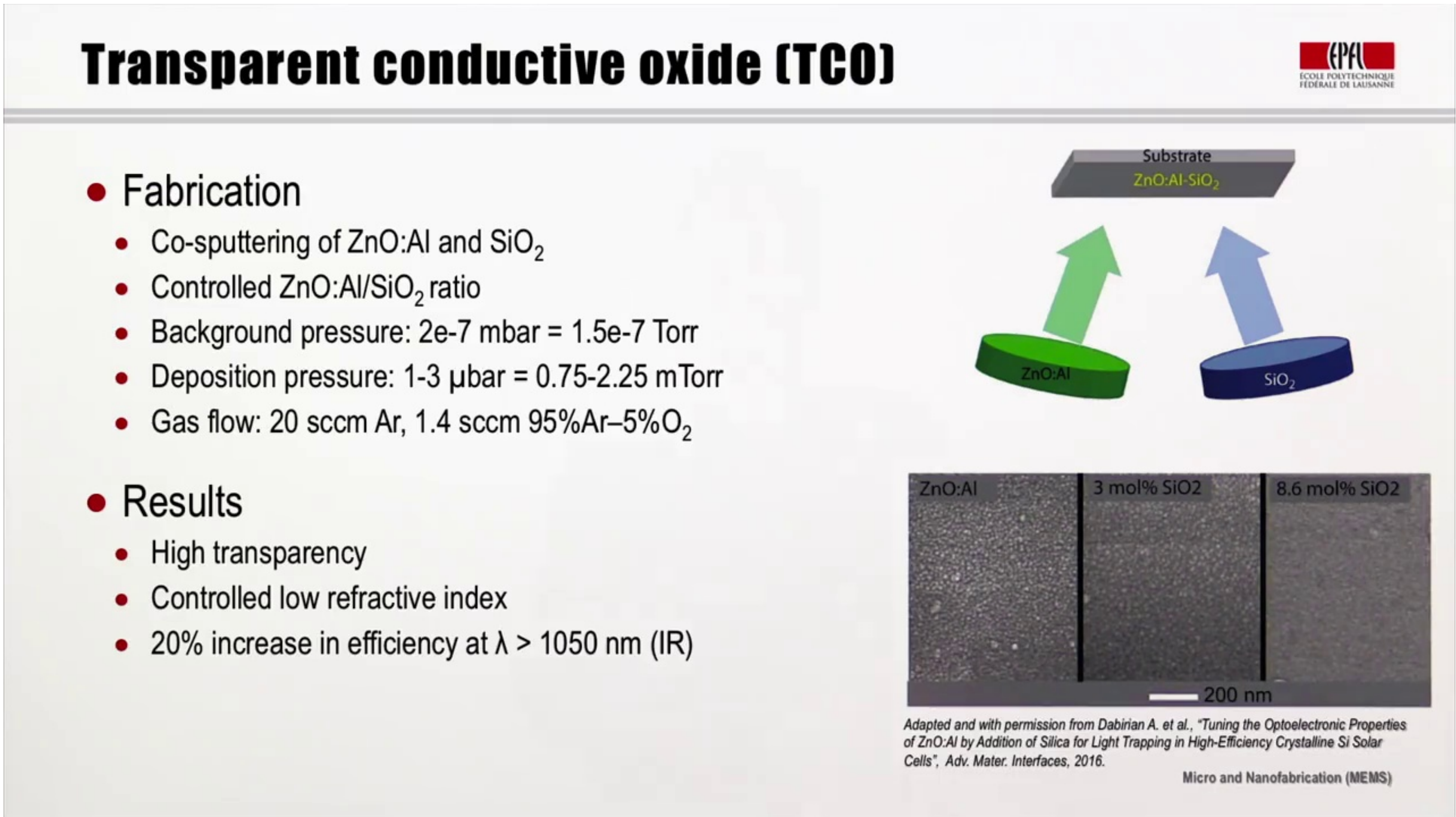

In this specific example, two different TCO are considered. First, the indium tin oxide or ITO is added at the front side of the device where the light comes in. And the second a zinc oxide aluminum silicon dioxide alloy, shown here, is added at the rear of the device.



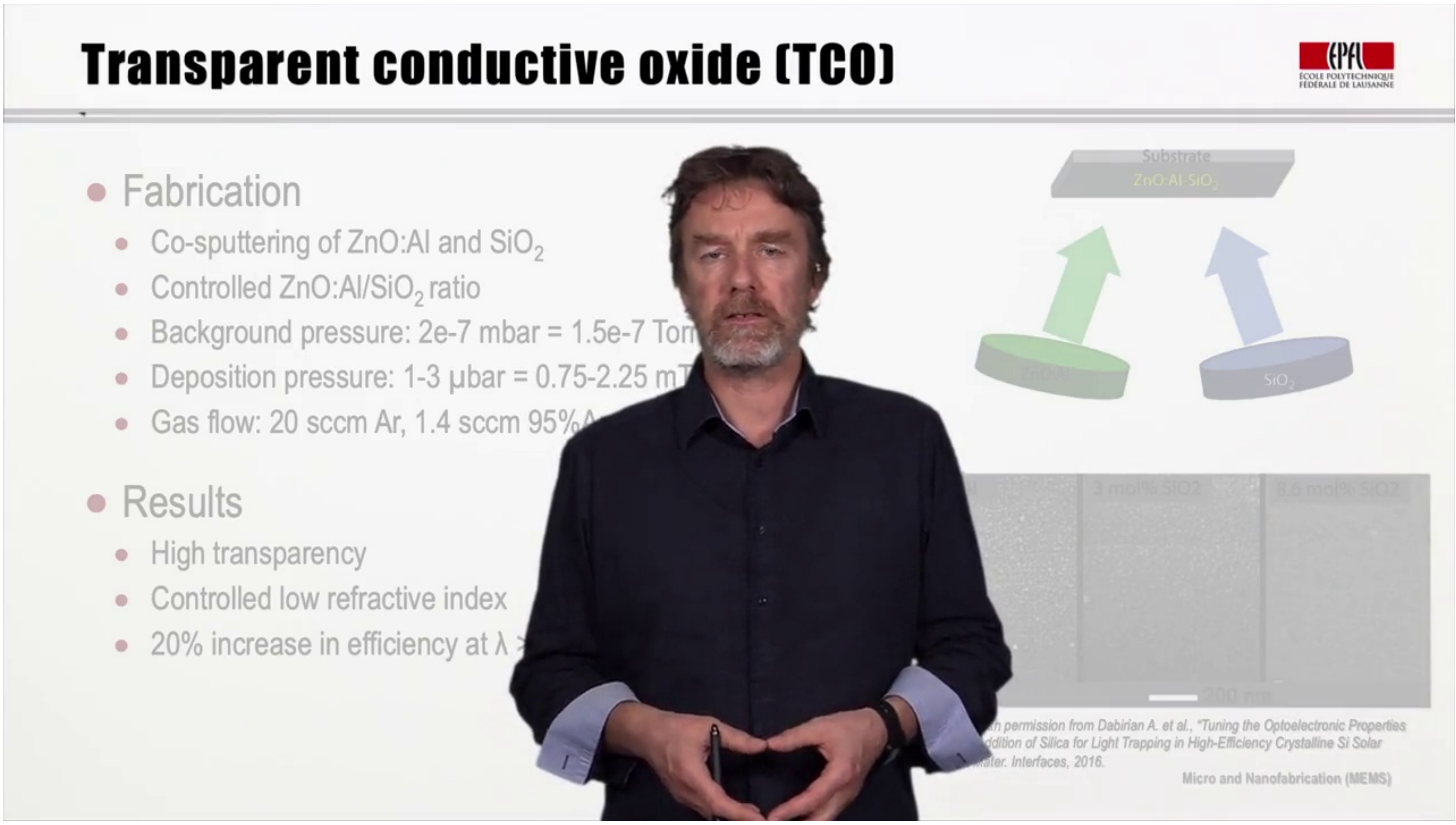

The first call of the TCO in the photovoltaic solar cells is to decrease ohmic losses between the electrode and the absorbing medium. However, TCO also functions as anti-reflection coatings at the front of the solar cell, as well as for infrared light absorption management at the rear of the cells.



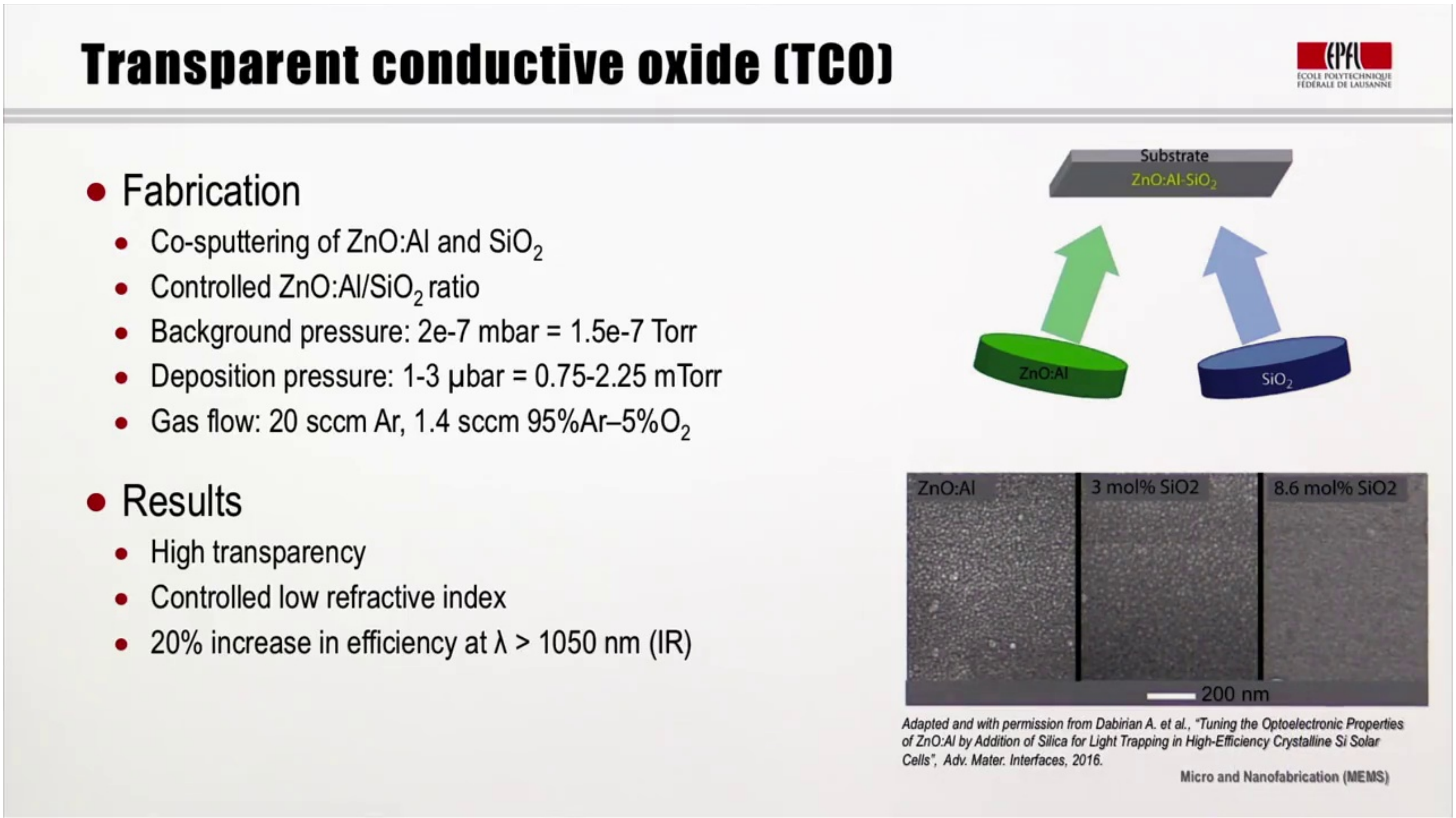

In order to fabricate cells with the highest efficiency as possible, TCO layers must have low resistivity, high transparency, and a low refractive index. To satisfy all these three requirements at the same time it is not that straightforward by using standard thin film materials. One way to succeed to 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.



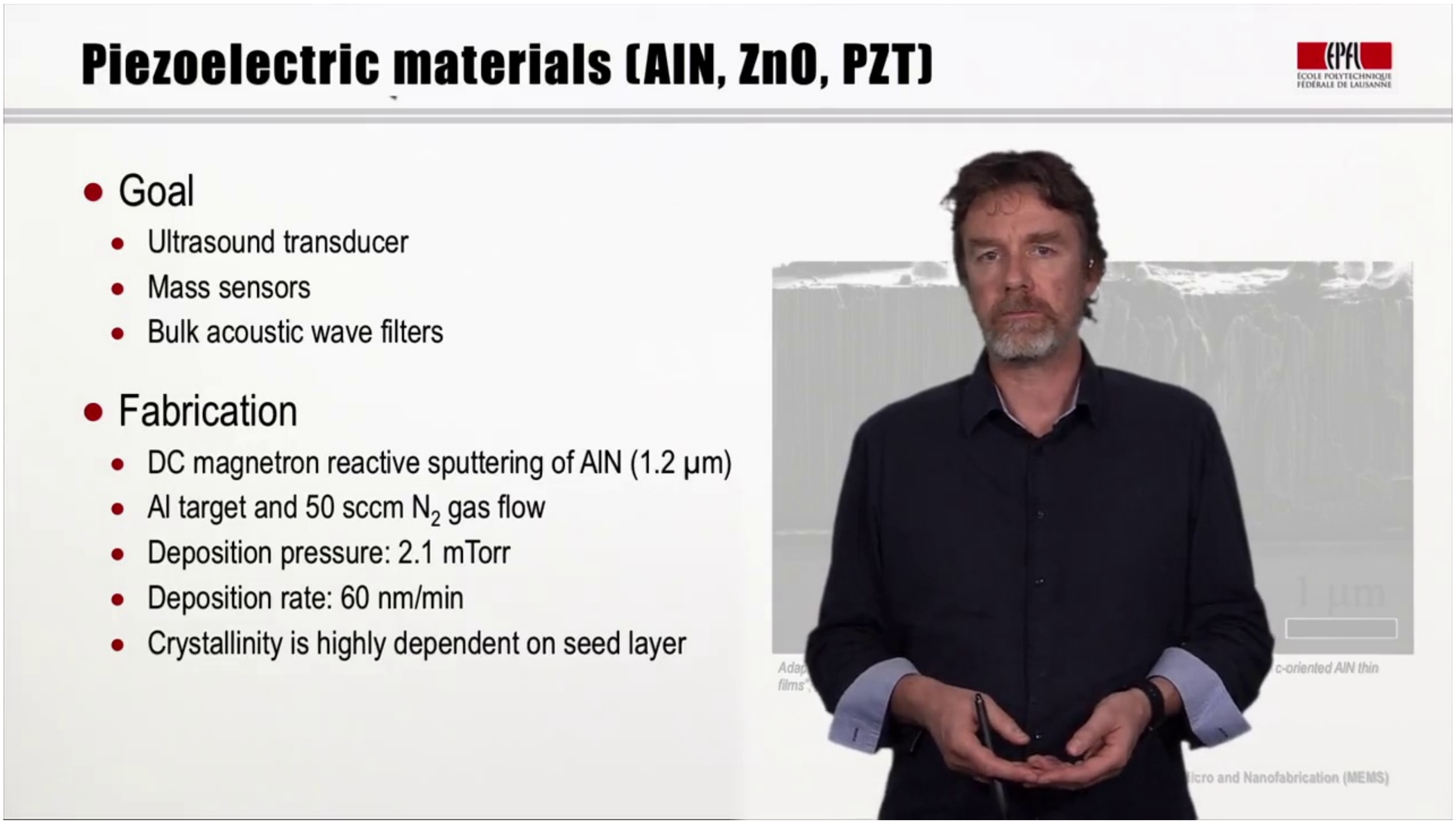

To deposit a zinc oxide aluminum SiO2 layer cool sputtering of zinc oxide aluminum and SiO2 is performed. As shown here, two targets are used within the same vacuum deposition chamber. Tuning the voltage on each target enables to change the zinc oxide aluminum SiO2 ratio into film. Formed here on the 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.



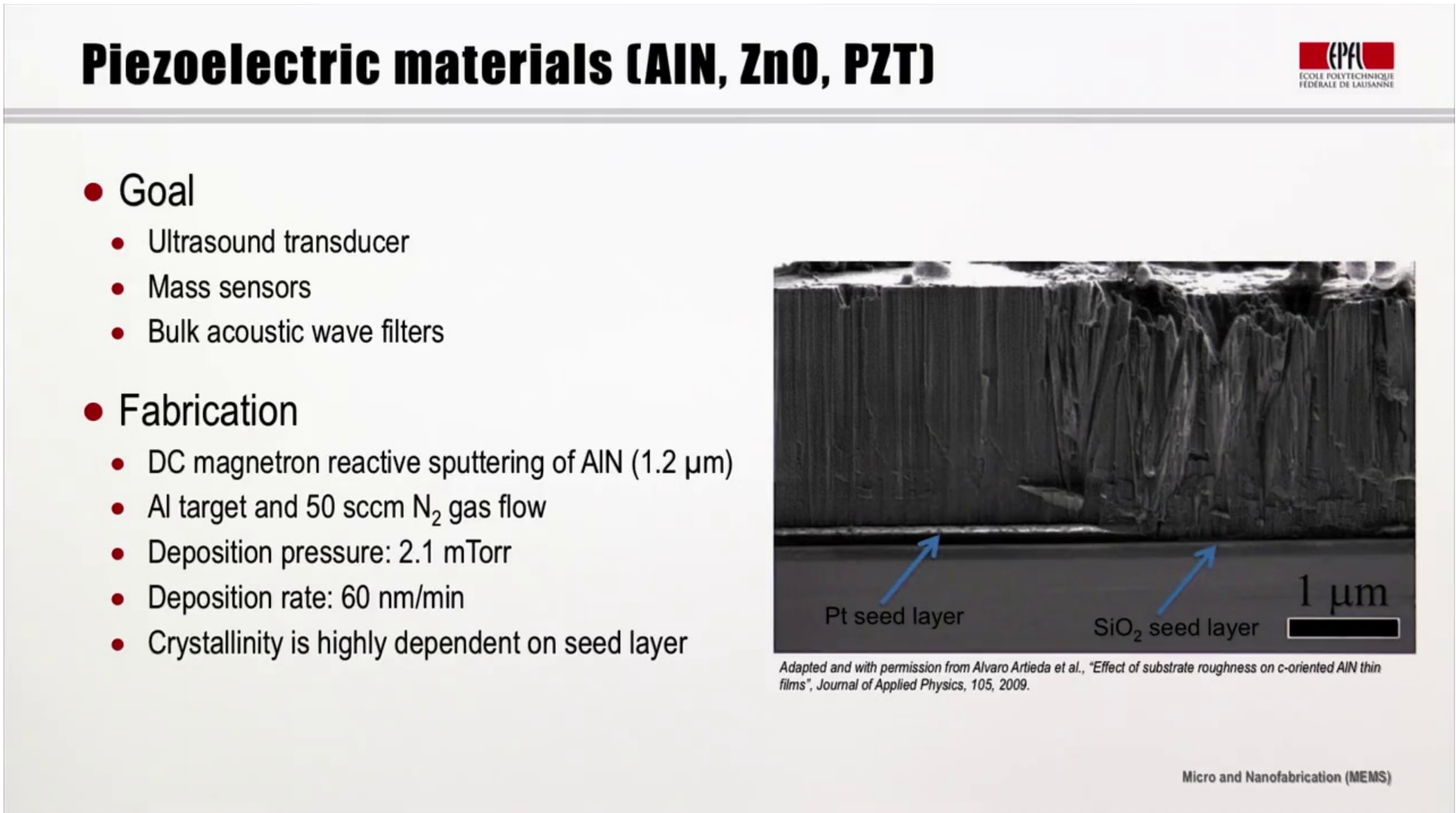

In this concrete example, sputtering enables the deposition of two compounds at the same time and thereby tuning the final stoichiometry of the deposited film. Such a performance is impossible to achieve with thermal evaporation. The fabricated films exhibit high transparency and low refractive index.



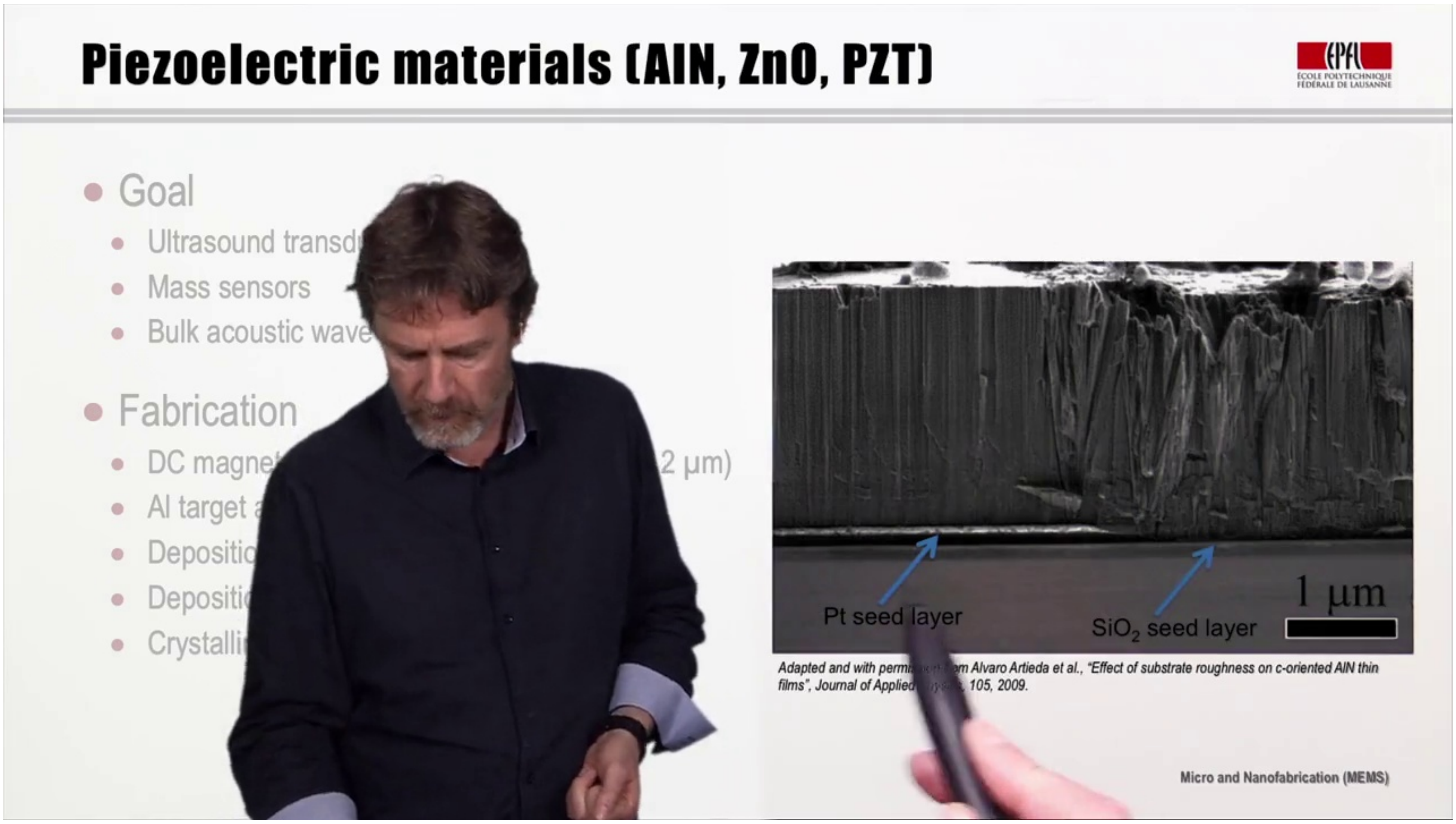

Three different coatings are shown here. First, on the left, the zinc oxide aluminum film without addition of SiO2. And then with increasing SiO2 concentration. It shows that the texture is changing towards less grainy morphology. At the same time, the solar cell efficiency increases by 20% in the infrared 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.



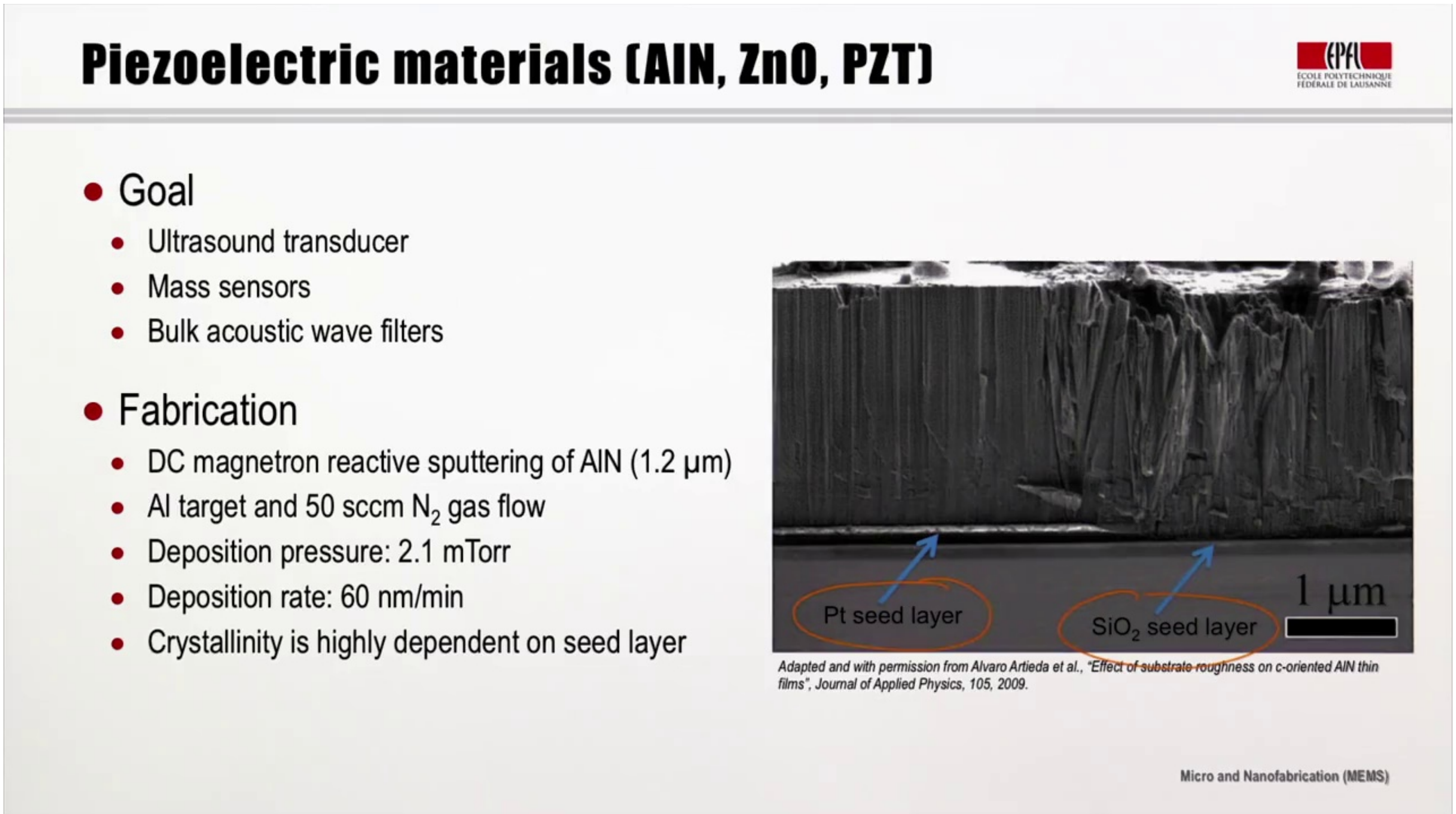

Our second thin film example of interest is based on piezoelectric materials, that are often deposited by reactive sputtering. Piezoelectric materials are very important and used in many MEMs devices such as ultrasound transducers, that means these devices convert a pressure wave into an electrical signal. 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.



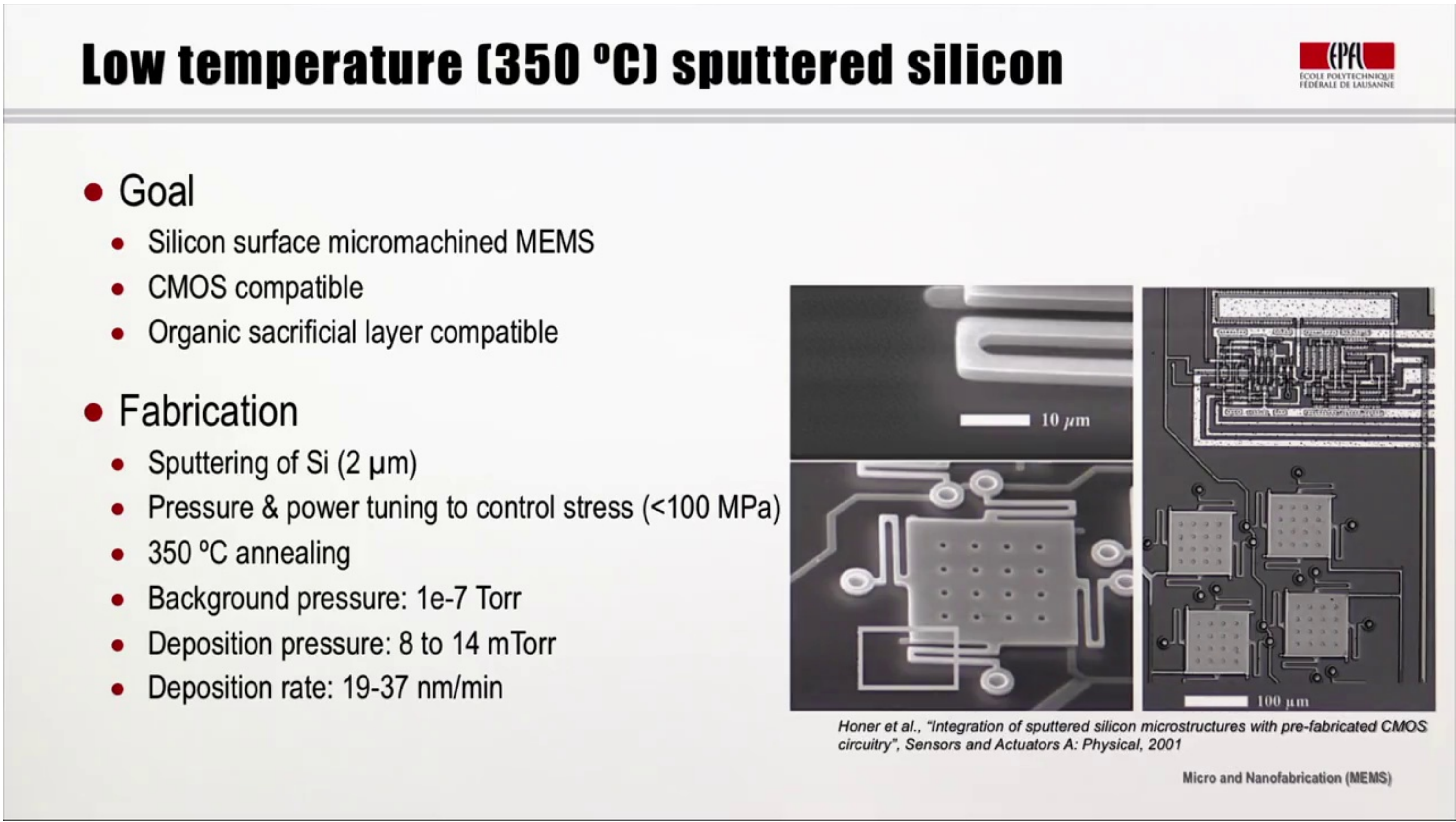

Typically, bulk acoustic wave filters are made of aluminum nitrate; because of the excellent electroacoustic properties of this material and its chemical compatibility with micro-fabrication processes. The quality of the filter is determined by the piezoelectric film crystal structure. Reactive sputtering 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.



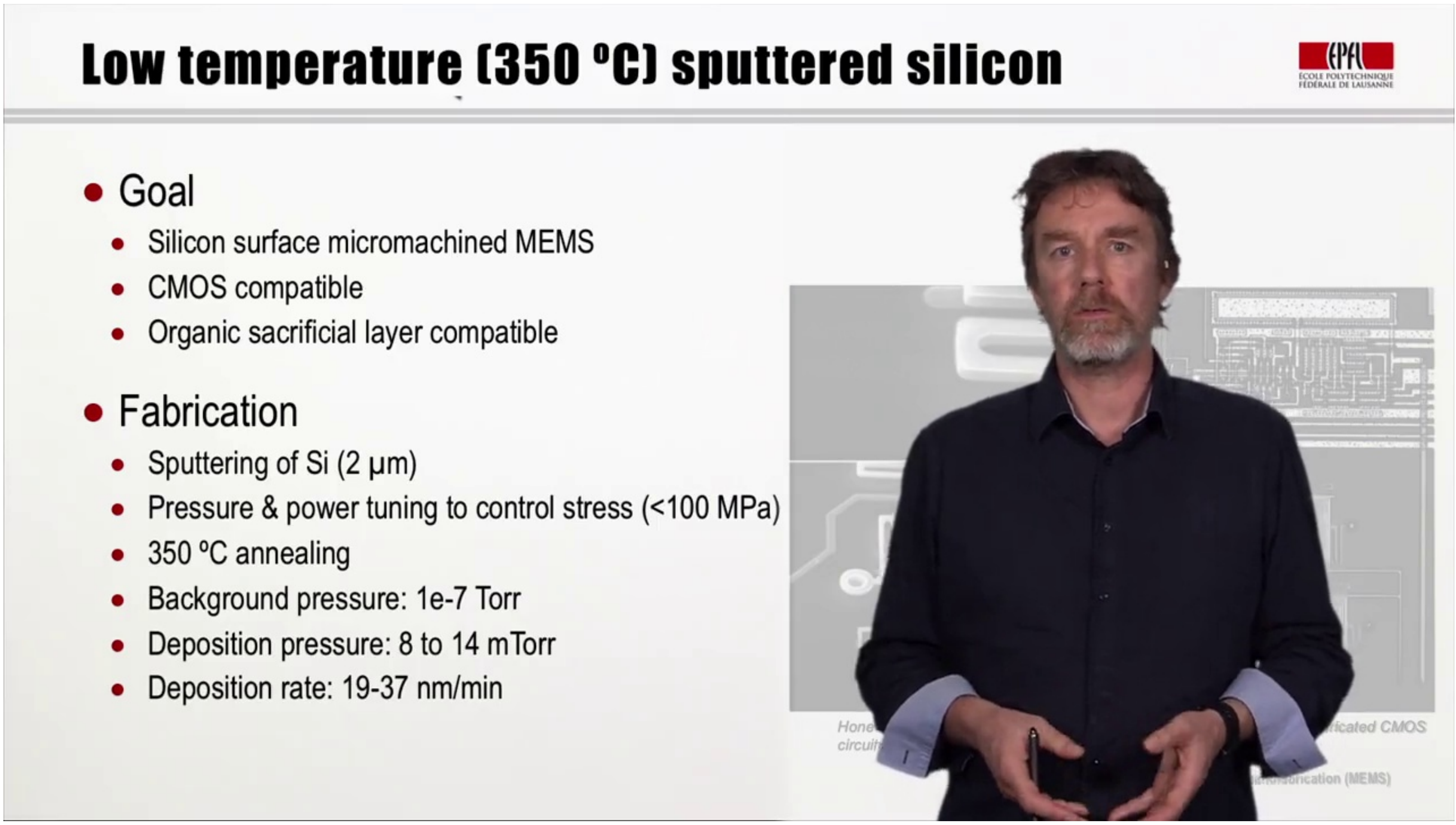

However, the film crystal structure is highly dependent on the underlying seed layer. Film growth structure and stresses are explained in details in the film growth lesson. In the case of bulk acoustic wave-filters this underlying seed layer consists either of the platinum bottom electrode.



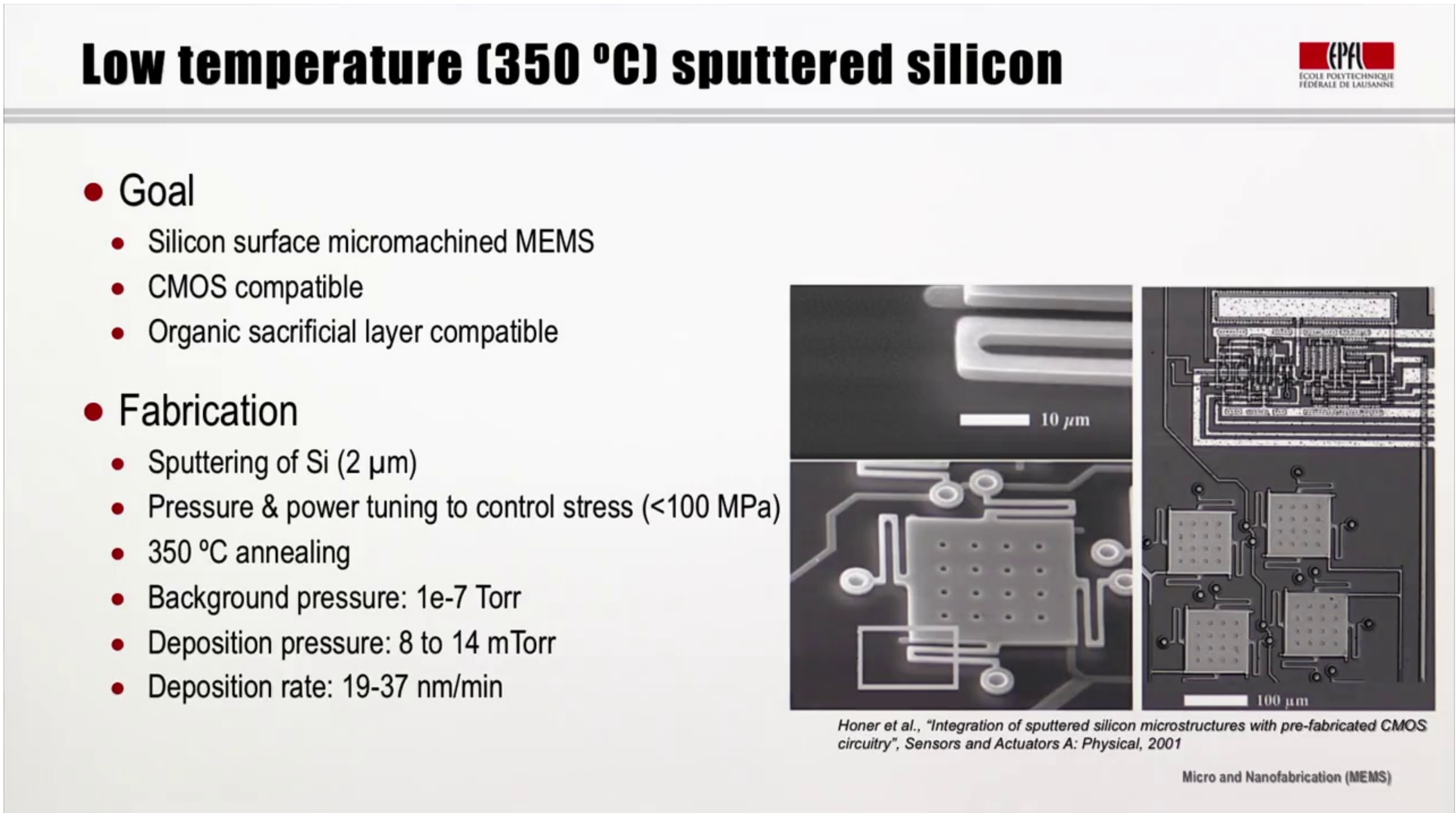

Shown here. Or of a silicon dioxide layer. Indeed, the platinum electrode is patterned and the wafer surface, prior to the aluminum nitrate deposition, is thus made of two different materials, platinum and SiO2. As you can see here on the right, the aluminum nitrate deposited on top of platinum, has a well-defined crystalline structure, compared to the aluminum nitrate that grows on top of the SiO2 which is less uniform. In addition, the residual stress of aluminum nitrate grown on platinum seed layer is also lower in the order of 200 MPa, tensile stress, versus minus 700 MPa, compressive stress, respectively on the SiO2. So the challenge here is to optimize crystallinity of the overall film in order to acquire the best piezoelectric properties as possible.



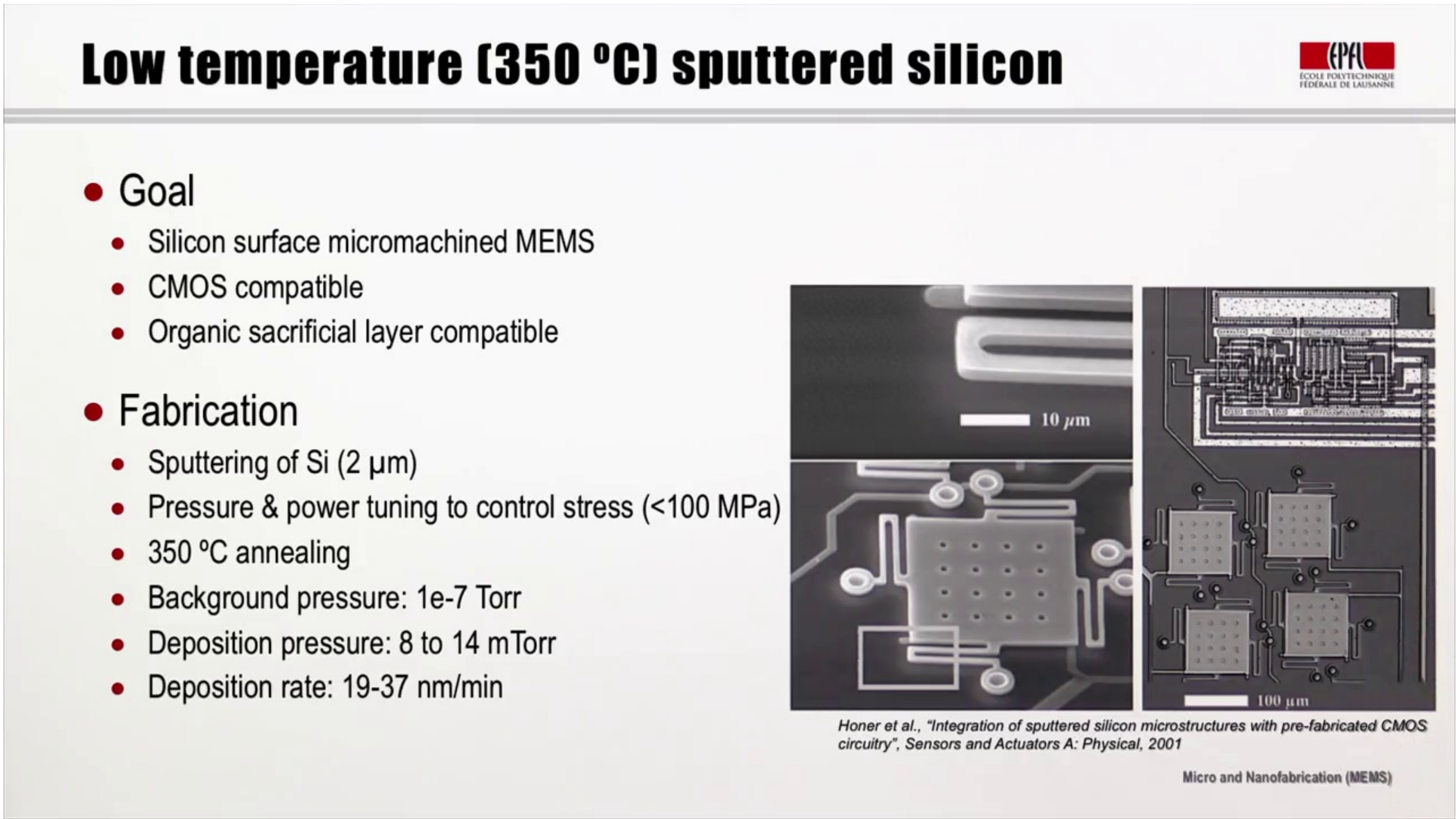

Here is one further example which illustrates how sputtering enables the manufacturing of MEMs. In this case, we are depositing a silicon thin film by sputtering and followed by lithography and etching.



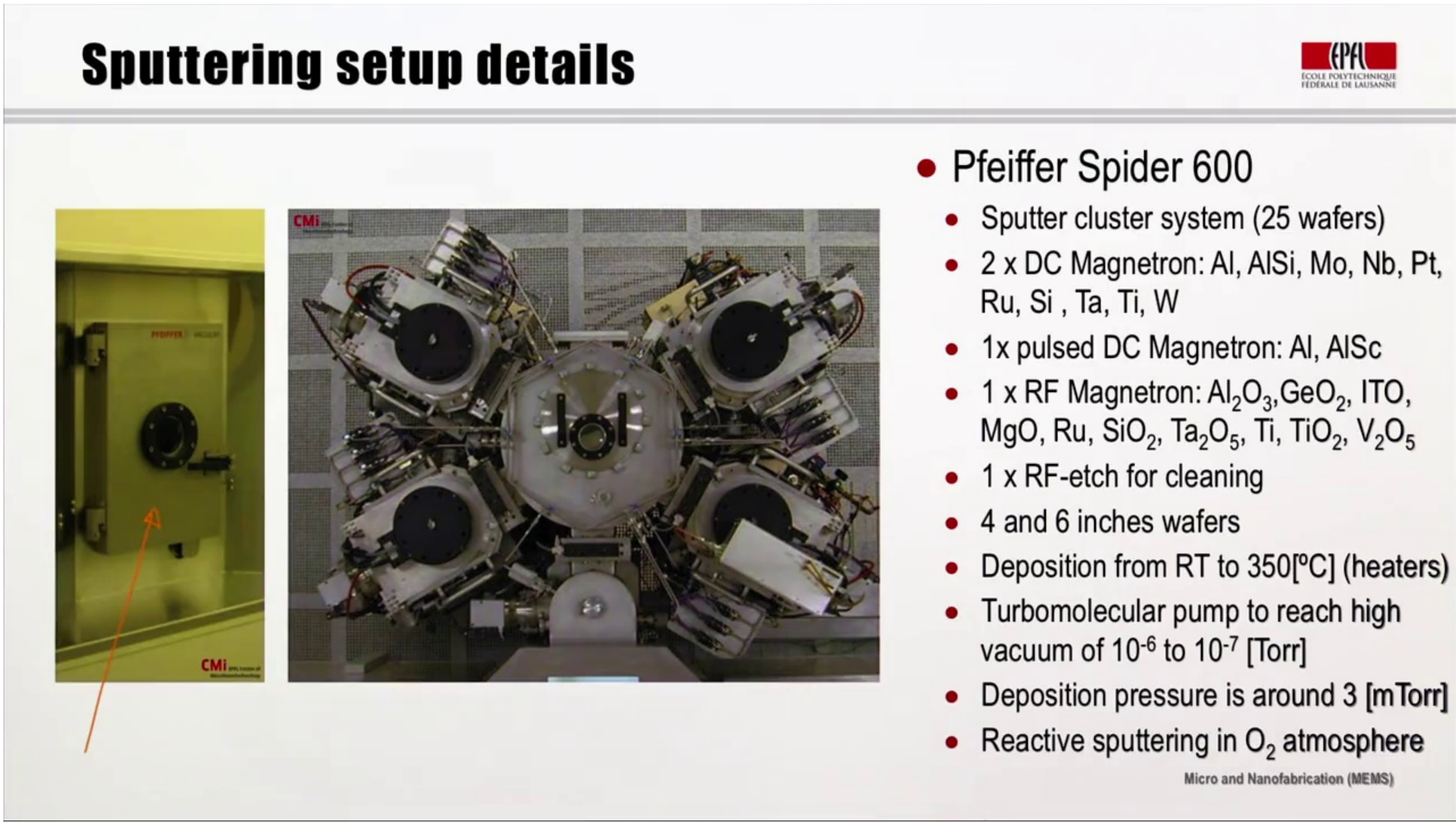

Many suspended microstructures are made of low-pressure chemical vapor deposition (LPCVD) polysilicon. Because of the well-characterized mechanical properties of polysilicon and because of the residual stress in thin films deposited by LPCVD can be tuned.



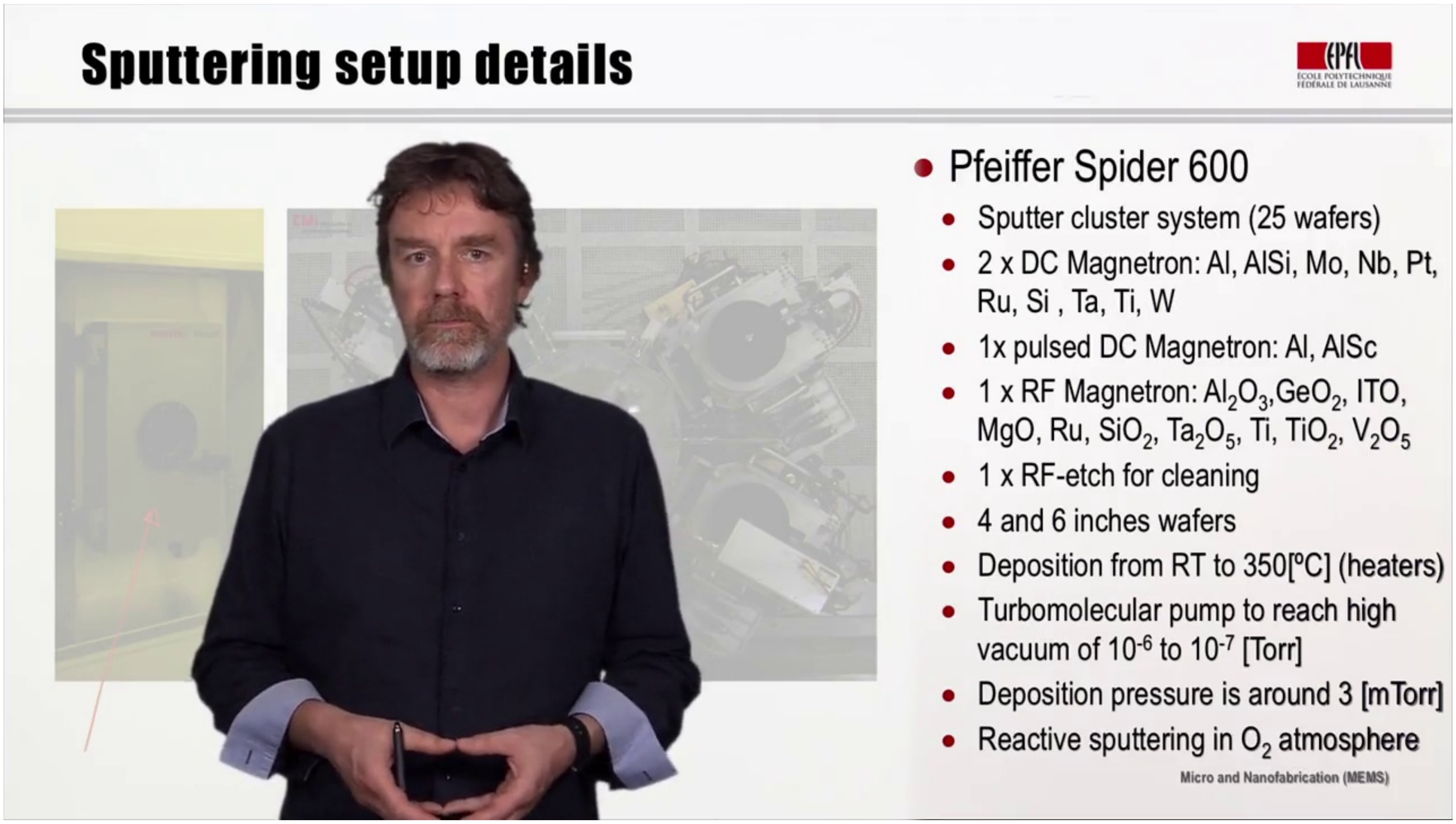

However, the LPCVD process requires temperatures higher than 600° C. And is thus not CMOS-compatible. Building the MEMs device directly on top of a CMOS circuitry to control a MEMs device, however, would increase the device performance as well as its functionality. Indeed, having signal amplification close to the signal source allows decrease in the noise, and on-chip multiplexers enable the dense integration of a large number of devices. We thus look for a low temperature, silicon deposition technique, and use sputtering instead of CVD. 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 SiO2 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, 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.