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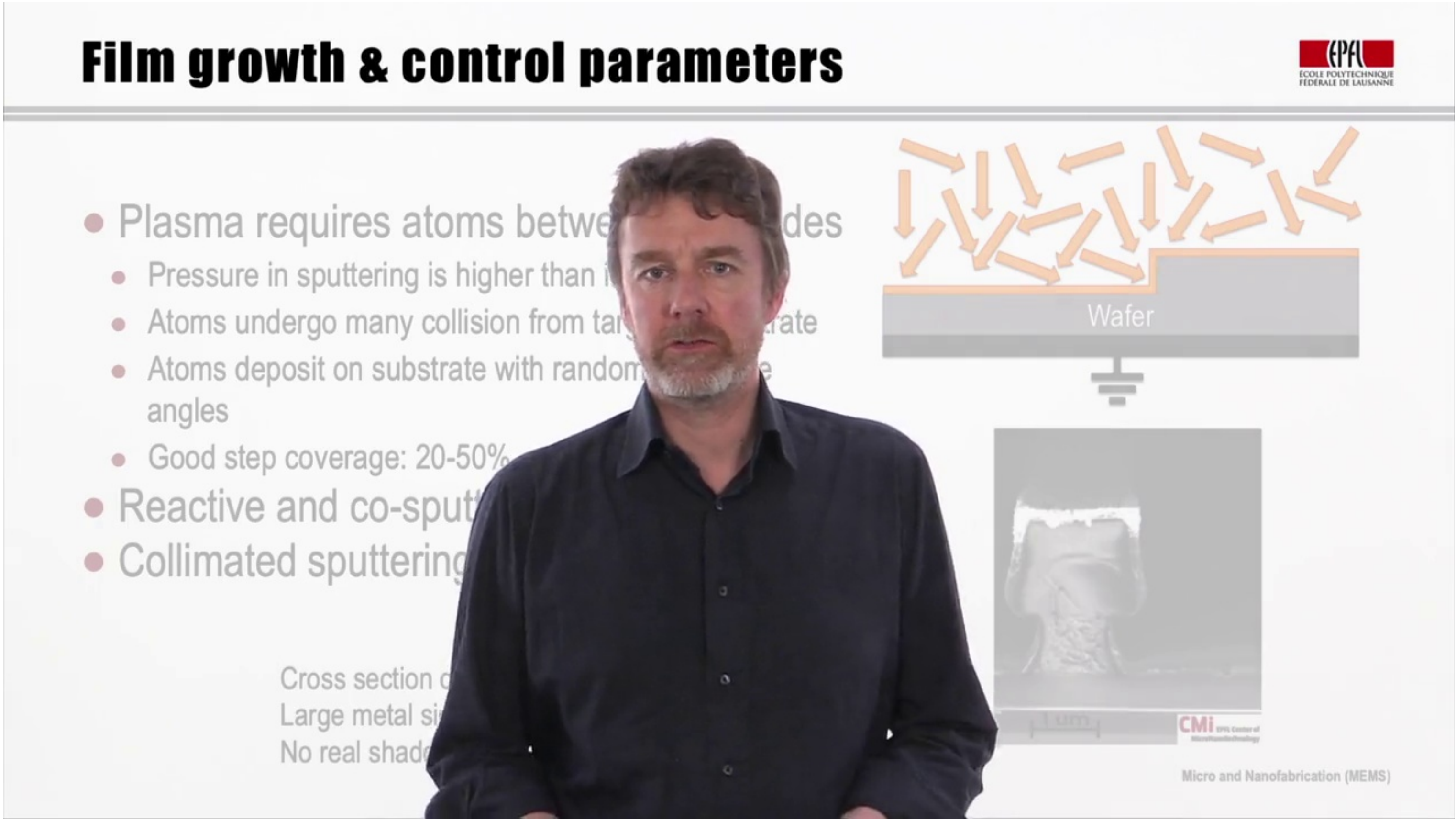
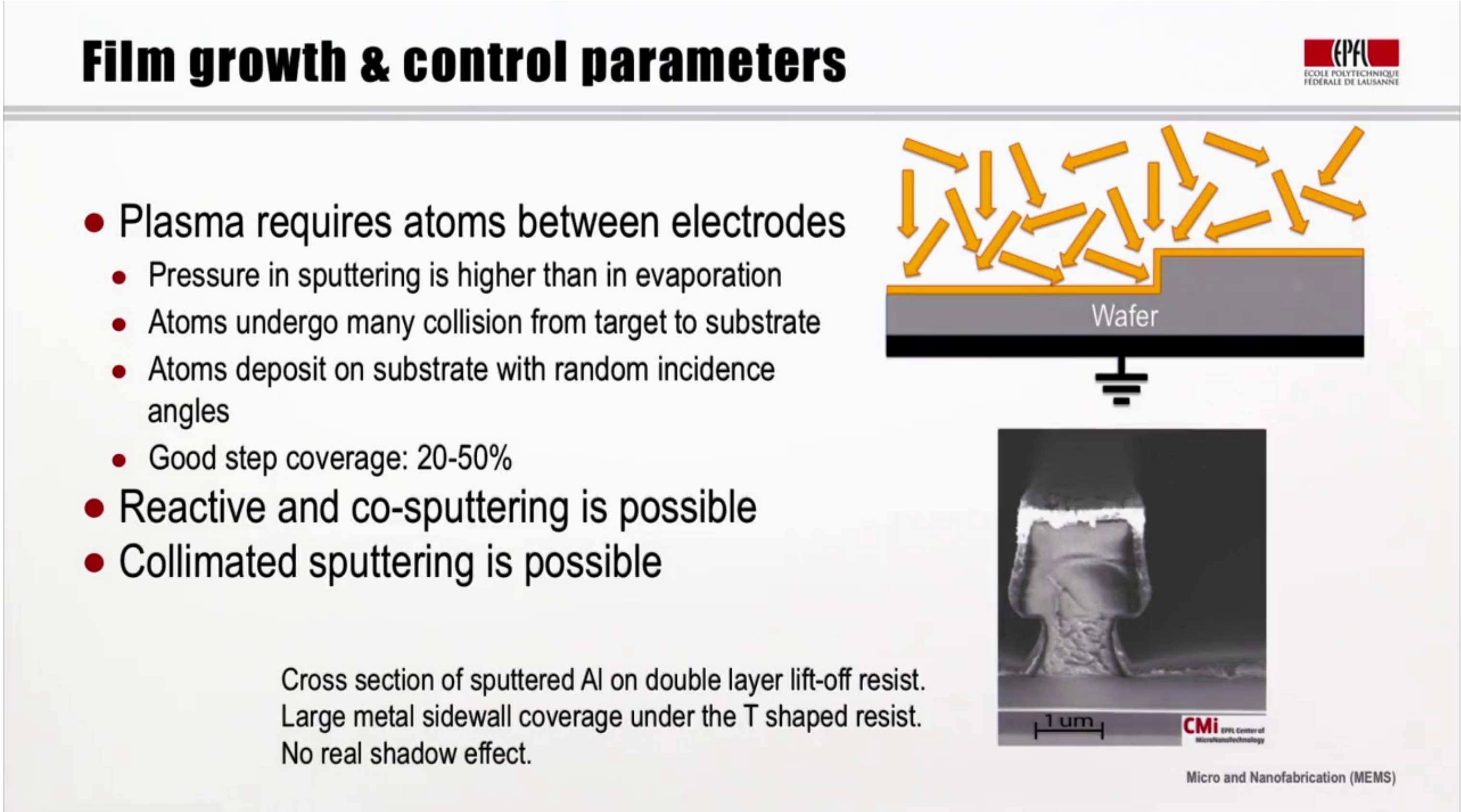
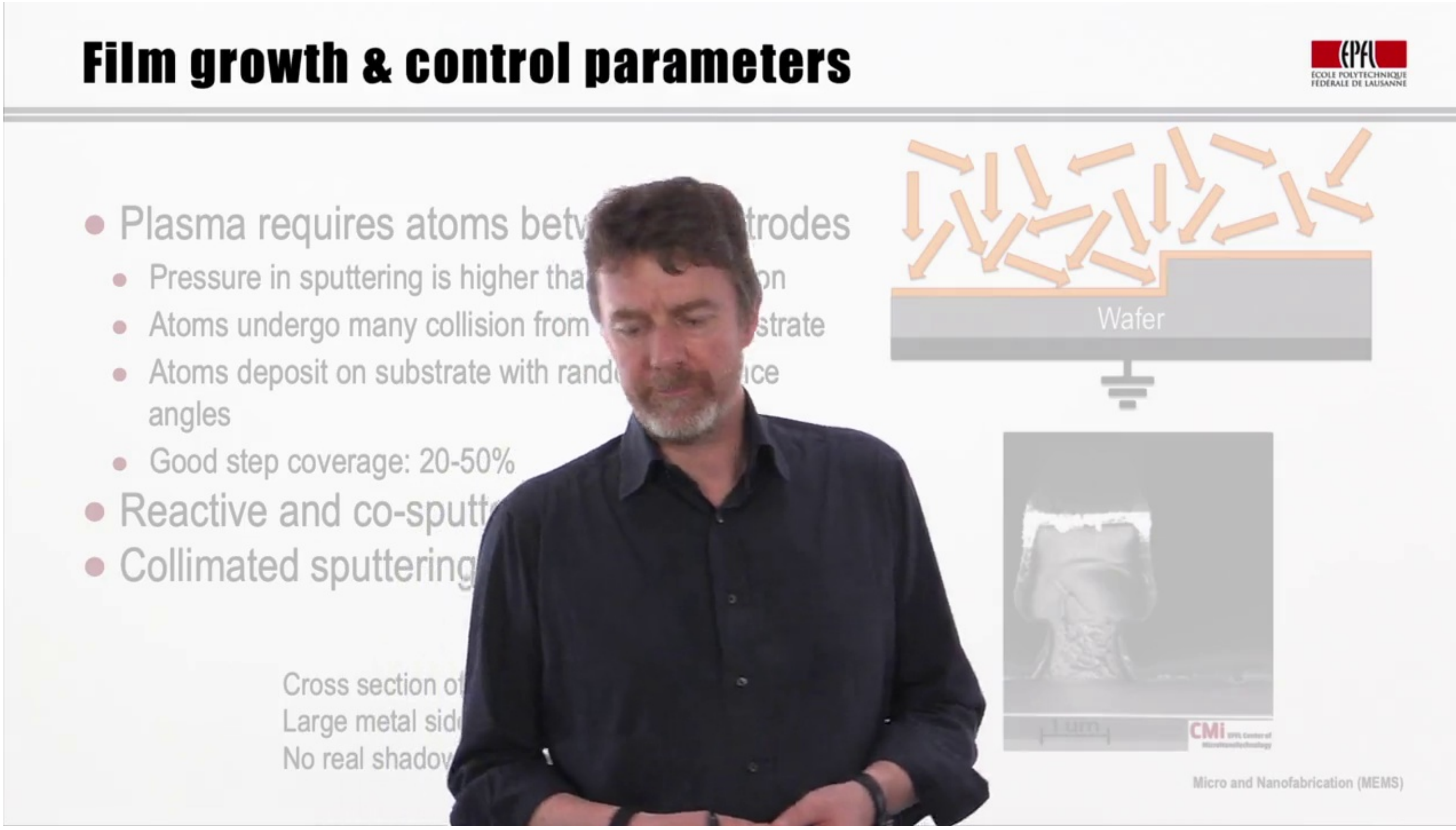


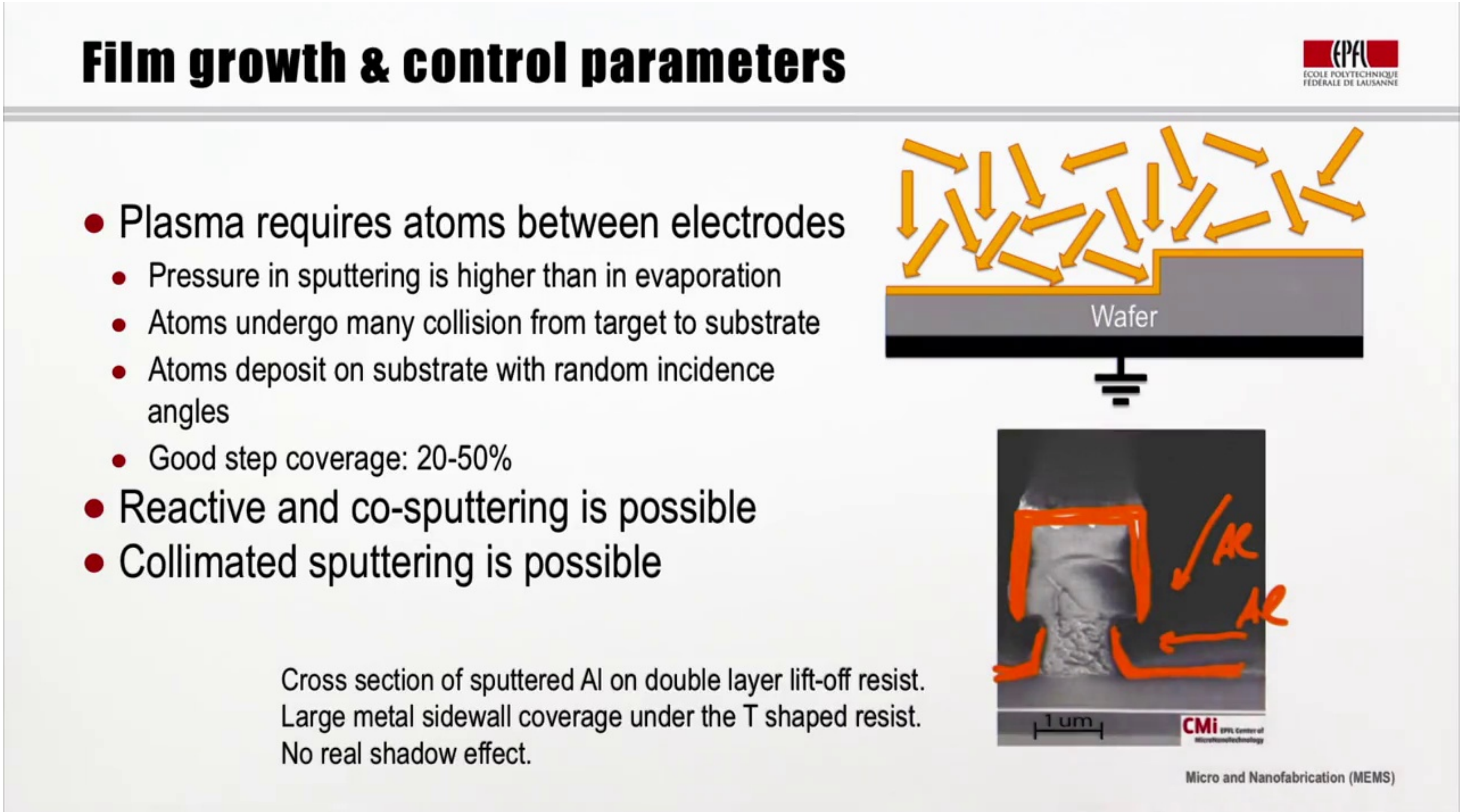
In order to create a plasma, a certain amount of gas molecules is required between the electrodes.



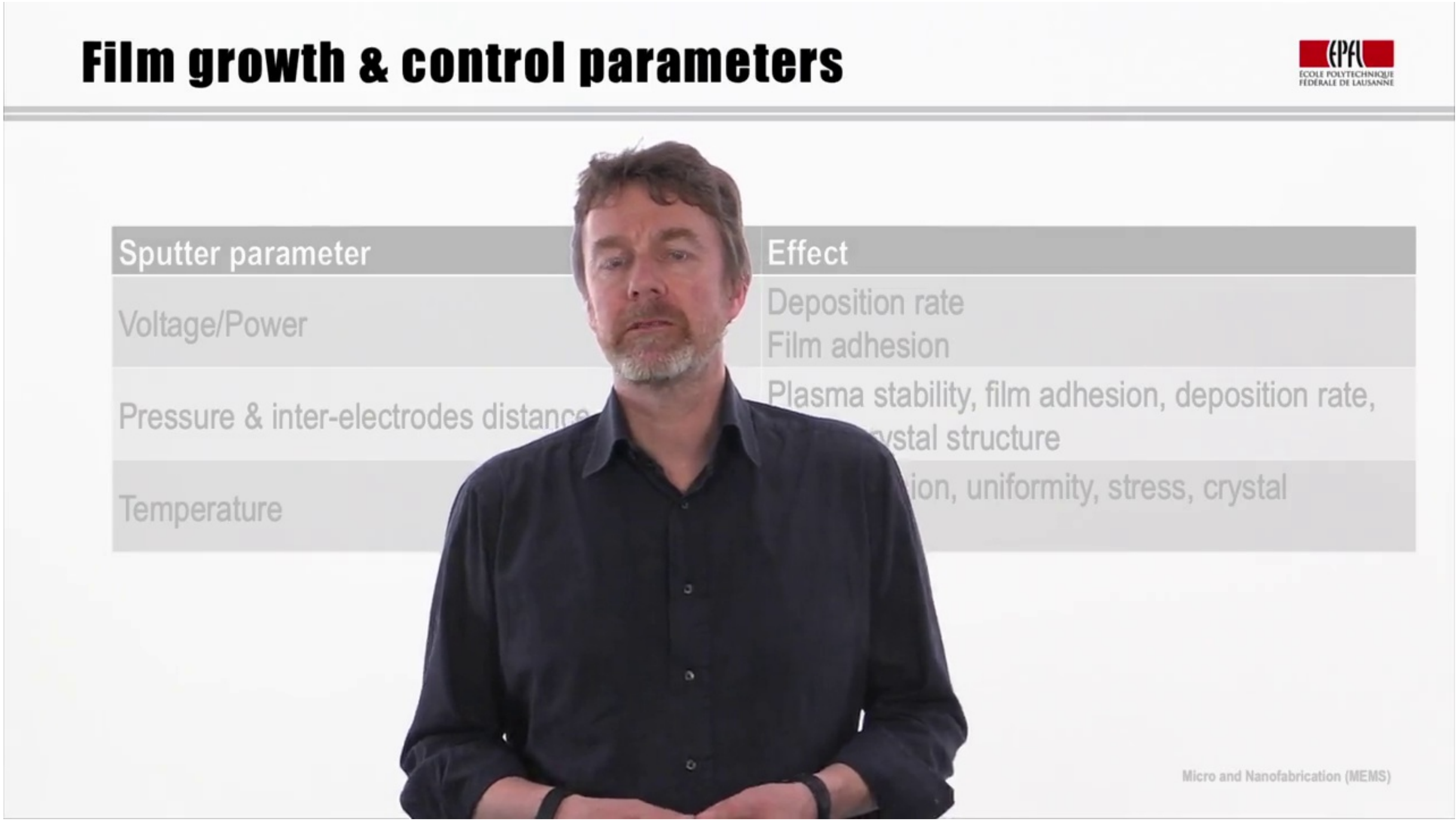
Consequently, the pressure at which the deposition in a sputtering system occurs is higher than that used for thermal or electron beam evaporation. We use typically 10^-1 to 10^-3 Torr for sputtering, instead of 10^-6 to 10^-7 Torr for evaporation. As a result, the mean free path in sputtering is only a few millimeters compared to meters in evaporation. Atoms ejected from the target will therefore collide with many gas particles and ions before reaching the substrate. Due to the multiple collisions, the atoms impinge on the surface with random incidence angles, shown here, with the yellow arrows on this cartoon. Thus, the way atoms deposit onto the substrate and the film grow is different from evaporation. For instance, having a random incident angle allows having a better step coverage compared to evaporation, where a long mean free path produces a line of sight deposition with a possible shadowing effect, as you may remember from the evaporation lesson.



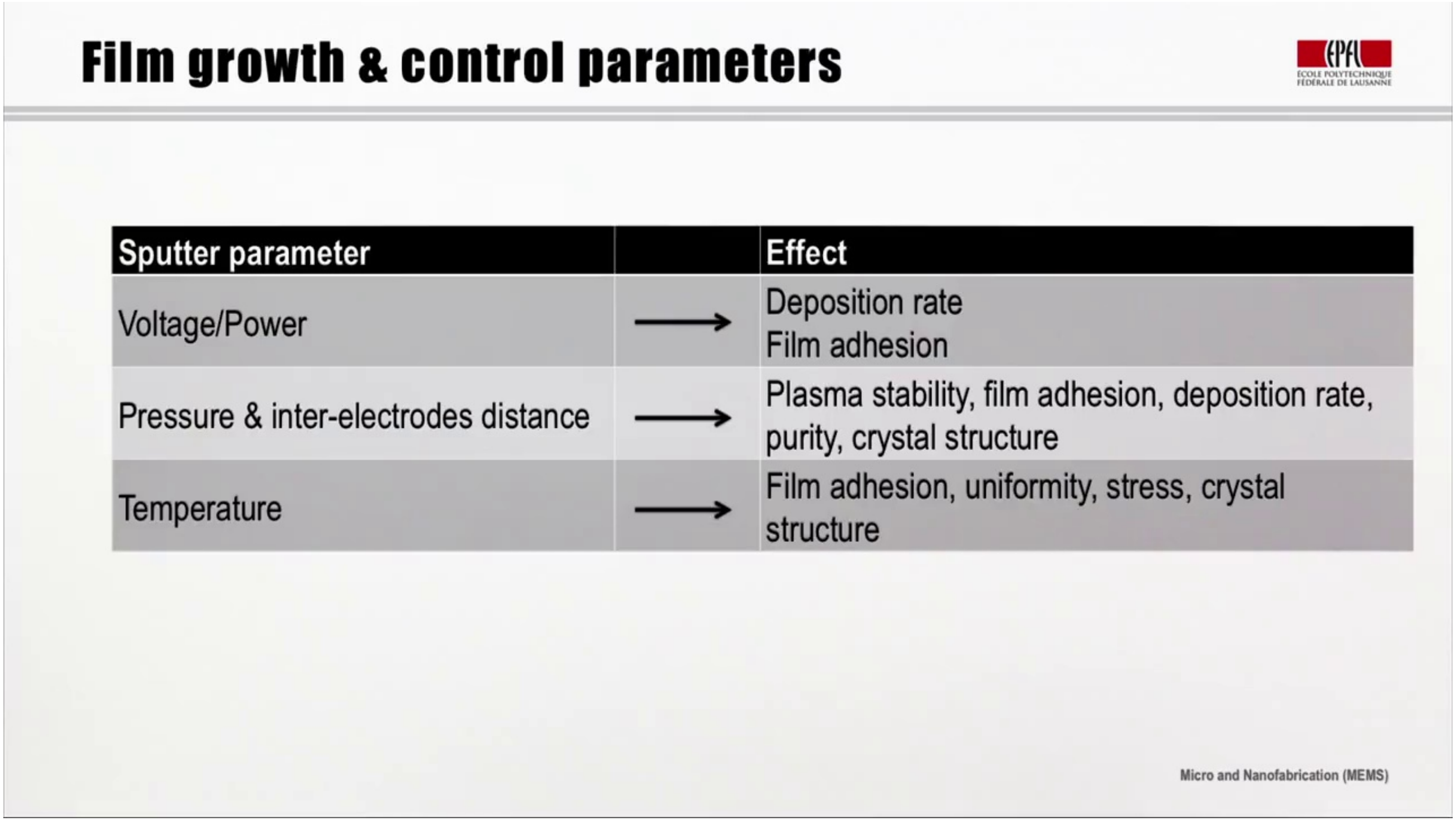
If we add a reactive gas in the chamber, reactive sputtering is possible. Atoms ejected from the target react with the gas, for instance oxygen, and form compounds such as oxides. Another deposition technique to deposit compounds is called "co-sputtering". Finally, if needed, a directional sputtering deposition is possible by using a collimated sputtering. It is done by placing a grid in between the electrodes and thus filtering atoms with high angles of incidence.



So on this micro-graph, taken by an electron microscope, you can see an example showing the capability of sputtering aluminum on a double layer lift-off resist. So you see here two layers of photoresist with an overhanging geometry, like a small mushroom, that has been coated by sputtering aluminum. And since the aluminum came under various angles, it was able to deposit also underneath the mushroom. If I'm drawing here again, where we see the aluminum on the mushroom structure, on top, then also here, we have again aluminum that has been deposited. Only just underneath the overhanging structure, there has been no or non visible deposition of aluminum because the incoming angles were for the aluminum. Atoms could not reach this shadow part.



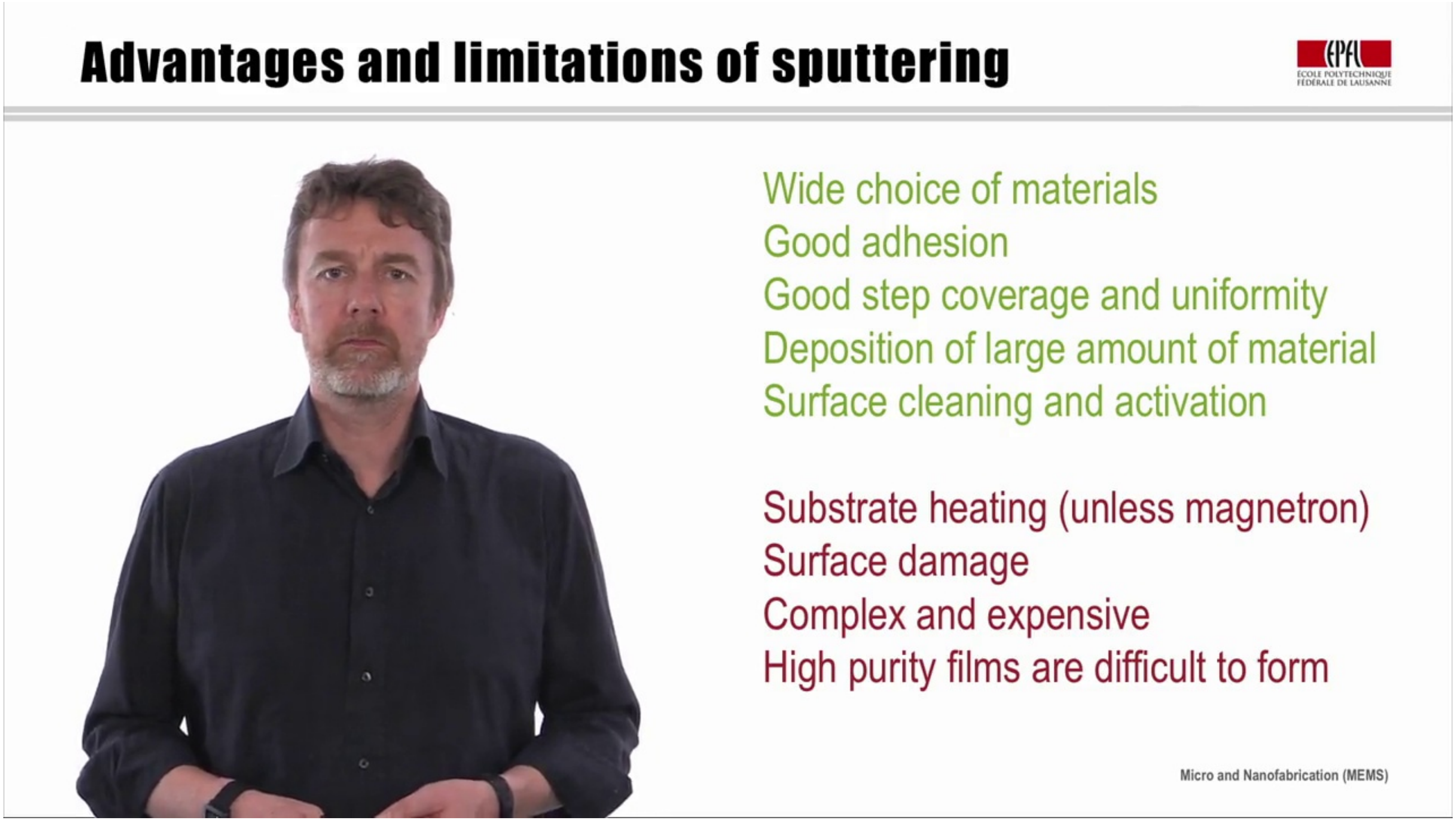
So let's have a look at how various parameters influence the sputter film quality. Increasing the voltage results in more energetic ions striking the cathode. Consequently, more atoms and more energetic atoms are ejected from the target which leads to a higher deposition rate, and a better film adhesion. Indeed, more energetic atoms have a longer penetrating depth at the wafer surface, and also allow cleaning the wafer surface from remaining contaminants.



Sputter parameter		Effect
Voltage/Power	→	Deposition rate Film adhesion
Pressure & inter-electrodes distance	→	Plasma stability, film adhesion, deposition rate, purity, crystal structure
Temperature	→	Film adhesion, uniformity, stress, crystal structure

Adjusting the pressure and the inter-electrode distance is a question of trade-off. As explained previously, Paschen's law gives the breakdown voltage as a function of the product between the pressure and the inter-electrode distance. Thus, for a fixed voltage changing either the pressure or the inter-electrode distance will alter the plasma stability. In addition, increasing the pressure or the inter-electrode distance leads to more collisions of the atoms on their travel between the target and the substrate. As a result, less atoms and less energetic atoms will deposit on the substrate which will lower the deposition rate and also the film adhesion. There is also a risk of contamination of the deposited thin film by argon atoms from the plasma if the pressure is too high. Too high pressure and large inter-electrode distance should thus be avoided. Finally, the pressure also impacts the morphology of the deposited thin film, if it is an amorphous, or forms crystal. This point will be seen in more details in the lesson about film growth. The substrate temperature is another controlled parameter. Increasing the substrate temperature increases the atom energy on the surface and thus improves the diffusion. This leads to better film uniformity and adhesion and lower internal stresses. The temperature also impacts the crystal structure as it will be explained in the film growth chapter.

One of the main advantages of sputtering over thermal evaporation is stability to deposit almost any kind of material including metallic and non metallic elements, alloys, ceramics and polymers. In addition, reactive and co-sputtering enable the deposition of oxides and chemical compounds such as nitrites, and carbides, among others as depicted in this table here on the right side.



In addition to the wide choice of material to deposit, sputtering ensures a good adhesion of the deposited thin film because of the relatively high kinetic energy of the atoms when they impinge on the substrate. Due to the non directional nature of sputtering, it means atoms arrive on the substrate with random angles of incidence. This deposition technique enables good step coverage, good uniformity over large areas and suppresses shadowing problems typically of thermal evaporation. Sputtering targets can be relatively large and thick, which allows to deposit more material than with evaporation. Sputtering systems are compatible with production processes as large amounts of material can be uniformly deposited over large areas. In addition, sputtering systems can be adapted to roll-to-roll deposition tools. Finally, surface cleaning and activation is possible with a process called "sputter etching". Reversing the electrode's polarity and creating a low energetic plasma will result in ions colliding on the substrate. As a result, these ions will remove contamination layers or particles on the surface and break oxide and surface bonds to activate the surface. Such dry cleaning process using a plasma is less efficient than wet cleaning but has no surface tension effects, doesn't require any drying step, and is performed directly in the chamber where the deposition will take place. In practice, a cleaning step is very common before starting the sputtering process. Sputtering can be done at room temperature, but unless used with magnetron, substrate heating is substantial because of the atom's kinetic energy and bombardment by secondary electrons. The chemical reaction between the substrate and the deposited layer can start. In addition, surface damage can also occur. Because of the substrate cooling system, the setup and material change is more complex than with the thermal evaporation system. And thus the sputtering equipment is more expensive. Finally, due to the high deposition pressure, it is difficult to have high purity films.