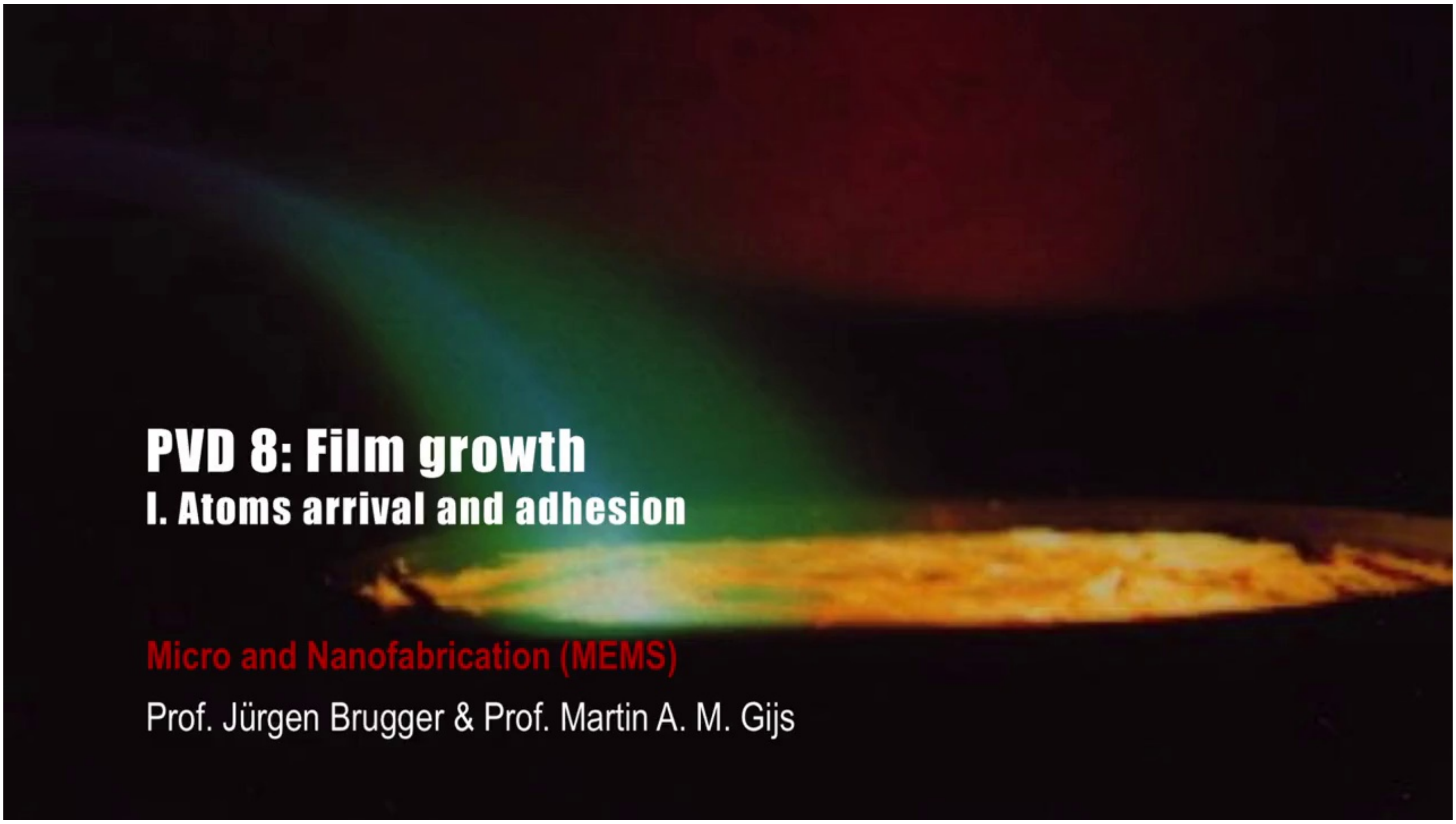

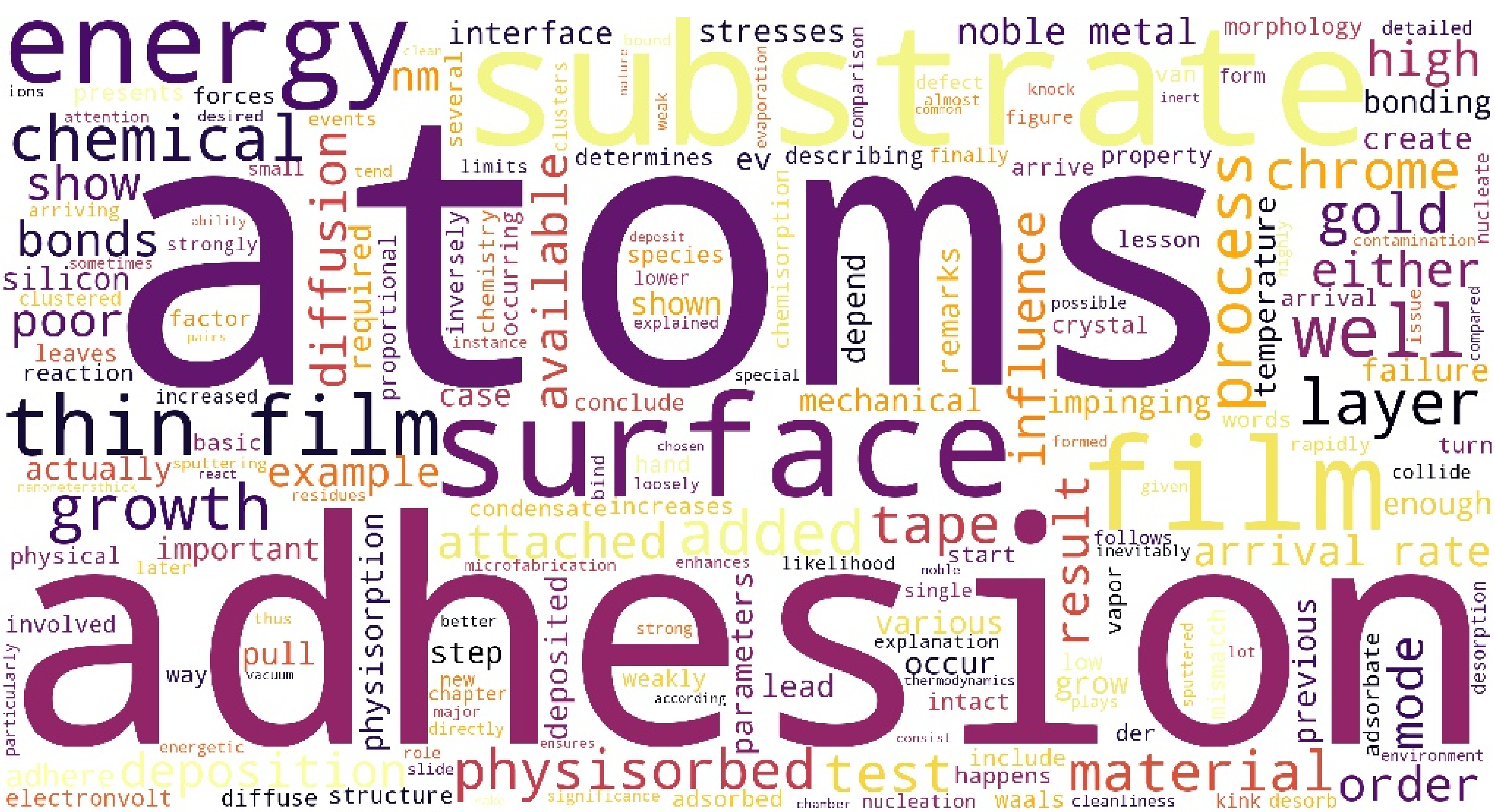

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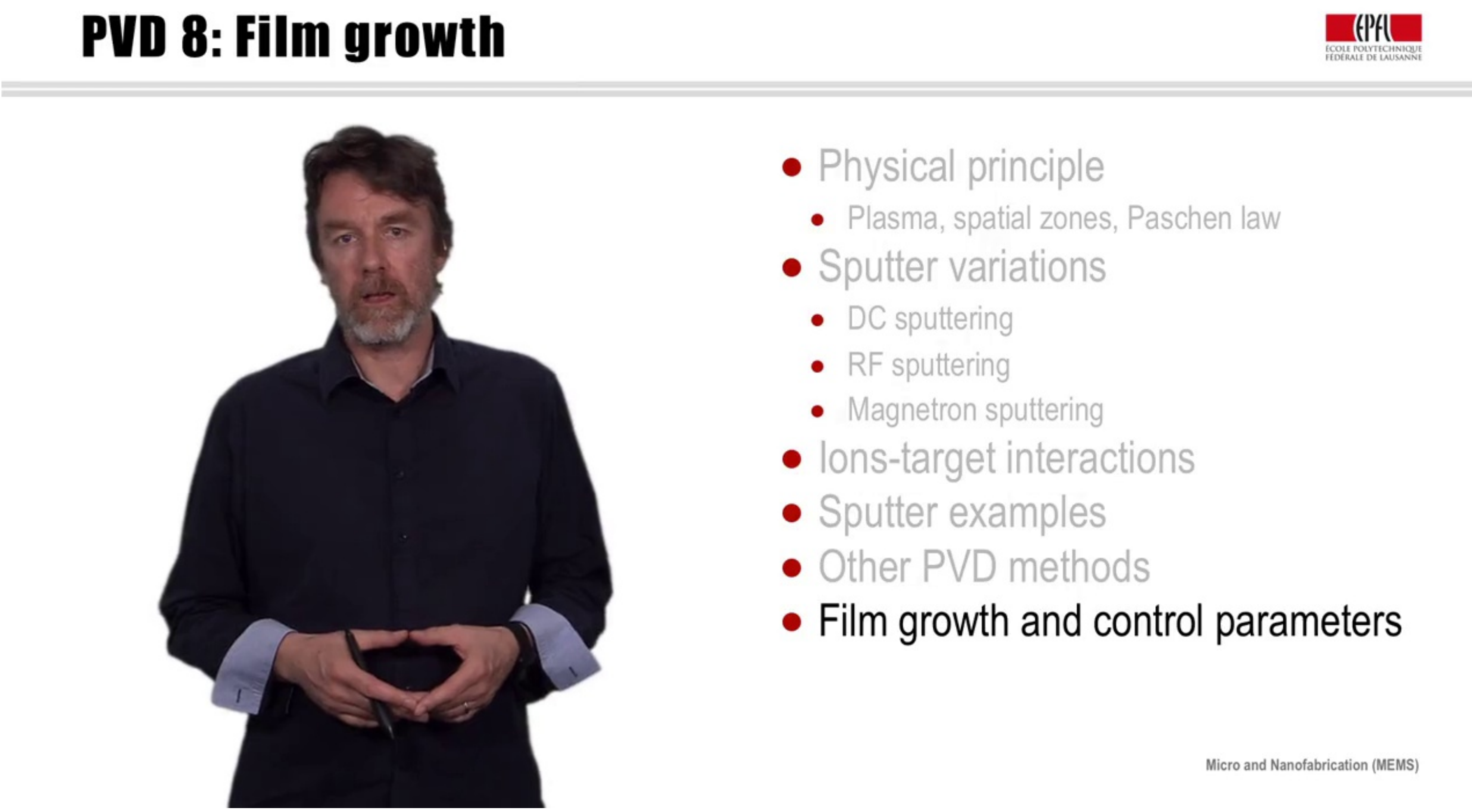
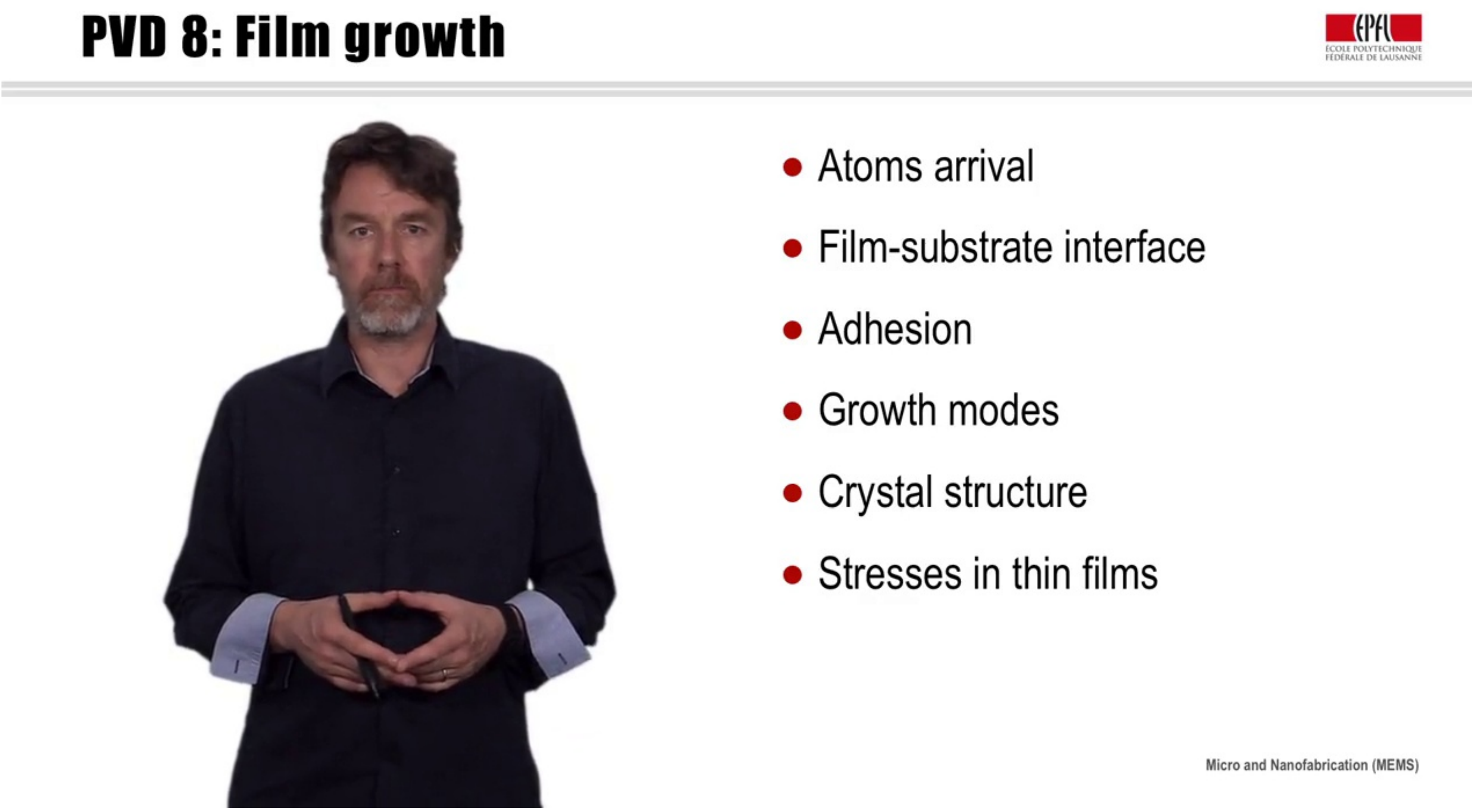
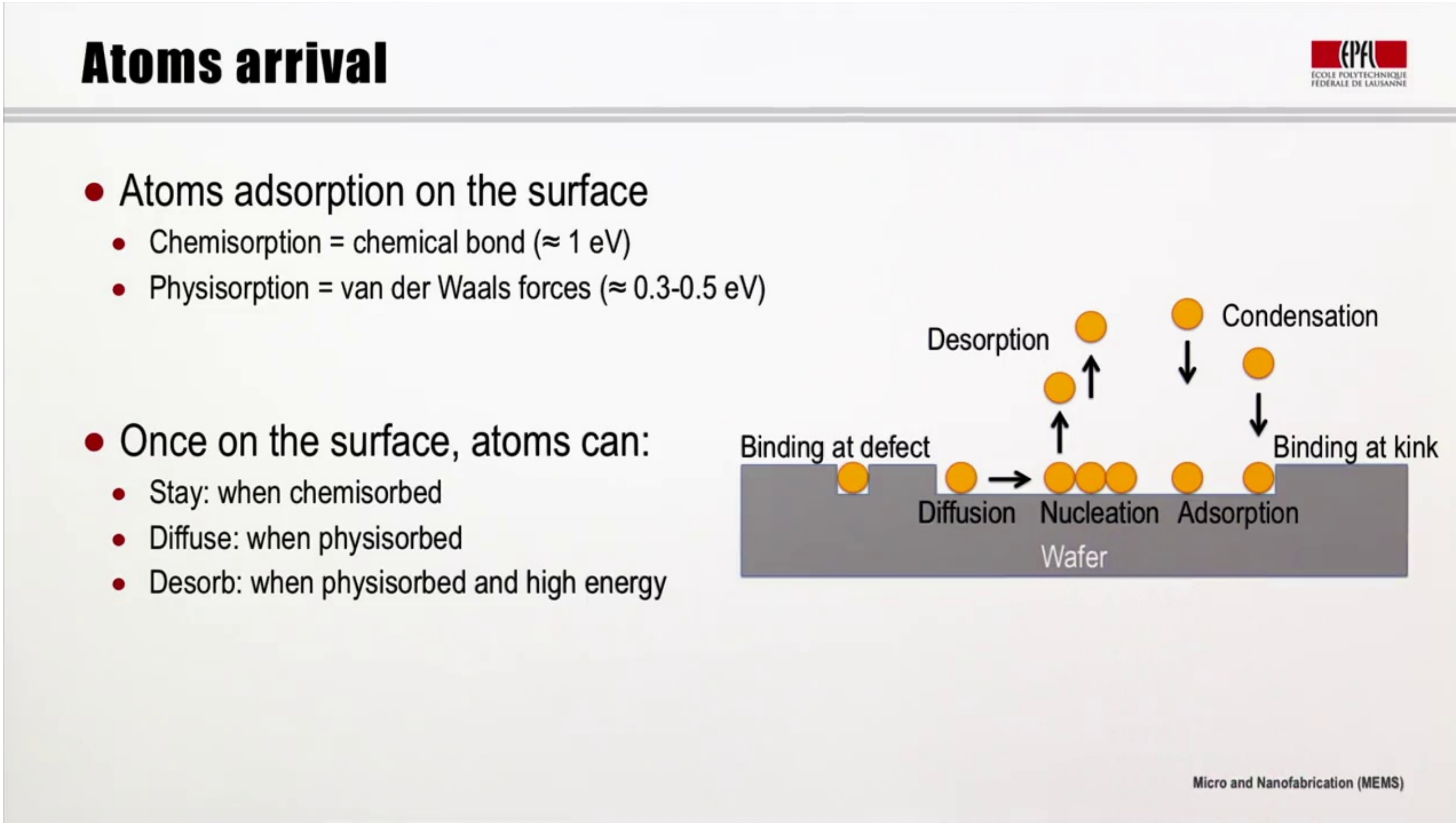


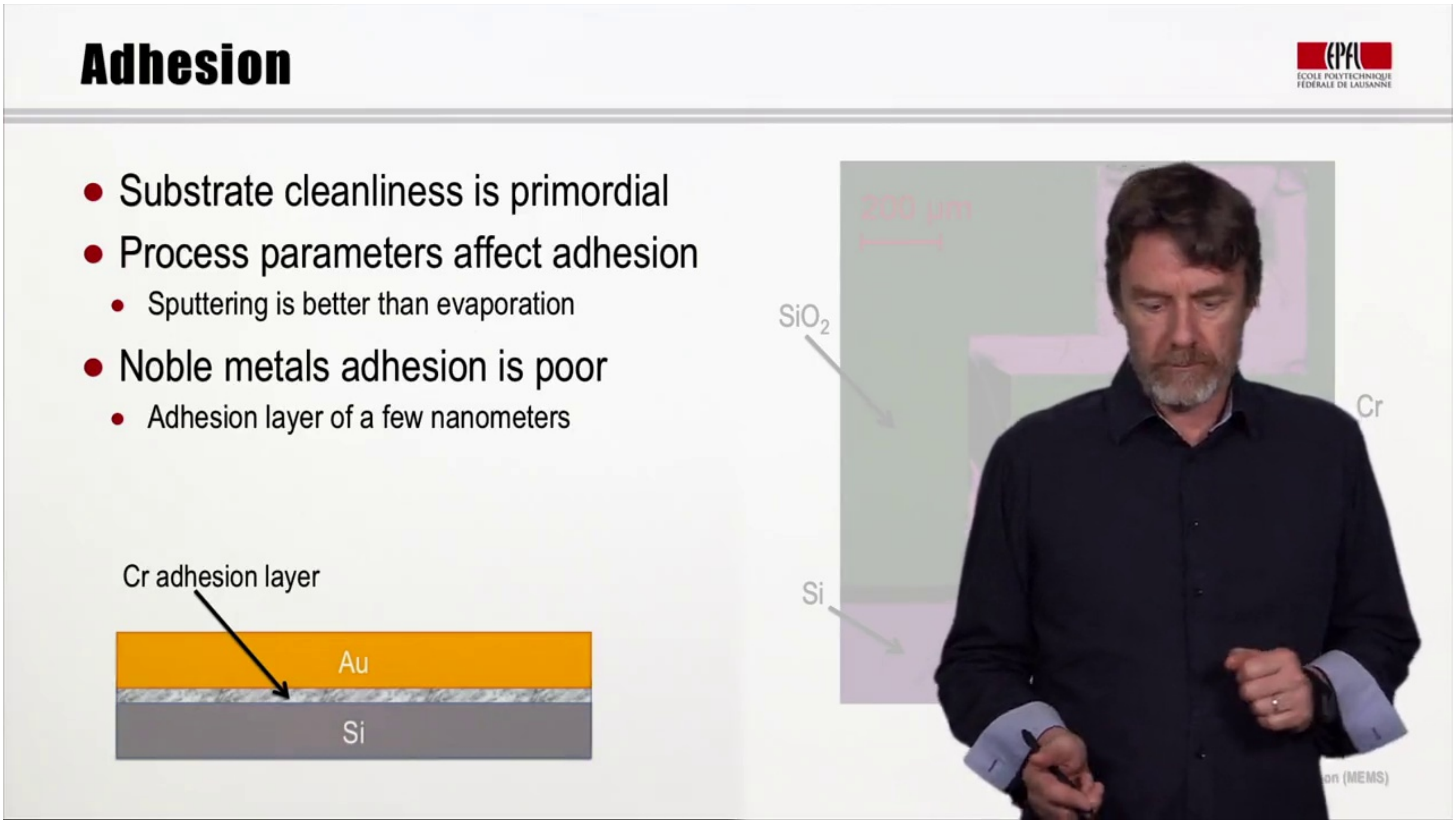
This lesson on the growth of thin films in physical vapor deposition presents the basic parameters that influence the morphology of the added material on the substrate.



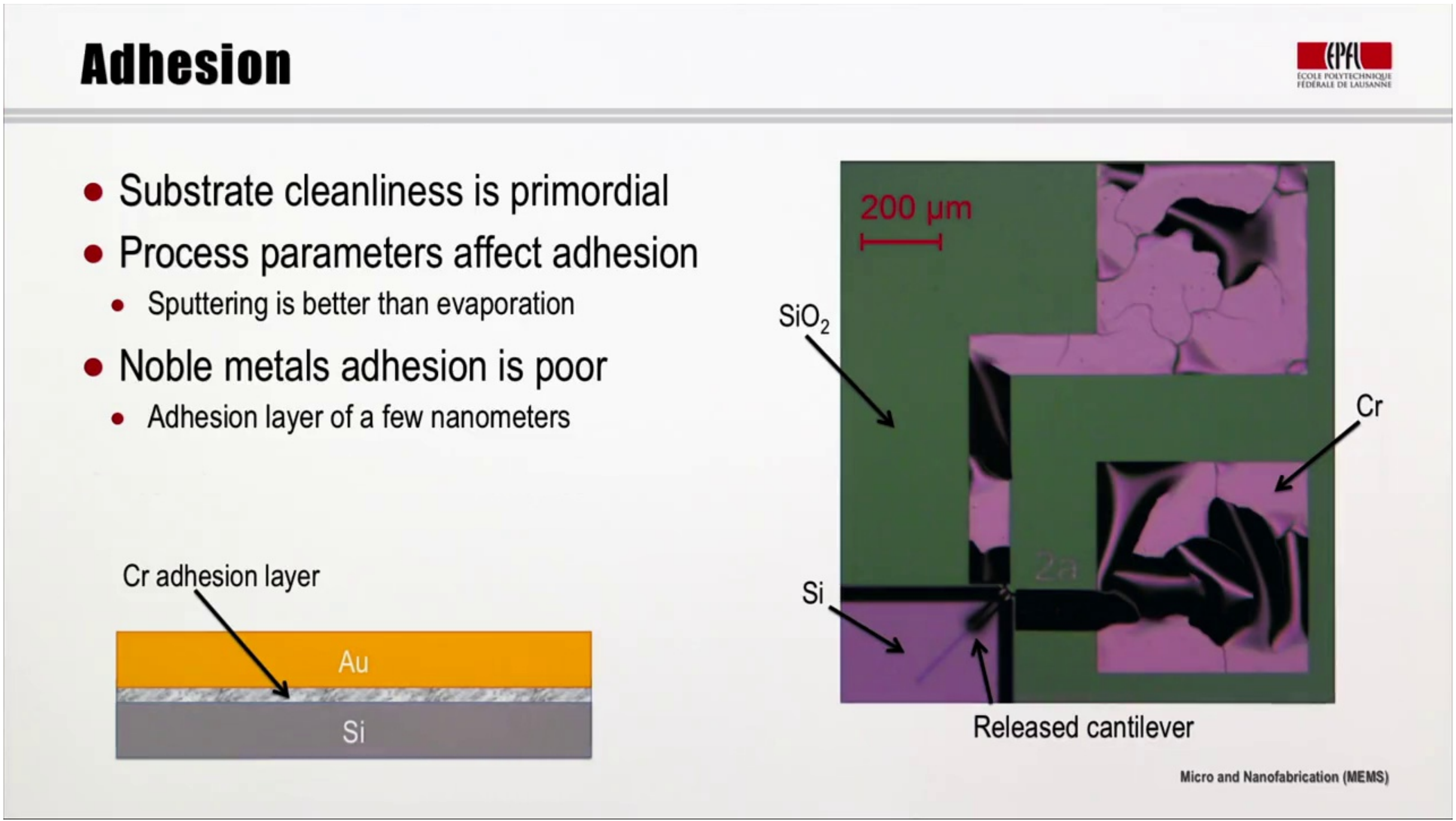
I will start by describing what happens when the atoms arrive on the surface. An important factor here is the interface property which determines the adhesion of the added film as well as the way the film actually grows. I will then show how the various growth modes influence, on their turn, the crystal structure of the film, and I will conclude with some remarks on the mechanical stresses in the thin films. with some remarks on the mechanical stresses in the thin films.



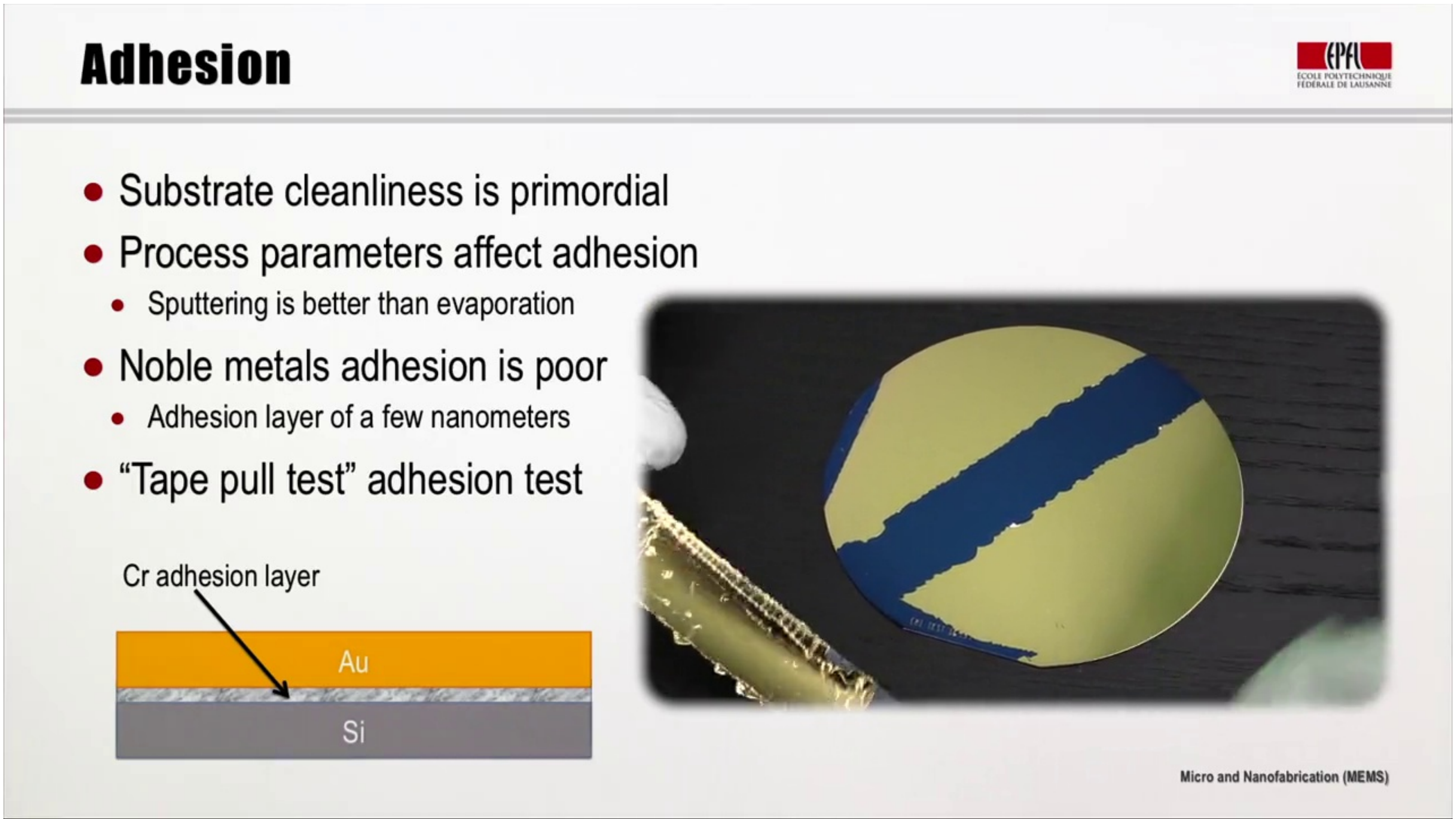
Thin film deposition and film growth depend on the materials involved as well as on several process parameters. These include the energy of the impinging atoms, their arrival rate and the substrate temperature. When atoms condensate on the substrate they are adsorbed and attached to the surface either by chemisorption or by physisorption. In the first case, atoms create chemical bonds on the surface with a bonding energy in the order of 1 electronvolt (eV). The available energy depends on impinging atoms energy as well as on the substrate temperature. On the other hand, physisorption occurs when there is a chemistry mismatch or when the energy is too low to create chemical bonds and which leaves the chemical species of the adsorbate and the surface intact. In other words, there is no chemical reaction occurring. Physisorbed atoms are weakly attached to the surface by Van Der Waals forces, with a bonding energy in the order of 0.3 to 0.5 eV. As a result, physisorbed atoms can diffuse on the surface. And the diffusion of physisorbed atoms increases with the available energy but is inversely proportional to the atoms arrival rate. Why is that so? The explanation is as follows: if the arrival rate is high, atoms on the surface will rapidly collide with new arriving atoms. And this limits the diffusion and strongly influences the growth mode. Growth modes are detailed later in this chapter. Here on the figure you can see various events that can occur after the arrival of the atoms on the surface. As a result of the surface diffusion, physisorbed atoms will either bind at the kink - shown here, a small step - or at the defect. Shown here. Or nucleate with other atoms and form clusters. Nucleation is increased with available surface energy. Finally, if the atoms energy is high enough, they can also desorb again from the surface. The likelihood of desorption is lower for clustered atoms in comparison to single atoms.



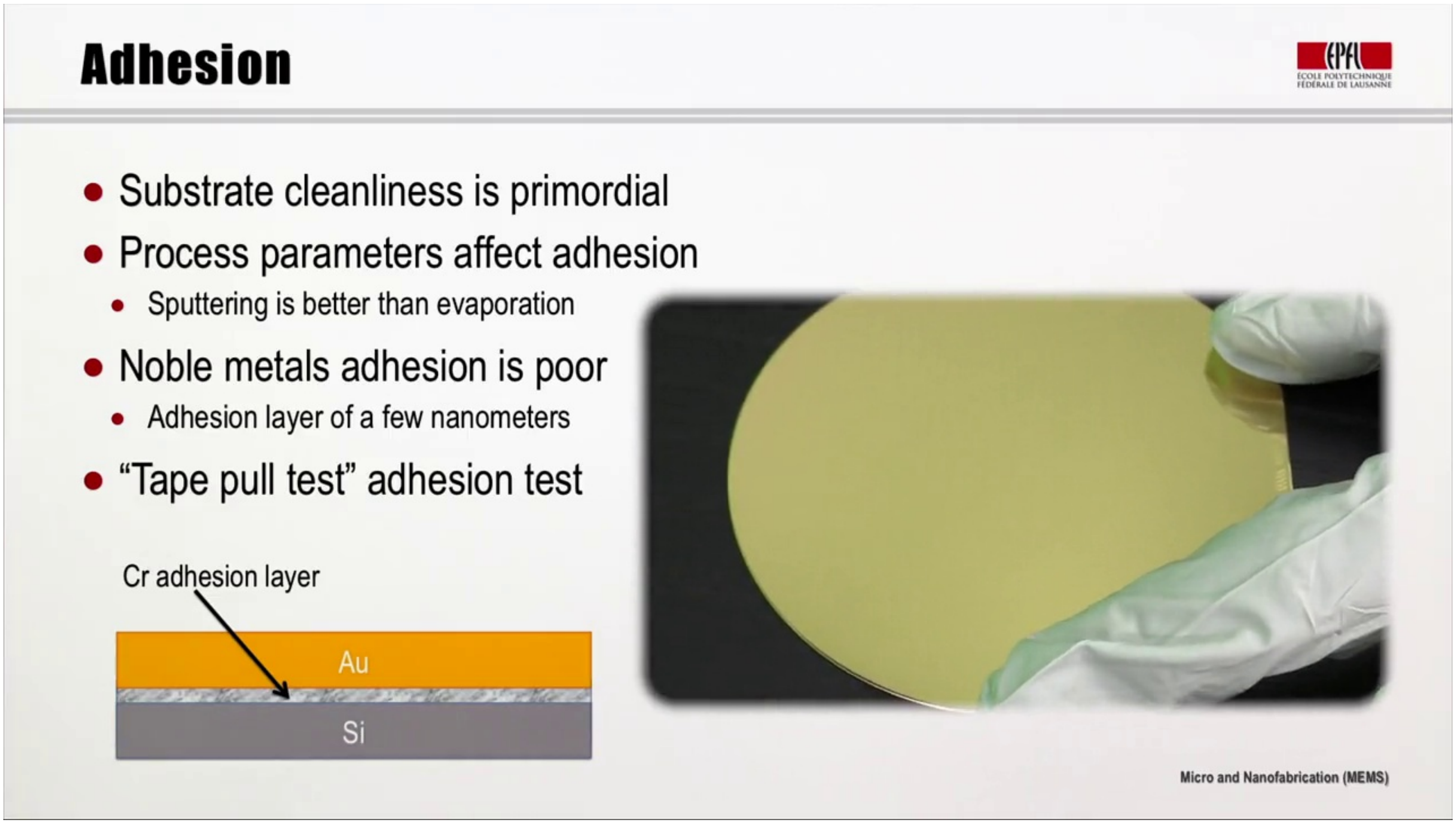
The adhesion of the added thin film to the substrate is a very important issue in microfabrication and special attention is therefore required. Particularly, substrate cleanliness is of a major significance as residues from the environment or from previous process steps will almost inevitably lead to poor adhesion. The thin film deposition process itself also plays a role if there is a strong or weak adhesion. For instance, in sputtering, highly energetic ions and atoms knock out surface contamination and loosely bound atoms. This enhances the adhesion a lot. Thus, sputtered films tend to have a better adhesion compared to films formed by evaporation. However, as explained in the previous slide sometimes it is not possible to grow a thin film of a desired material directly on the given substrate because of thermodynamics. Examples are the cases of noble metals, which are inert and do not react by nature. As a result, they do not adhere well to silicon or SiO2. So, what do we do? To deposit noble metals, adhesion layers are therefore required. These adhesion layers, which are chosen according to their ability to make chemical bonds, consist of few nanometers-thick films deposited just before the noble metal, in the same vacuum chamber. This ensures that we have a clean interface and substrate. Two common pairs of adhesion noble materials in micro and nano fabrication are titania and platinum as well as chrome and gold.



Here is the example that shows the silicon substrate with the chrome adhesion layer, and then the deposited gold, that is now well adhering to the substrate. This photo here, on the right side, actually shows a failure process. A 500 nm thick chrome layer aimed as electrical conductor to drive current through a bimorph actuator has poor adhesion to the substrate, and is detached, or ”delaminated” as we call it, from the substrate. You can see this in this optical microscope. This is either due to poor adhesion, and/or to high intrinsic stress, or both. This will eventually lead to the complete failure of the device and needs to be overcome.



To test thin film adhesion, a first, straightforward test called the "tape pull test", can be performed. A standard office tape is attached to the wafer and then pulled off. If the film peels off with the tape, then adhesion is not good enough, and the process or adhesion layer should be modified.



In the second example, we added 10 nm chrome, between the silicone nitrate and the added 100 nm of gold film, and as you can see, now the gold film adheres very well, under the tape pull test. There are, of course, more sophisticated equipments that measure the adhesion of thin films, but for a first order information, this tape-test is very convenient.