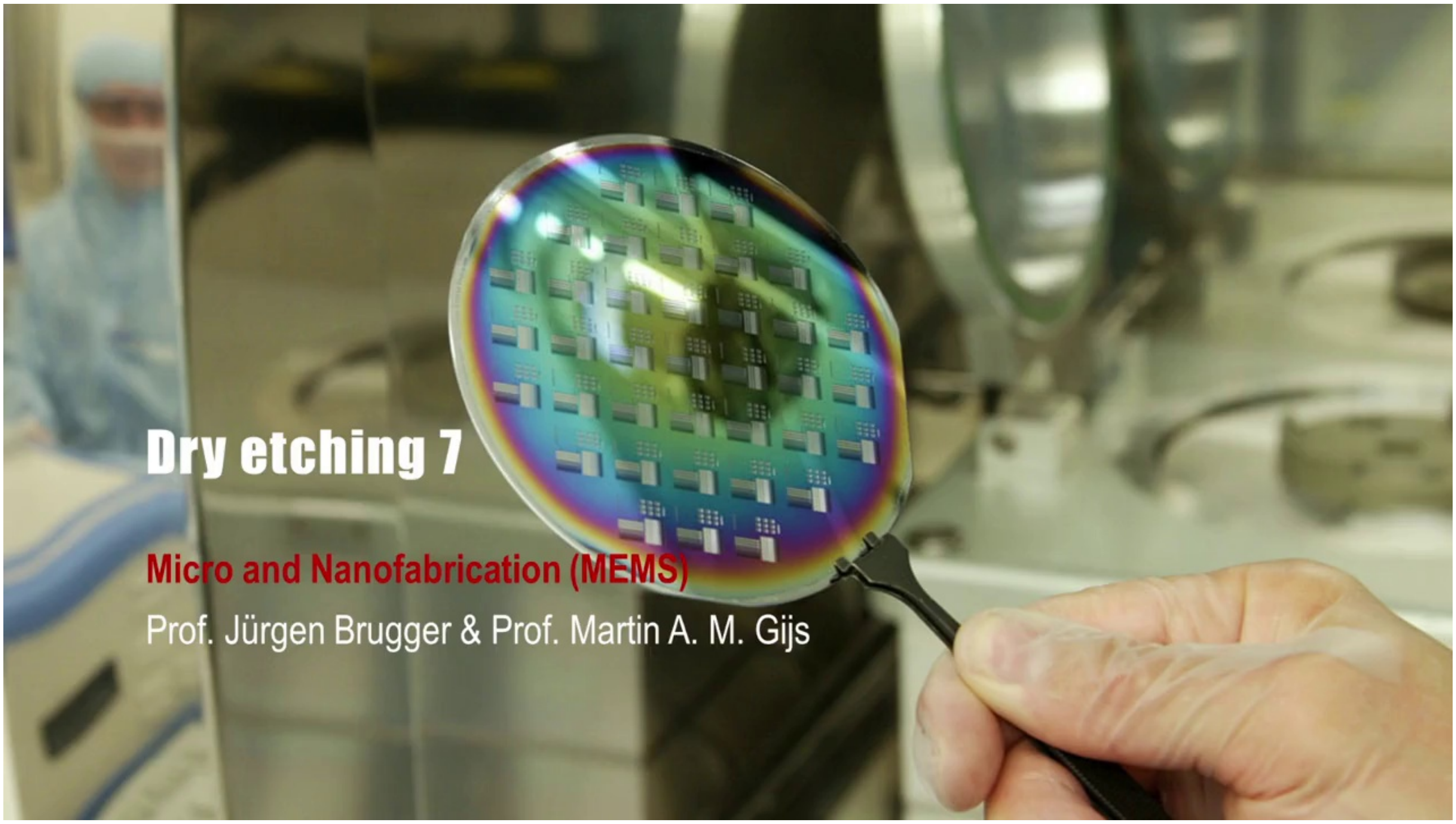

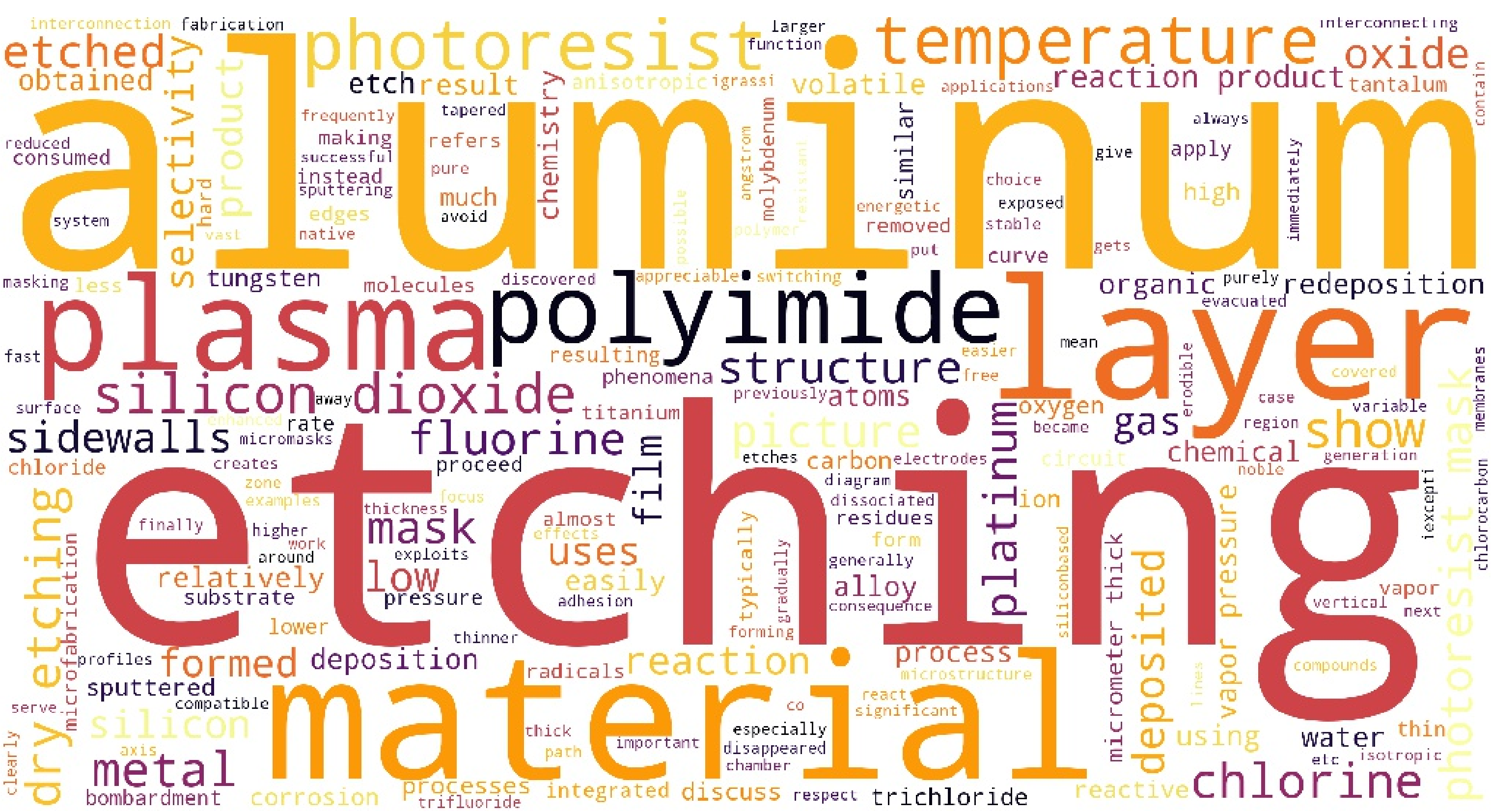

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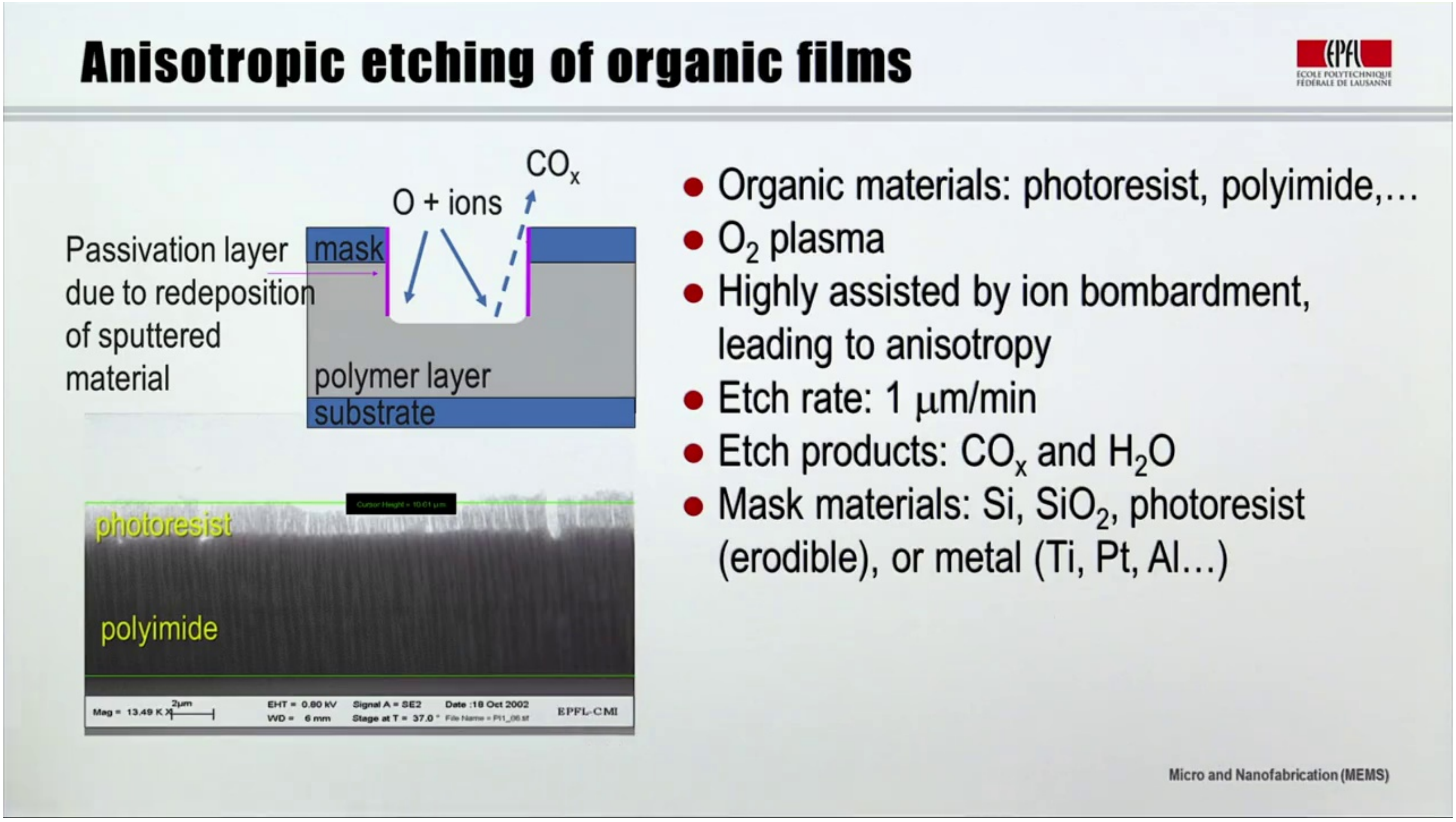
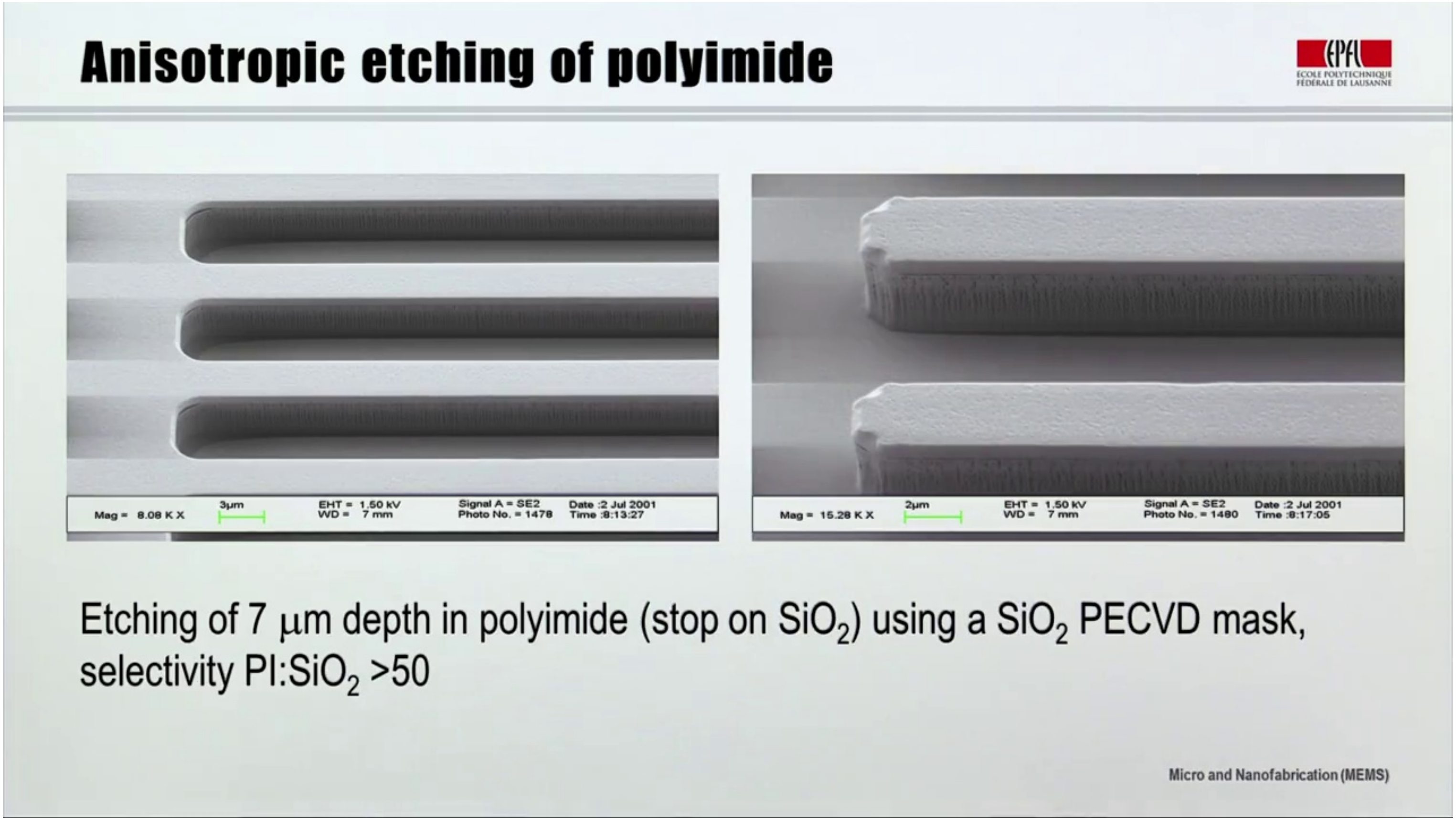
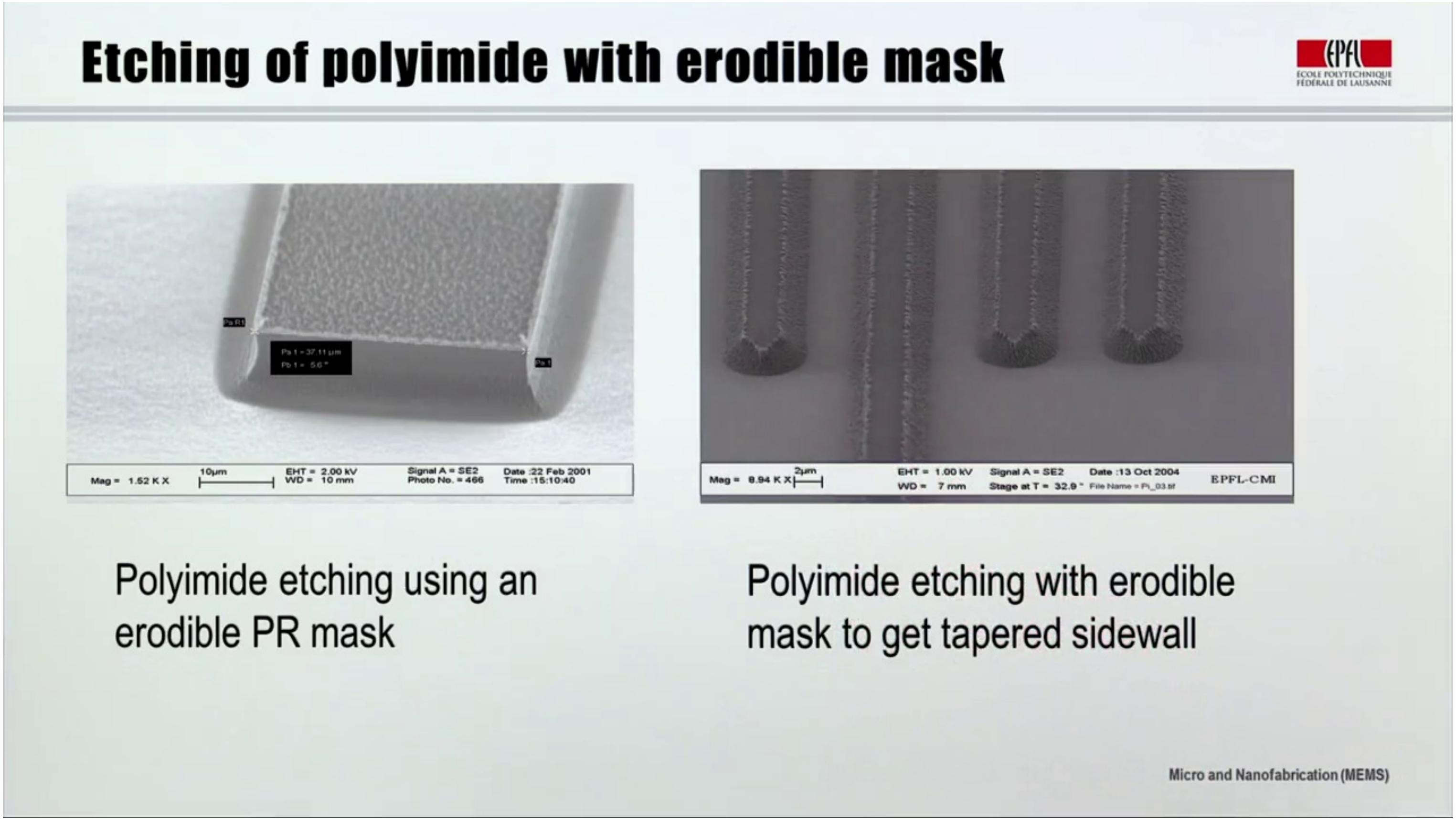
While previously we have discovered some of the processes used in dry etching of silicon and silicon-based materials, now we focus on the dry etching of organic films, like photoresists, and the material, polyimide, and of metals.



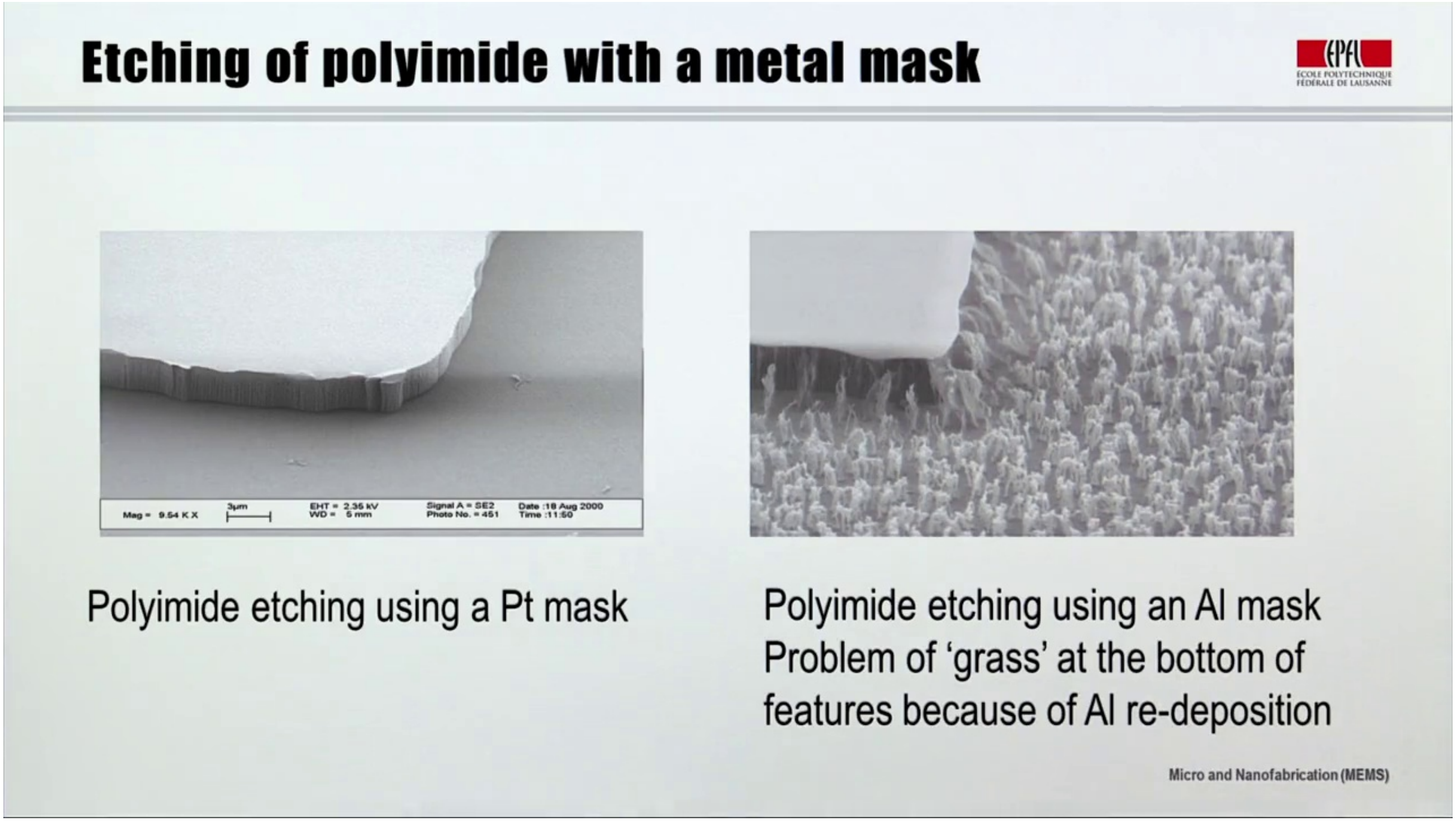
One typically uses an oxygen plasma for the etching of organic materials like photoresist, polyimide, etc. If one uses ion bombardment, one gets anisotropic structures when one exploits the redeposition of sputtered material to the sidewalls. Etch products are water, CO gas, and CO2 gas, typically. There is a vast choice in mask materials, like silicon, silicon dioxide, photoresist, or metal. The picture shows a photoresist mask, which was put on a polyimide film to etch a microstructure in the polyimide layer.



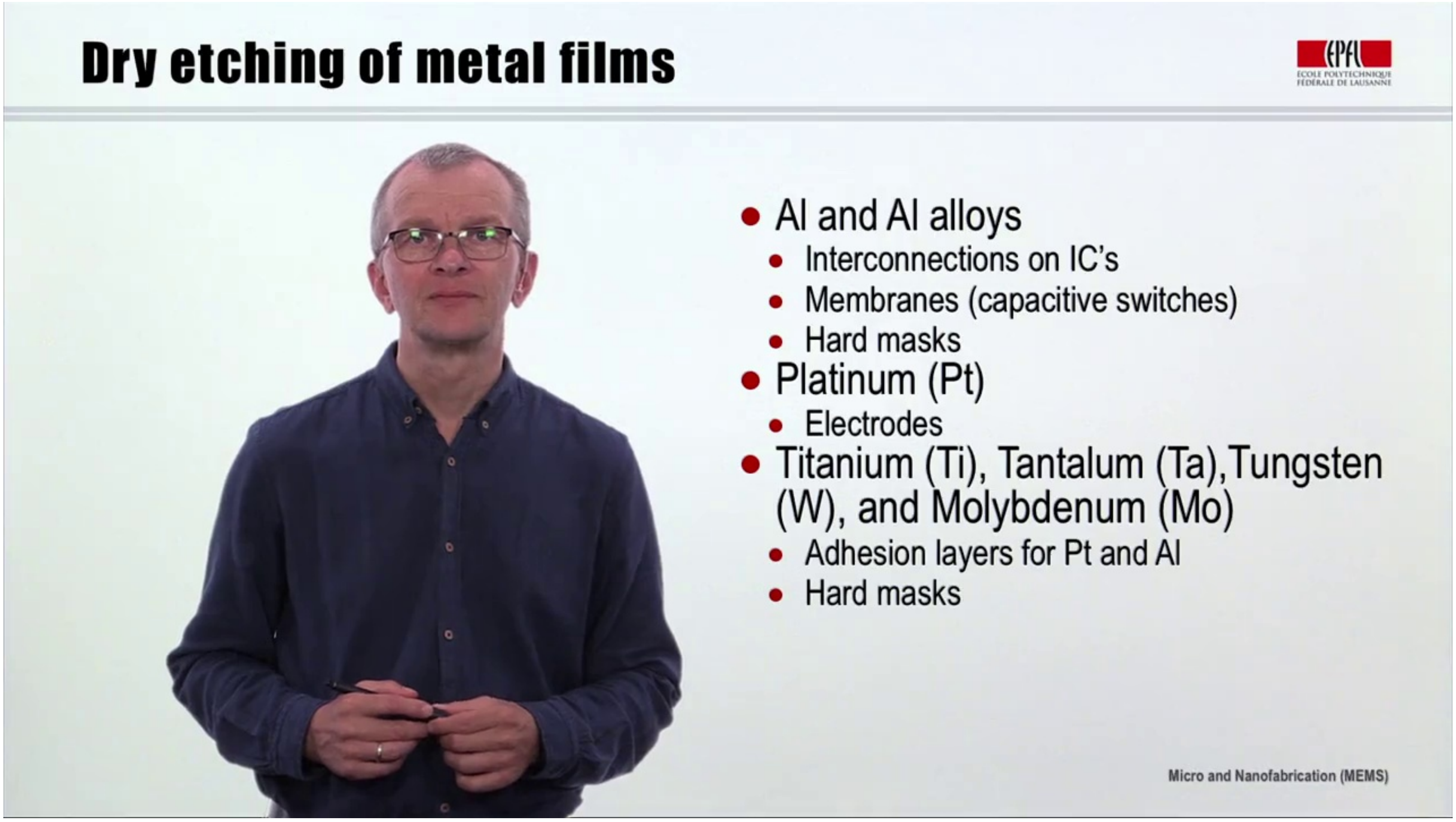
These pictures show the etching of a 7 micrometer thick polyimide layer that was deposited on a silicon dioxide layer, and where one has used silicon dioxide as a mask. The silicon dioxide was deposited using a plasma enhanced chemical vapor deposition system because one can apply then a relatively low temperature to the polyimide during deposition of the masking layer. The etching selectivity of the polyimide, with respect to the silicon dioxide, is over 50.



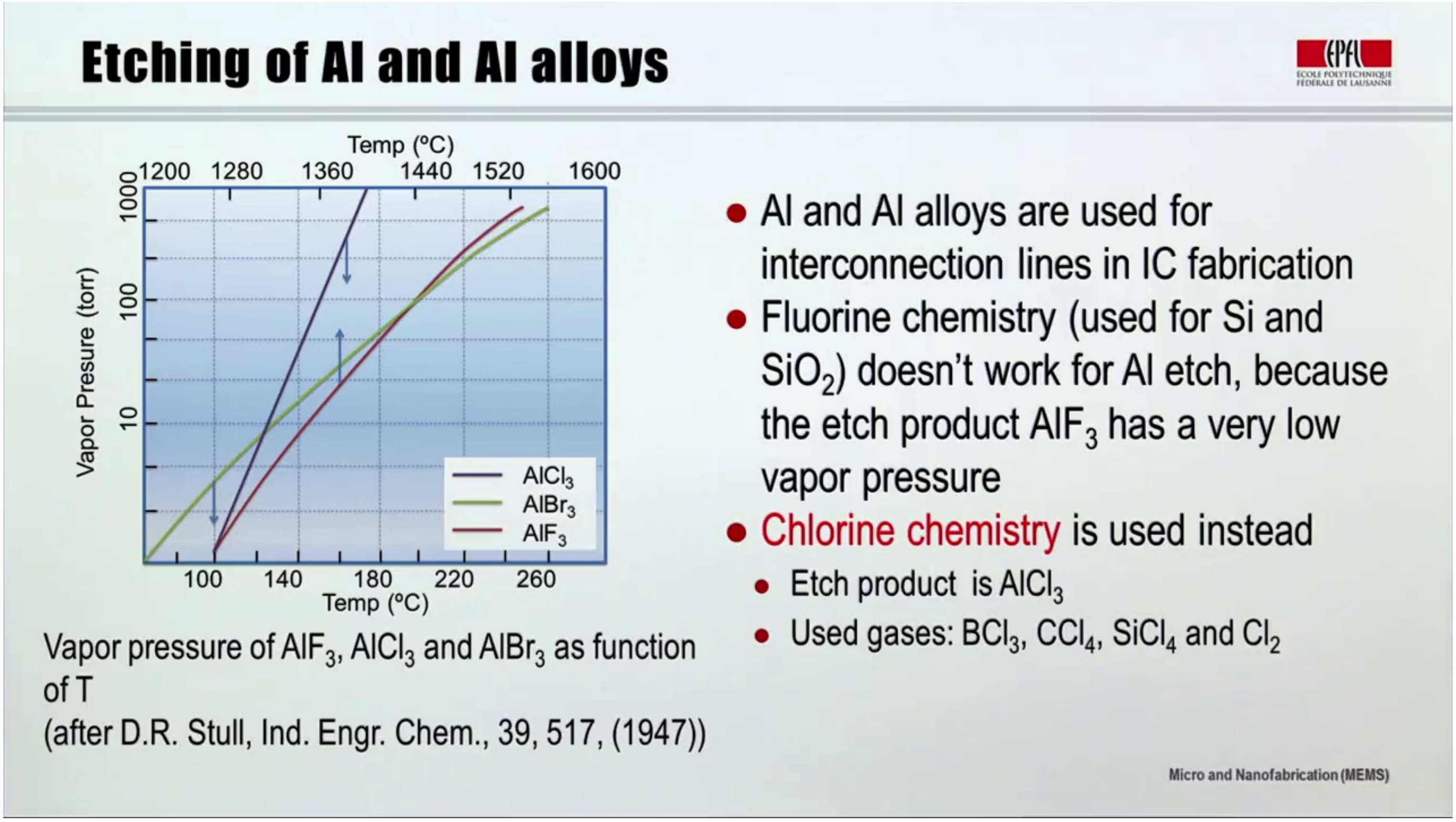
These pictures show the result of polyimide etching using an erodible mask of photoresist. Both polyimide and photoresist have similar etching rate, so that the photoresist is gradually consumed during etching, especially at its edges. That is why the resulting polyimide structure has tapered sidewalls, as the photoresist mask at its edges became thinner first, and first disappeared there.



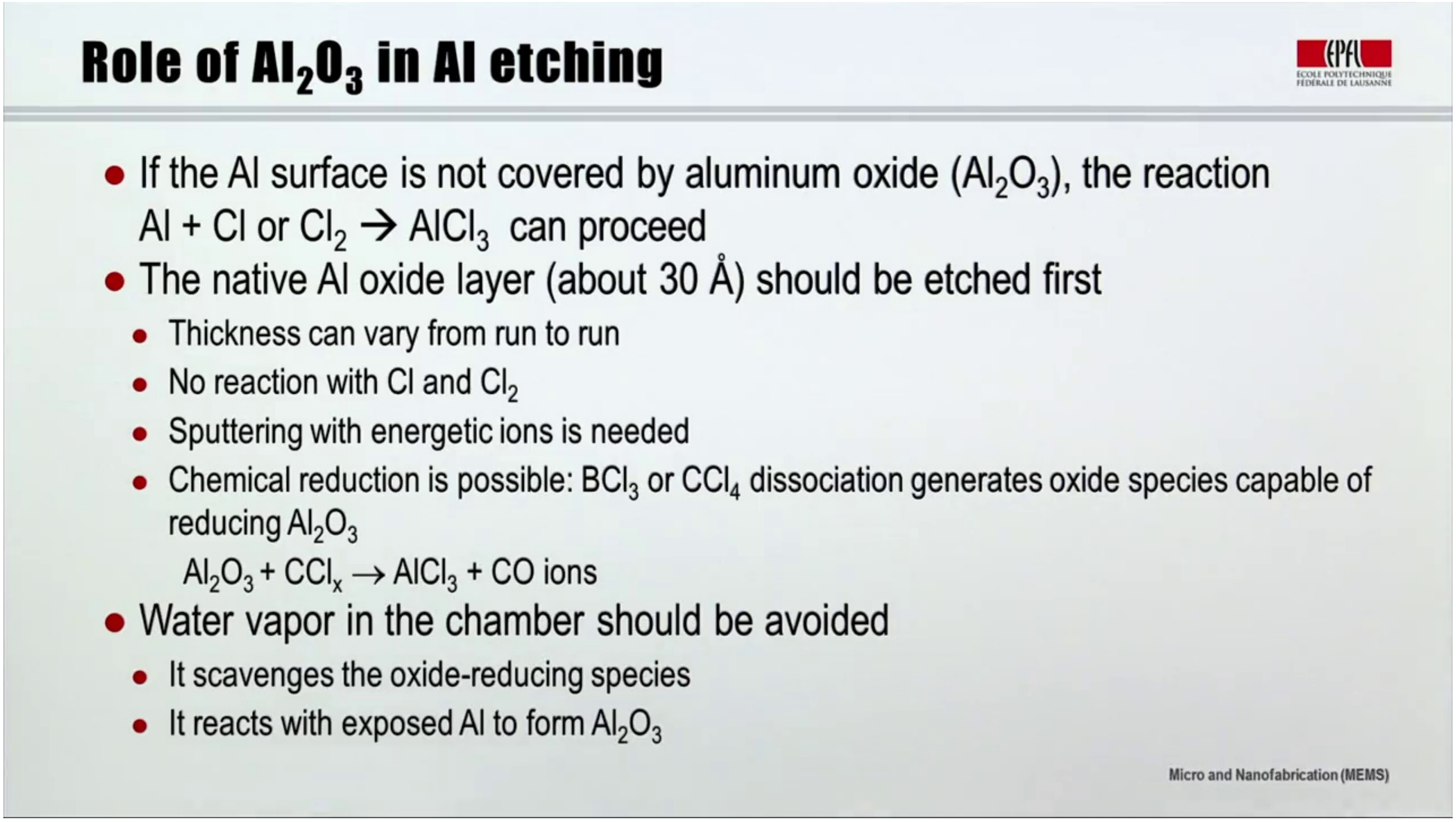
A metal mask, like platinum or aluminum, is much more resistant to the plasma, and hence, can be used to etch structures with vertical sidewalls. This picture shows effects of aluminum redeposition in the etched structure. So, this material is removed, and it creates micro-masks in this region, resulting in the generation of <i>grass</i> as the etching proceeds. Generally, such redeposition phenomena can be reduced when one uses a plasma at the lower pressure, in which the mean free path of molecules is larger. In this case, sputtered material can then be more easily evacuated from the zone of etching.



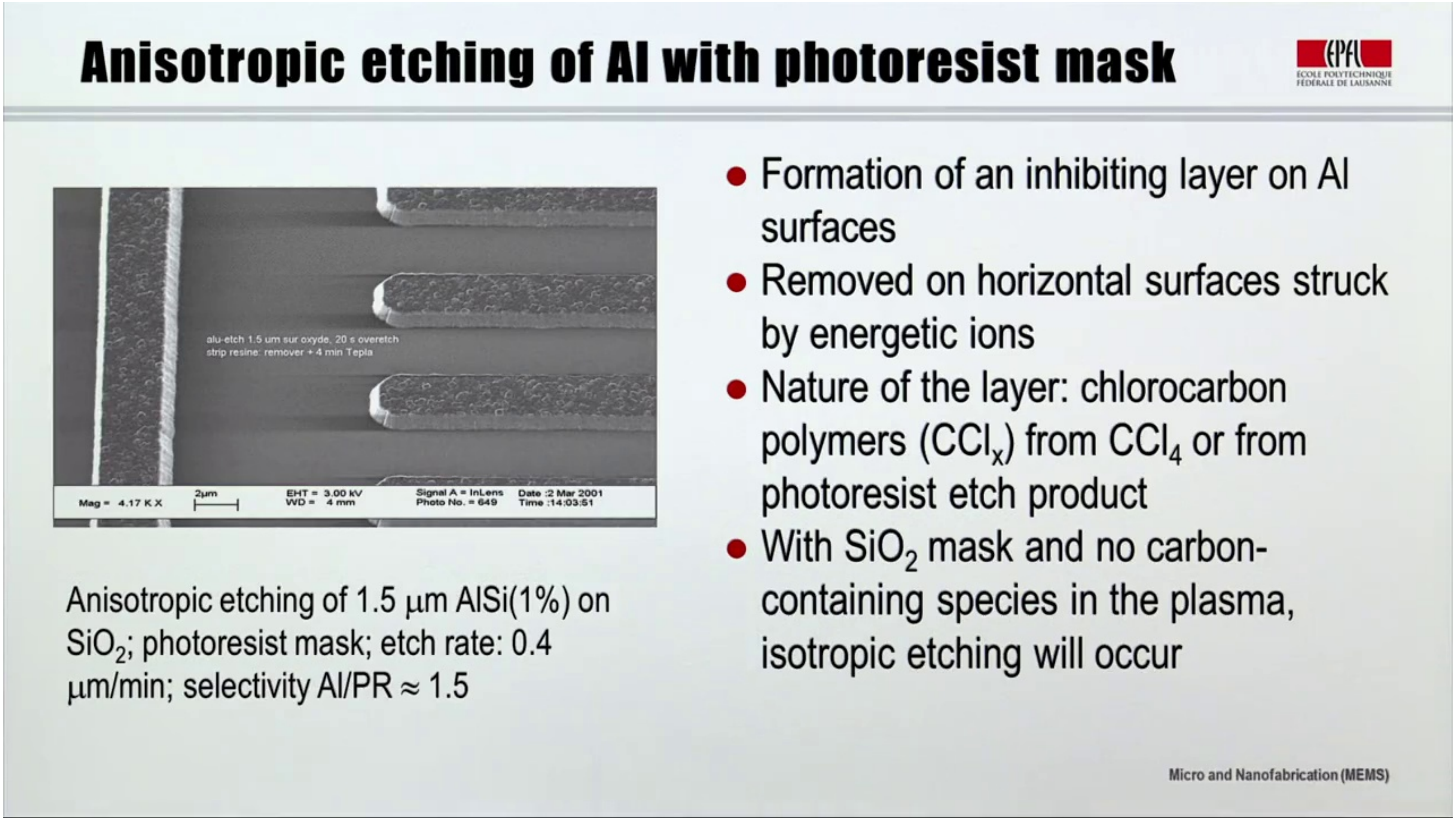
Now we will give a few examples of dry etching processes for metals. We will discuss the etching of aluminum and aluminum alloys. These materials are used for making interconnecting structures on integrated circuits. They can also be used as membranes in switching applications, or as hard masks in a dry etching process. Next, we discuss the dry etching of platinum, which is an important material for microfabrication of electrodes. Finally, we will discuss the etching of titanium, tantalum, tungsten, and molybdenum, which are frequently used as adhesion materials for the deposition of the noble metal, platinum, or aluminum. These materials also serve as hard masks in etching processes.



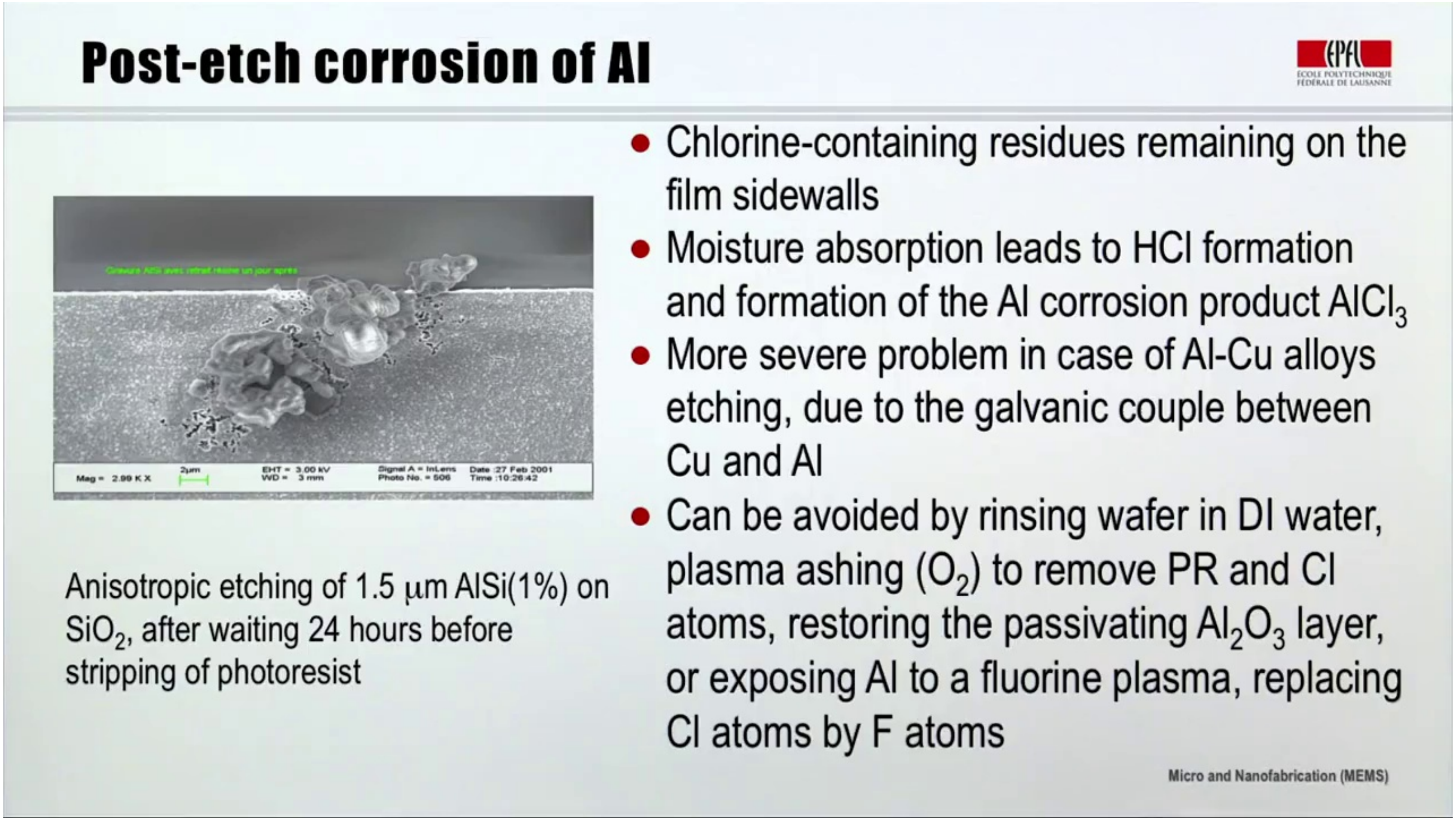
Aluminum and aluminum alloys are used for making interconnection lines in integrated circuit fabrication. Because dry etching is a consequence of the use of a reactive gas, etching will be easier if the formed chemical product is more volatile. This diagram shows the vapor pressure as function of temperature for three reaction compounds. If one uses fluorine as a reactive gas, the formed aluminum trifluoride product has a relatively low vapor pressure, so this curve refers to this temperature axis. So, vapor pressure is significant only at very high temperature, much higher than used in etching. These temperatures are clearly too high for microfabrication. That is why fluorine chemistry, which is successful for silicon and silicon dioxide etching, does not work for aluminum. Instead, one can use chloride chemistry. As the formed reaction product, aluminum trichloride, this curve refers to this temperature. So, for this material, one has an appreciable vapor pressure at much lower temperature, a temperature which is compatible with the dry etching temperature. The result is that this reaction product can be easily removed from the substrate after the chemical reaction.



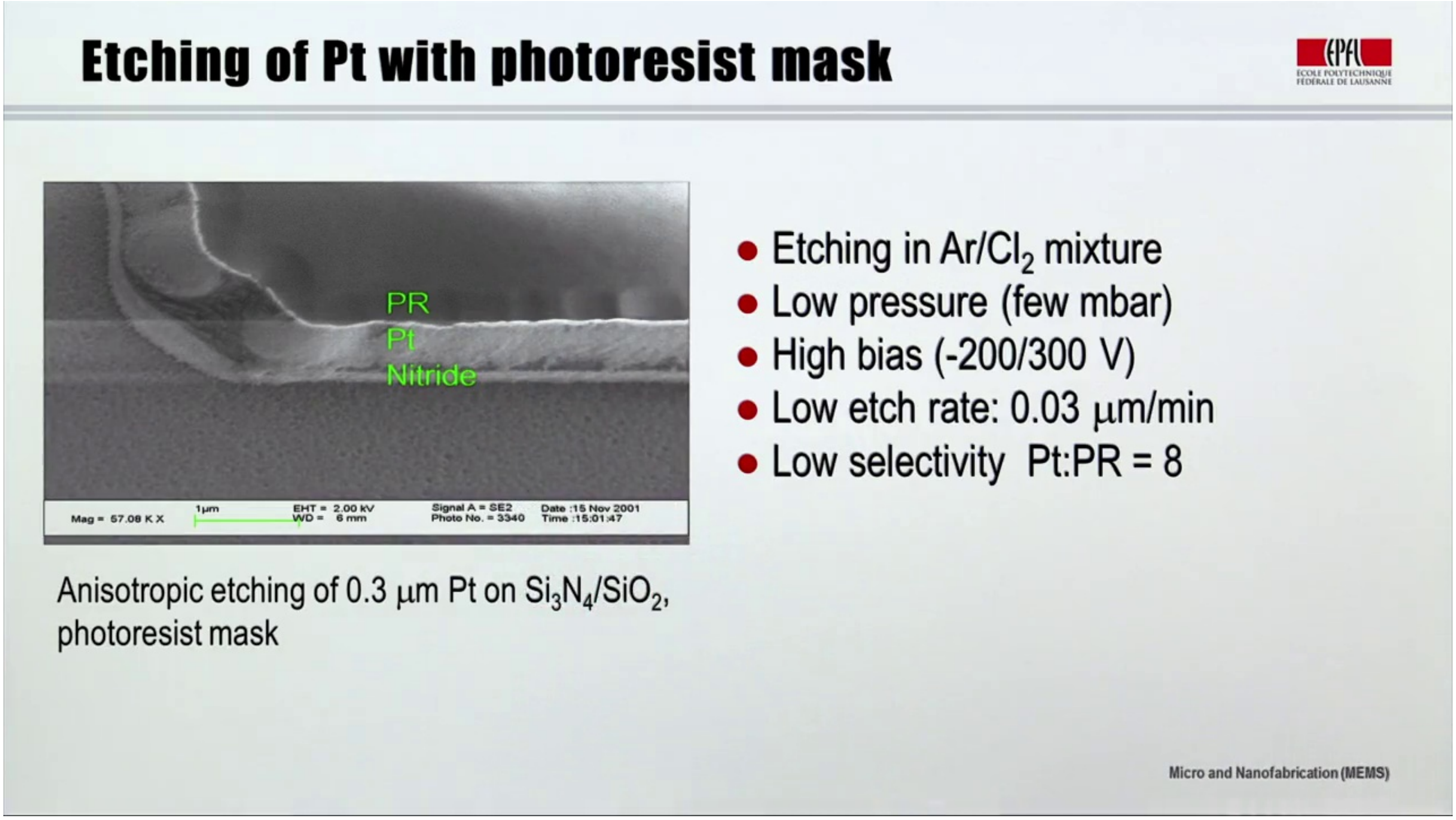
If one would have a pure aluminum surface that is not covered by an aluminum oxide layer, the reaction with chlorine radicals and molecules can immediately proceed. However, as aluminum is very reactive with oxygen, it always has a native aluminum oxide layer of about 30 angstrom, which should be etched away first. This thickness is, more or less, variable, and the oxide is so stable that there is no reaction with chloride atoms, <i>except</i> if sputtering with energetic ions is used. Then, only, the aluminum oxide can be dissociated, forming the volatile aluminum trichloride reaction product. Also, one should avoid water vapor in the reaction chamber as water can easily react with the chlorine radicals and with the exposed aluminum to form aluminum oxide.



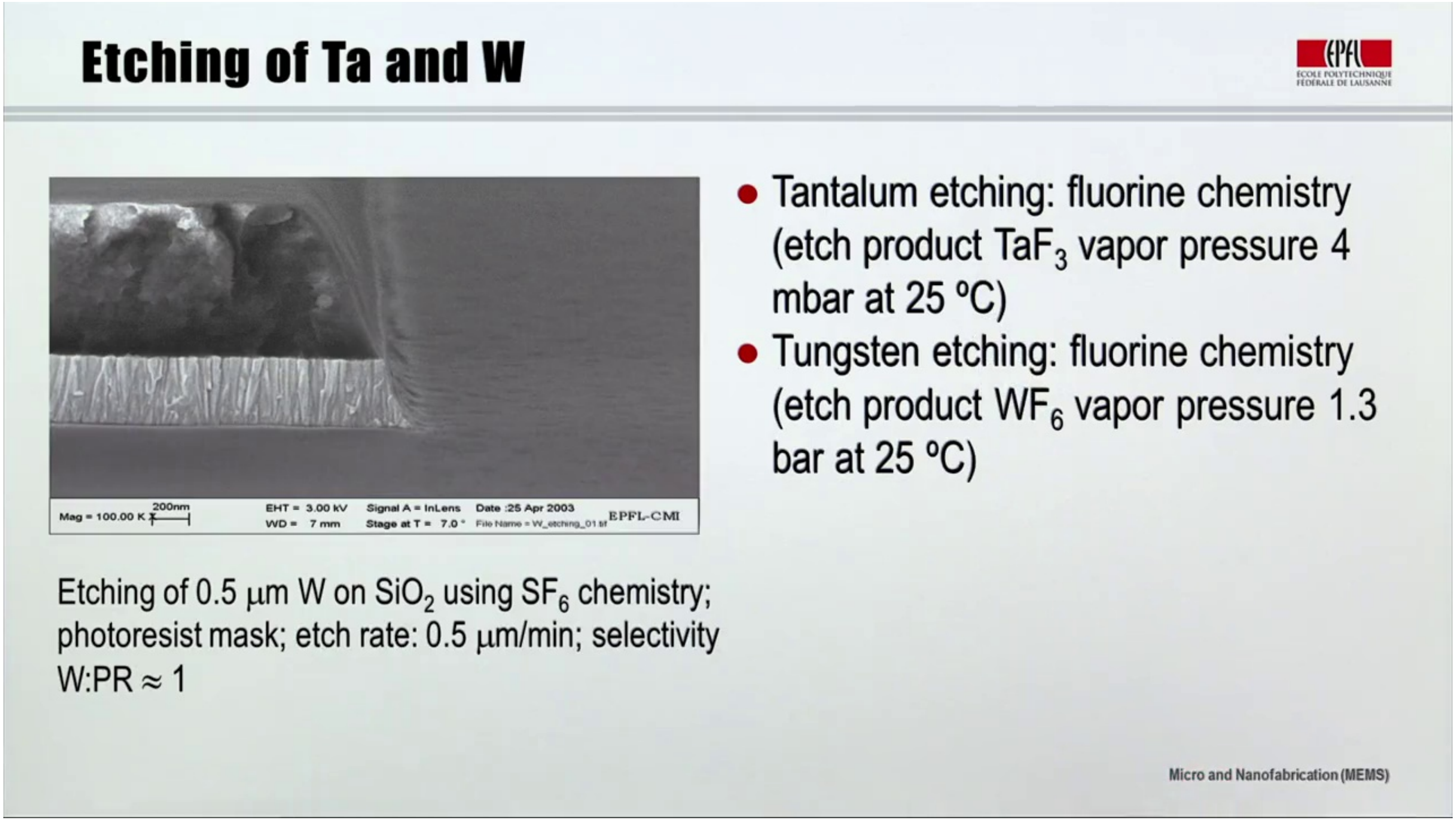
Here, we show the etching of a 1.5 micrometer thick aluminum silicon alloy that was deposited on silicon dioxide. One has used photoresist as a mask, and obtained a selectivity around 1.5. That is, the aluminum etches almost as fast as the photoresist. Anisotropic etching profiles are, more or less, obtained because one has used a chlorocarbon plasma that results in polymer deposition on these sidewalls. Also, redeposition of sputtered photoresist on the sidewalls is possible. If, instead of a photoresist mask, one would have used a silicon dioxide mask, and a plasma gas that did not contain carbon, or few carbons, one would have obtained a purely isotropic etching process.



Sometimes, we observe corrosion phenomena on the etched aluminum structures. This is believed to originate from chlorine-containing residues that remain on the etched film sidewalls. If these residues are combined with moisture absorption, the corrosive acid, HCl, forms, and this leads to aluminum corrosion products like aluminum trichloride. The problem is even more severe for aluminum copper alloys. Corrosion can be prevented by rinsing well the wafer in deionized water after removal from the chlorine plasma. Also, one can apply a plasma etching step in oxygen to remove residual photoresist and chlorine atoms, and at the same time, restore a thin passivating aluminum oxide layer. Another possibility is to expose the etched structure to a fluorine plasma, during which chlorine atoms are replaced by fluorine atoms.

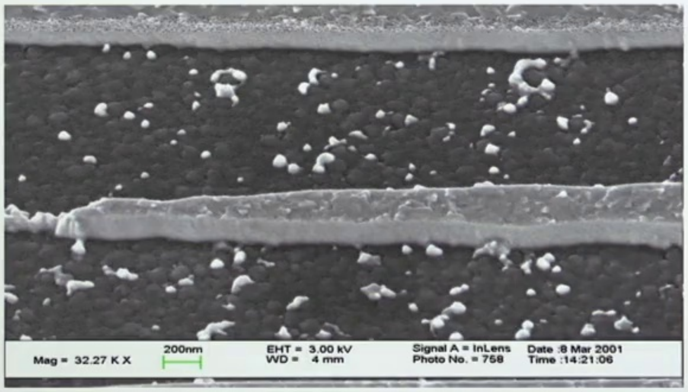


Here, we show the etching of a platinum film using a photoresist mask. The platinum was deposited on a thin silicon nitride layer on a silicon dioxide layer. The etch rate is very low, and the selectivity is also relatively low: 8, because the platinum is such chemically inert material. We have used here a low pressure argon chlorine mixed plasma with a high negative voltage bias on the substrate. In the picture, almost all of the photoresist has been consumed for etching through the platinum layer.



The picture here shows the etching of a 0.5 micron thick tungsten layer deposited on a silicon dioxide layer, and one has used here fluorine chemistry and a photoresist mask. The selectivity is only 1. The etched product formed is tungsten hexafluoride. The metal tantalum can be etched in a very similar way.

Etching of Ti and Mo



Etching of 0.2 μm Ti on amorphous carbon using chlorine chemistry, photoresist mask; etch rate: 0.1 μm/min; selectivity ≈ 2

- Titanium etching: chlorine chemistry (etch product $TiCl_4$, vapor pressure 20 mbar at 25 ºC) or fluorine chemistry (etch product TiF_4 vapor pressure 3×10^{-4} mbar at 25 ºC)
- Molybdenum etching: fluorine chemistry (etch product MoF_6, vapor pressure 700 mbar at 25 ºC)

Micro and Nanofabrication (MEMS)

This picture shows the etching of a 0.2 micrometer thick titanium layer, which was deposited on an amorphous carbon film. One has used chlorine chemistry and a photoresist mask. The process has only a low selectivity, 2. When etching molybdenum in a fluorine plasma, similar results can be obtained.

This ends our lesson on the dry etching of organic materials, like photoresist and polyimide and metals. Etching organic layers is a relatively easy task using a plasma, as volatile reaction products can be easily created. On the other hand, etching metals is more difficult, and one needs ion bombardment for etching to occur. Whether one uses a chlorine or a fluorine plasma depends on if a suitable volatile chemical reaction product can be formed at the temperature of the etching process.