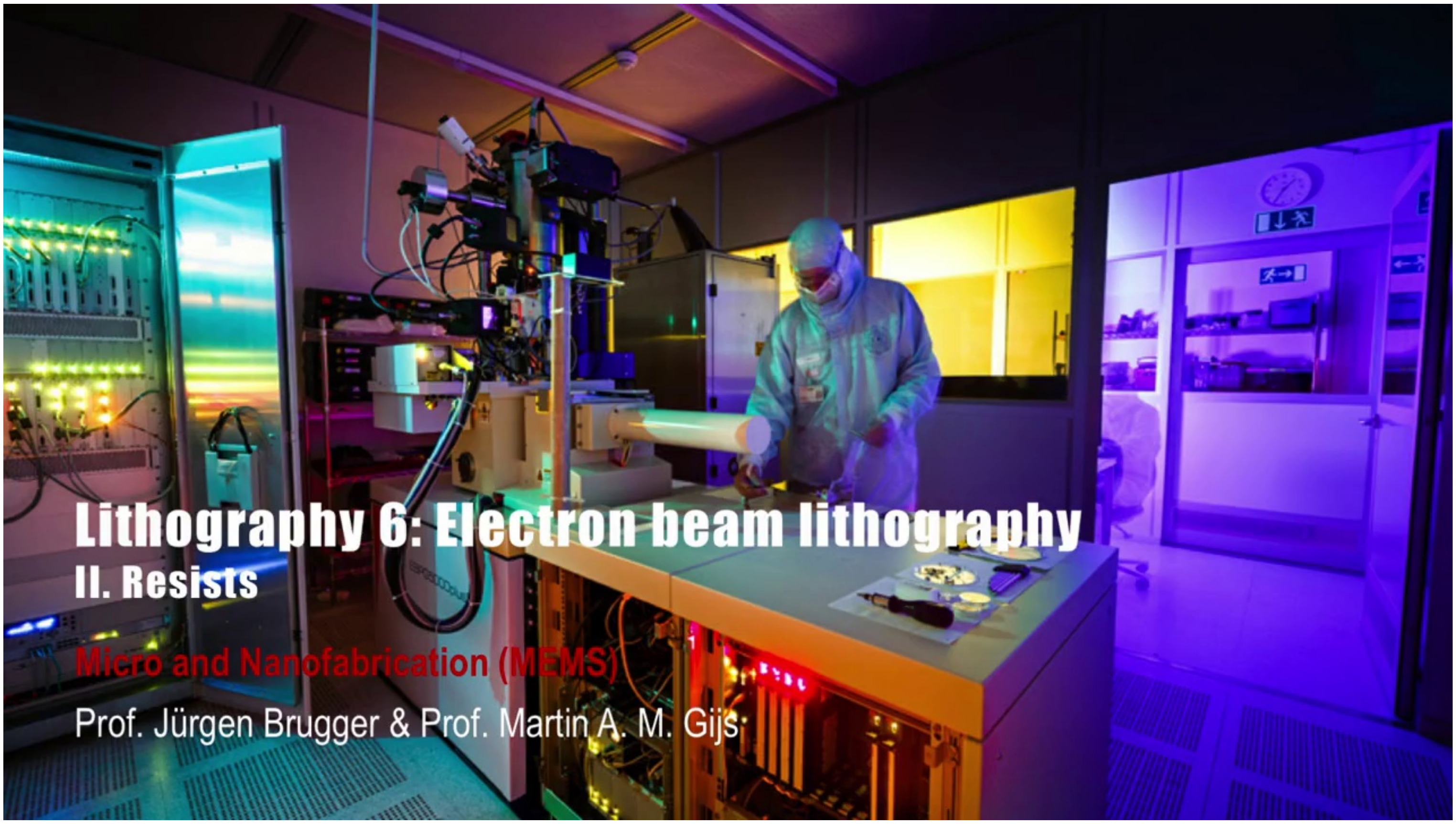

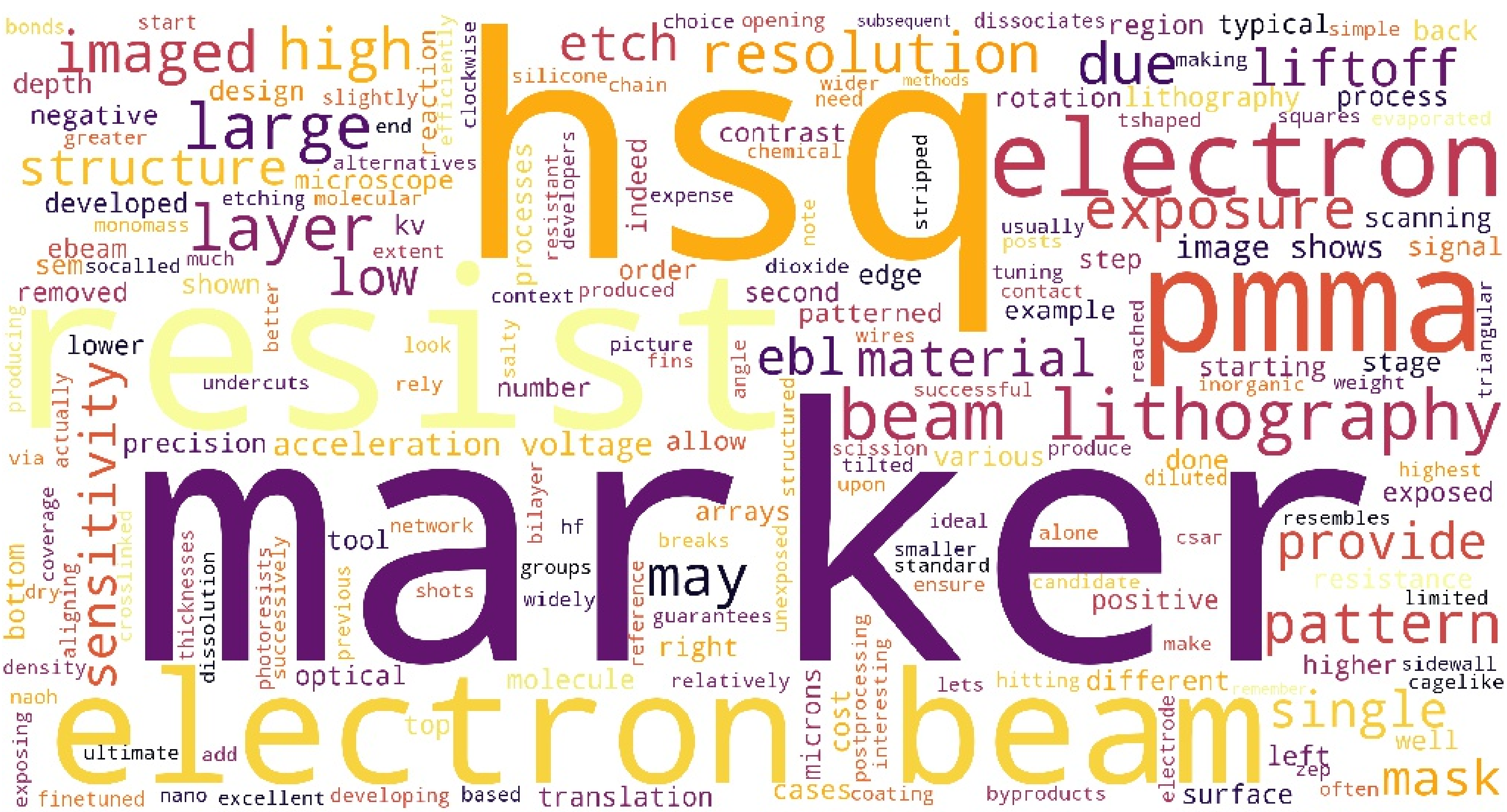

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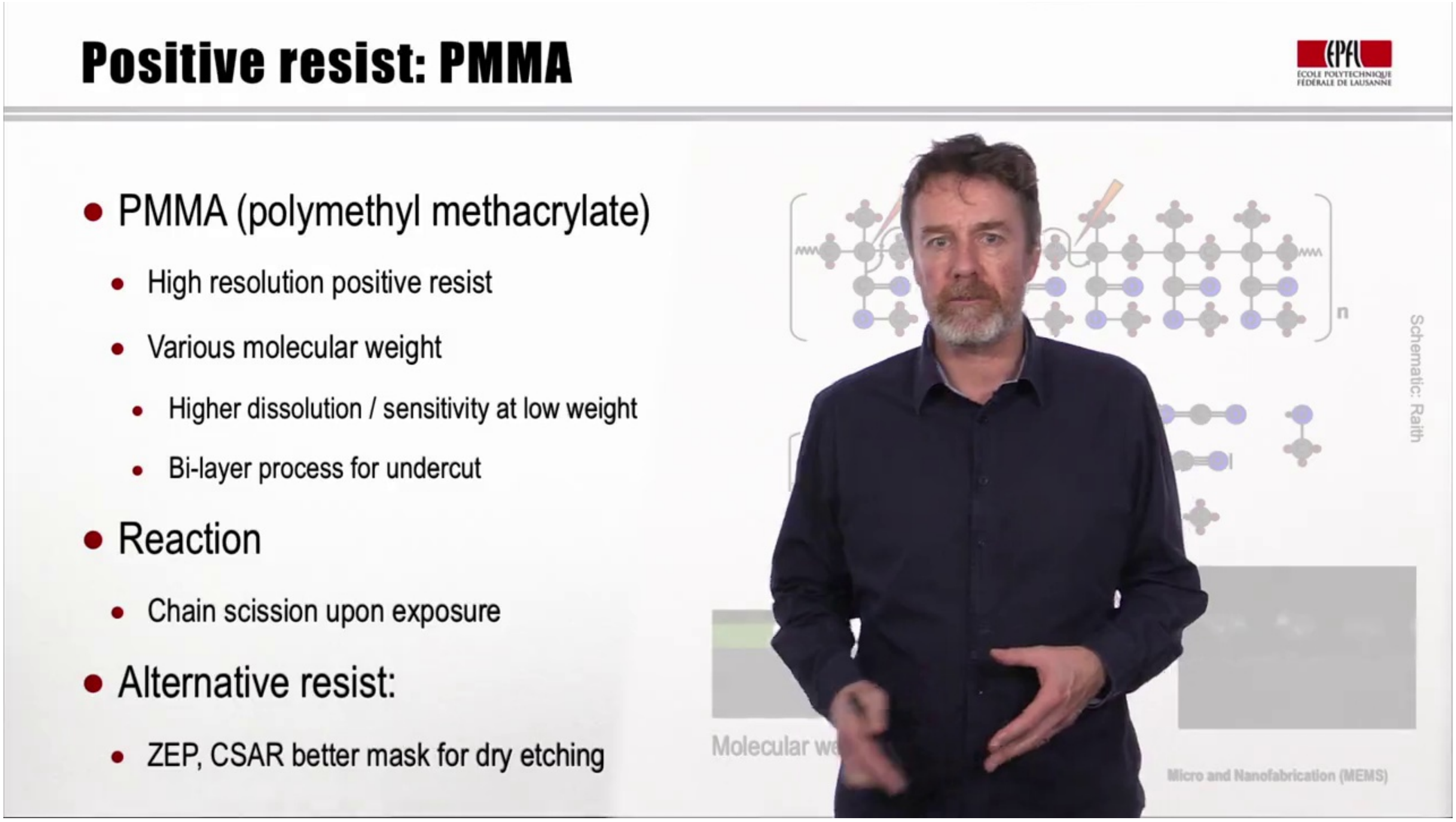
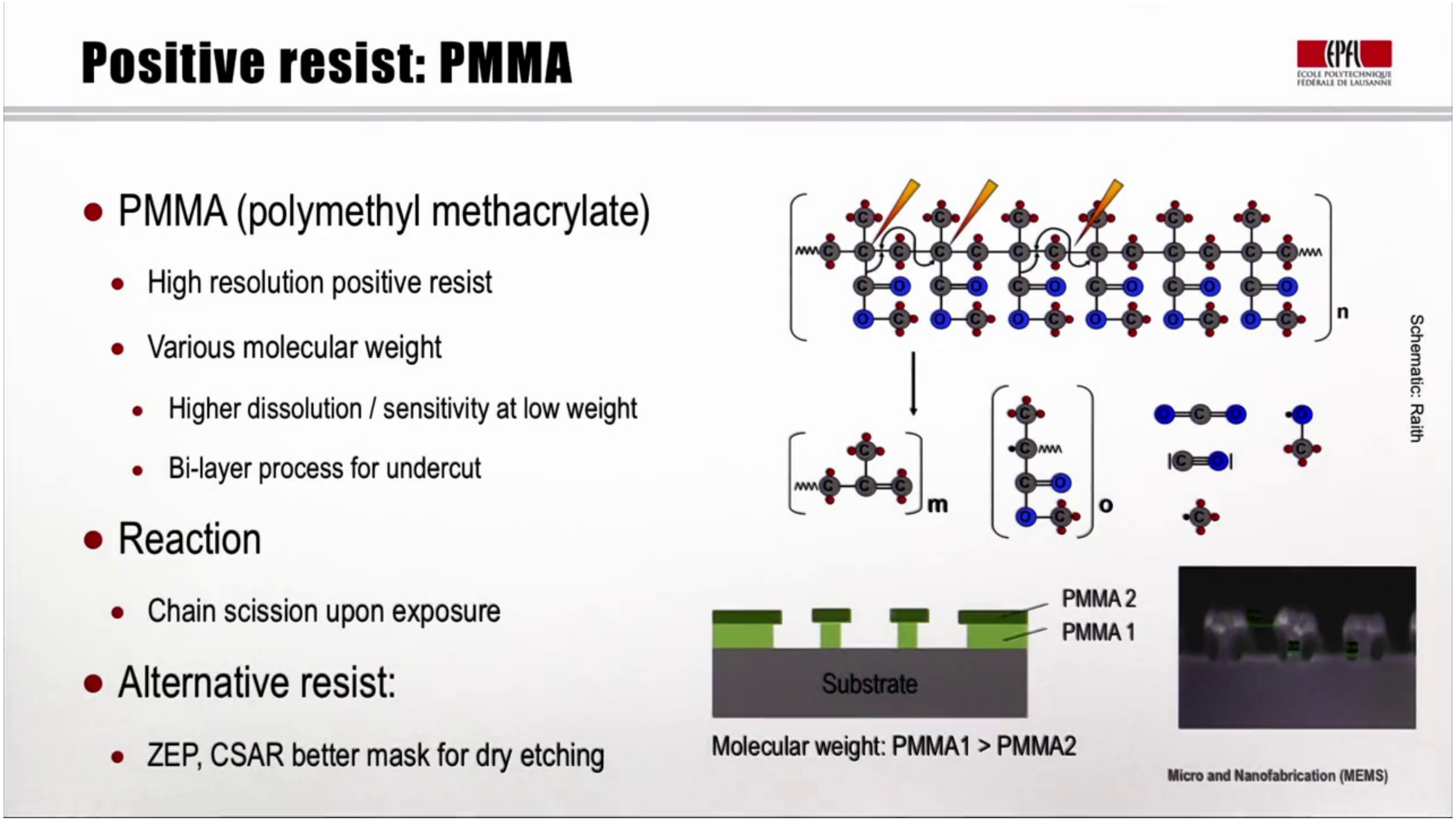
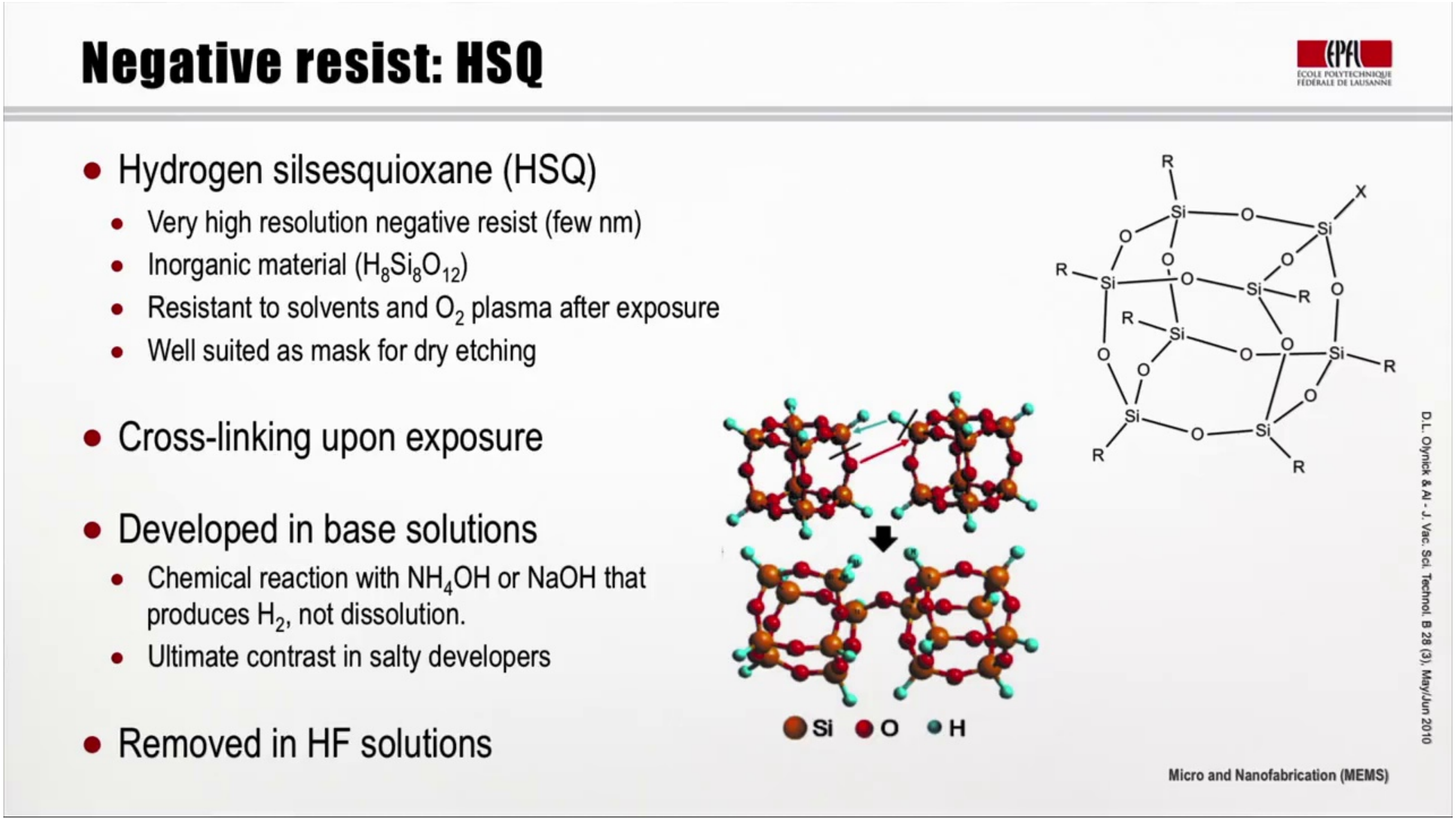


Let’s now have a look at some typical EBL resists. We start with PMMA, that is a positive resist widely used in electron beam lithography due to its high resolution and low cost. PMMA usually provides a relatively low etch resistance but it is an excellent choice for lift-off processes.

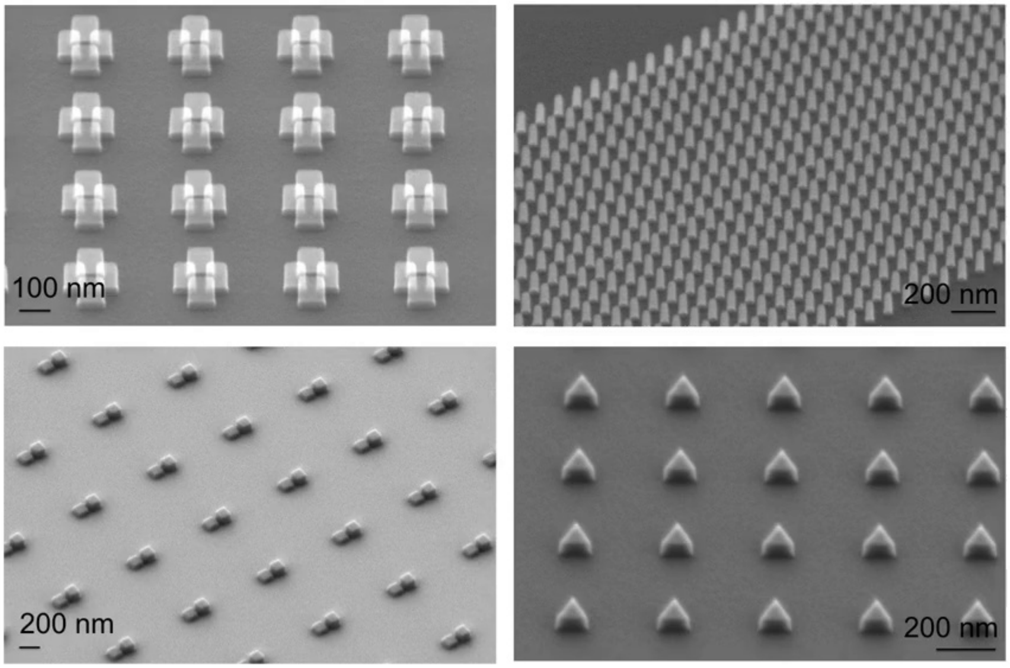


When an electron is hitting the molecule of PMMA, it breaks the bonds and dissociates the large molecule into smaller byproducts and mono-mass, which are then removed by the developing step. By tuning the molecular weight of PMMA, the resist sensitivity can be fine-tuned to a large extent. Therefore, by coating two layers of PMMA, starting with one of higher and the second one of lower sensitivity, T-shaped undercuts are produced. Indeed, via a single exposure, the chain scission reaction of PMMA after e-beam exposure will produce a wider opening in the first resist layer. This bi-layer process is a standard for EBL based lift-off that guarantees limited sidewall coverage of the evaporated material to ensure a successful lift-off, like shown here in this SEM picture. In the context of positive resists, other alternatives such as CSAR and ZEP provide higher sensitivity and a better etch resistance but to the expense of a slightly lower resolution and much greater cost.

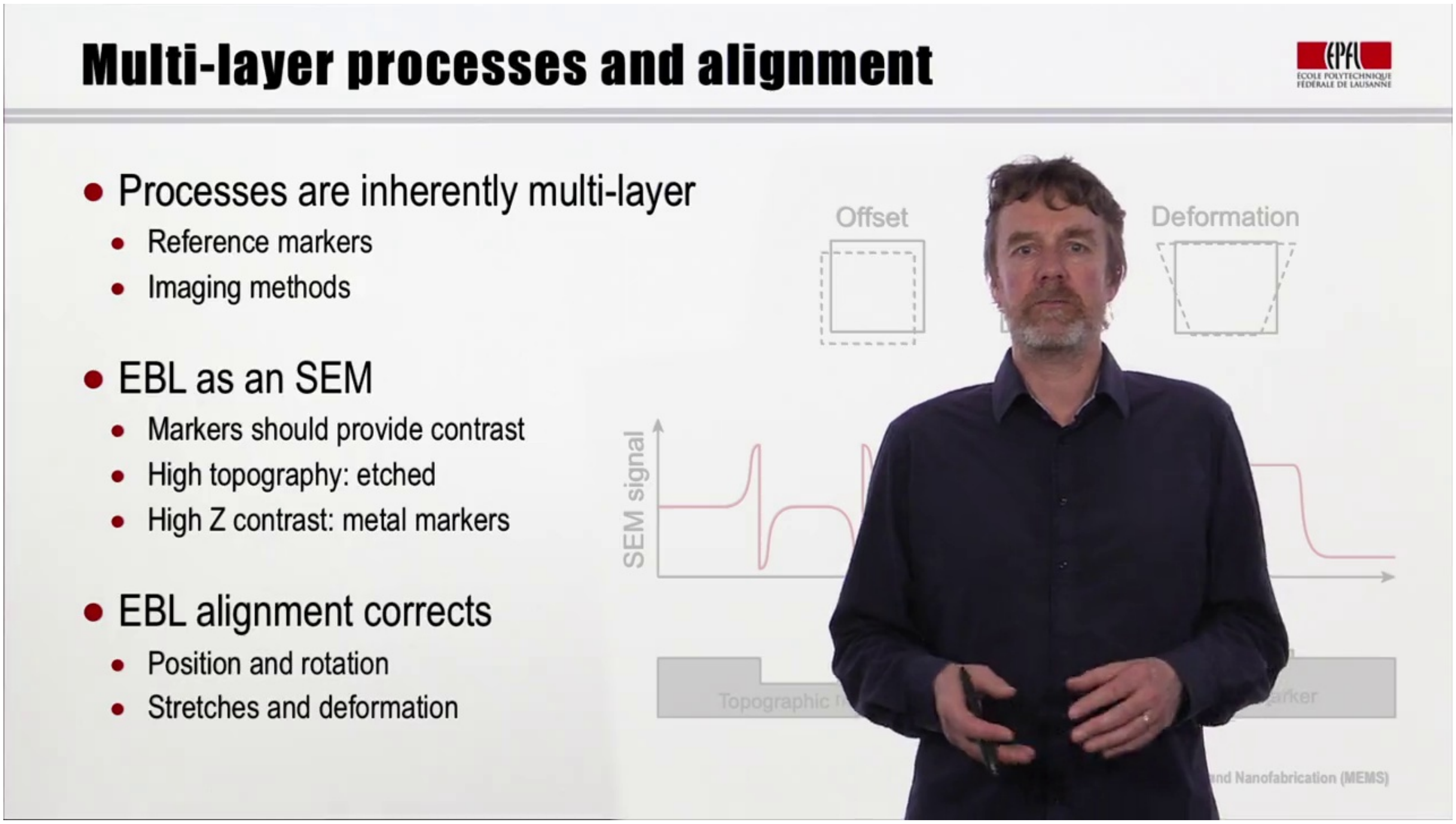


HSQ is one of the highest resolution EBL negative photoresists. Its inorganic, cage-like network resembles that of low density silicone dioxide. Upon exposure, HSQ is cross-linked and very resistant to further post-processing, making it an ideal candidate as mask for dry etching. It is interesting to note that the unexposed regions are developed by chemical reaction with NaOH, producing H2, and not by simple dissolution. Ultimate contrast and resolution is reached in so-called salty developers. HSQ is efficiently removed, or stripped, by diluted HF.

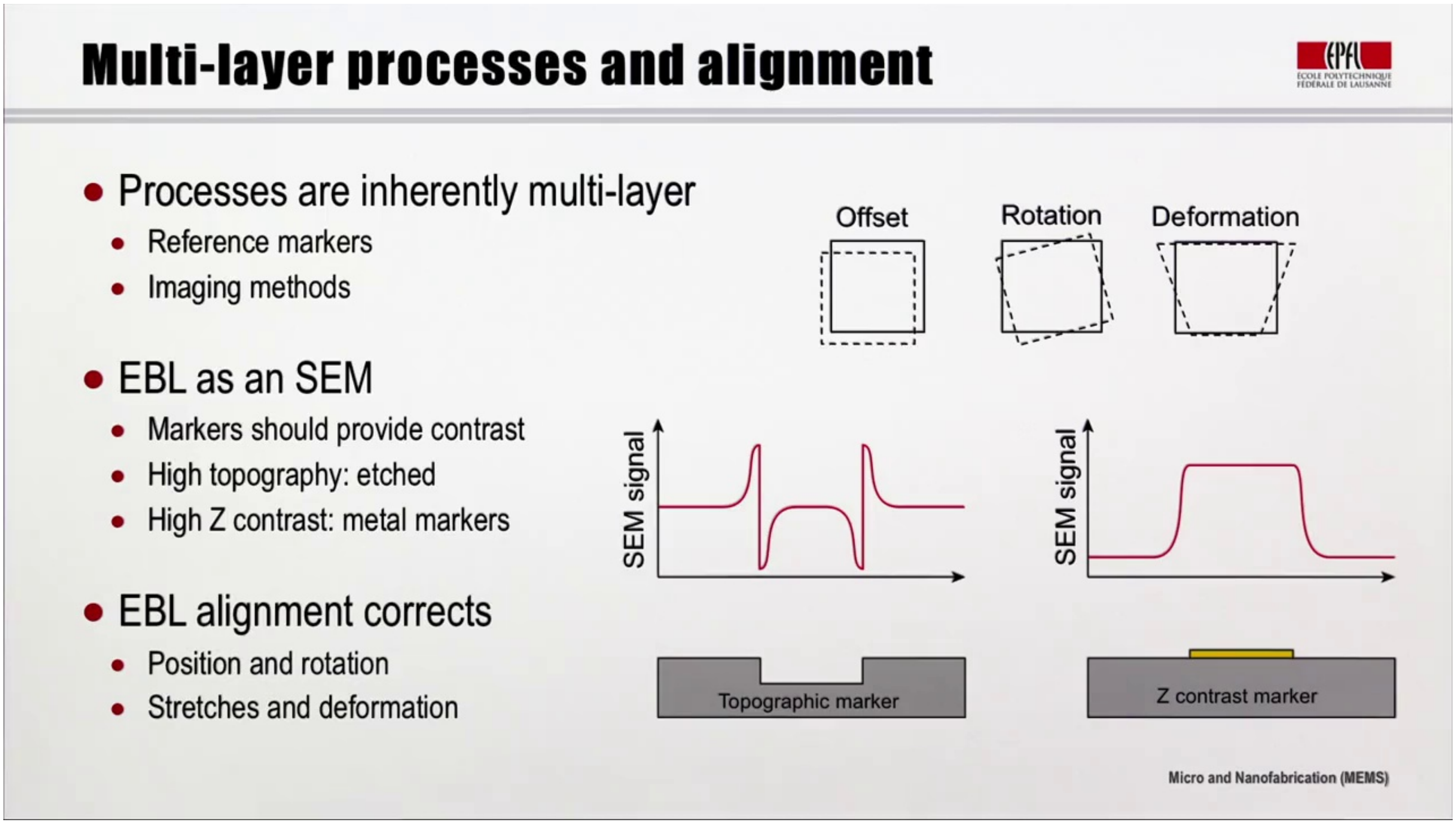
Examples with HSQ



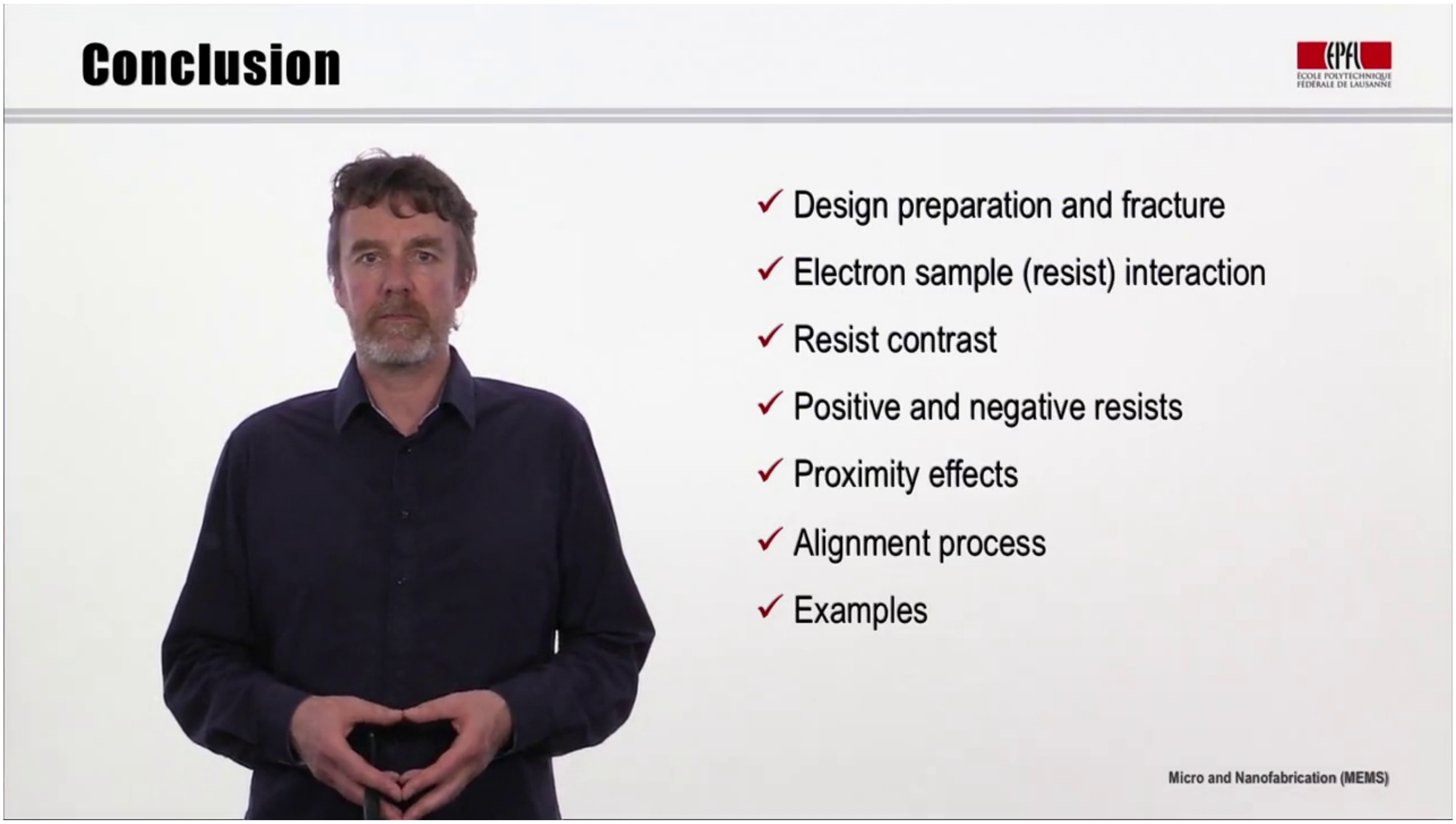
All the structures here are exposed and developed HSQ negative resist patterns, imaged under a tilted angle in a scanning electron microscope. From clockwise from top left, you see first groups of four HSQ fins due to the 20 kV electron acceleration voltage one can actually see through the HSQ structures. The top right image shows arrays of HSQ posts exposed with single electron beam lithography shots. The bottom right image shows triangular arrays of HSQ imaged at 2 kV acceleration voltage. And the bottom left image shows HSQ squares of two different thicknesses done by exposing successively two different layers.



Very few lithography processes rely on a single layer alone. Often we need to add a second layer of structured material with high precision to a previous structure, for example to make contact electrode to some nano wires. To this end, reference markers are patterned on the surface. They allow aligning the electron beam in subsequent exposure steps. In optical lithography, as you may remember, these markers are imaged by optical methods. The one-to-one transparent mask with the chrome pattern is then aligned mechanically by means of a high precision stage controlling x, y and theta to correct for rotation and translation.



In electron beam lithography, the markers cannot be imaged optically, but as we know the e-beam tool is also functioning as a scanning electron microscope, allowing to see the surface. Due to large acceleration voltages and associated penetration depths, the markers, which are 10-20 µm wide, are either etched in the substrate, like shown here, with a depth of several microns or made of a high atomic number material to provide sufficient contrast. In both cases, the tool finds the marker etch by monitoring signal variation. But not looking at the marker itself but at the edge of the marker which gives a strong signal in the back scattered electron. Also, markers may be large: the typical marker edge detection accuracy is in the order of a few tens of nanometers. Due to back scattering and the search range of the marker these shouldn't be positioned closer than a few hundreds microns from the region of interest to be patterned. Beside the SEM imaging approach, electron beam lithography offers another unique advantage when compared to mask aligner schemes. Indeed, a large number of markers per pattern may be used for redundancy and the patterns may be corrected beyond rotation and translation. The dynamic nature of electron beam lithography allows, for example, for a deformation of the design in order to project it on the base defined by the marker.



Well, this wraps up the lesson on electron beam lithography. We have seen the various stages of the process starting from the design preparation, electron resist interaction, various resist properties as well as limitations, such as proximity effect, and how alignment is done. In the accompanying exercises, you will have a chance to train your knowledge and apply it to some real application cases.
