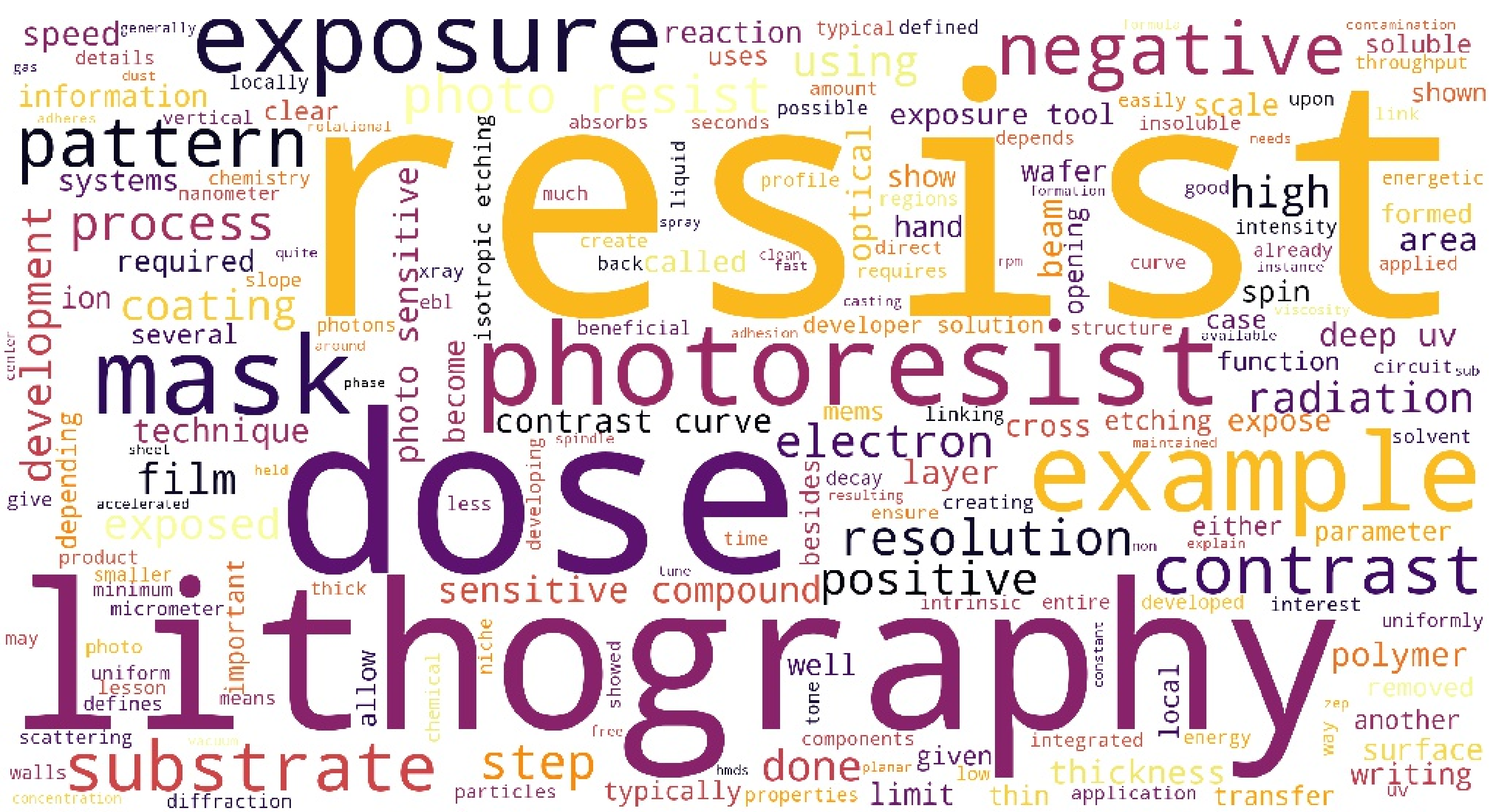

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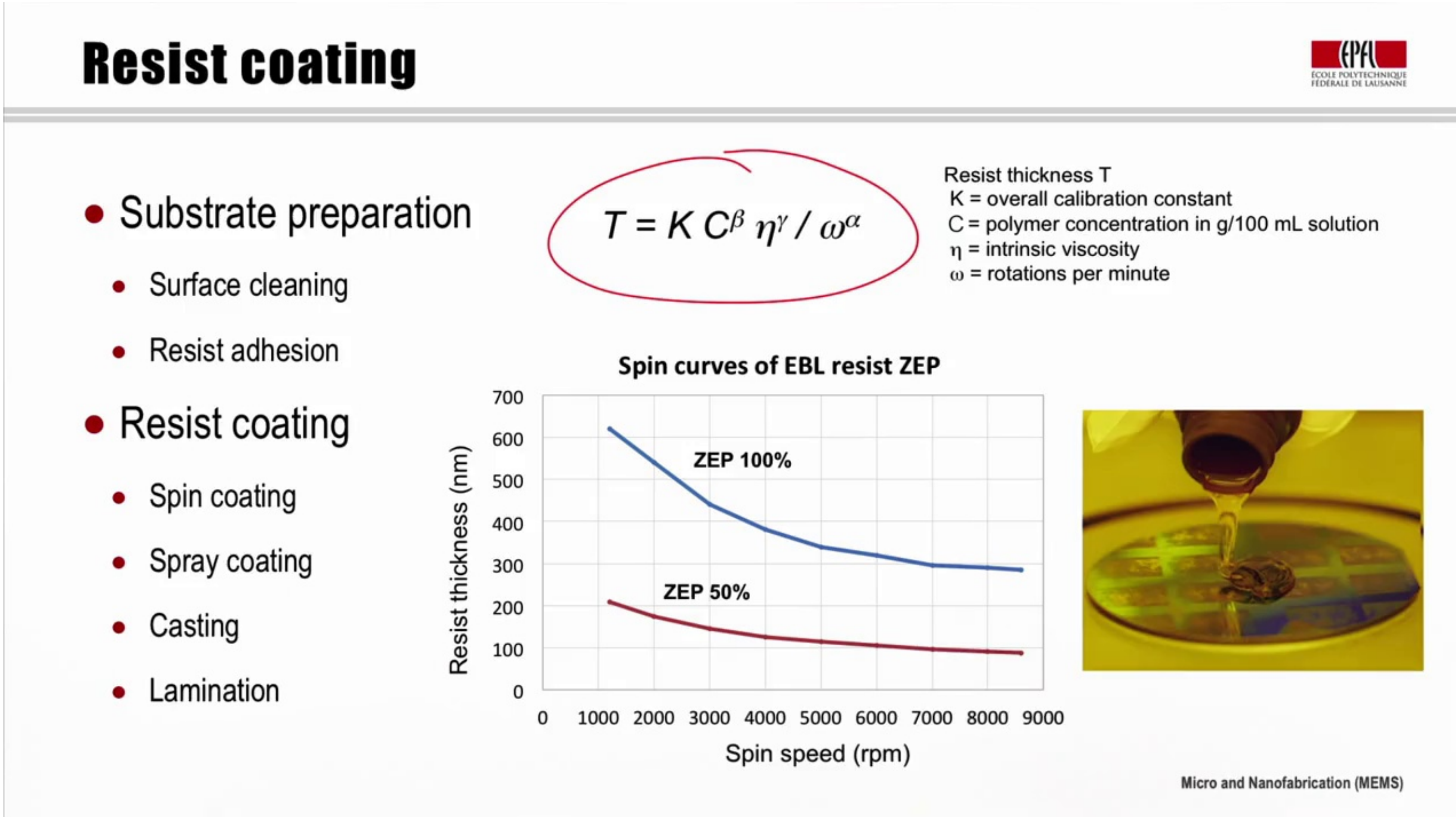
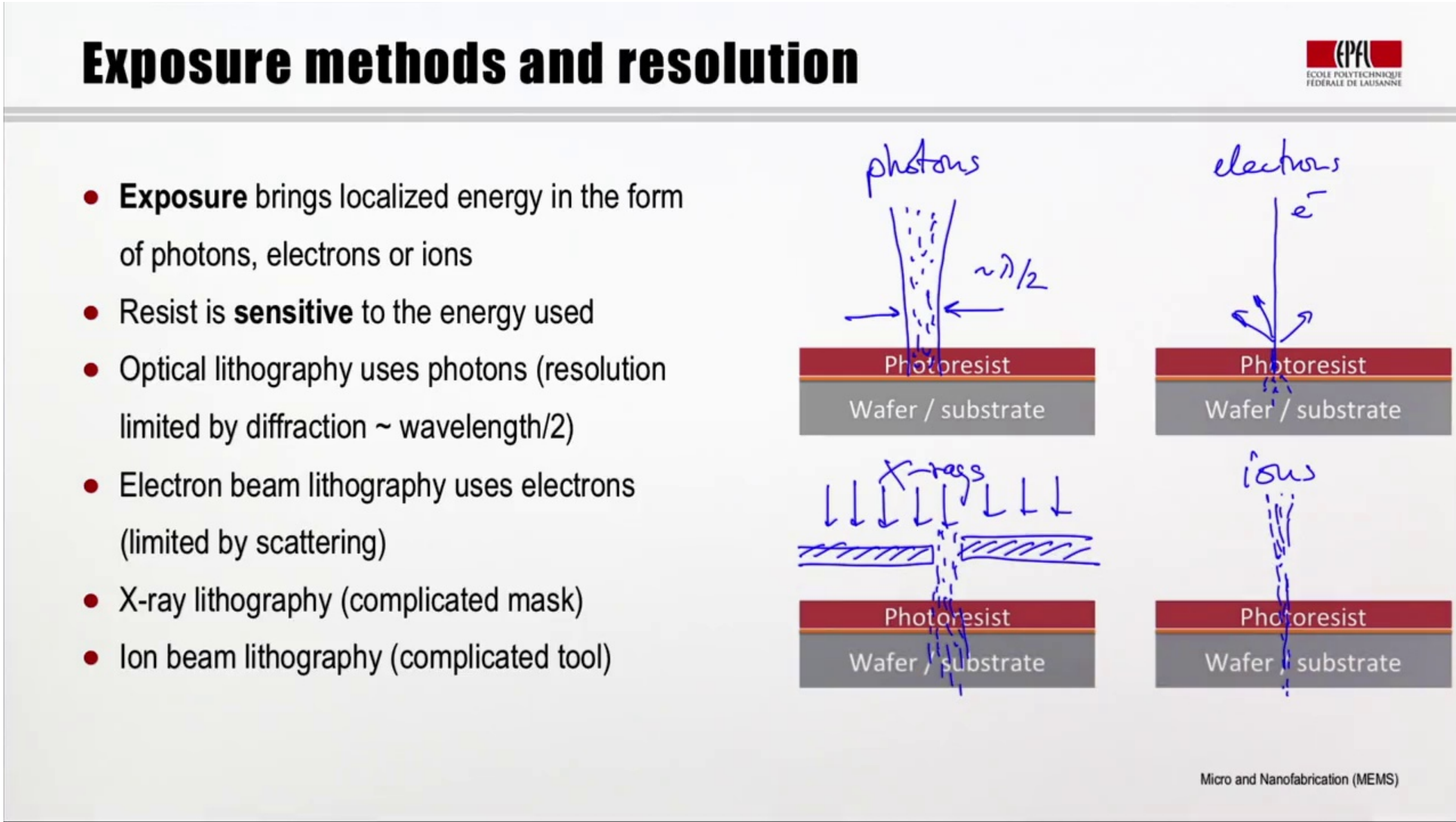
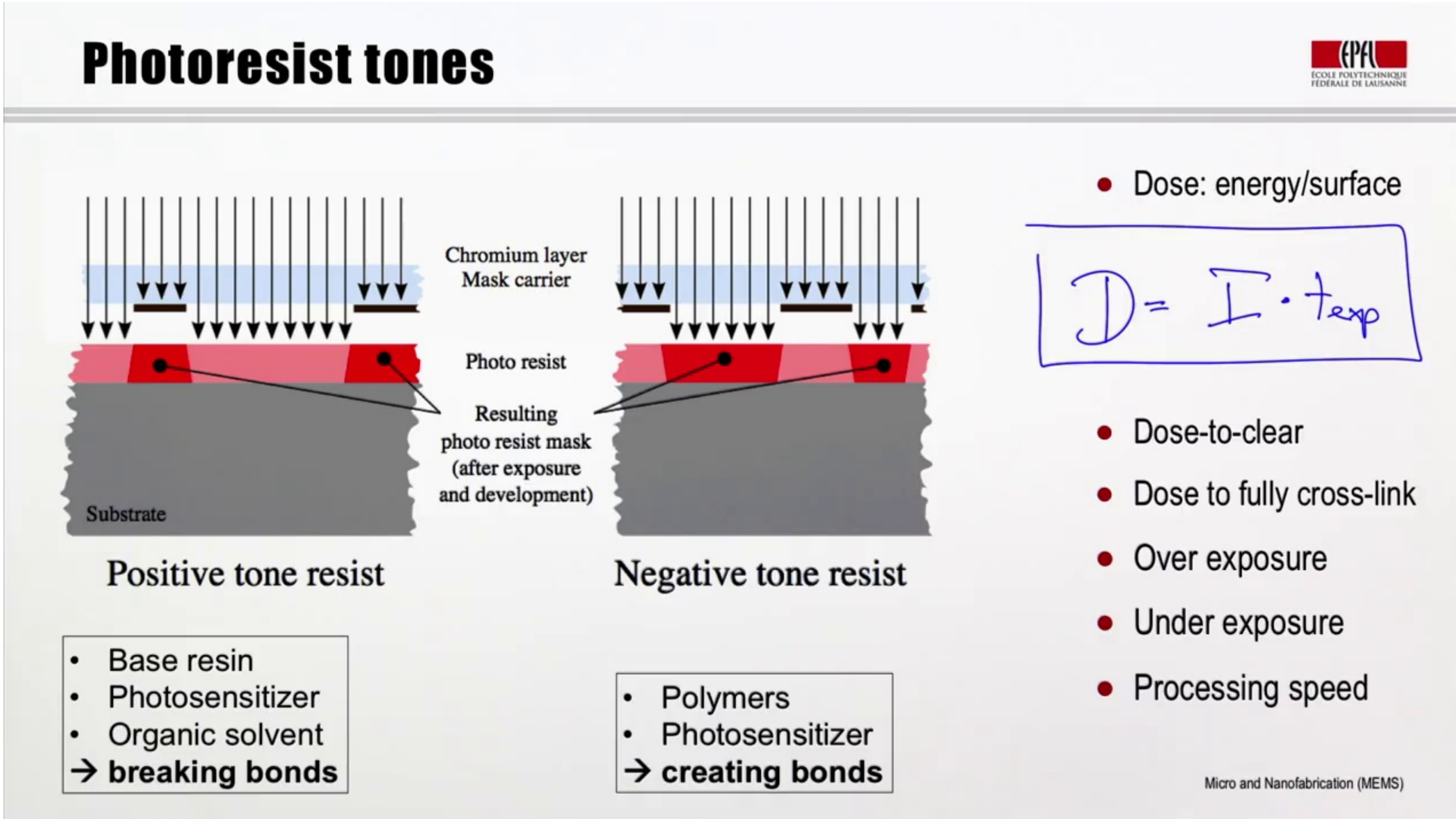


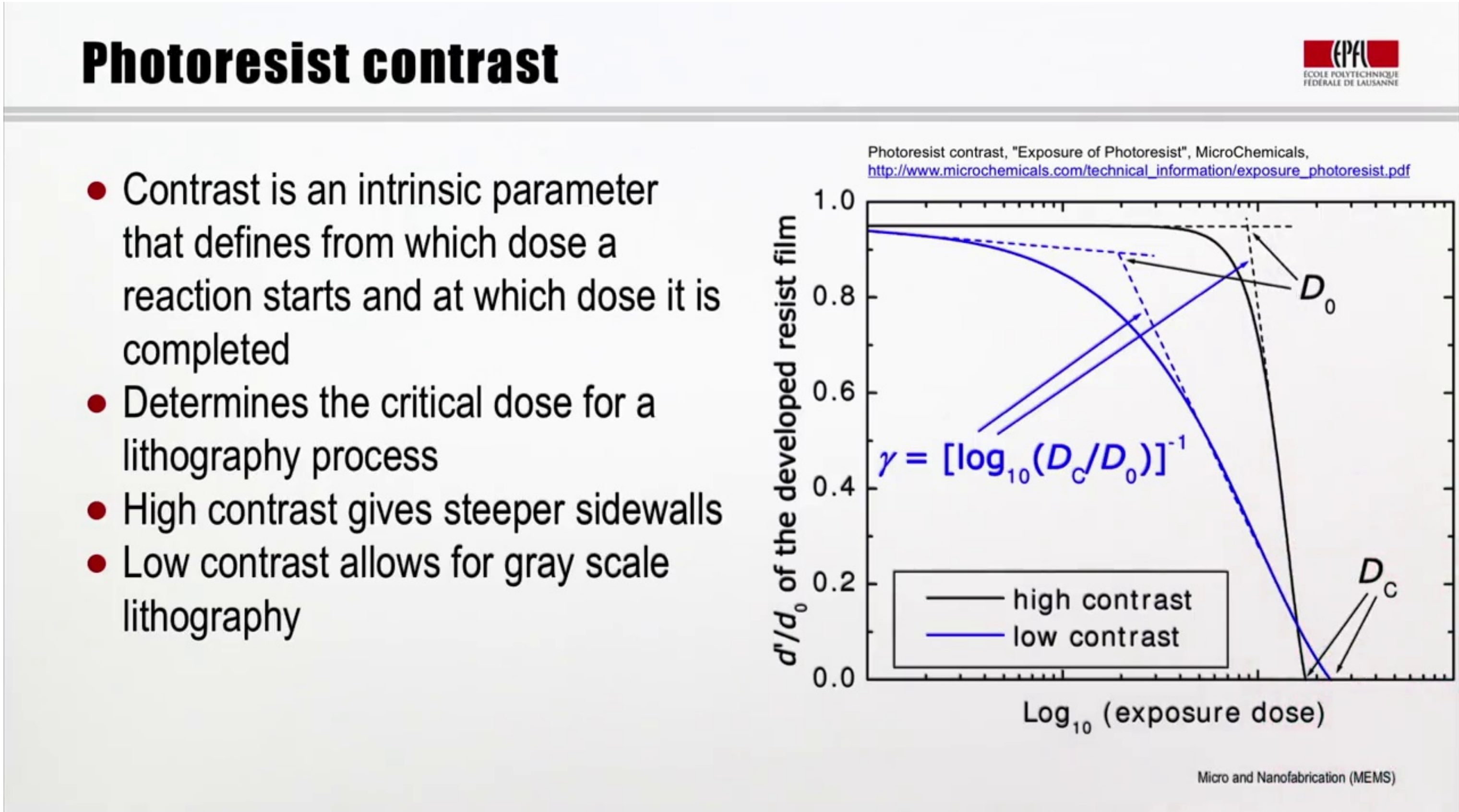
Here I explain a few details on the resist coating steps. First, one needs to ensure that the surface is clean and free of any contamination particles such as dust to allow a uniform film formation. Besides that, it is very important to tune the surface properties of the substrate for a good resist adhesion. This is typically done using HMDS coating either in the liquid or gas phase. This ensures that the photo resist, also in very thin layers, adheres well and uniformly on the surface. For the resist coating, the wafer is held on a vacuum spindle and a well defined amount of liquid resist is applied to the wafer center like shown here. The wafer is then accelerated up to a constant rotational speed which is then maintained for around 30 seconds. The thickness of the resulting resist film is given by this formula shown here which depends on the polymer concentration and viscosity as well as on the spin speed. Spin speed is quite fast, generally between 1,000 and up to 10,000 RPM to give uniform films from as thin as sub 100 nanometers to several micrometers, depending on the lithography application. The curve here shows the film thickness as a function of spin speed for a typical electron beam resist called ZEP. Such curves are done for each resist product and are available on the product information sheet. Besides spin coating, there are also other resist coating techniques. For instance, spray coating allows using non planar substrates. Another technique is ”casting”, that uses a mechanical doctor blade to uniformly spread a very viscous resist. Finally, a technique called ”lamination” transfers an already formed dry resist film directly onto the substrate. The two latter examples are of great interest for very thick photo resist layers.



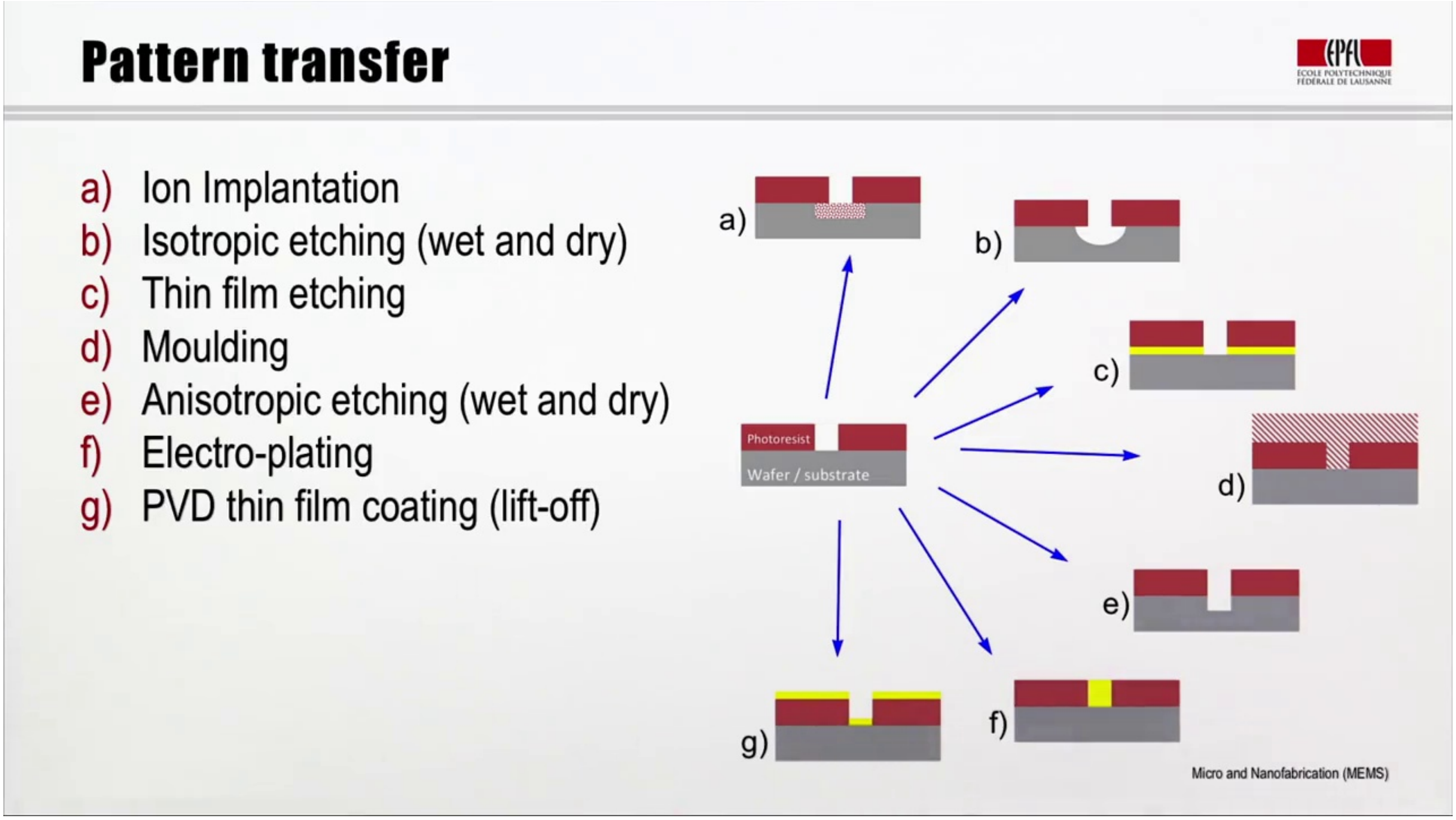
There are several ways to expose resist. In every case, it is a sort of energetic radiation that alters the resist chemistry as explained before. The first and mostly applied way is to use photons. Indeed, the majority of exposure tools for integrated circuit components and MEMs, are optical systems using ultraviolet light. Optical lithography uses masks to create the pattern, either in contact for 1 micrometer scale, typically for MEMs, or by projection systems for deep UV, typically for CMOS. Optical exposure is limited by diffraction. However, state of the art deep UV exposure tools are capable of high resolution down to 10 nanometer scale thanks to the deep UV wavelengths, new resist chemistry, and resolution enhancement. The advantage of optical lithography is that the entire wafer or part of it can be exposed at once which allows for high throughput. Electron lithography is primarily used to produce the photo masks that are then used in UV and deep UV litho. But more and more direct writing using modern EBL systems is now possible with reasonable throughput. Here the electron beam is focused on the resist and then raster or vector scanned to write the pattern. The resolution limit of EBL is given by the back scattering of electrons that expose all the resist area near the writing zone. More details on this will be provided in the dedicated lesson. X-ray lithography uses a highly energetic beam to expose the resist. It has in principle extremely high resolution as diffraction is much smaller than for deep UV and UV photons. But this technique requires a very special and complicated mask that is opaque to the x-rays. Therefore it is not used for integrated circuit or MEMs fabrication but is used for specific niche applications. One of them is the exposure of very thick PMMA resist in the so called NIKA process. A further possibility is to use ions which are like electrons, charged particles, but they are also much heavier and have therefore less back scattering in the resist and the substrate which increases the resolution. Ion beam lithography systems are constantly developed further but it is not clear whether they will be used for mainstream lithography. So they should be considered as a niche technique.



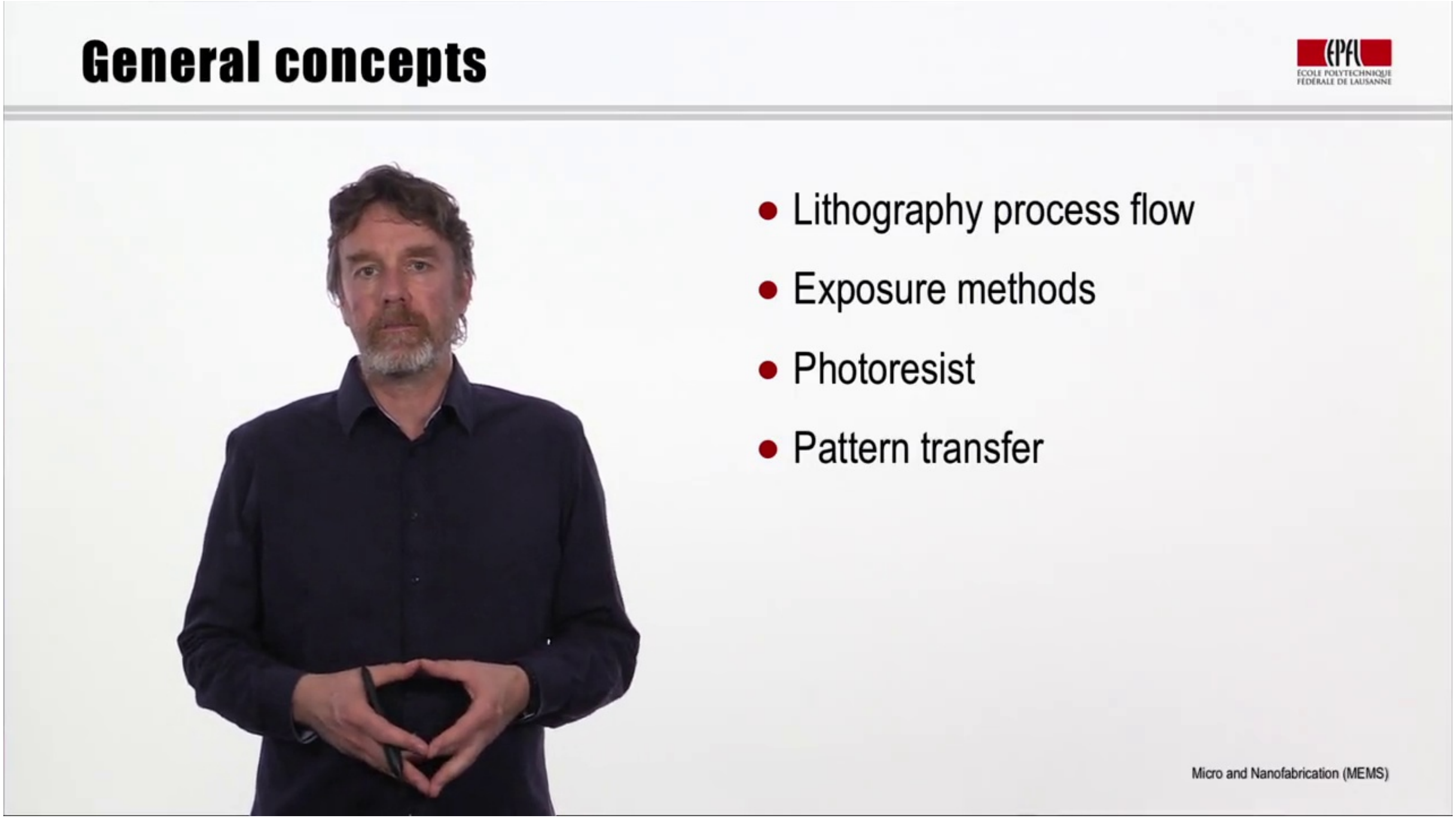
Now let's talk about resist, which is besides the exposure tool, the other very important ingredient of a successful lithography at micro or nano scale. The photo resist is a radiation sensitive compound. Photoresist can be classified as positive and negative depending on how they respond to radiation. For positive resist, the exposed regions become more soluble, and thus more easily removed in the development step. The net result is that the patterns formed in the positive resist are the same as those on the mask. For negative resist, the exposed regions become less soluble and the patterns formed in the negative resist are the reverse of the mask pattern. A similar classification can be done for electron beam sensitive resist. Thereby the exposure is not done via a mask, but by direct writing. Depending on the writing area, it is beneficial to choose either positive or negative e-Beam resist. Positive photoresist consists of 3 components. A base resin, a photo sensitive compound, and then organic solvent. Before the exposure, the photo sensitive compound is insoluble in the developer solution. After exposure, the photo sensitive compound absorbs radiation in the exposed pattern areas, changes its chemical structure and becomes soluble in the developer solution. Upon development, the exposed areas are removed. Negative tone photoresists are polymers combined with a photo sensitive compound. After exposure, the photo sensitive compound absorbs the optical or electron energy and converts it into chemical energy to initiate a chain reaction. This reaction causes cross linking of the polymer molecules. The cross link polymer has a higher molecular weight and becomes insoluble in the developer solution. Upon development, the unexposed areas are removed. One major drawback of negative tone resist is that in the development process, the entire resist mask swells by absorbing developed solvent, which may limit the attainable resolution of negative resist. The resolution of a lithography process depends on one hand on the exposure tool and on the other hand on several key parameters of the photo resist. One of them is the resist sensitivity and corresponding required dose. Because the radiation is also absorbed in the resist medium, there is a minimum amount of radiation dose required to expose the resist from the top to the bottom so that it can be cleared in the development step. The required dose is called "dose to clear", or "dose to fully cross link" in the case of negative resist. The dose can be calculated by knowing the lamp's intensity distribution in watts per centimeter squared and the exposure time in seconds. So the dose is equal to the intensity times the time.



The performance of any photo resist can be characterized by its contrast curve. It is an intrinsic resist parameter that defines the minimum dose limit that is required to start a reaction, and the upper dose limit at which the reaction is completed. Photoresist contrast is important for both resolution and profile. The example here is for positive photoresist but the same holds also for negative resist. The contrast curve of a photo resist, plots the remaining resist thickness after developing in relation to the thickness before the development, D’ over D_0, as a function of the logarithmically plotted exposure dose. The transfer of information from a given contrast curve to an individual lithographic process requires information of all process parameters which impact on the developing rate such as the resist thickness, soft bake, rehydration, air temperature, and humidity, etc. The contrast curve of an ideal positive resist, is a step function where the contrast is infinite. Realistic contrast curves show a D’ over D_0 already smaller than 1 for an exposure dose of 0, which is the dark erosion, and a non-infinitesimal logarithmic decay in the D’ over D_0, bigger than zero over a non-zero range of the dose towards D_c which is the dose to clear. The slope of this decay defines the contrast. High contrast is beneficial for the resist profile. On the one hand, it is easy to achieve vertical walls while on the other hand it can be tricky to find the correct dose for high contrast resist as they are easily over exposed or saturated. Low contrast may be good for example for grey scale lithography. So this shows the slope for a low contrast photoresist versus the one for high contrast photoresist.



Once the lithography step is done in the resist, we can now see what pattern transfer steps can be done using the resist as a local mask. Here is an overview of possible process steps. The first example a) is using the photo resist as a mask for local implantation with ions to do a local doping of the substrate with incoming ions that are masked by the photoresist. Or... Example b) is to use it for isotropic etching, the mask is protecting the substrate and when the etching reaches the substrate it shows isotropic etching, that means etching in all directions with the same speed which gives this circular shape. Or example c) would be to etch a thin film that has been previously coated on the substrate so an example of gold, or another metal layer can be etched locally through the opening in the photoresist. Example d) would be to use the photo resist structure on the surface as a mold, for creating a replica by pouring for example, another polymer over and cross linking, and then creating the negative of the opening of the photoresist pattern. Example e) would be to use the mask for anisotropic etching, in this case, in contrast with the isotropic etching we create vertical walls the well defined geometrical feature in the substrate. Or example f) would be to do electroplating, that means filling the opening in the photoresist by growing a layer locally in that aperture. And the last example g), would be to use the photo resist as a mask for lift-off processes in a physical vapor deposition step.



So this concludes this introduction lesson on the lithography. I have shown you the process flow of a typical photo lithography process, and showed you some exposure methods that exist to irradiate the photoresist. I gave you some first information about intrinsic resist properties, and also showed at the end, how the photoresist pattern can then be transferred into a layer of interest.