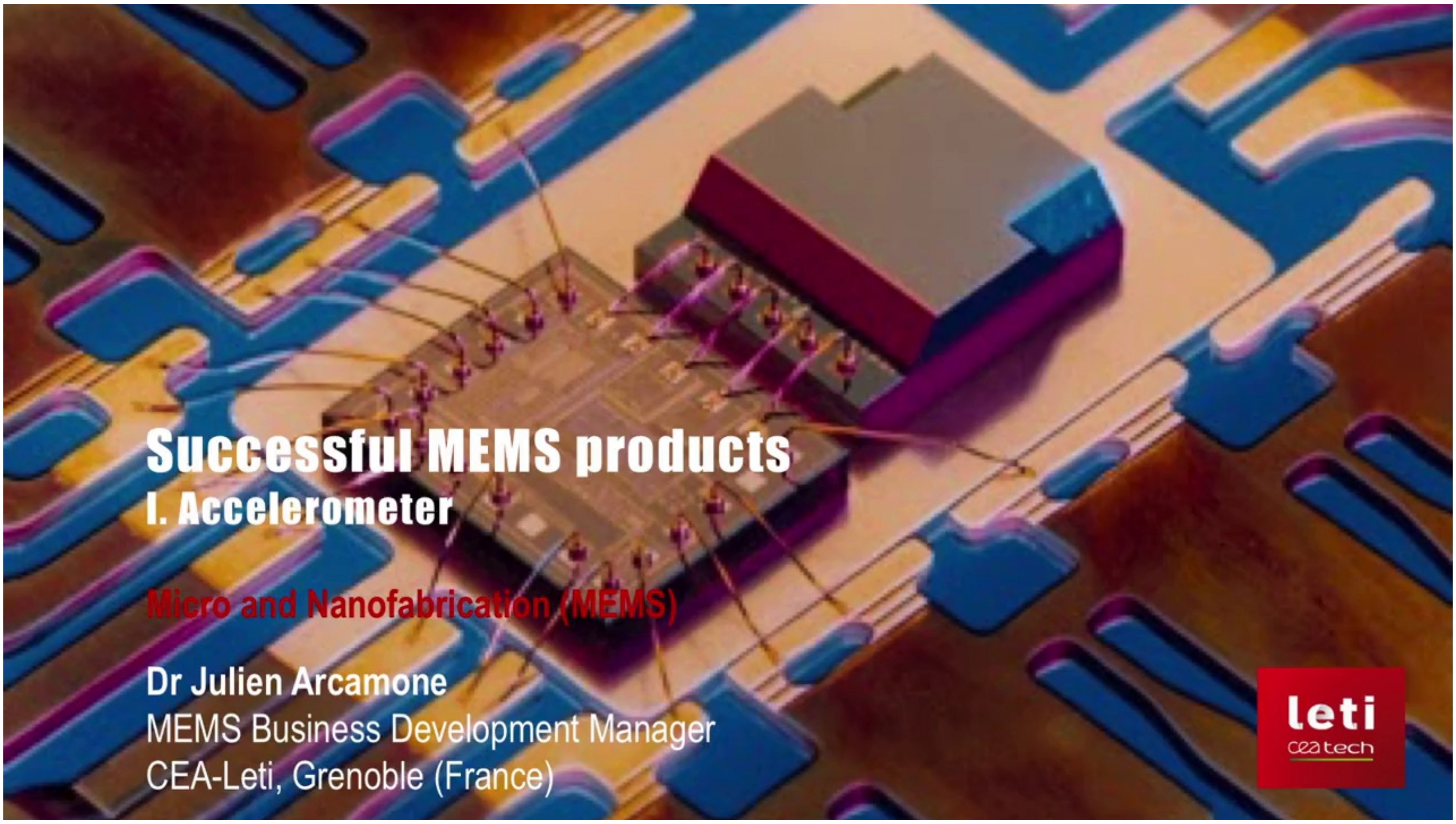

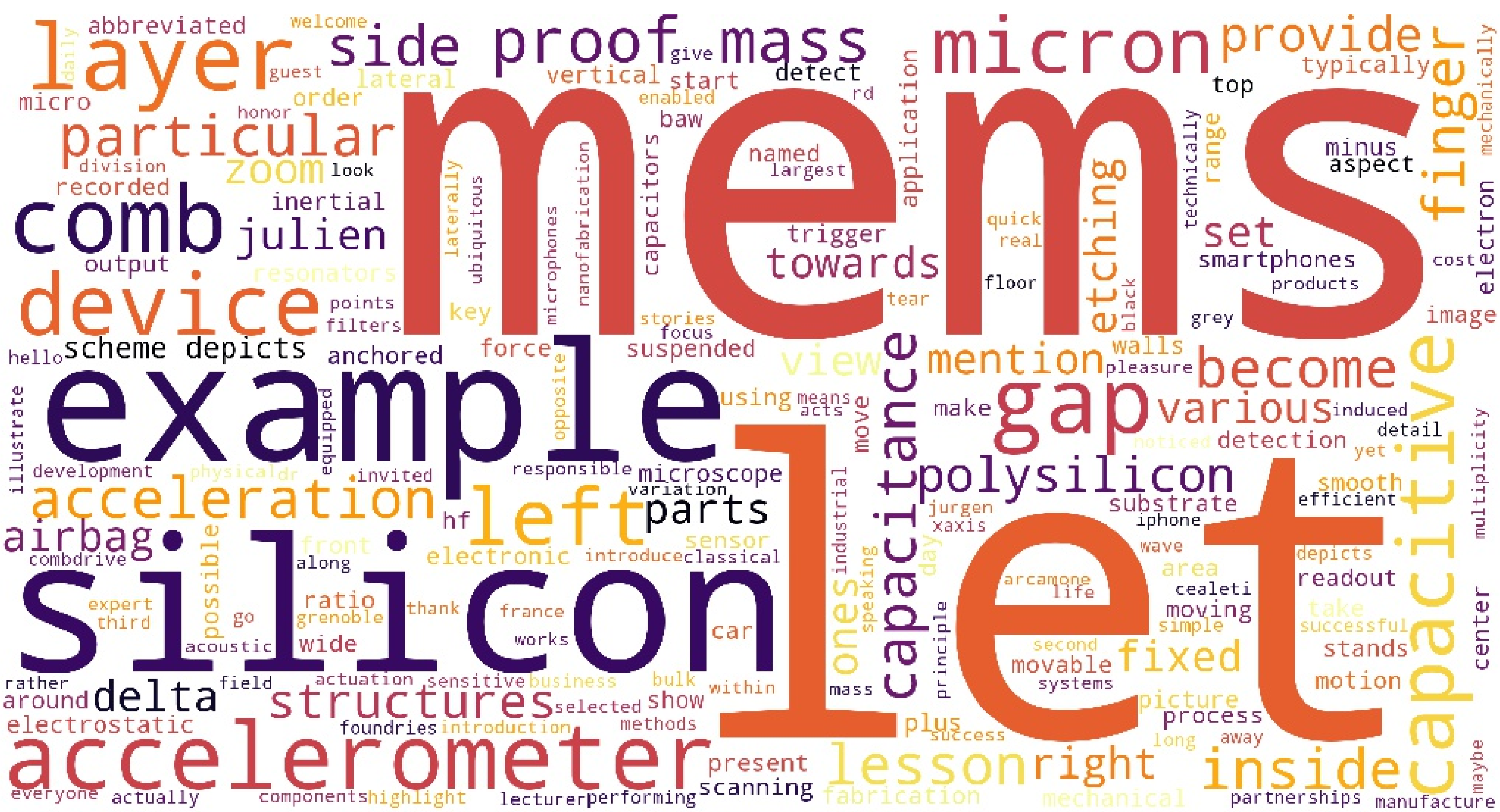

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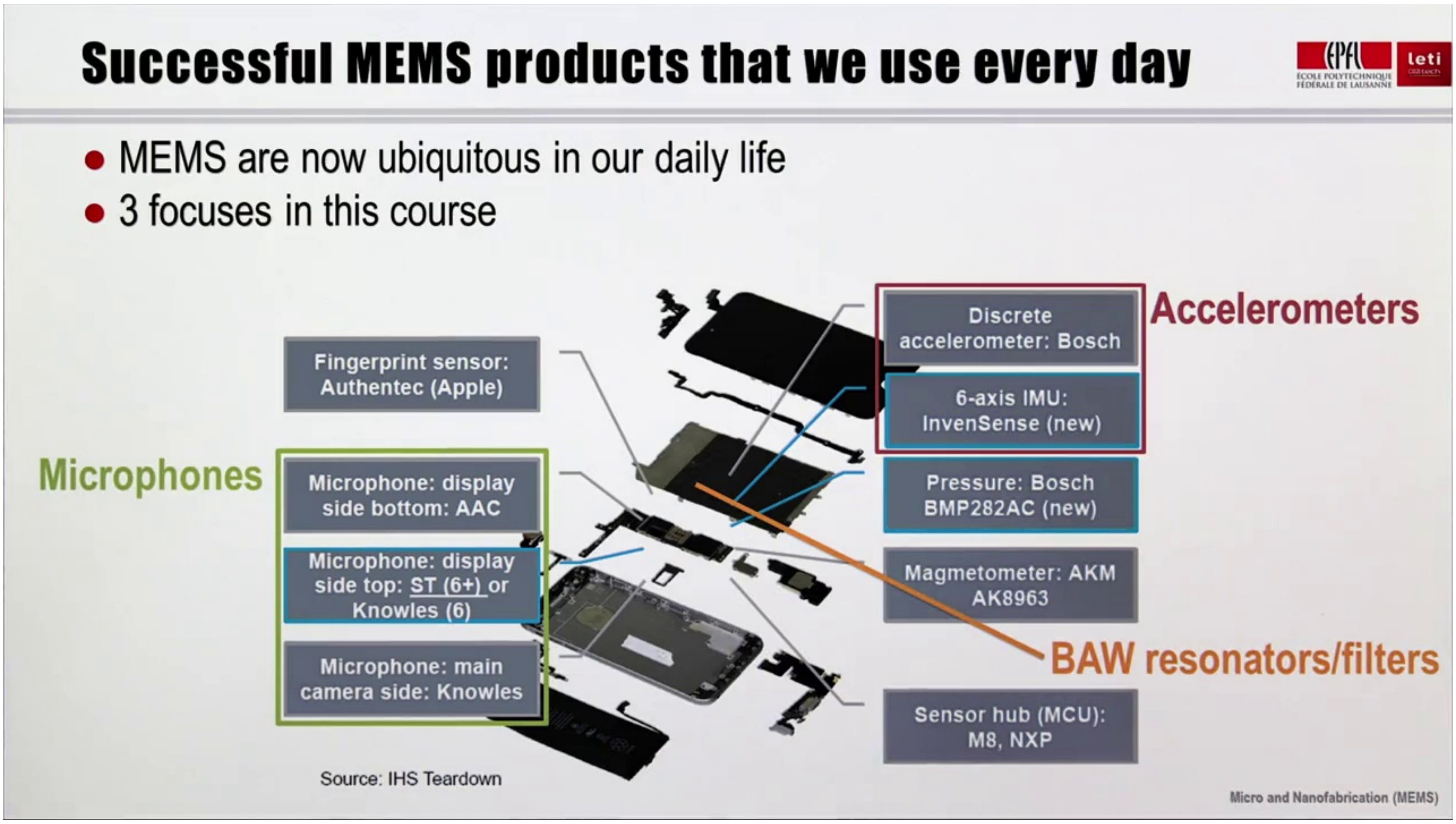
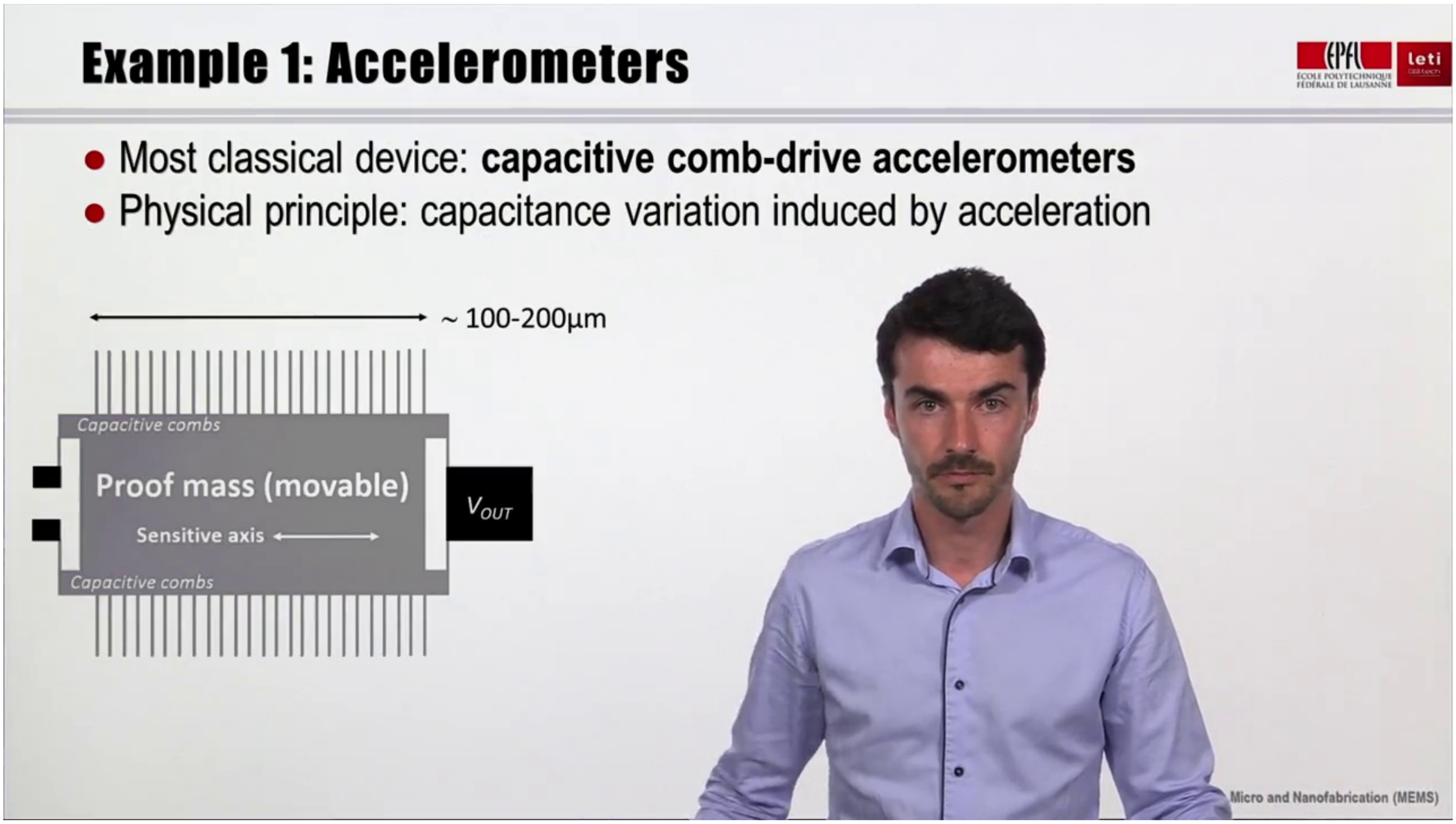
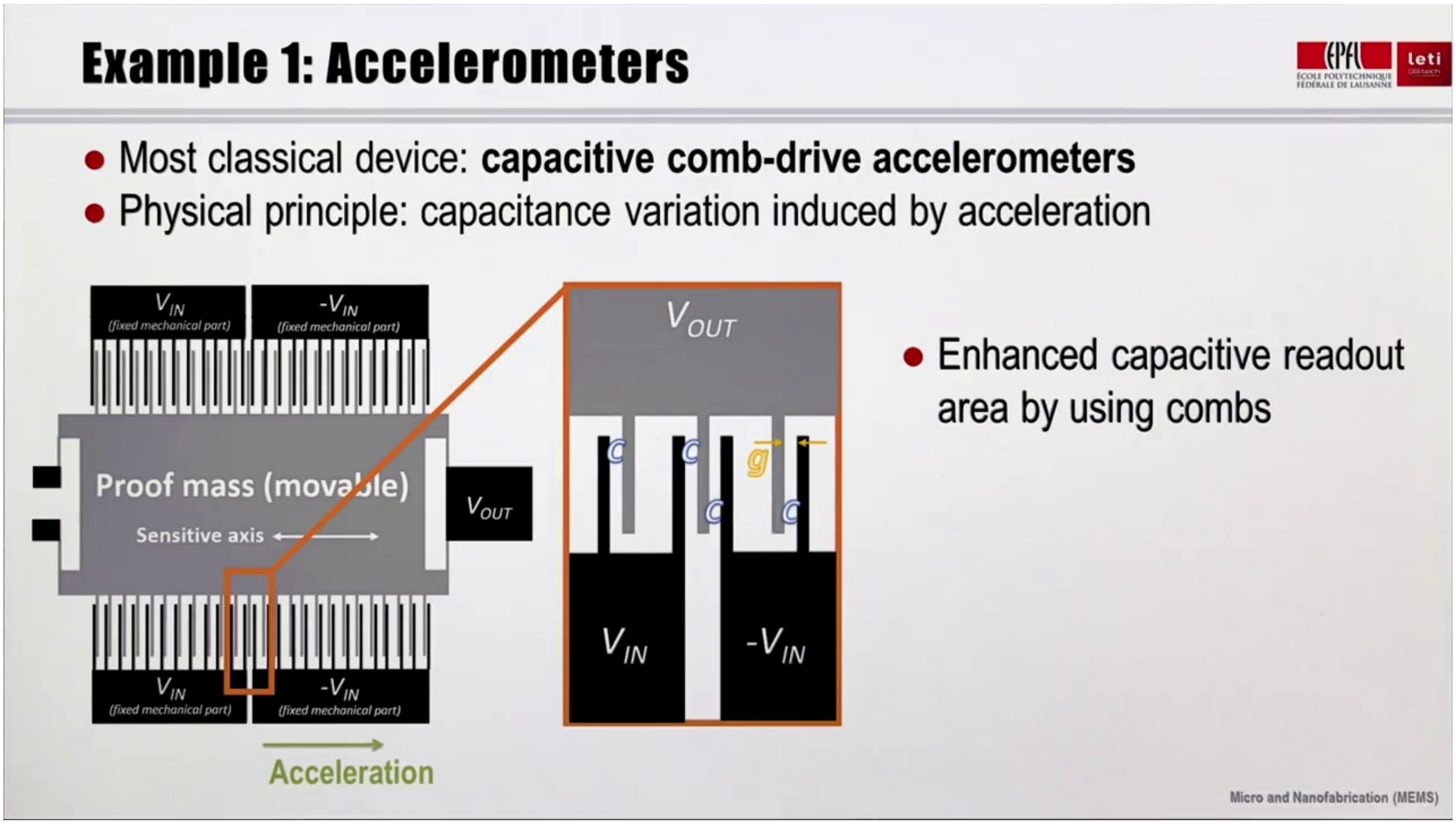
- Welcome to this lesson on MEMS success stories. Before we go into detail of the various micro nanofabrication methods, let's have a quick look what MEMS are and how we are actually using them day by day. We have invited for this lesson a guest lecturer who is a real expert in the field, so let me introduce Dr. Julien Arcamone. He is responsible for the industrial partnerships and business development in MEMS within the Silicon Components Division of CEA-LETI in Grenoble, France, one of the largest MEMS RD centers and foundries. Julien will show you some selected MEMS examples, he will in particular highlight how micro fabrication has enabled such systems to become so performing and cost efficient to manufacture. So Julien, the floor is yours ! - Thank you Jurgen for the introduction. Hello, it's my honor and pleasure to give this lesson on successful MEMS products. Let's start right away !



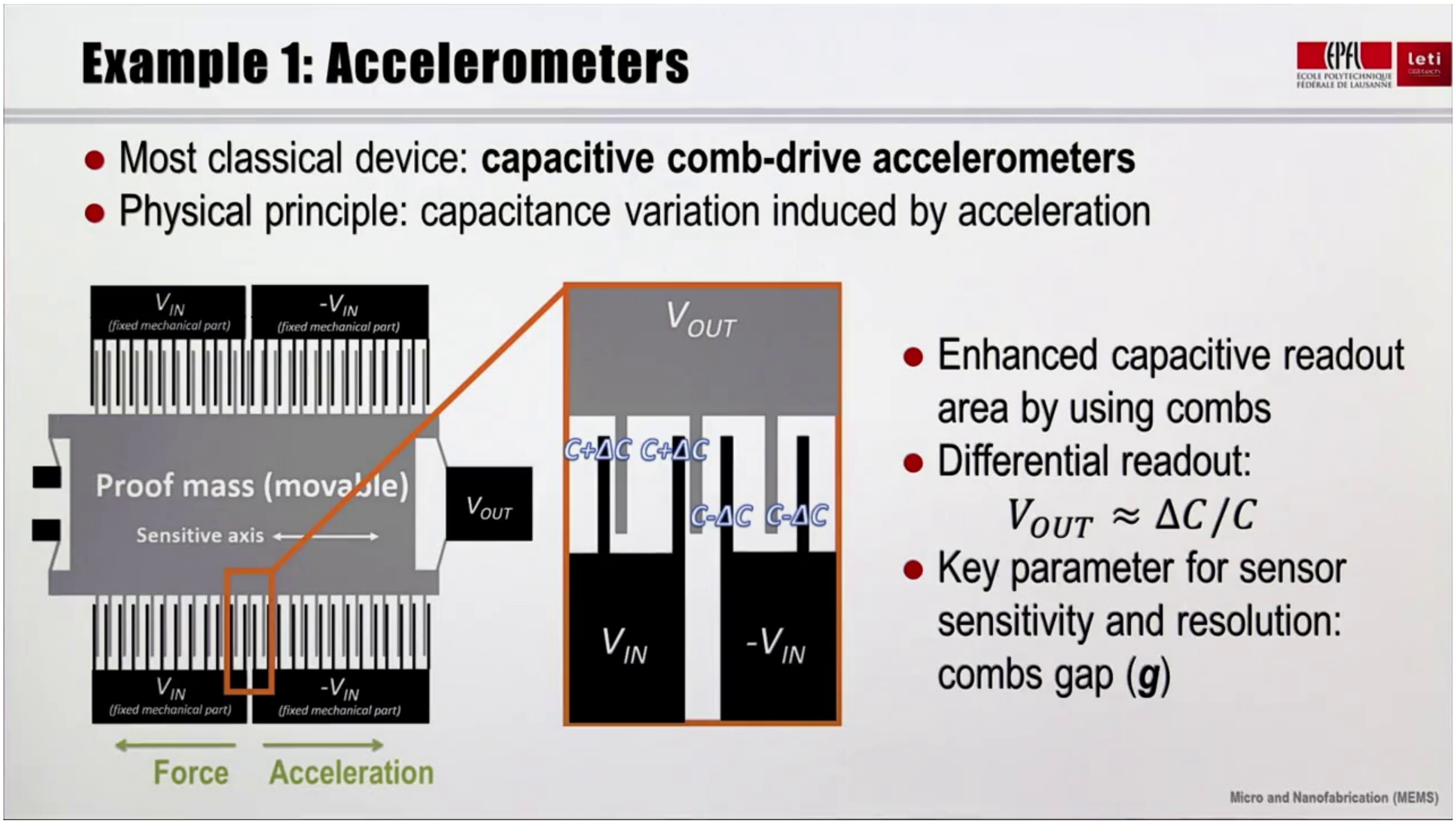
So maybe not everyone has noticed yet but MEMS have become ubiquitous in our daily life. One example is a multiplicity of MEMS devices inside smartphones. This scheme depicts a tear down view of the iPhone 6 and the various MEMS devices present inside it. In this lesson, I would like to focus on 3 applications. First accelerometers, so acceleration sensors. Second, microphones Third, BAW resonators and filters BAW stands for Bulk Acoustic Wave Resonators.



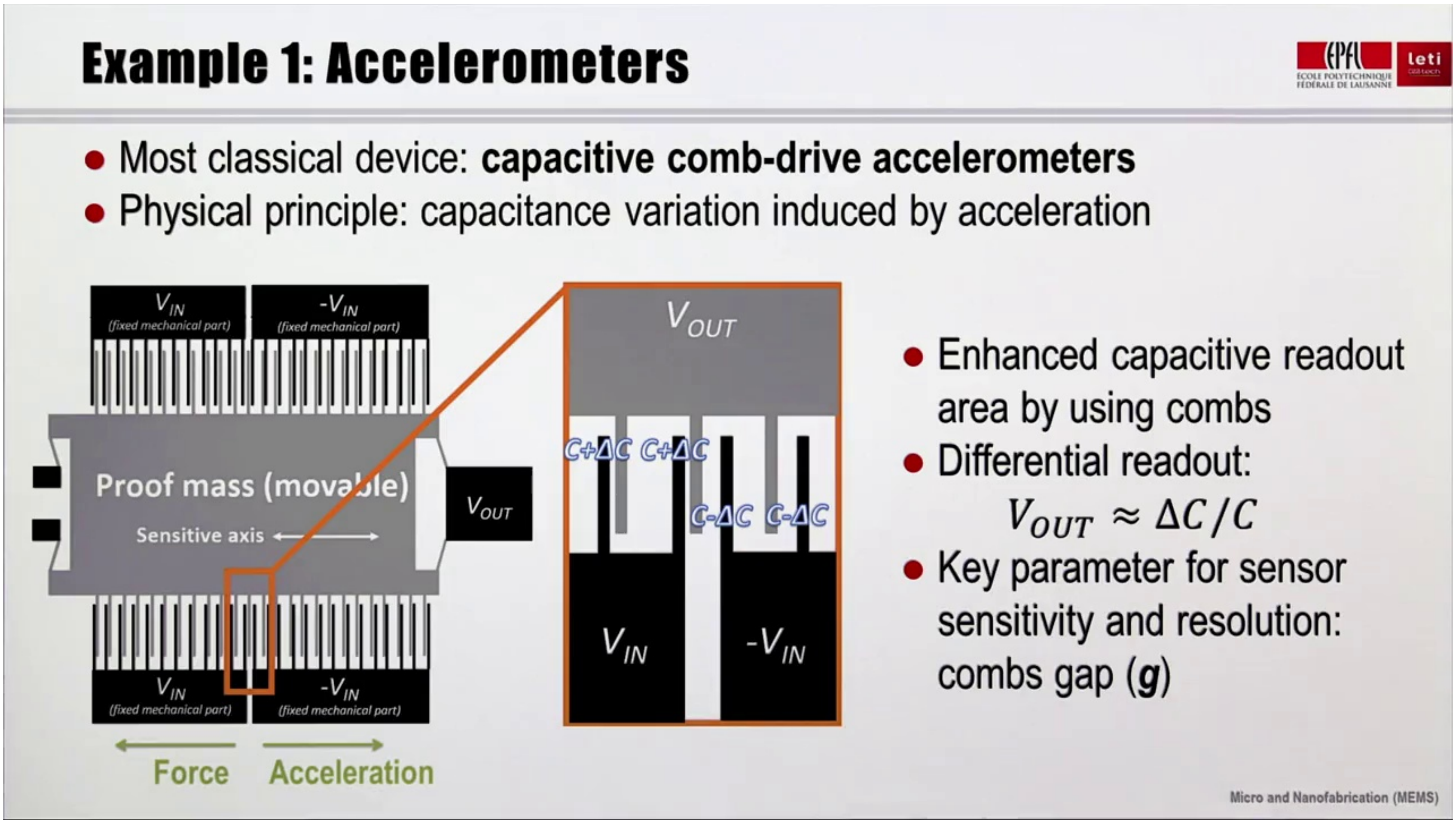
Let's start with the accelerometers. Technically speaking, the most classical device is a capacitive comb-drive accelerometer with electrostatic actuation and capacitive detection by means of a set of lateral combs. The physical principle is rather simple. This sensor detects a capacitance variation induced by an acceleration. Let's illustrate how this device works. This scheme depicts a top view of a proof mass, which is sensitive to accelerations along the x-axis. This proof mass acts as an inertial mass. It can move laterally and is anchored in 4 points. In this picture, the movable suspended parts are in grey, the anchored or fixed ones are in black. Typically a proof mass is between 100 and 200 microns wide and long. This proof mass is equipped with a set of lateral comb fingers. They all have an opposite and mechanically fixed comb finger.



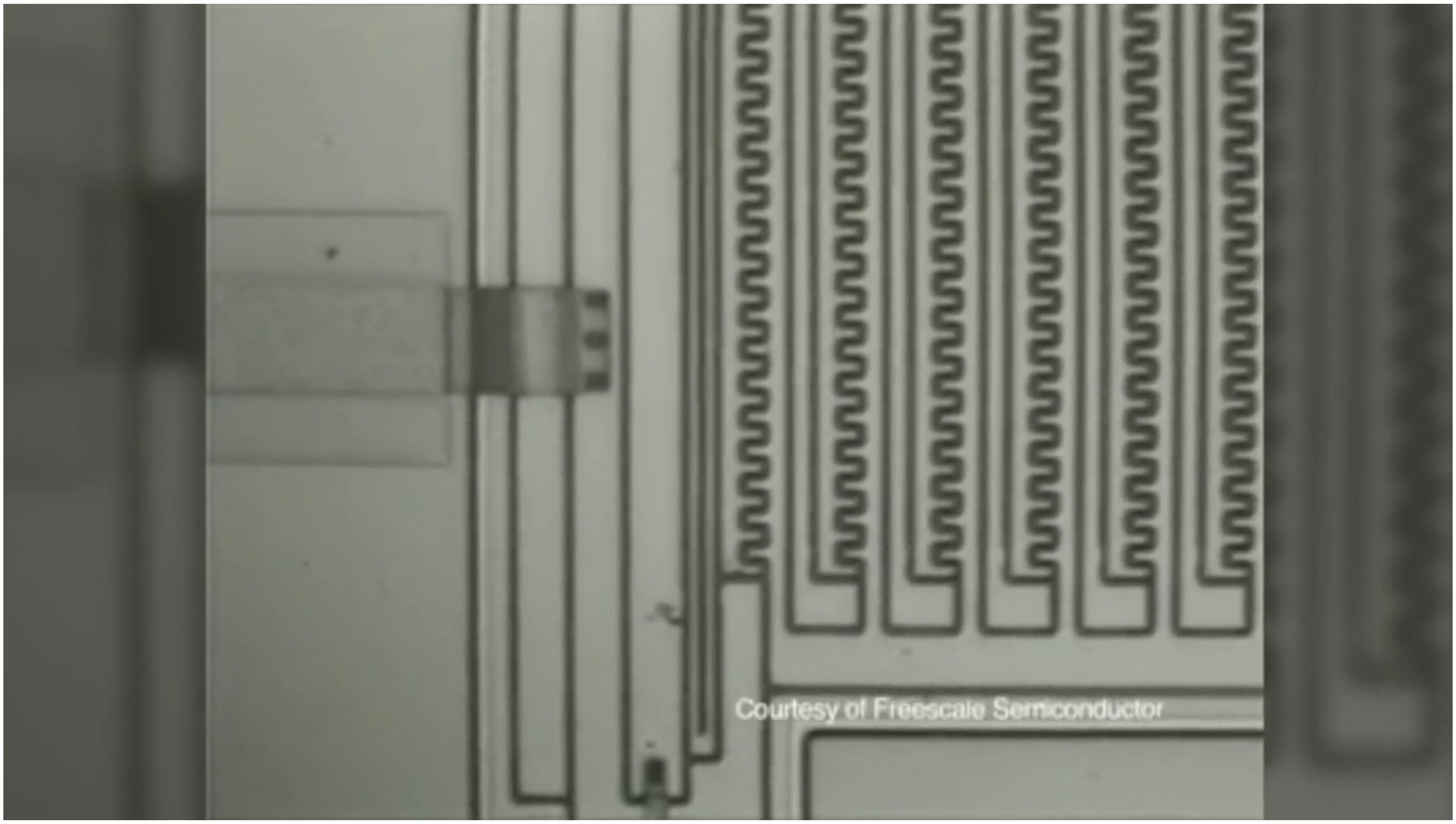
The fact of using combs provides a larger capacitive area which turns into an enhanced capacitive readout. Let's zoom in on a few fingers. In this example, 4 capacitors are depicted. Always a capacitance C, and a gap G. The 2 ones on the left are polarized at plus V IN. The 2 others at minus V IN. Let's suppose for example an acceleration towards the right side.



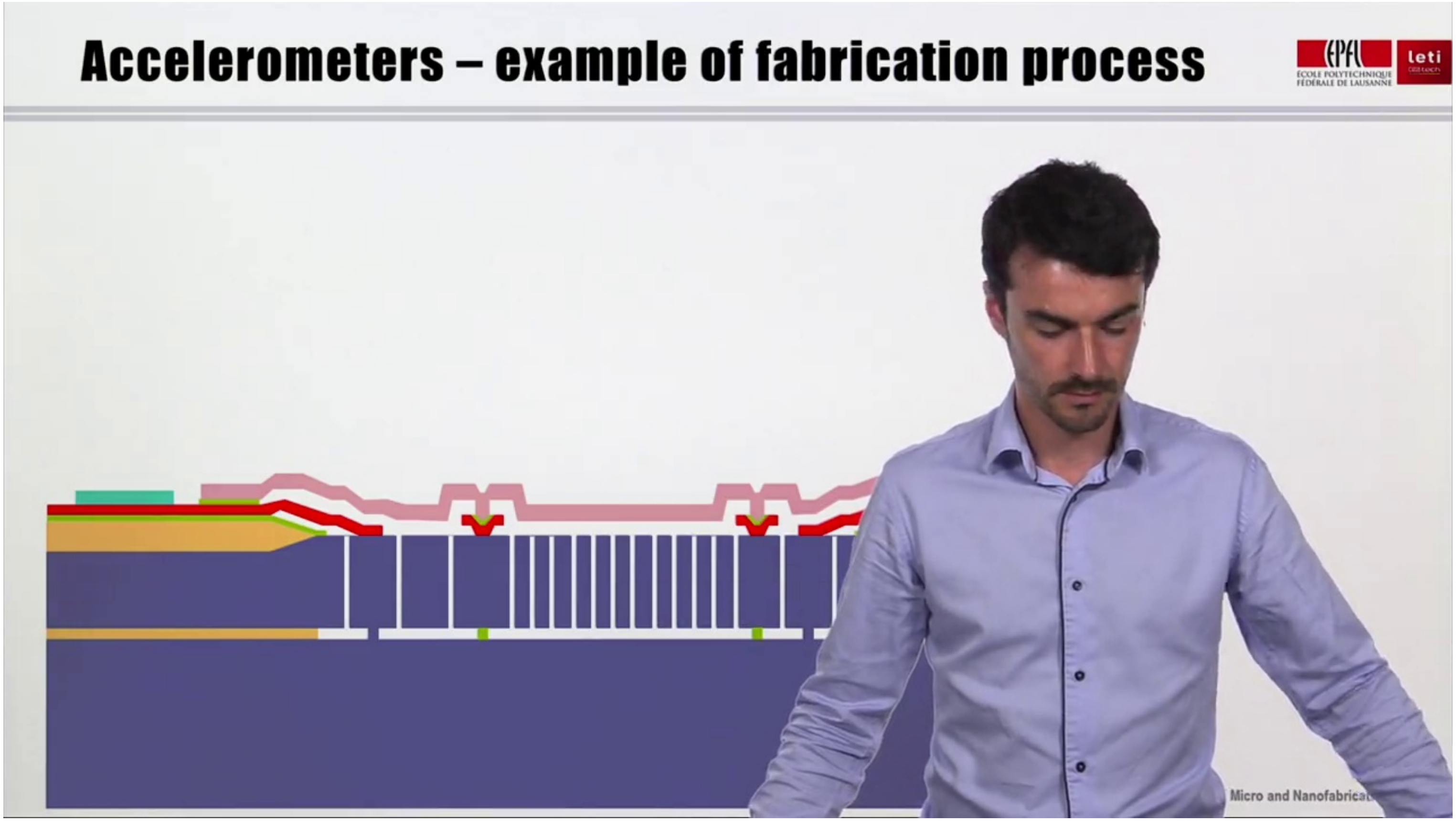
It induces a counter force towards the left which makes the proof mass and its combs move towards the left too.



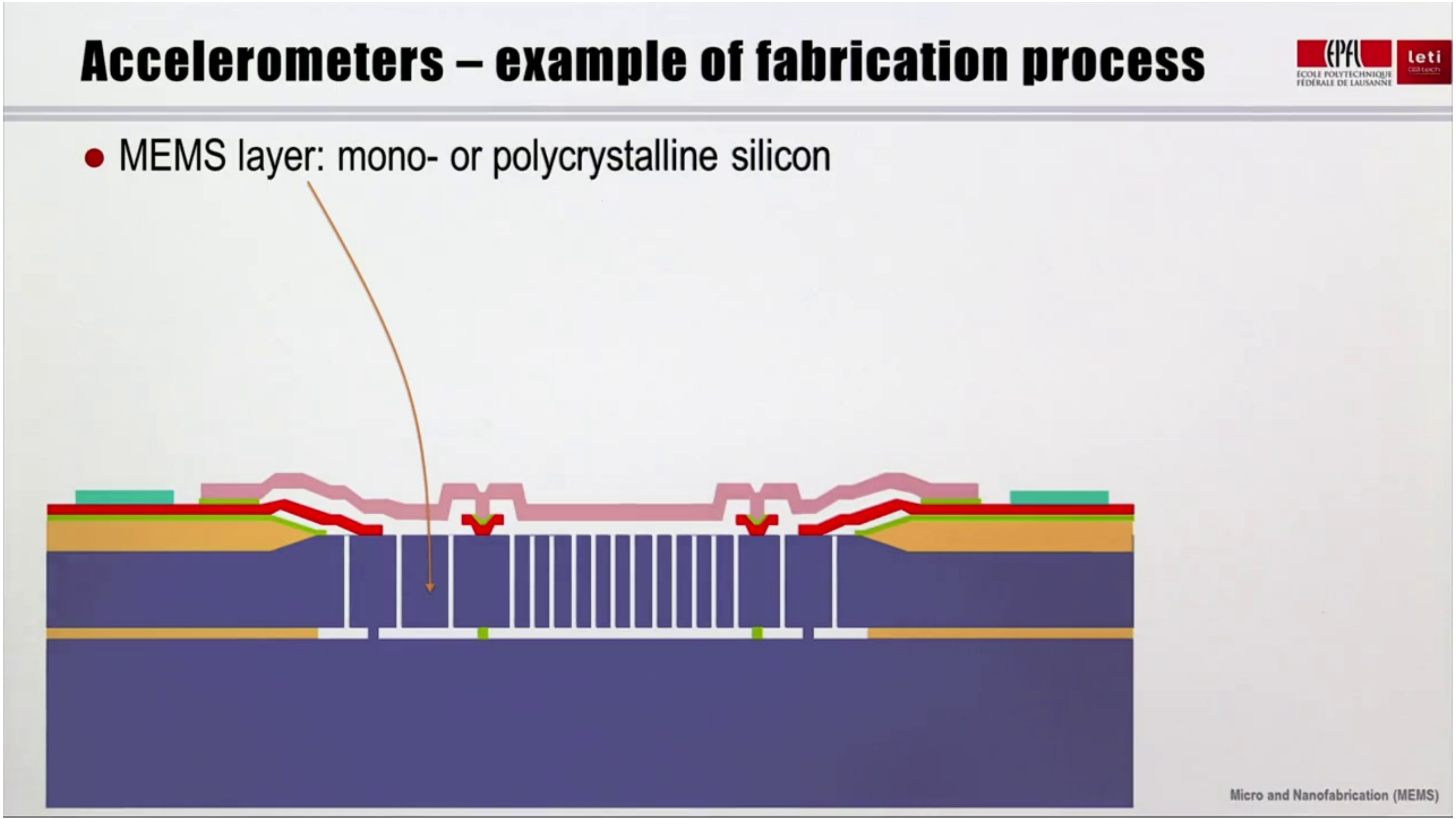
So let's show it again. Consequently as the gap narrows, the capacitance of the 2 left capacitors becomes C plus delta C. The capacitance of the 2 right ones becomes C minus delta C as the gap widens. Overall, this provides a differential readout and the output voltage is approximately equal to delta C over C. The key parameter in terms of sensitivity and resolution, also named ”limit of detection”, is a gap G which must be minimized as much as possible. It is generally in the range of 1 micron.



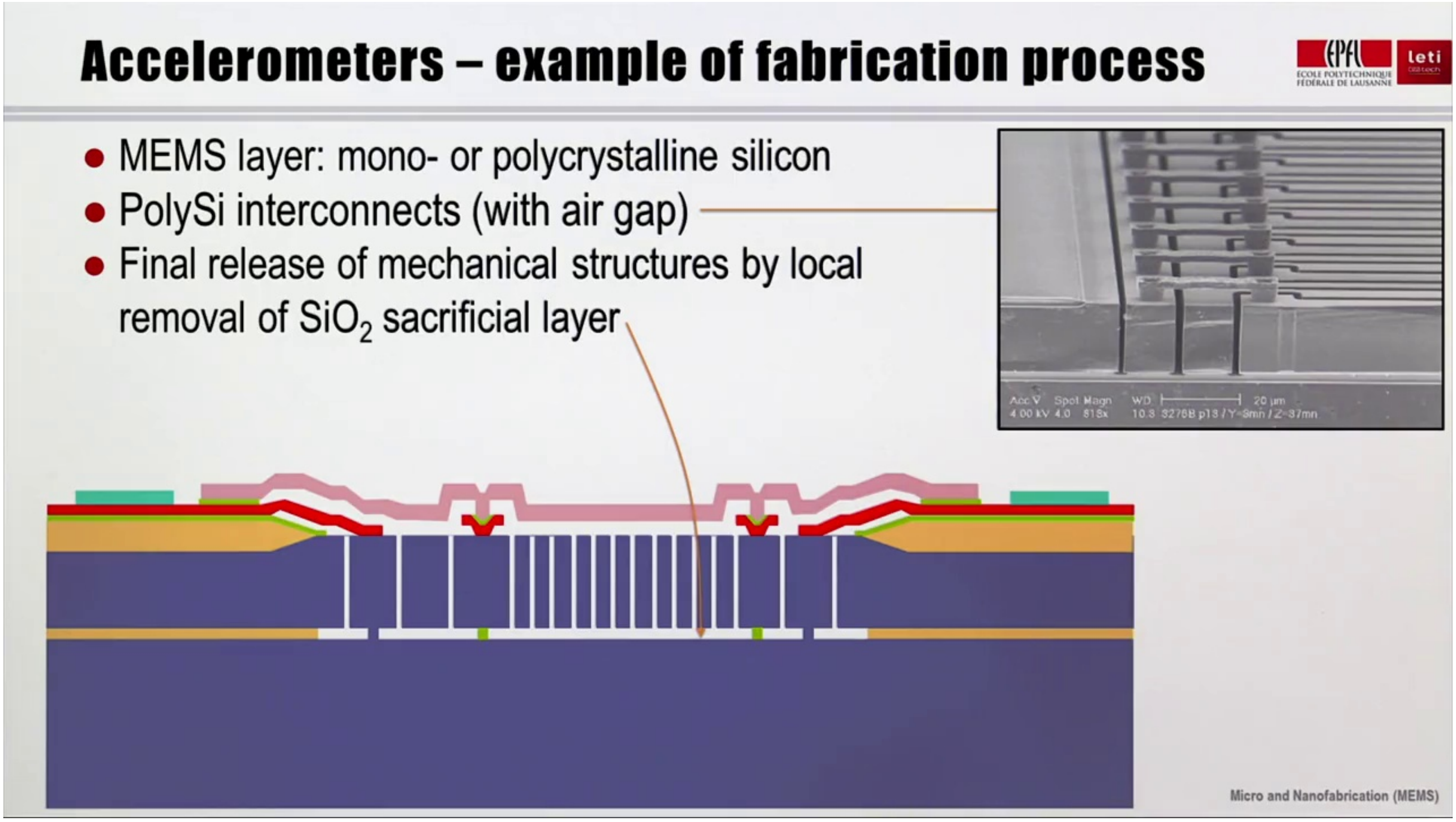
This video is recorded inside a scanning electron microscope. So the images here are recorded with an increasing zoom. Here you can see the polysilicon structures, with the moving parts, in particular the combs moving in front of the reference electrodes. So the motion is the combination of the electrostatic attraction and the restoring force of the springs. Basically here the motion is in the range of a few microns, naturally. This is just an example of layout



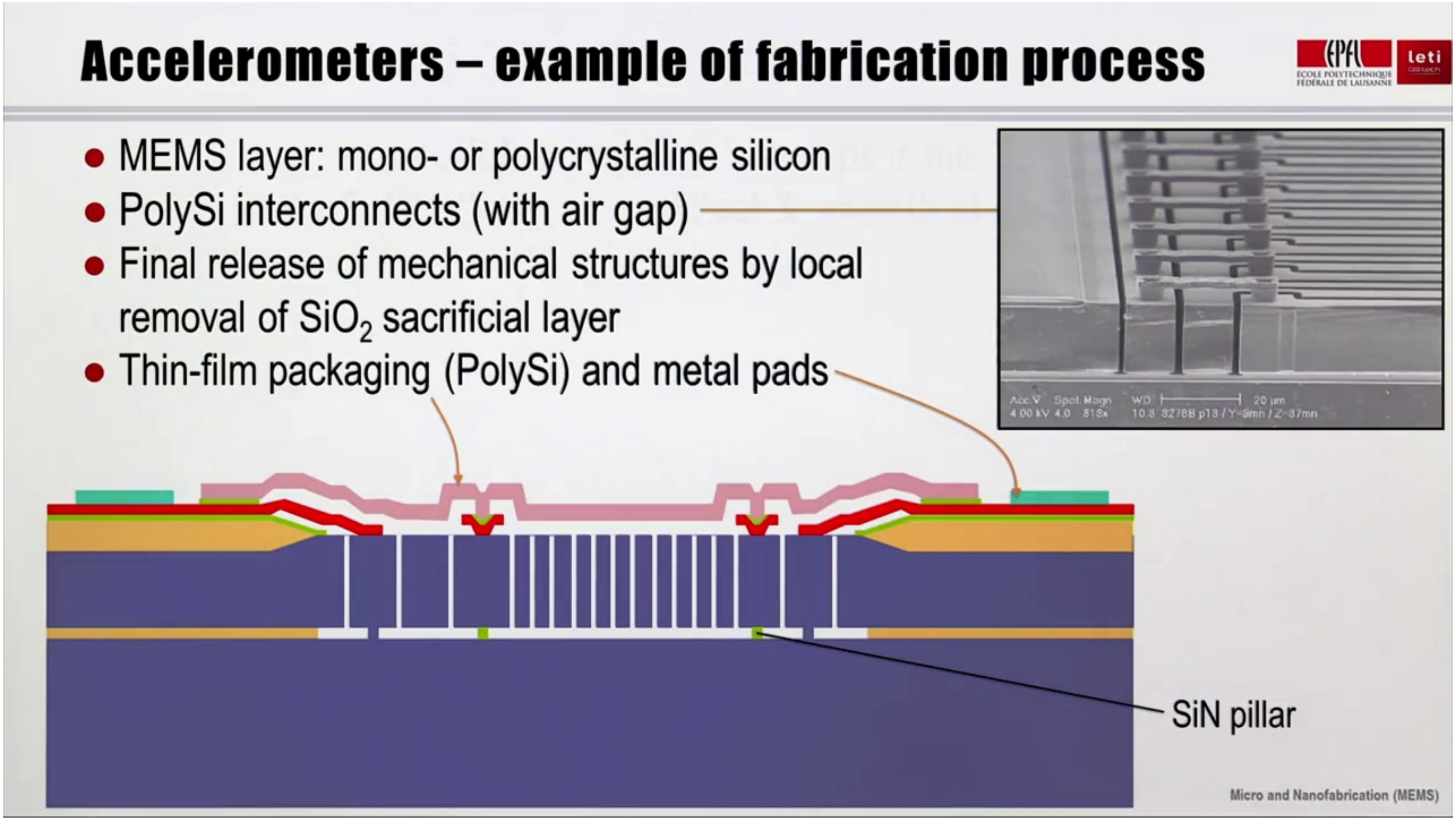
but of course, many designs are possible to make the same function. Let's take an example of fabrication process of such capacitive accelerometers. This scheme depicts a cross sectional view at the end of the process.



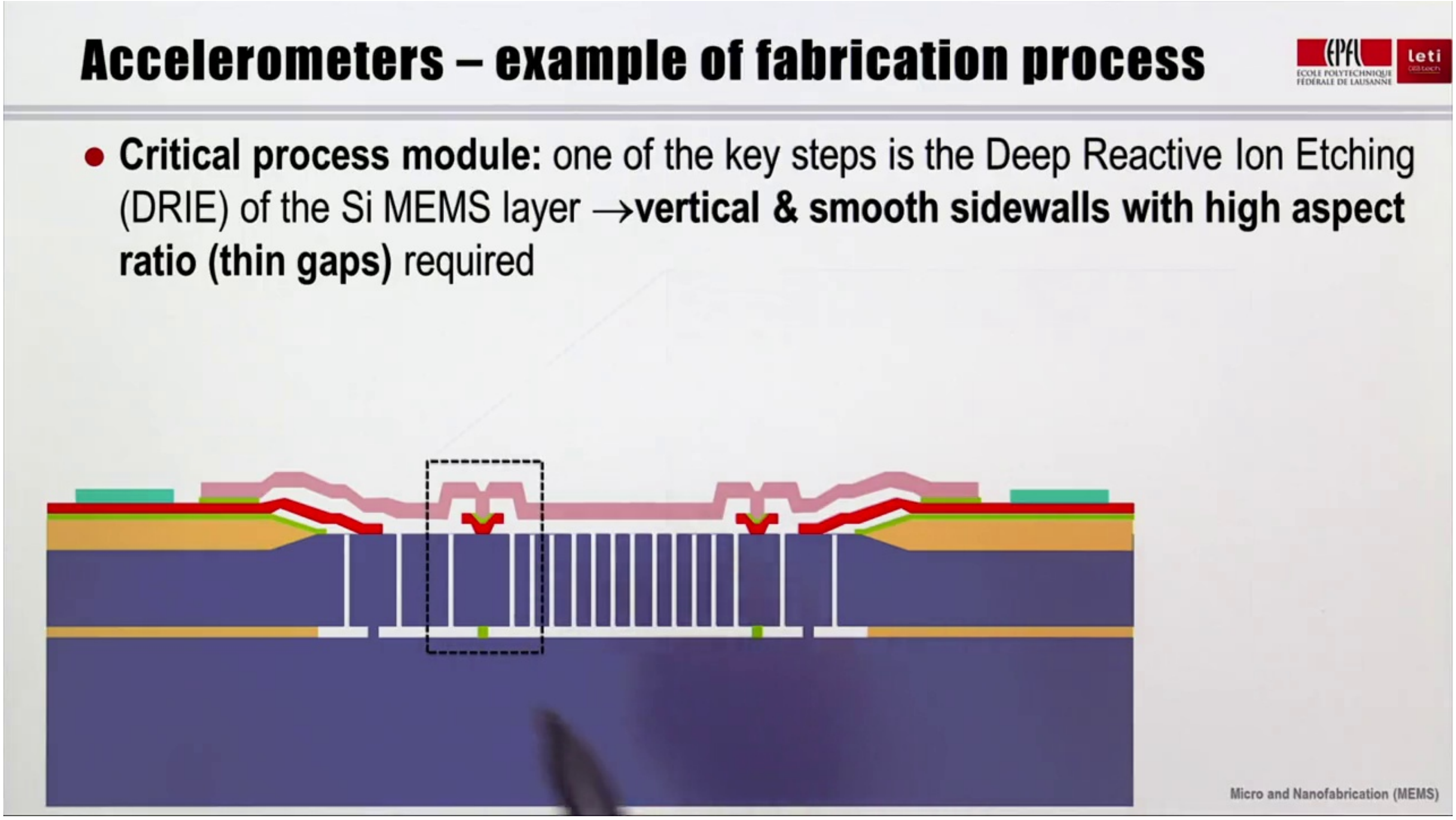
The MEMS layer can be either a monocrystalline silicon layer, if an SOI substrate is used, or a polycrystalline silicon layer, also named ”polysilicon”.



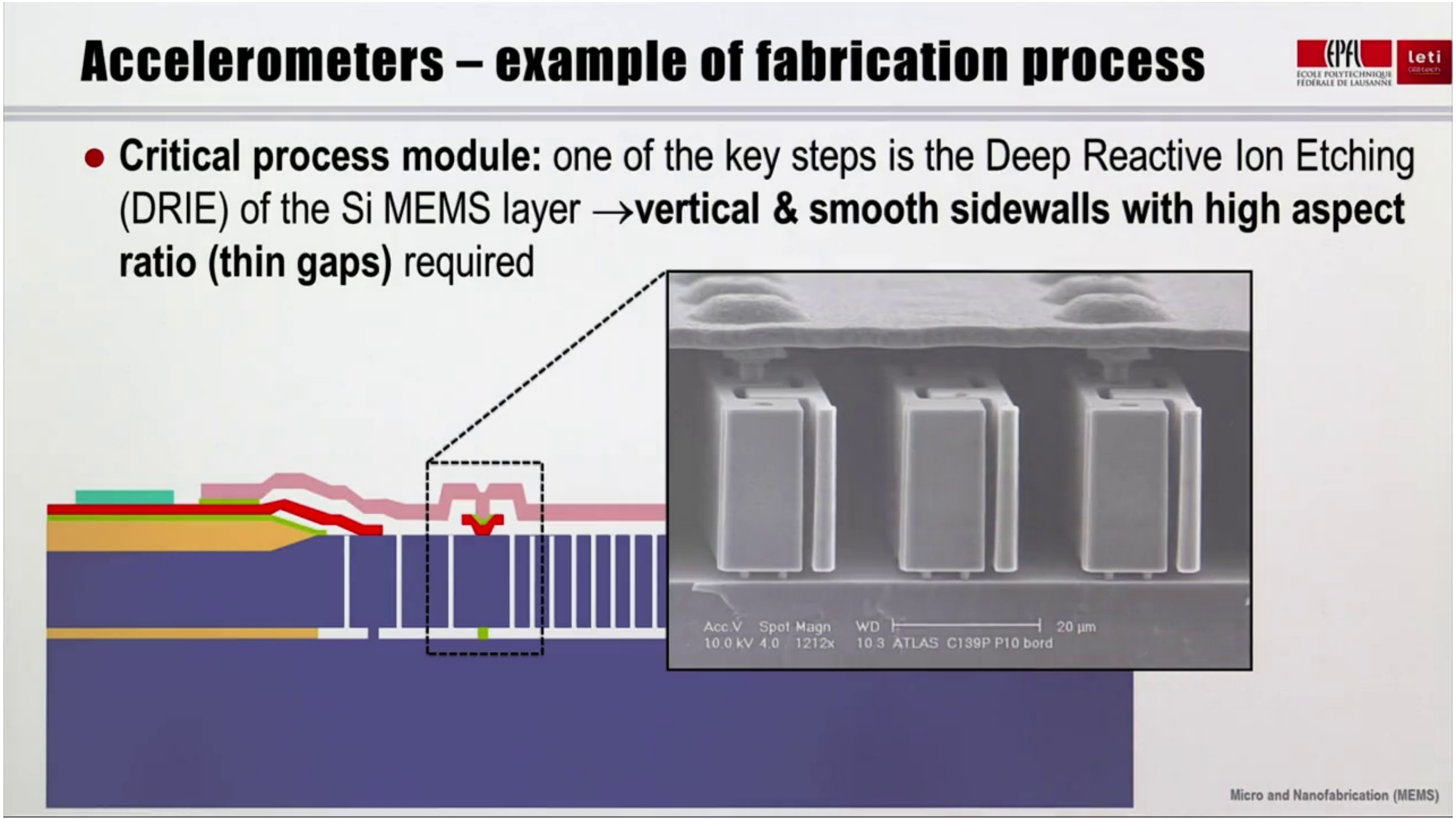
The routing of the mechanical structures is made with partially suspended polysilicon interconnects. the mechanical structures are released by removing the underlying silicon oxide sacrificial layer by wet or vapor HF etching. HF stands for hydrofluoric acid.



The MEMS active parts are encapsulated by a polysilicon thin-film packaging which provides an hermetic cavity at ambient pressure protecting the MEMS from moisture, humidity and dust. The input and output signals are brought and picked up through metal pads, here for example. Or here. Let's also mention that some silicon structures are on top of silicon nitride pillars, in order to electrically isolate them from the substrate.

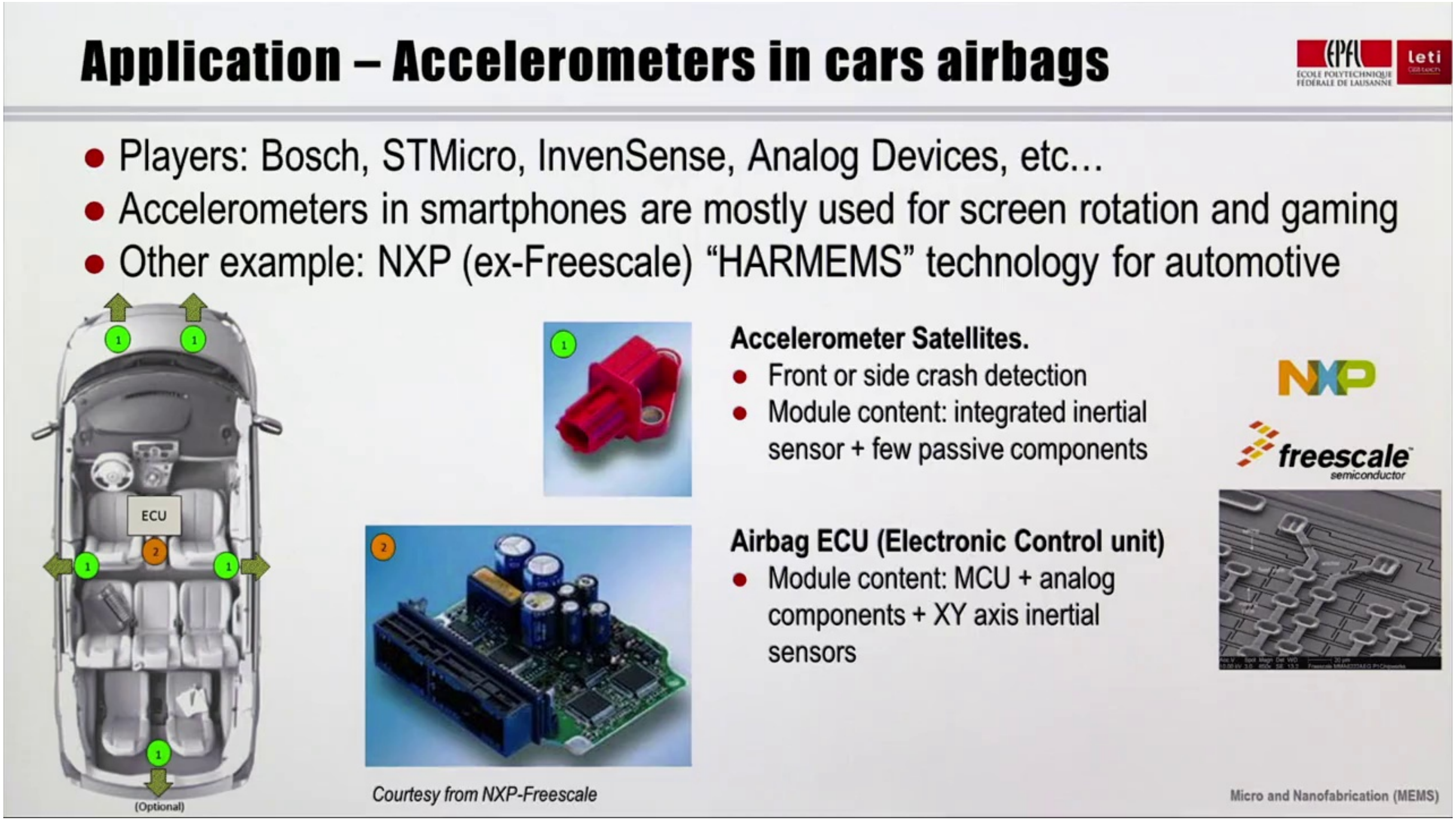


One of the key steps is the Deep Reactive Ion Etching, abbreviated as DRIE, of the silicon MEMS layer. This etching has to provide vertical and smooth side walls with a high aspect ratio of at least 20. The thicker a silicon MEMS layer, the wider is the gap due to the maximum affordable aspect ratio. Typically, the silicon MEMS layer is around 20 microns thick and the gap is around 1 micron wide. Let's zoom on a particular area.



This scanning electron microscope, abbreviated as SEM, image depicts a set of movable and fixed comb fingers. They feature all the necessary characteristics I mention. They have vertical and smooth side walls and small gaps.

So let's talk about application now. First, which MEMS companies sell these kinds of devices? Let's cite Bosch, STMicro Electronics, InvenSense, Analog Devices, etc. As I mentioned before, accelerometers are present inside smartphones, in particular for screen rotation and for gaming.



I like to mention another use case. Inertial MEMS are also widely used in automotive for various purposes. Let's take the example of NXP's HARMEMS technology. Such accelerometers are implemented to detect front or side crash in order to trigger airbags. In the left picture, the car contains 5 so called accelerometer satellites or modules. At the center of the car, an airbag electronic control unit, ECU, also senses crashes and triggers airbags.