Fabrication Techniques for Mems-based Sensors: Clinical Perspective

Prof. Hardik J Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

Lecture - 11
Micromachanics

Hi, welcome to this particular class. This would be series of modules that you need to go through and the idea is to explain the importance of Micromachining. Now, when we talk about MEMS, what exactly MEMS are? MEMS are Micro Electro Mechanical Systems right. So, electronics when we design electronics using micro technology, we can understand what is a mechanical right? Micro Electro Mechanical, why various mechanical things comes into picture?

So, if you know right we perform machining in a mechanical workshop right, we have seen we use a lathe machine, we use the drilling machine and we work from machining right. So, you take a material, you as the material right, you can form some something similar to etching of this particular material right. So, you can we can create this machining in a in a bigger surface, a bigger area. What about you want to perform machining in a smaller dimension, in a micro dimension that will be your Micro Machining right; machining at a micron skilled, Micro Machining

So, let us learn and let us see why this machining knowledge is very important for us to understand and how we can use it to fabricate some sensors right. So, when you talk about machining there are two types of machining; one is Bulk machining and second is Surface machining; so, Bulk Micro machining, Surface Micro machining. So, let us see what exactly bulk micromachining is and then, we will see what is surface micromachining and then, bulk plus surface micromachining and we will take few examples right. So, let us see what is Micro machining?

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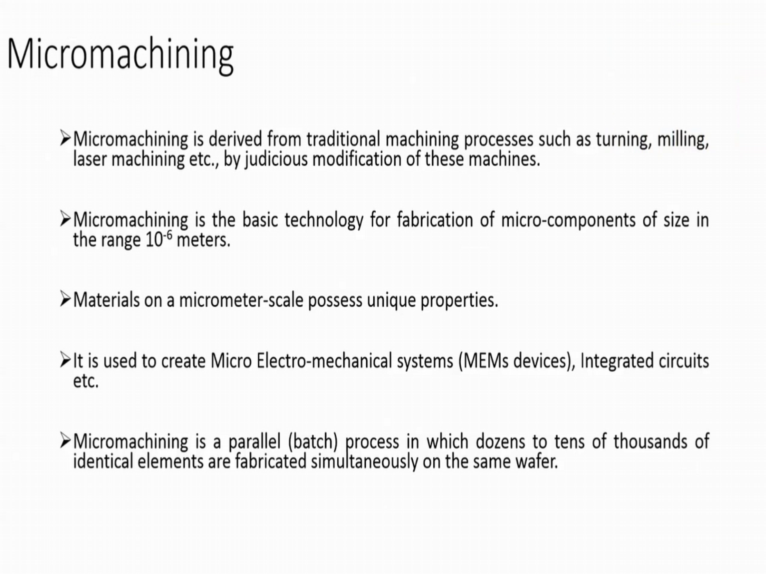

Micromachining is derived from a traditional machining process like I said such as turning, milling, laser machining etcetera, by judicious modification of these machines alright. Then, Micro machining is the basic technology for fabrication of micro-components, micro, what does micro means? 10 to the power minus 6 of a meter micrometer right, components of size in the range of 10 to the power minus 6 meters.

Materials on a micrometer-scale possess unique properties. Micro machining process is used to fabricate MEMS based devices, Integrated circuits etcetera. Also micro machining is a parallel that is batch process in which dozens to tens of thousands of identical elements are fabricated simultaneously on the same wafer right. So, if you see the machining technology, then you will understand that we can have a batch processing where thousands of identical elements can be fabricated on a single wafer at one time that is simultaneously.

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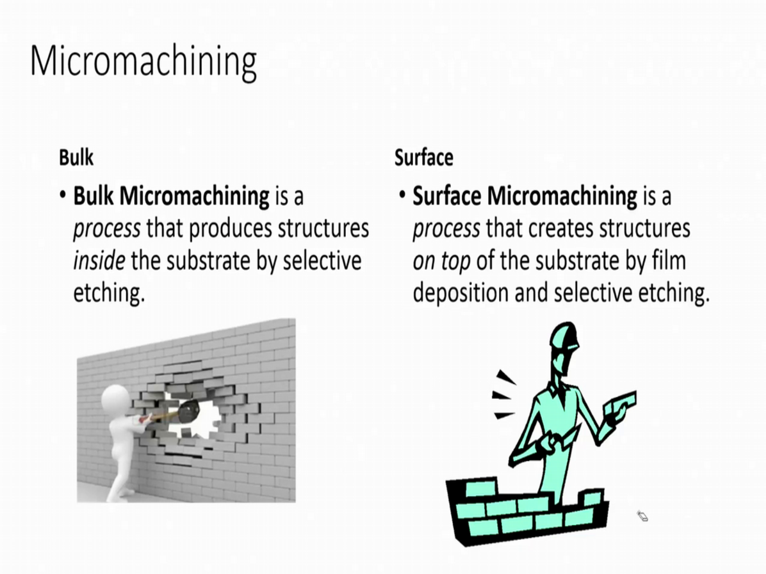

So, now let us further see Bulk and Surface Micromachining right, Bulk and Surface Micromachining. Bulk Micromachining is a process that produces structure inside the substrate by selective etching. You see he is only etching this part right; he is only breaking this part. These parts are intact, remaining parts are intact.

So, selectively breaking something or etching something right within a substrate, we can we can define as a Bulk Micromachining right. We will see a better example. While, in case of a Surface Micromachining, this is a process that creates structure on the top of the substrate by film deposition and selective etching right. We can deposit a film and selectively etch the film. So, there is a fundamental difference as we can see between Bulk Micromachining and Surface Micromachining technologies.

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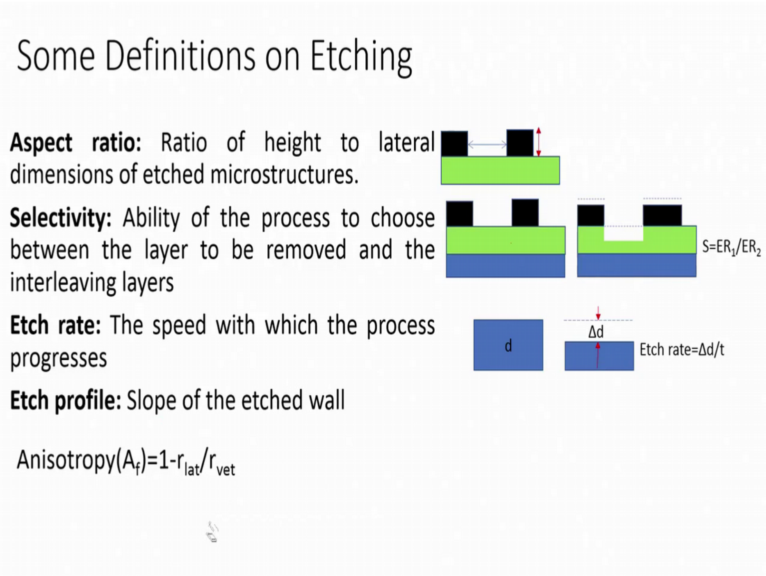

So, let us understand very important definitions on Etching. You can say parameters; you can say properties right; what are these properties? First property is Aspect ratio, what is Aspect ratio? Ratio of height to lateral dimensions of the etched microstructure. You can see here right, height to lateral dimension is an Aspect ratio; Ratio of high to lateral dimension of etched microstructures.

Second is Selectivity. What is Selectivity? Selectivity is the ability of the process to choose between the layer to be removed and interleaving layers. So, if you see in this particular case right, if you see this example right, in this example what we are doing? We are selectively etching only the surface, only the surface; you can see here right. This etched this green section is etched without affecting any black section, without affecting the black section we are selectively etching this area. This is the Selectivity, selectivity ok.

Next, what is next? Next is Etch rate. Etch rate is the speed with which the process progresses. Suppose, I want to I have a silicon dioxide; let me just try it once again ok. I have an oxidized silicon wafer, what is the oxidized silicon wafer; Silicon, Silicon dioxide, Silicon dioxide right. Now, using photolithography, I have created a window and etch silicon dioxide right. Now I want to etch Silicon. So, how fast I can etch silicon is my etch rate right.

So, I have we know that for etching silicon using wet etching, chemical etching, we have potassium hydroxide and we have TMAH right and if you remember potassium hydroxide, we perform etching at 80 degree centigrade TMAH at 25 degree centigrade. KOH is faster etching. TMAH is slower etching. KOH, the surface reference is poor right, surface reference is poor. TMAH surface is smoother; so better right. This is coarser; this is smoother. This smooth, this is rough right; everyone takes it as disadvantages.

Now, one thing that we have seen is the Etch rate for KOH is higher; that means, the silicon can be etched faster that is what etch rate means; that is what etch rate means right. Now when I am dipping this wafer in KOH or TMAH, only silicon will get etch and silicon dioxide will not get affected. Silicon dioxide will not get affected. So, silicon dioxide is not affect getting affected and only silicon is getting etch that is our Selectivity right. So, I just quickly wanted to show you an example.

Now, next would be Etch profile. What is Etch profile? Slope of the etched wall; slope of the etched wall and it is nothing but etch rate 1 by etch rate 2. Also Anisotropy, what is Anisotropy? Anisotropy is 1 minus r later divide by r vertical; rate of later etching divide by rate of vertically etching right. So, these are some of the definitions when we are talking about etching right. Etching like I said very important and you can create several structures using Bulk Micromachining and Surface Micromachining.

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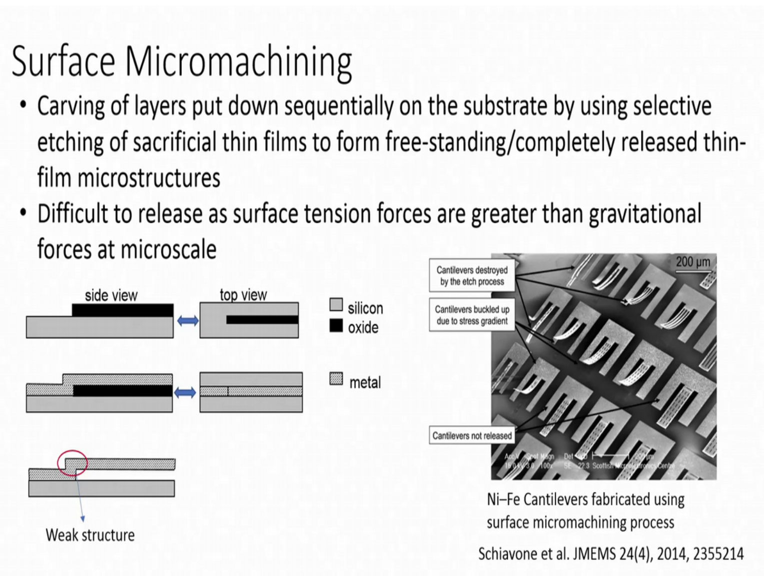

So, let us see what kind of structures, we can design or we can fabricate using Surface Micromachining? So, you can see here, this is an example of Surface Micromachining and if you see this example the gray colour is silicon and black colour is oxide. If you see the side view right, we have oxide on silicon.

Now we are depositing a metal, we are depositing metal and then, we are etching oxide; we are etching oxide, what will happen? We will have a cantilever right. We will have cantilever of what? We will have cantilever of metal right.

So, this is how we can create a cantilever. Now, Carving of layers put down sequentially on the substrate by using selective etching of sacrificial thin films to form freestanding completely released in film micro structures; that is wall surface micromachining does right.

What it does? Carving lay of layers put down sequentially on substrate. You see here, we have silicon dioxide and silicon, we deposited a metal right and then, we have etched the silicon dioxide. So, silicon dioxide here would be a sacrificial layer. It will sacrifice itself, sacrificial layer.

So, when I sacrifice silicon dioxide by etching silicon dioxide in buffer hydrofluoric acid, what I will have? I will have a cantilever made up of a metal. Next is it is difficult to release a surface tension forces are greater than gravitational forces at micro scale. So, at micro scale you should understand that the gravitational forces are less compared to surface tension forces and that is why it is difficult to release Cantilevers.

Now, you can see here, there is a nickel iron cantilever fabricated using surface micromachining process and you can see multiple cantilevers the author has tried to fabricate right. Some are really beautiful; you can see here, it is a perfect example of how Cantilever can be released. Some have the curvature right, some are not released.

So, you can see here cantilevers which are released are this cantilevers, but they are buckled up right. This cantilever in particular is not released because otherwise, it will come up. So, this container is not released. This one is released again buckled up right, same way this cantilever is not released right. So, it is difficult to release the cantilever like I said because surface tension forces are greater than gravitational forces.

However, if you see that there are few cantilever that were destroyed during the fabrication process, few cantilevers their quad buckled up because of the stress in the metal film right. However, you can get if you optimize the parameter, you can get excellently released cantilevers right. I will show you an example of how to release a cantilever, but using a bulk micromachining process in the in the following slides.

The point is using surface micromachining, we can easily fabricate a structure; but then, we need to optimize the parameter otherwise because of the surface tension being higher or greater than gravitational force the, it is very difficult to release the structure in a proper fashion right. So, when you see now, if you go back to the slide, what you will see?

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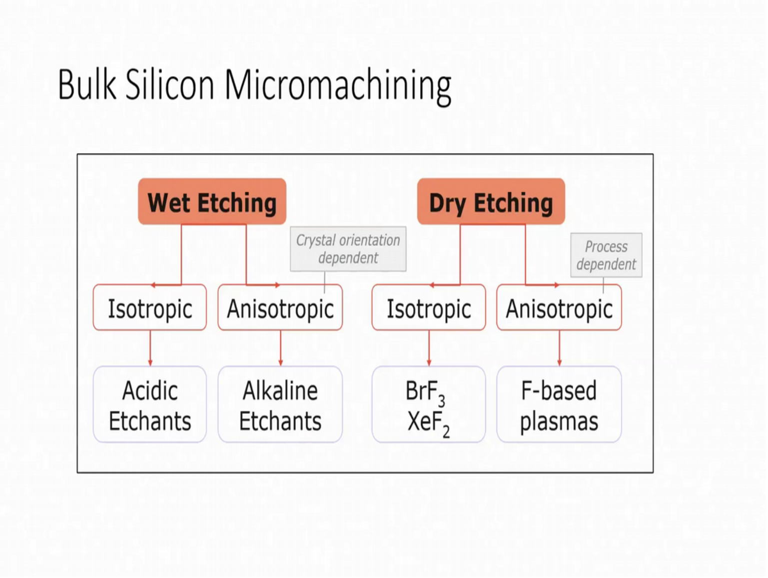

There is a Bulk Silicon Micromachining right; Bulk Silicon Micromachining. So, in Bulk Silicon Micromachining, we will see two kind of etching; one is a Wet Etching and another one is Dry Etching alright. One is Wet Etching another one is Dry Etching.

Now, in Wet Etching there is Isotropic etching and Anisotropic etching. Similarly in Dry Etching, there is Isotropic etching and there is Anisotropic etching. Now Dry Etching Anisotropic property depends on the Process; while in case of Wet Etching the Anisotropic is dependent on Crystal orientation.

Now, the feed is Acidic Etchants, then we will generally get Isotropic; while if it is Alkaline, will get Anisotropic. In the case of F-based plasma, we will get Anisotropic, while this is the case of dry etching while we have BrF 3 or XcF 2, we can get Isotropic etching.

So, DRI is a Deep Reactive Ion etching is a example of dry etching and dry etching is also commonly known as Plasma etching because we are generating a plasma and the electron energy in the plasma creates a very high temperature; but the oral process it has is at low temperature.

So, the gases will etch the silicon and for silicon, we use generally C4F8 and SF6; while we also use helium and oxygen in case of the deep reactive energy. We will see a video of how deep reactive NHR can be used from STS.

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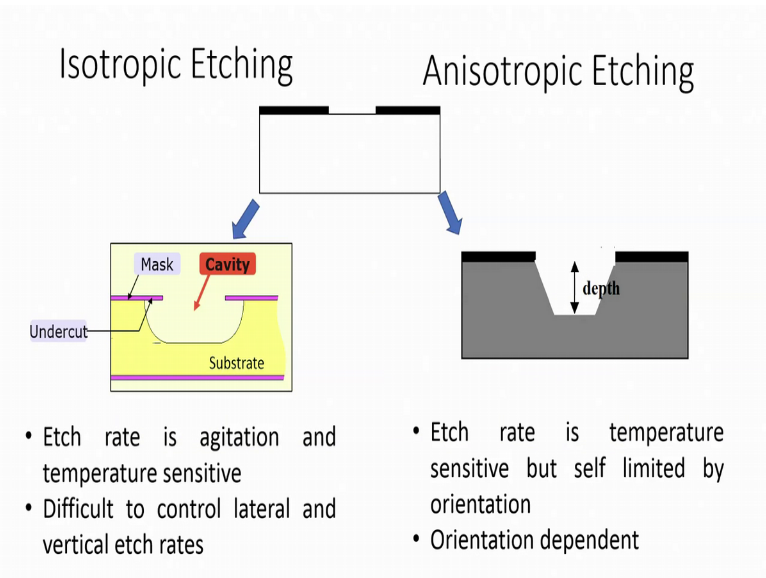

So, the one of the big problem in the isotropic in the etching world is the undercut problem right. So, you can see here isotropic etching and anisotropic etching. So, if we if this is the window, we want to etch this window. Then etch rate is agitation and temperature sensitive. So, here it will be temperature sensitive and depending on the chemical, difficult to control lateral and vertical etch rates right.

This and this very difficult to control lateral and vertical etch rates very difficult to control. While in the case of anisotropic etching, etch rate is temperature sensitive; but self limited by its orientation and of course, it is orientation dependent; it is orientation dependent. So, this is about the isotropic and anisotropic etching.

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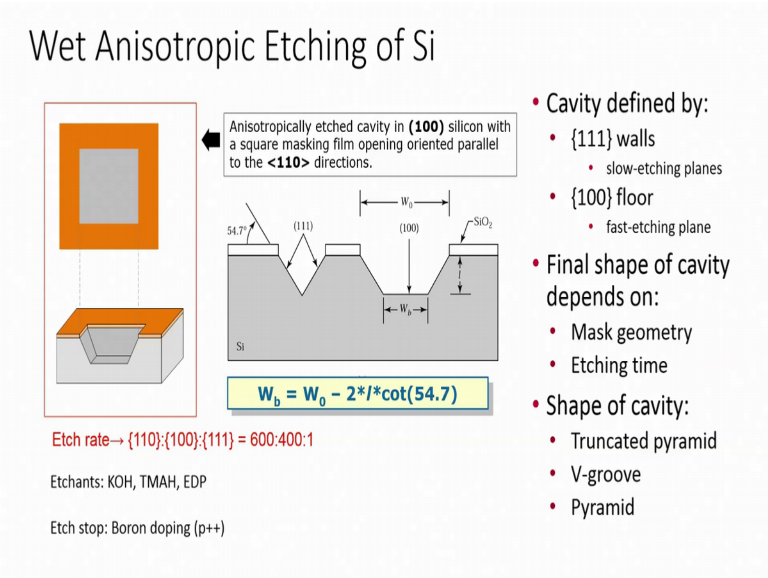

Now, when we are talking about isotropic and anisotropic etching, let us talk about Wet Anisotropic Etching, Wet Anisotropic Etching ok. So, you can see here that anisotropically etched cavity in 100 Silicon with a square mask film opening oriented parallel to the 100 direction right.

So, when we want to etch, we have to take this the etch rate is defined in this particular fashion, where the 110 is to 100 is to 111. As you can see 111, will not get etched compared to 100 and 110 right. So, the cavity defined walls 111 walls slow etching planes; while 100 which is floor right. This one is slow etching plane, by the floor which is 100 is a fast etching plane; the floor is faster the cavity walls would be slow because of the 111 crystal orientation.

If you want to see this is what is the final depth the that you are you are etching right that you want to see, then you need to calculate what is the final depth that you want and depending on that you have to open the window which is Wo.

So, if I say the opening of the window is W o, the final depth this one; this width right. This one, this will be my W b. Initial window that I had to opened is W o. How is related? So, W b equals to W o minus 2 into I into cot theta, where, cot theta is nothing but 54.7 degree. So, when you want to etch it right, the etching is done, wet etching is wet etching of silicon it creates an angle of 54.7 degree.

Now, you can we I said I, but you can say L or I, it is a length, it is a length. Of course, the silicon dioxide will act as a mask. So, when you dip this wafer in the KOH or TMAH, the silicon below silicon dioxide will not get etched. As you can see here or here right and if it is a 111 a wall creating plane, then you can see that you know it is low. But if it is 100 creating plane, it is faster. So, the opening of the window if I want a particular depth with a particular little etching, I need to know what is the initial opening of the window that I do create.

For example, if I have oxidized silicon wafer, if I create a window which is the my W o right. What would be my final etching W b? This W b can be calculated using this formula right. What is a depth that I want to etch; right what is the initial window that I will have and if I know the angle, then I can create, which is angle is 54.7 degree. I can create my w W o accordingly so that I can receive, I can achieve my W b of a particular dimension right.

Now, the final shape of the cavity also depends on geometry of the Mask and Etching time ok. So, a Etching time and geometry of the Mask are the another two factors that decides the final shape of the cavity. Also the same of the cavity can be V grew like a V grew; it can be a pyramid right or it can be a truncated pyramid. So, these 3 are the patterns that you can obtain, when you are etching a silicon wafer. V grew pyramid or a truncated pyramid.

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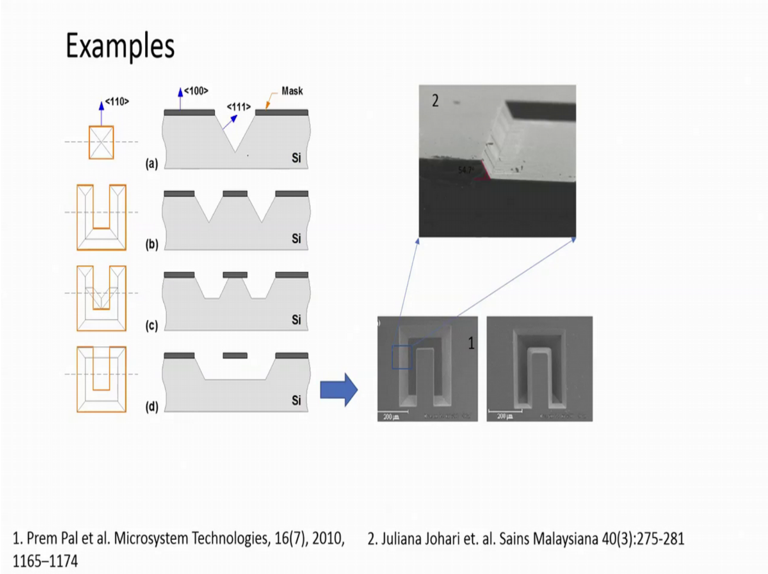

So, if you see the example here, you can see right V grew pyramid or truncated pyramid and these are cantilevers which are released, you can see here a completely released cantilever right and of course, this is taken from micro system technologies region by Prem Pal et al is just a schematic diagram. Also there is another paper that we have used from Johari J et al to get the idea of how the cantilever looks like, when it is released with the help of the etching technology right.

So, like I said we can have V grew, we can have truncated pyramid and we can have pyramid 3 types of structures, when we are using Micromachining.

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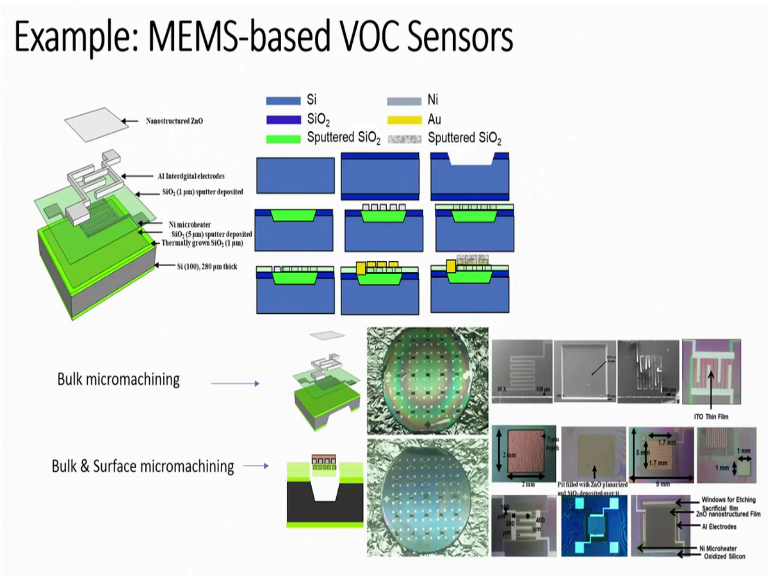

So, until now, what we have seen? We have seen that the micromachining can be 2 types; one is Bulk Micromachining; one is Surface Micromachining and then, we have seen how the Bulk Micromachining and Surface Micromachining can be used with the example of releasing a cantilever using Surface Micromachining.

Now, we will see an examples that is will be I will I will show you the examples in the next module of how to create volatile organic compounds based sensors using Bulk Micromachining and using Bulk plus Surface Micromachining right. Till then, you just go through this module; I will see you in the next module to discuss more about how to use micromachining technologies to create a device.

Yeah, till then take care. I will see in you in next class. Bye.