Introductory Neuroscience and Neuro Instrumentation
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Introduction to Cleanroom and IC Fabrication Techniques

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Hi, welcome to this module. As you already know, Dr. Mahesh has been discussing on various aspect of neuroscience including how the anatomy of a brain is, what are the EEG signals and how we can use those signals for several applications,

I will be taking few lectures, you can consider me as a TA for this course. So, what we need to learn in terms of instrumentation? Or in terms of designing electronic modules and why these electronic modules are required when we talk about neuroscience? And when we talk about neuroscience, that means you are talking about acquiring signal from brain, either it is EEG, which is electroencephalogram, where you take the or you record the neural activity through the scalp.

You understand what is going on inside your brain by recording ECoG, which is called electrocorticography. Electrocorticography is when the skull is opened and you are placing a chip on the brain to acquire the signal directly from the brain is called ECoG.

Now, let us see, how we can use the fabrication or micro fabrication for developing or designing these electrodes which can either be used for EEG or it can be used for measuring ECoG.

So, we will be discussing in this module the micro fabrication, what kind of sensors we can design with micro fabrication, including an example of EEG and we will be looking at the anatomy of a brain as a video at the end of this particular module.

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So if you see the slide, I am a professor here in Biomedical and Electronics Engineering Laboratory, I head this laboratory, and I also head the Advanced Micro System and Biomedical Device Facility for Clinical Research. I work with Department of Electronic Systems Engineering, which is in the division of EECS at Indian Institute of Science, Bangalore. So, like I said, I will be helping to cover the instrumentation part of this course.

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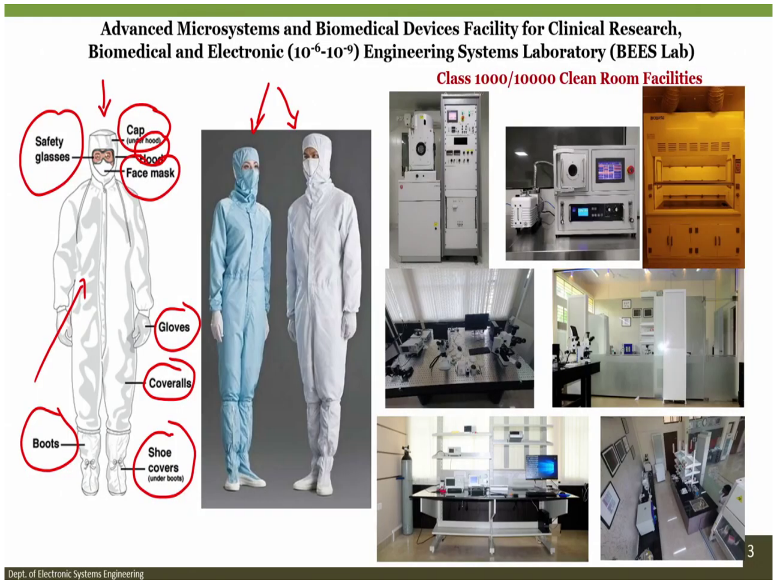

And when we talk about instrumentation, we want to see how we can fabricate the electrodes. So we will be talking about what kind of facilities you require to fabricate electrodes. And when we talk about electrodes, we will talk about the micro and nanotechnology that can be used to design such electrodes.

Now, what you see in this slide, like I said, I am heading 3 different laboratories, 2 laboratories some photographic images as shown here. The slide shows multiple photographs, if you see the one on the left, this is a gowning procedure or after a person gowns, before he or she enters into the lab. So, what are the different PPEs? PPEs is called Personal Protective Equipment.

One is we start from the head, there is a cap; second, safety glasses; third, hood; fourth, face mask; fifth gloves; sixth, coveralls, that means this whole gown coveralls; seventh boots; eight shoe cover, which are under the boots.

You can see here. So, why to cover like this? Are the bacteria inside the lab, are there viruses inside the lab? No, it is a clean room. So what are we protecting from? What are we protecting ourselves from the equipment? No. We are protecting the environment that means the clean room environment within the laboratory, because humans in this clean room are the source of contaminants.

So, what do you mean by that? If you have ever tried, I am sure that you may have tried already to see how your thumb taste. Have you tried? You will see that it is salty. What is the reason of this taste? Because there is NaCl. Same way there are other contaminants in our hands. If I touch the wafer, what is this wafer? It is a silicon wafer. What is silicon, we will look in the slides.

If I touch the wafer, these contaminants from my hand will transfer onto the wafer and this will kill lot of chips during fabrication. Additionally, to avoid falling of hair, avoid any contaminant from your shoes entering the laboratory, avoid any beard hair falling into the lab. When you sneeze, it should not contaminate the wafer and overall to protect and to conserve the environment within the lab. So that the silicon wafer or the substrate are not affected with the contaminants.

Thus, it is very important to wear this particular gown along with PPEs, it is called lab gown, is also called coveralls and this is used when a person wants to work inside a clean room or a nano fabrication facility.

Having said that, I will be talking about some of the equipment within the facility, but let us look at the slide and some of the equipment that we have in our department in my lab shown in the slide.

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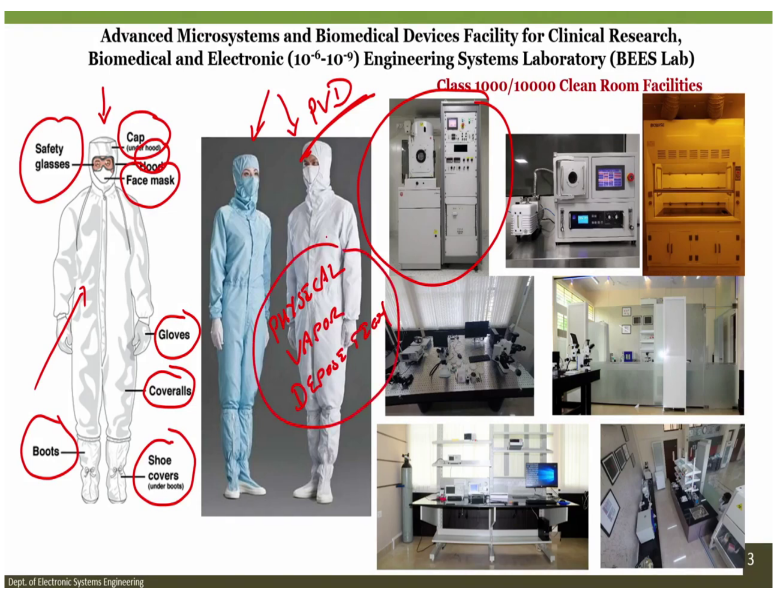

So, if you can see the slide the, this one is called thermal evaporation and it is also combined with electron beam evaporation. Now, we will discuss what is thermal evaporation, we will also discuss what is electron beam evaporation.

Both comes under PVD technique. What is PVD? Physical Vapor Deposition. We use this technique to deposit a thin film of metal semiconductor or insulator on to the substrate. We will discuss this technique in detail at some point of time.

We have oxygen bonding system or oxygen plasma system. This is used for bonding silicon with glass or is used for bonding PDMS with glass, this process is called anodic bonding or oxygen plasma bonding. Two different stuff, anodic bonding is when you mold silicone with glass; and oxygen plasma bonding is used when you want to bond PDMS with glass. The PDMS with glass is used for several applications and one of those is for micro fluidic devices.

Now, if you know the fabrication techniques, if you know the process and the equipment you can design several electrodes, several devices, several sensors, and our focus would be sensors that can be used for understanding or capturing the signal from the brain.

Fume hood is used in photo lithography technique, we will be discussing photolithography at some point of time. What you see here is a micromanipulator and the use of micromanipulator is to indent a tissue.

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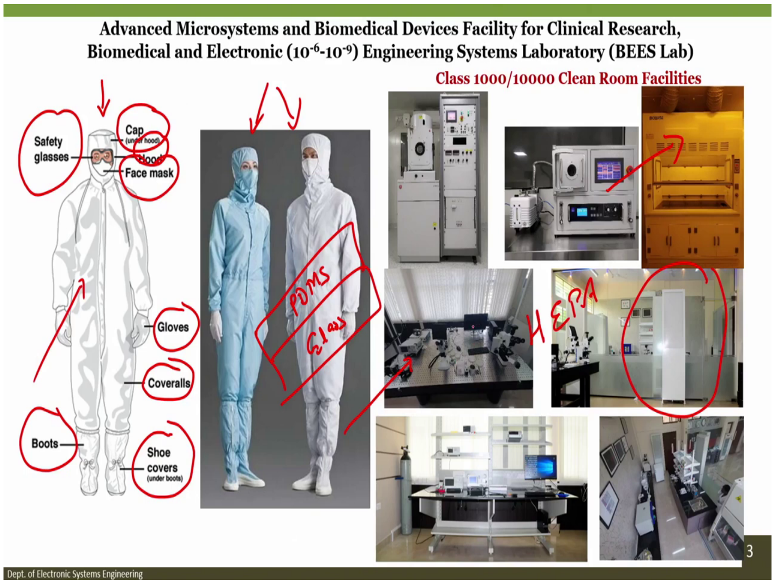

HEPA, High Efficiency Particulate Air, these filters are used for filtering out the particles in the lab and to maintain or to conserve the environment within the laboratory depending on whether it is class 10 or class 100 or class 1,000 or class 10,000 the number of HEPA filters would increase. These are workbench and you can see here is a nitrogen cylinder.

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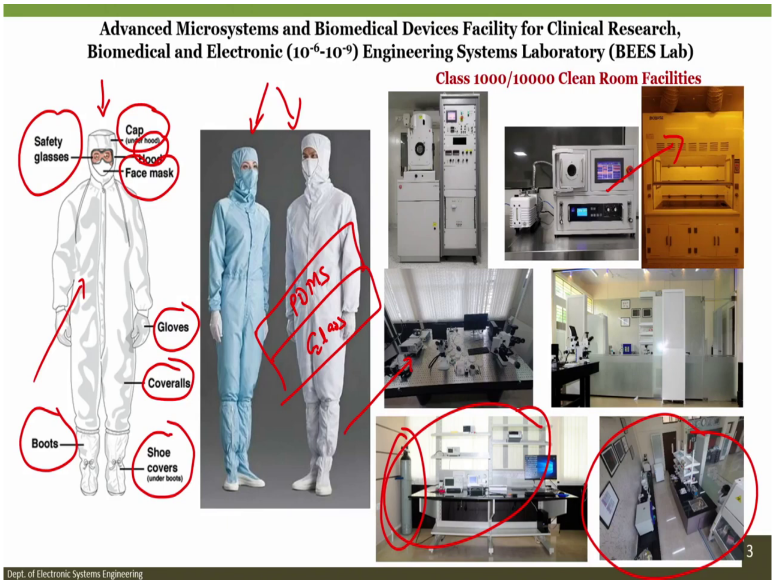

Finally, this is the science side of the lab, where we can do a lot of experiments when it comes to using wet electrodes, we can use gel and use the electrodes. If you want to do some experiments, we can use this part of the laboratory.

Anyway, this is just to show it to you that we require some kind of lab with a certain standard to perform all these experiments.

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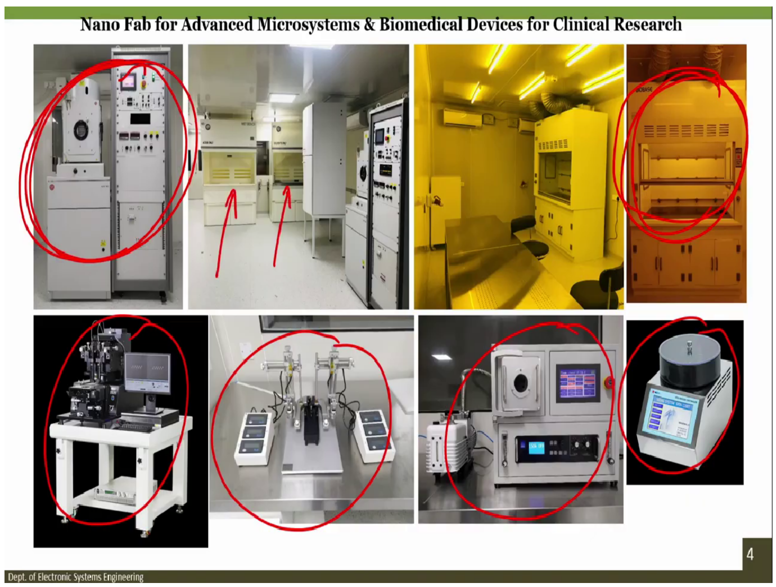

Now, we already have seen a fume hood, we have seen thermal e-beam evaporator. Now we will show you how to operate this particular system and how to operate the fume hood, how to operate the oxygen plasma system. What is the use of lithographing system and spin coater? And same way we have this system, which is called, which is used for holding the rat.

A stereotaxic equipment is used for holding the rat and then we can perform experiments with rat. Our focus again is to understand the ECoG signals from rat's brain. We will see if time permits, we will also show you how to operate this system.

If you have a laboratory equipped with several facilities, you can not only design and develop the sensor, but you can also perform the experiment within the same clean room area.

Now, one thing, when you talk about micro fabrication is etching. And what is etching? Etching is to remove the substrate, remove the part of the substrate. What is substrate? Substrate is a material on which you will be depositing or growing or developing a sensor transducer or any device per se.

So, if I want to edge the substrate, if I want to remove some part of the substrate, there are two techniques, one is called wet etching and other one is called dry etching. So now in wet etching there are two hoods that are used on wet benches that are used, one is for acid and one is for solvents, we cannot mix acid with solvent and vice versa.

So, if you see the slide, you can see here, we have a solvent bench and we have the wet bench for using the acids.

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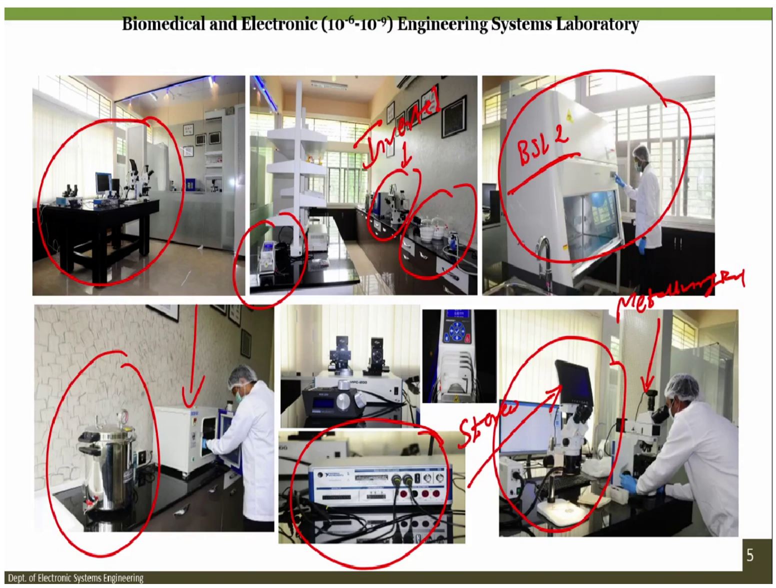

Alright, so these are some of the things that are there in the fab lab. There are many more things that we have in the lab and we are going to talk about it in the experimental class, we will show you how to operate several equipment and tools that we have with us in this department.

You can see the this is a BSL-2 or Biosafety Level-2 hood, BSL-2, there are several Biosafety Levels, BSL-1, 2, 3, 3 is generally used when you talk about virus, when you talking about viruses such as coronavirus. We need to use a BS-3 facility. When you talk about bacteria, when you want to use cancerous tissues, bacteria, again, you are talking about E. coli or MRSA then you can use BSL-2 facilities.

Fortunately, for measuring the signals from brain we do not require bio safety hood, so we do not have to worry about it. Then what you see is we have a microscope, so I will show you how to use the microscope. This is particularly used when we will design a microchip that can be used for measuring the ECoG signal. We have NI DAQ card, this is a signal conditioning, it will be used for capturing and acquiring the signals and to trans, to convert it to a required domain. That means that, if I want to see how the sensor is performing, I can take help of the NI DAQ card and display it on a monitor.

We have an oven with us. We will discuss about this, how it is useful. And finally, you have a autoclave system. Autoclave is whenever you use any device, you need to autoclave it and then, you must discard it. That is the right procedure in the engineering, particularly when engineering is for medicine and other applications.

So, having said that, of course, this is a anti vibration table, and this is the bio side of the laboratory that we have. We have a peristaltic pump you can see here a peristaltic pump is there and then we have desiccators microscope, this is an inverted microscope and there is a difference, this is a stereo microscope. See, this one is a stereo microscope, this one that you can see my student working on this particular microscope, it can be inverted microscope, it can be metallurgical microscope, it can be stereo microscope.

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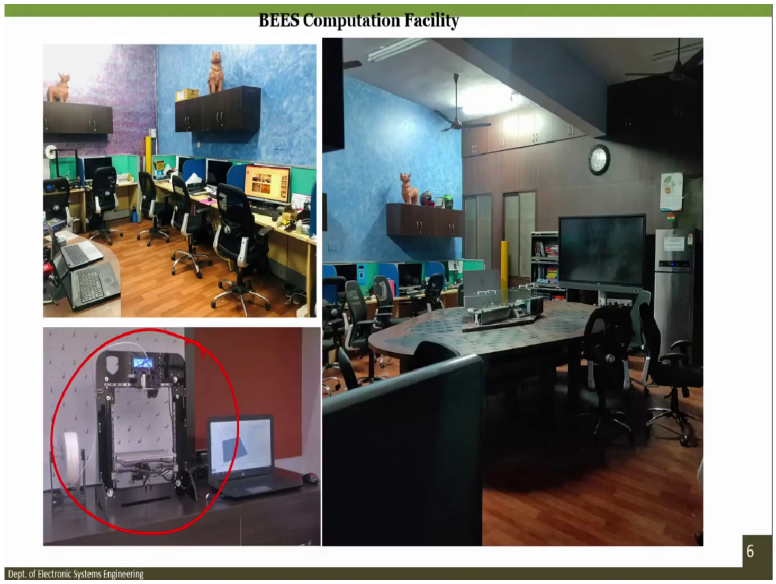

So, let us go to the next slide this is nothing but a 3D printing, you can see here 3D printing. Now, 3D printing is extremely important for developing the casing. We will be discussing about 3D printing on one of the modules for this course. And then, we have some competition facility, which is right now, we will not talk about that.

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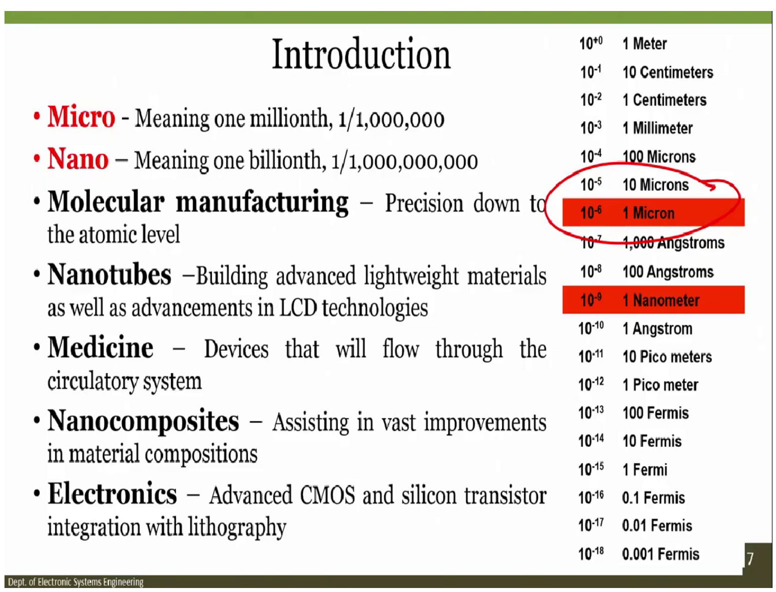

So, let us see, from the micro and nano perspective what exactly you mean by micro and why it is important when we talk about devices.

So, one is that the surface to volume ratio increases when you talk about micro and when you talk about the gas sensing. But at the same time, when you talk about getting the signals, acquiring signals from cell, on a single cell, it can be a glial cells, it can be a neural cells. So, in that case, you have to fabricate a device, which is micro in dimension, because you only want to get the signal from a single cell and single cell can be somewhere around 5 to 10 microns, some are really small.

So, how can you capture the signal from a single cell? In that case you require to fabricate a device that can be used for such applications. At the same time, if you want to also deposit a metal layer to understand or to capture the signal from the scalp, which is your EEG signal, then you need to deposit a metal which is a few microns thick.

So, when we talk about microns on nanometer, what exactly you mean when it comes to unit, this slide shows that if you talk about micron, one micron is close to 10^{-6}. In fact, it is not close to, it is exactly 10^{-6} in terms of unit. Where one nanometer will be 10^{-9}.

So, in definition, we say micro meaning 1 millionth and nano meaning 1 billionth. What are the applications? Molecular manufacturing, nanotubes, which can be used for building advanced lightweight materials as well as advancements in LCD technologies, several applications in the area of medicine, nanocomposites, electronics, electronics if you already know what are the CMOS techniques or CMOS transistors and particularly useful when we fabricate this transistors using e-beam lithography technique.

And our focus is not on the fabrication of transistors, focus is more towards our neuro instrumentation. But when we say instrumentation, that means it is a system and system consist of the sensor to the electronic module to the application and acquiring the signal and displaying it on a monitor so that a clinician can understand the change in the brainwaves, if a person is suffering from certain disease.

Now, what kind of diseases can be there? There can be stroke, there can be epilepsy, and there can be hearing problem and there are many. When you talk about brain, brain is the most complex thing to study. We know a lot of things about heart, how it functions. We know a lot of things about the muscle activities, how it functions, when it comes to brain, there is still a lot of gaps and lot of science and engineering required to study brain parameters.

We here along with Dr. Mahesh are working on several applications when it comes to brain right from EEG signals, to neonatal hearing, to understanding the attention of a person working in the lab. Also, we are working on developing ECoG chips, the chips can be measured, can be used for measuring ECoG and these chips are bioresorbable, that means, it is made up of material that once you implant in the body, it will dissolve. It is not just biocompatible. When you implant it, lot of things that you see are biocompatible, but when you need to retrieve or retract it back it causes trauma to the patient.

So we are working on a chip that you can implant and it will dissolve in the body, because it consist of bioresorbable materials. We are working on that. We are also working on a stroke model, we are working on epilepsy model. And thus, this course is a two-part course. The first focus would be on introductory part and maybe in the next semester we will talk about the advance part.

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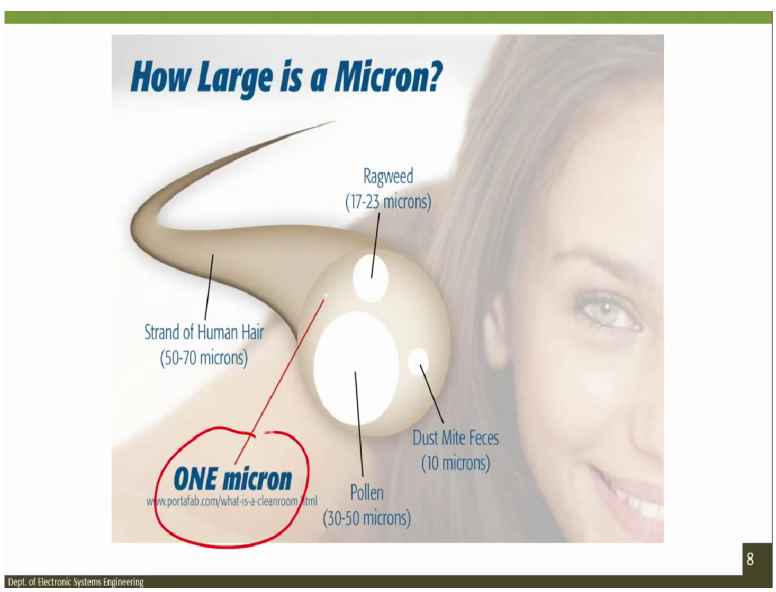

So, let us go to the next slide. And when you talk about how large a micron is, then you can see from the slide that a strand of human hair, 1 single strand is around 50 to 70 microns. Now we talk about ragweed, is a weed is about 17 to 23 microns. When you talk about pollen, pollen is 30 to 50 microns. Dust mites around 10 microns. While what we are talking about is 1 micron, you can see compared to all this, this is 1 micron, a white spot. This is the, how large is a micron, you can just imagine that this is what we are talking about. And we are not just talking about micron, we are also talking about the nano technology.

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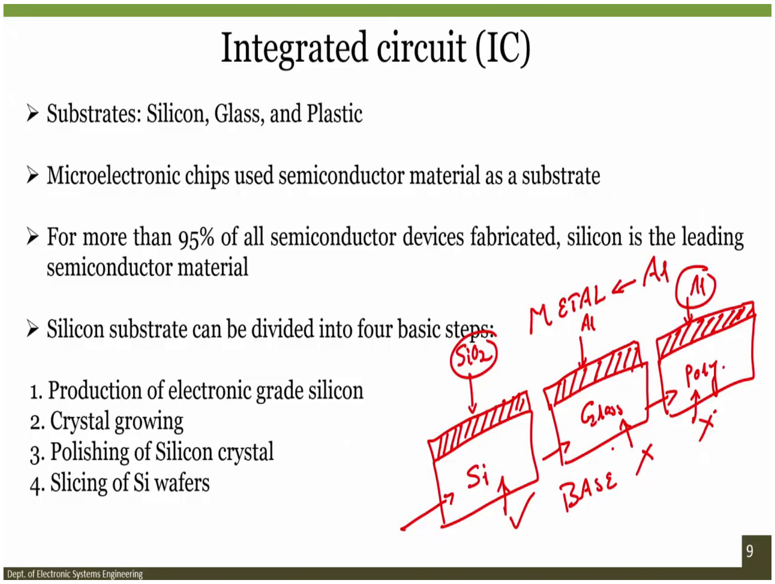

Now, let us quickly see what are ICs? Because we will be using electronic modules for capturing the brain signals and processing it further. So, when you talk about Integrated Circuit or ICs we talk about substrates. Substrates can be silicon. what is substrate? Let me give you an example. let us say you want to deposit a metal; you want to deposit let us say aluminum on a substrate. So, what is the substrate? Substrate can be silicon, substrate can be glass, substrate can be polymer.

Now, if I deposit aluminum directly on silicon, same way I deposit aluminum on glass and I deposit aluminum on polymer. Then the metal that is deposited on a material like silicon glass or polymer, then in this case silicone glass and polymer becomes a substrate. In this example, silicon, glass and polymer are the substrate, because it is a base material, base material on which you are depositing metal.

Now this is an example of metal. You can also deposit semiconductor, on semiconductor you can deposit insulator on semiconductor for example, instead of aluminum on silicon, we can deposit silicon dioxide, silicon dioxide on silicon, still silicon will be your substrate, silicon dioxide is a material grown or deposited onto the substrate.

Now, in microelectronics industry or in microelectronic chips semiconductor materials are used as a substrate. So, can you tell me which one is semiconductor, polysilicon is semi, polymer is semiconductor? No. Glass, no. Silicon, yes. So, when you see the integrated circuit, you will find that more than 95% of the semiconductor devices fabricated silicon is a leading semiconductor material. And the question comes is how we can fabricate a silicon substrate or how can we develop a silicon wafer then for that we have four different steps.

The first step is production of electronic grade material. Second, so, this electronic grade material is developed or grade silicon, production of electronic grade silicon, silicon is produced from silicon dioxide.

Now, what is silicon dioxide? Silicon dioxide is sand. There are two techniques for developing the electronic grade silicon one is called Czochralski technique, another is called float zone technique. And we will see both the techniques.

Now, having said that this is our first step. Second step is crystal growing. Third step is polishing of silicon crystal. And fourth step is slicing of silicon wafers. So, we will see each step in some slides. When you finish all four basic steps, what you get is a silicon substrate.

Now I am drawing a cross section of the silicon wafer. Silicon wafer looks like this, there is a reason of having this flat we call as a primary flat, in some cases, you will see that there is a secondary flat here and the reason of having primary flat and secondary flat I will discuss in few slides.

So before moving to discussing about silicon wafer, how it is, how we can know whether it is 100 or it is 111 or it is 110? What are the crystal planes are orientation?

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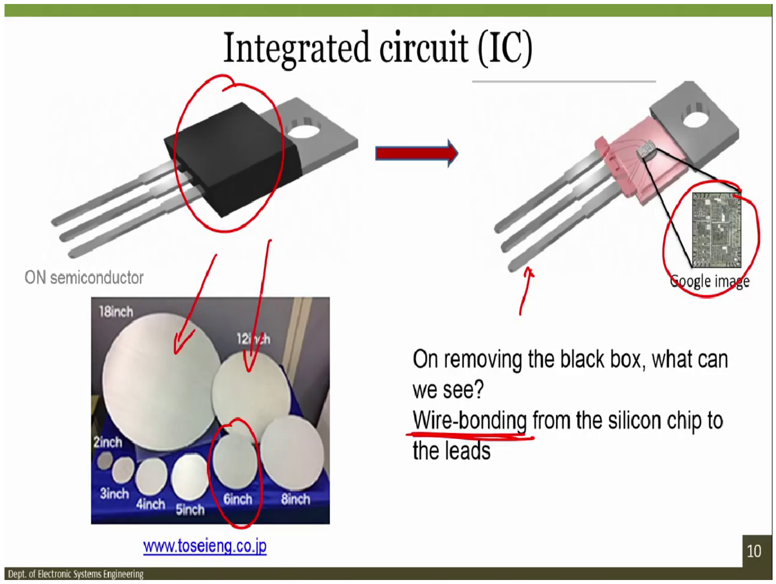

Before we go to that particular topic, let us take an IC, and on removing this black box If you ever tried, do not try without a proper supervision, it is not advisable. But if we remove this box, then what we can see is a chip that is mounted on the substrate and this chip has billions of transistors and the subset is silicon, while the connections are the contact to the external leads, these are external leads, are using the wire-bonding. So, wire-bonding is a technique of connecting the external leads with the contact pads and it is used generally in the silicon chip.

So, what are the size of silicon wafers that are available? We have a 2-inch wafer, then we have a 3 inch wafer, 4, 5, 6, 8, 12, 18. What is the advantage of having a wafer, which is of larger diameter? The advantage of having wafer of larger diameter is that we can integrate lot of transistors simultaneously. So, for example, if I can have 1 million transistors, 1 million transistors in 2-inch wafer then you understand that in 18 inch wafer how many transistors can accommodate. So, that is the advantage of using the larger substrate.

Most of the laboratories where they use the wafer in academics, they restrict themselves to 6-inch wafer. Where industry tries to go for 18- and 12-inch wafer, even larger diameters.

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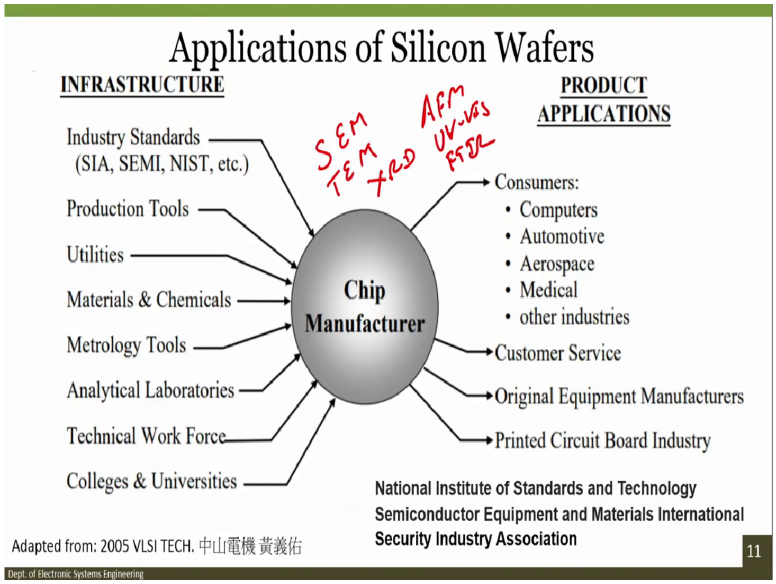

What are the applications of silicon wafers? See, from an infrastructure point of view there is, there are industry standards that chip manufacturer must obey, there are production tools, utilities, material chemicals, metrological tools. Metrology is to understand the properties of the material, it can be SEM, SEM is called Scanning Electron Microscopy, it can be TEM called Transmission Electron Microscopy, it can be XRD called X-Ray Diffractogram, it can be AFM called Atomic Force Microscopy and then there are many more UV–vis, UV-visible technique, then there is FTIR, Fourier-Transform Infrared Rays and many more.

So, then there are analytical laboratories, then technical workforce, and finally, this apply to college and universities. When it comes to consumers, the computers, automotive, aerospace, medical and a lot of other industries they use the silicon chip, customer service, original equipment manufacturers, PCB manufacturers have the usage of the silicon wafers exclusively.

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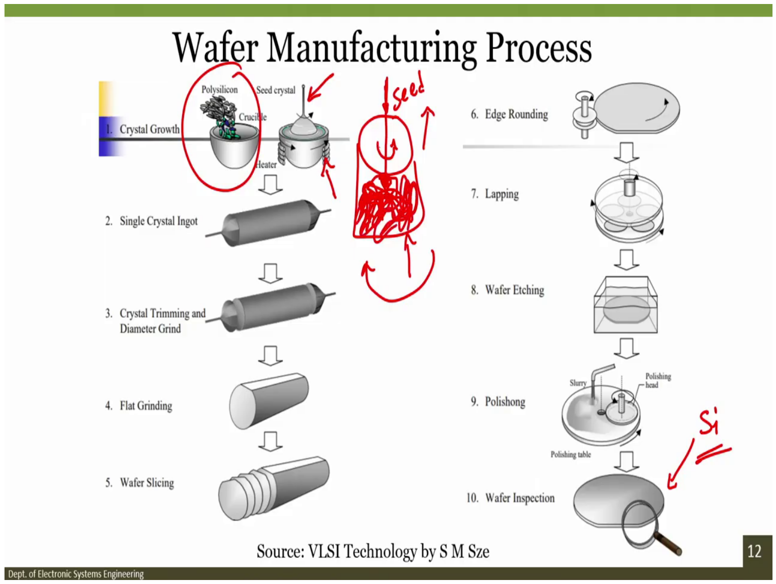

Now, we were talking about the and manufacturing or developing a silicon wafer, which you can see here, silicon wafer from sand. So, first you take a sand, you extract polysilicon and you with this polysilicon you heat in a crucible. This crucible is at extremely high temperature, so, that it will melt the polysilicon. Then you insert the seed crystal, it is a seed crystal, like this you insert it into this crucible and crucible has the molten polysilicon. When you insert it down like this, insert it down and you rotate it, so this seed crystal, let us say rotates in the anti clockwise direction, then the crucible will rotate in a clockwise direction.

So, it is opposite to each other. Seed crystal will rotate in a anticipate-clockwise then crucible will rotate in a clockwise direction. And slowly you need to pull out the seed crystal, you need to pull out the seed crystal, because seed crystal is at lower temperature compared to the molten polysilicon, what will happen? The crystal will start forming across the seed and you will be able to achieve a single crystal ingot.

I will show you a video so, that it becomes easier for you to see how this is, this can be done. This is just to make you understand that how, what are the procedure or what is the procedure to obtain the silicon wafer that we use as a substrate for semiconductor industries for manufacturing microelectronics chips as well as for a lot of devices related to not only sensors and other domain, but also for developing several chips for instrumentation, which is used in neuroscience.

So single crystals ingot, then you must trim. So the sides are trimmed. Next one is you grind it, this is grinding. What is the reason of grinding? The reason of grinding is to obtain a flat. What is the use of flat, I will show you in coming slides.

Finally, after you grind it, you slice the wafer. Slicing is done with the help of a diamond, a diamond cutter, you do the edge rounding, edge rounding is done. After edge rounding, you perform lapping, now we need to make the wafer extremely smooth, all the way to 2 nanometer roughness, wafer etching, polishing and finally, inspecting.

So, these are the steps that are used right from crystal growth to ingot trimming, flat grinding, wafer slicing, edge rounding, lapping, etching, polishing and inspection.

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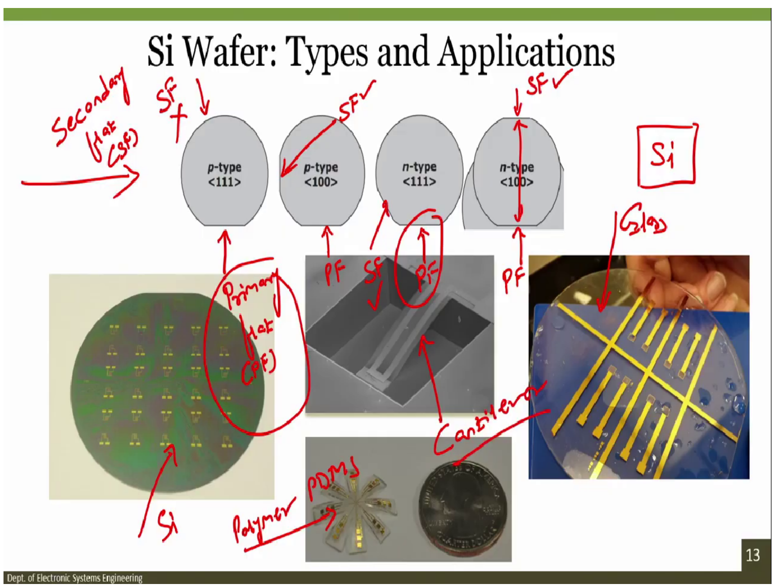

Let us see what is the role of the primary flat, this flat grinding, you see flat grinding, what is the role? And how it can be used to identify the crystal orientation and the type of the wafer? So there are two types. If the silicon is not doped, it is called intrinsic. If it is doped what is doped, means adding impurities. Impurities can be, if it is a silicon, and if I add p-type impurities, trivalent impurities, it becomes p-type silicon.

If I add n-type of impurities, it becomes n-type silicon, which is pentavalent impurities. So, how would I know looking at silicon whether it is p-type or n-type? The second question is how would I know what is the orientation of the wafer?

So, if you see this particular image or schematic, you will see that all these four different kinds of wafers, of course, all of them are silicon wafers, they have primary flat, let us say PF. So this paper also has primary flat. This wafer also has primary flat and same with this wafer as well.

Now, you see, is there another flat in this effort? No flat. So if you have a secondary flat, let us call this as SF. Does it have any SF? No. What about this wafer? Yes, SF is there. What about this wafer? Yes. SF, which is secondary flat is there. In this case, secondary flat is there.

So, we can see there is a primary flat in one of the wafer there is no secondary flat, in remaining three types there is a second flat.

Now, if the wafer is p-type 111, there will be only primary flat and no secondary flat. If the wafer is p-type 100, there will be secondary flat at 90 degree with respect to primary flat. See this is at 90 degree with respect to primary flat. Then, if it is n-type 111, then the secondary flat will be at 45 degree with respect to the primary flat. And if it is n-type 100 then it is 180 degree with respect to the primary flat, secondary flat is at 180 degree with respect to primary flat.

So, depending on whether there is secondary flat or not and if secondly flat is there, then with respect to primary flat, what is the angle of secondary flat will help us to determine the type of the wafer and the orientation of the wafer. That is the use of primary flat.

When we fabricate the silicon wafer, we also fabricate a secondary flat with respect to the primary flat. Now, that means silicon is a substrate, what can be other substrate? Glass. So, if you see the slide what you will see is that we have used glass in this case as a substrate, we can also use polymer as a substrate. So, silicon, glass, polymer, can be PDMS and this is just an example of a cantilever, cantilever fabricated using silicon.