Mathematical Aspects of Biomedical Electronic System Design
Department of Energy Science and Engineering
Indian Institute of Science Bangalore
Lecture 03
Microfabrication Basics for Biomedical Systems

Hi, welcome to this particular class, in this class we will see the substrates that are used to fabricate this biomedical devices. Because as the name of the course suggests that we will be looking at the Mathematical Aspects of Biomedical Electronic System Design, you should understand what are the biomedical systems and if you understand what about medical systems, then you will understand that what are the different parts integrated into a particular system.

Now, most of the system that we develop that has either a sensor or an actuator. So, if I talk about micro sensors, then how to integrate or how to design and fabricate those sensors is something that is of importance. Now, to do that, we will see where exactly this fabrication happens, what kind of laboratory environment you require and then we will also see what are the substrates that are used to fabricate those sensors, substrate is a base material on which you can fabricate different layers, so as to realize a sensor. So, if you see, if you see the slide, this topic we will cover introduction to cleanroom and overview of micro fabrication process.

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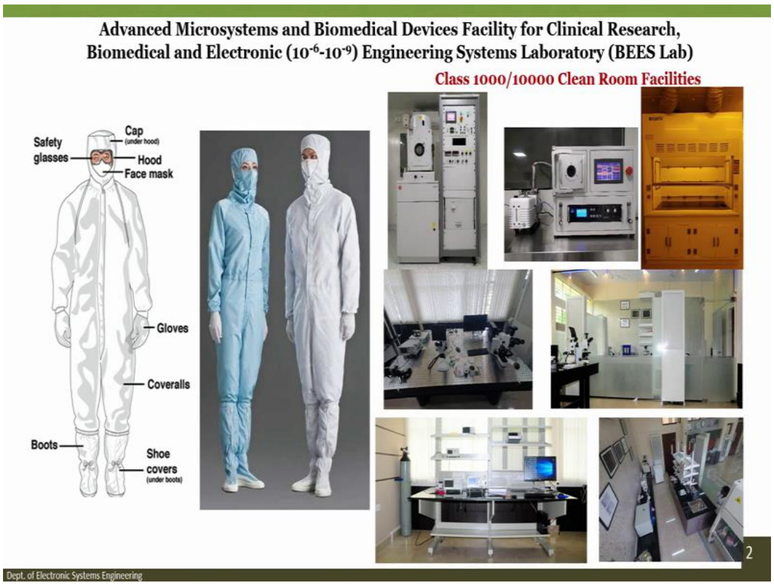

So, as you can see in this slide, whenever you want to enter a clean room, it is very important that we avoid as much contaminants as possible and the way to avoid contaminants is by following the cleanroom protocol. When you talk about cleanroom protocol the first thing and foremost thing is how to wear the gowns, how to wear clean room, clean room hoods or gown and then how to wear the gloves it can be clear safety glasses, cap hood, face mask, boots and shoe covers. This all comes under PPEs or personal protective equipment.

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Now, once you understand the process of how to enter the cleanroom you will see that that within the cleanroom, there are several equipment such as thermally operation EVV operation that can be sputtering CVD which is P CVD LP-CVD MO-CVD that would be oxygen plasma systems, there would be chemical benches for wet etching and dry etching, then there would be a parylene deposition system, you will find a photoresist spin coater, you will find a mask aligner or photolithography system it can be front lithography or it can be front to back alignment and they do perform lithography.

Then we also have the RIEs which is a dry etching, either it is reactive ion etching for chemical. So, using chlorine its chlorine nature, if it is using fluorine, it is called reactive ion etching for fluorine and then we, the final is you will see in a cleanroom a deep reactive anything system. Again, all the things that I am talking about are the technology, are the equipment that you will find, when you are inside the cleanroom.

There is a role of each equipment at certain point of time and I will try to cover few of the things and then we will associate those things with the, with the theory and see that how the understanding of mathematics will help us to understand the design and fabrication of devices.

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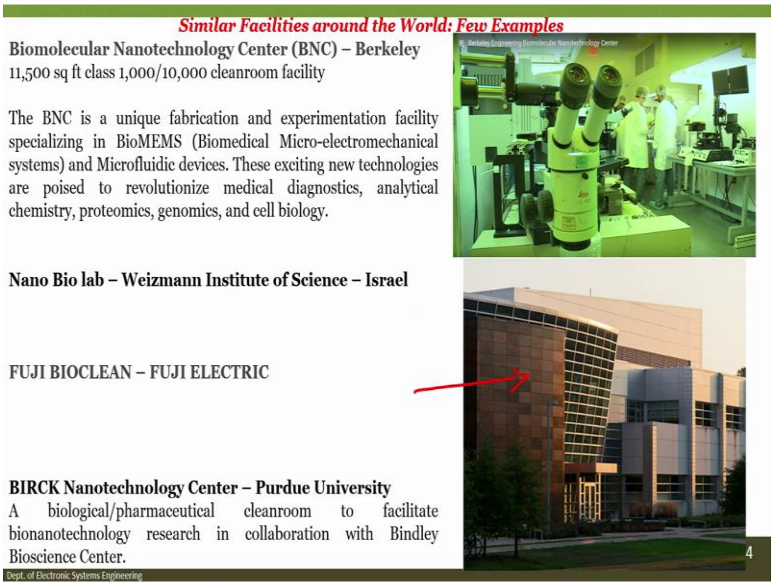

So, having said that, few of the similar world class facility will say around that we have at IISc are from one from Berkeley, you can see they have about 11,500 square feet of 1000 10,000 clean room facility and it is a unique facility which works on biomedical, micro electromechanical systems and of course microfluidic devices, they work on medical diagnostics, analytical chemistry, proteomics, genomics, cell biology.

Then we have another lab in Israel, Weizmann Institute of science, these are some of the cleanroom laboratories that I am talking about. The reason of showing you this particular slide is to make you understand that there is a huge investment in this particular research area, particularly as it is linked with the healthcare technologies and when it, what healthcare technologies all these healthcare technologies would have, at some point of time, they use sensors and they use actuators or transducers.

So, there is another nano technology center from Purdue it is called by BIRCK, I am sorry you cannot see the full screen but it is BRICK and Fuji electric, they have a Fuji FUJI Bioclean. So, this is a cleanroom that they have, the entire building is a cleanroom, so it is world class facility that we have, what I am showing in this slide. However, the point of showing you this slide is also to make sure that the same things we have at Indian Institute of Science and if you go to the IISc website and clean room facilities, you will see the similar kind of facilities we have everything under one roof.

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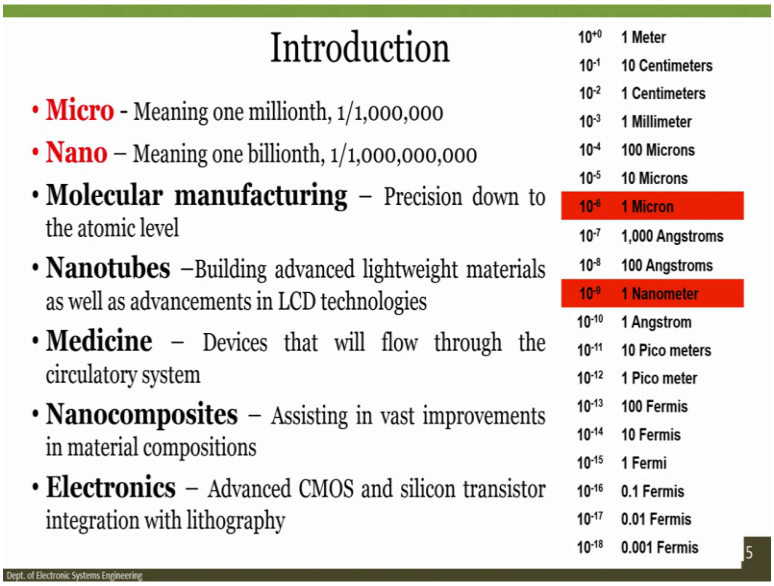

Having said that, let us come to the actual terminology and the terminology that we will be utilizing in this particular course, would be on micro and nano. The micro means one (meaning of) meaning is 1 millionth or in the another terms you can say 10 to the power minus 6, when you say nano it is meaning 1 billionth or in other term you can say 1 to the, 10 to the power minus 9.

Now, if I want to give you a very simple example of microns, then I will just show it to you in the next slide. However, just quickly understand that this micro and nano technologies are used in several areas from molecular manufacturing to nanotubes to medicine, nano composites and finally, electronics whether you talk about advanced CMOS silicon transistors or micro-fabricated devices for several applications like pressure sensors, then we have actuators which we can (())(06:36) electric actuator or piezo resistive actuators. We can develop a transducers like PMUT or CMUT and so on and so forth.

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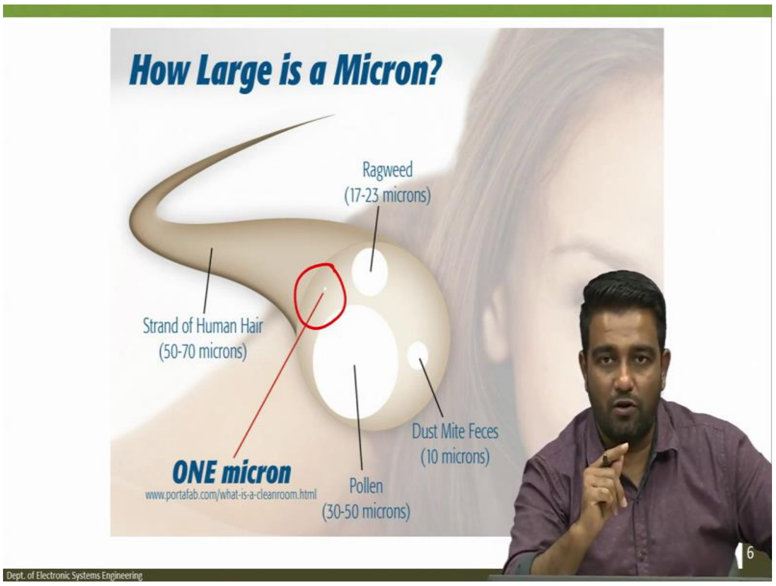

So, as I said in the last slide that how exactly or how large is one micron. So, a human hair is close to 50 to 70 microns and that is the thickness of a human hair and then when we talk about pollen, it is about 30 to 50 microns, our dust mite is about 10 microns and ragweed is around 17 to 23 microns. So, if I take, if I talk about 1 micron, you can see that dot that you see on this slide, this dot, white dot within this red circle is one micron.

Now comparatively within 1 micron in today's, with today's technology of developing several transistors we have, we can accommodate billions of transistors onto this one micron, single micron will have millions of transistors. So, that means that if there is a dust, falling on this one particular one micron area, it will kill few transistors, it will kill few transistors. So, that is why we should require a cleanroom facility.

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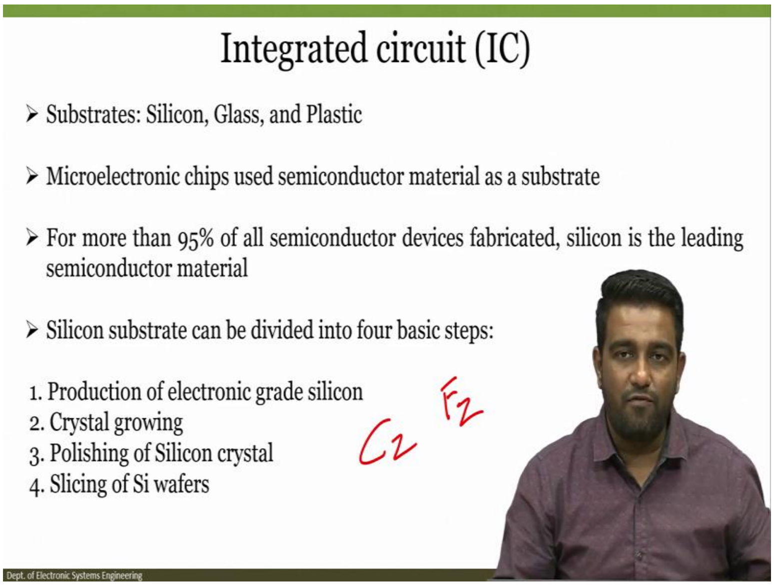

So, now, when you talk about cleanroom again you have to understand that there is an integrated circuit, because half of the things in electronics that we see today are all IC based and when you talk about integrated circuits, then you understand that integrated circuits are made up of the base material is silicon. Now we have different materials and there are SOI wafers or gallium nitride wafers and many more, but the basic still remains the base still remains a silicon 90 percent of the industry still uses silicon as the base material or as a substrate.

And if we are going to make different devices, then you can also use glass as a substrate you can use plastic as a substrate, then the silicon substrate again if you want to divide into further steps, then there are four basic steps. First is a production of electronic grade silicon, second is a crystal growing, third is polishing of wafer and the fourth one is slicing of silicon wafer.

So, right from the sand to silicon, what are the process. There are two techniques if you have understood the, if you already have undergrad degree or you are learning we are in fourth semester or fifth semester, sixth semester, you must have learned the VLSI technology and design in that you will see there are two techniques called a CZ technique CZ, C and Z and then there is FZ, FZ. So, CZ stands for Czochralski technique and FZ stands for Flow Zone technique.

Depending on the pronunciation it will be different but the techniques remains the same that these are techniques to realize a silicon wafer from the sand, so sand to Silicon what is the process that is shown in CZ and FZ technique.

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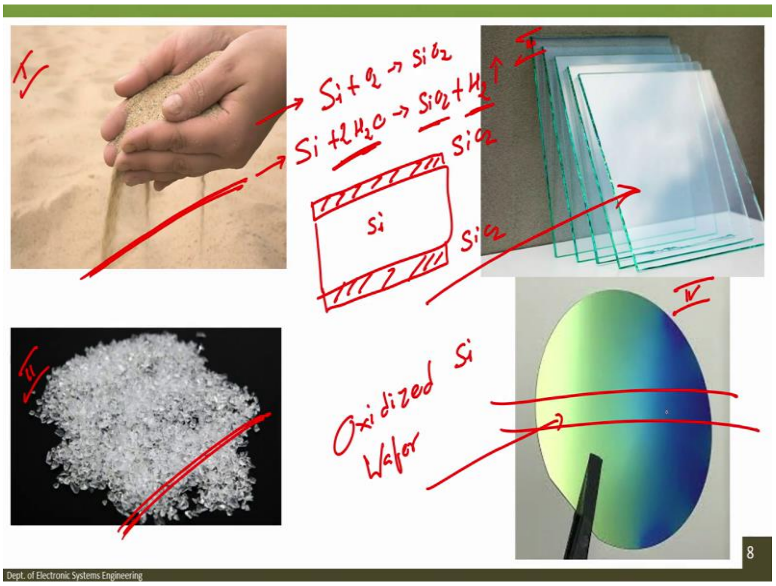

So, you can see here, the slide shows the left topmost slide shows the sand, this is a sand and through sand these are the glass crystals and this is glass right very easy to see and what is this, this is oxidized silicon, oxidized silicon wafer, oxidized silicon wafer that means you have a silicon wafer if I draw a cross section of this wafer, it will be the one that I am showing you here.

Now, if you do oxidation process, we will look into oxygen processing in either this class or other class, you will understand that when you heat the wafer at level 1100 degrees centigrade, and if you pass oxygen and oxygen reacts with silicon, it gets SIO2. So, silicon plus O2 gives us SIO2, this is dry oxidation process.

Now, there is a wet oxidation process in which you have silicon plus H20 gives you SIO2 plus H2. Now, you see, we have to balance the equation. So, you said 2H2O. So, you have a SIO2 and H2 gas comes out this is when you use water vapour to grow silicon dioxide, silicon plus oxygen this is dry oxidation because here there is no water vapour in the second equation we use water vapour, that is why I say SI plus 2 H2O gives SIO2 plus H2.

And then what do you see further is that we will now show a thermal oxidation technique in which you can grow the silicon dioxide layer on to silicon substrate. So, when you grow silicon dioxide layer on to silicon substrate, you will see like this, this is a silicon dioxide, silicon dioxide and the silicon is there. So, the wafer that you see in this particular picture, let us say we name it the first one second, third and fourth in the fourth picture that you see here, is an oxidized silicon wafer. Let us go to the next slide.

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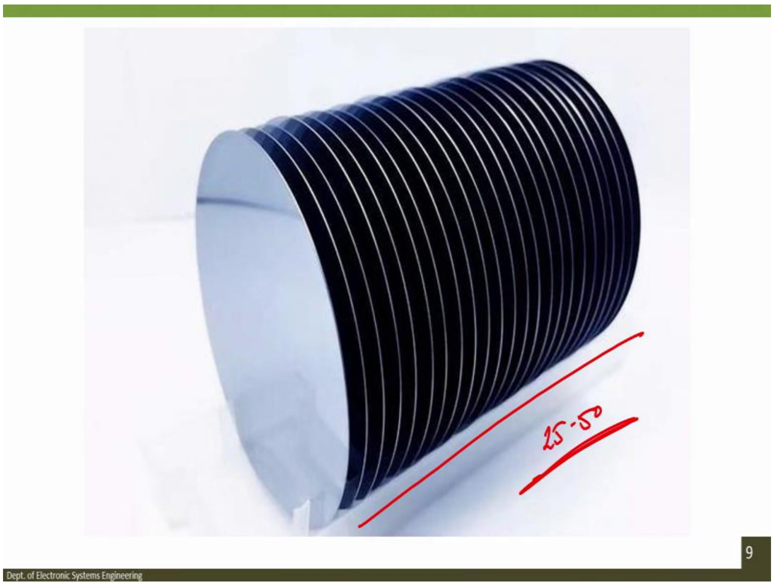

These are the racks of silicon wafer, racks of silicon, rack of a silicon wafers, all stacked together, it can vary from 25 to 50 depending on how many silicon wafers you can, you want to oxidize in one time, you can do oxidation of all the silicon wafer in one go in something called or in a process called thermal oxidation, which uses horizontal tube furnace, we will see that process.

Here you need to understand that how silicon wafer looks like. Now, why we are again looking into this particular system or the techniques is to understand that silicon will be used as a substrate to fabricate several devices and once you have devices you can integrate those devices into biomedical systems and then we will look at the mathematical aspects of how we can use different basics of the math into this biomedical system to understand the several important properties into healthcare, it can be a tissue property, it can be a cell property, where we use AC versus DC how the properties would change, how you can create a model, how it can fit with the data and lot of understanding about those aspects.

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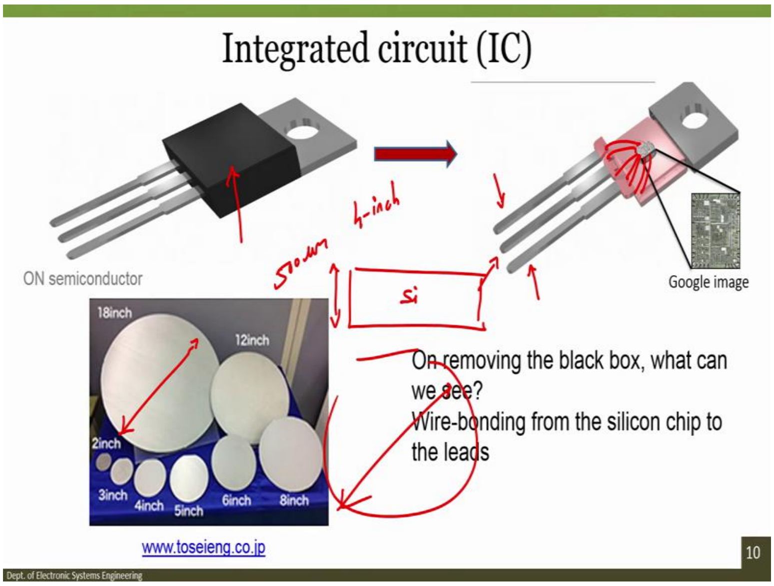

Now, but before that, if you take any integrated circuit, you will generally find that when you open this integrated circuit, this is a casing. This one is a casing, if you open the casing what you will see is that there is a small chip which is on the, integrated under this particular casing and then there are wires like this connected to the external lead, these wires are nothing but wire bonded right to the external lead and this wire bonding is done by something called wire bonder as the name says wire bonding wire bonder.

So, this connection to your fabricated chip is done through the wire bonding mechanism. There will be wedge bonding that will be the different end of bonding mechanisms but you cannot do shouldering or breastfeed contact in this case, you had to rely on wire bonding. So, once you bond the wire, these are your external leads. Lead 1, lead 2, lead 3 that you use for different processes.

So, what we see further is that when you want to use silicon wafer as a substrate, it sizes from right from 2 inches, dimensions changes from 2 inch all the way to 18 inch. Now when I talk about 2 inch or 3 inch or 5 inch or 6 inch, 8 inch, 4 inch, 12 inch 18 inch, what does I mean, I mean that the inch says about the diameter of the wafer, what is the diameter of the wafer.

So, the for example, if you take a 4 inch diameter wafer and if I see the cross section of 4 inch diameter wafer, the thickness would be close to 500 micro-meter, the thickness will be close to 500 micro-meter, this is we are talking about the thickness of silicon wafer 4 inch silicon wafer. That means that if I take silicon wafer and if I measure diameter, it will be 4 inch, 4 inch diameter. So, this is what it means and then the photo shows different kind of wafers size available in market.

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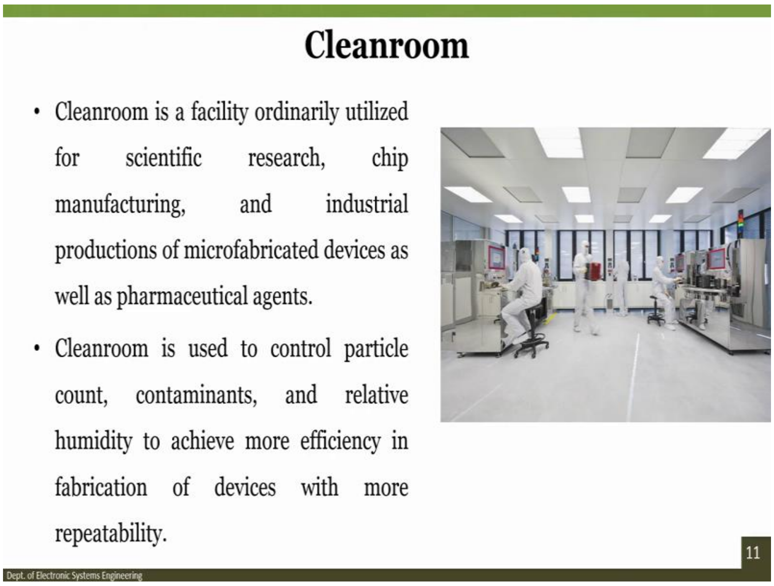

Now, as I told you that to fabricate these devices, we have to require, we have to have facility which is called cleanroom and is a facility ordinarily utilized for doing research, for chip manufacturing and national production of micro-fabricated devices, it is also used heavily in pharmaceutical industries to create drugs and when we also talk about cleanroom, you also have to understand that it is a facility that controls the particle count contaminants relative humidity to achieve more efficiency in fabrication of devices and of course, with repeatability, repeatability efficiency, both goes hand in hand if there is no repeatability there is no point of having more efficient process. So, that is what we are talking about.

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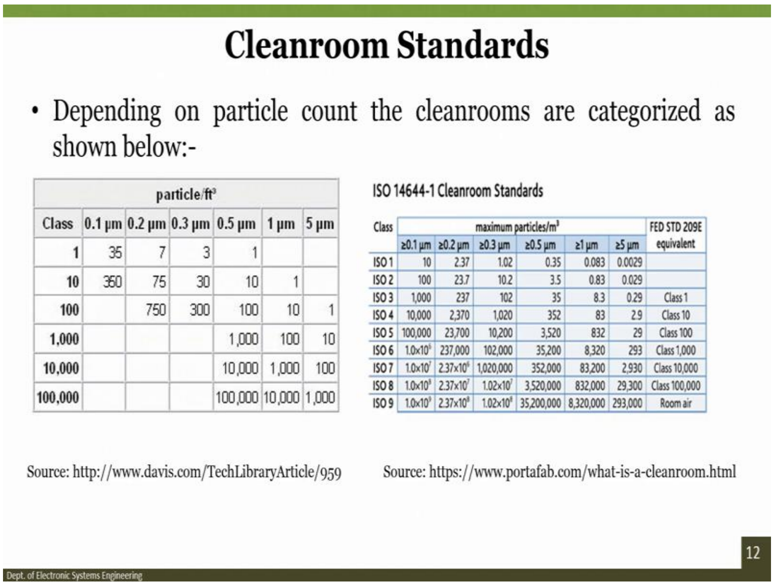

Cleanroom Standards

• Depending on particle count the cleanrooms are categorized as shown below:-

particle/ft³						
Class	0.1 µm	0.2 µm	0.3 µm	0.5 µm	1 µm	5 µm
1	35	7	3	1		
10	350	75	30	10	1	
100		750	300	100	10	1
1,000				1,000	100	10
10,000				10,000	1,000	100
100,000				100,000	10,000	1,000

Source: http://www.davis.com/TechLibraryArticle/959

ISO 14644-1 Cleanroom Standards

Class	maximum particles/m³						FED STD 209E equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	
ISO 1	10	2.37	1.02	0.35	0.083	0.0029	
ISO 2	100	23.7	10.2	3.5	0.83	0.029	
ISO 3	1,000	237	102	35	8.3	0.29	Class 1
ISO 4	10,000	2,370	1,020	352	83	2.9	Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1.0×10^6	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7	1.0×10^7	2.37×10^6	1,020,000	352,000	83,200	2,930	Class 10,000
ISO 8	1.0×10^8	2.37×10^7	1.02×10^7	3,520,000	832,000	29,300	Class 100,000
ISO 9	1.0×10^9	2.37×10^8	1.02×10^8	35,200,000	8,320,000	293,000	Room air

Source: https://www.portafab.com/what-is-a-cleanroom.html

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Dept. of Electronic Systems Engineering

If you see again in this slide, I do not think you can see on the right side. So, can you just move me out please on the slide. Avinash, thank you so much. So, here you can see that depending on the particle count the cleanrooms are categorized as shown below, generally it is categorized based on the particle per cubic feet and it goes depends on the particle per cubic feet either it is 0.1 micron particle or 0.2 0.3 0.5 1 5 micron particles.

And you can see that as you go towards the lesser number that means, class one is cleaner than class 10, class 10 is cleaner than class 100 and class 100 is cleaner than 1000 to 10,000, to 100,000. So, in class 1 and class 10 as you can see that almost 5 micron particle is not an existing 1 micron is just 1.5 micron is 1 and then 5.5 micron in class 10 is 10, in 0.3 micron 30, 0.2 75, 0.1 350 the purpose of showing you this slide is to understand that the clean rooms are further divided into several classes based on the particle per cubic feet.

And depending on that there are several standards right from ISO 1 to ISO 9 and ISO 3 is for class 1 environment, ISO 4 is class 10 and ISO 8 is class 100,000 environment, ISO 9 which is just a cleanroom air. Now, that means that if you go to a clean a laboratory and the air that you find it out hoping that is clean, you can give the laboratory ISO 9 certification in terms of class, but when you want to create a cleanroom, you have to make sure that the particle counts falls within these particular parameters. So, as to make sure that the device is not, the chip is not deteriorated, the contaminants are minimum.

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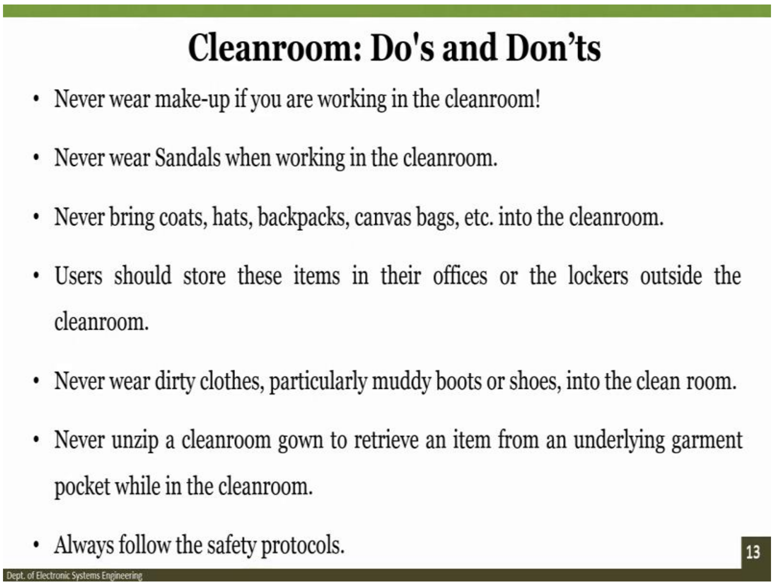

Now, having said that, when you work in a cleanroom, we will just quickly see this slide so that you understand that the working and the protocols of the cleanroom, what you do not have to do that is very important, see in most of the subjects that you take is very important to understand what not to do also and what to do.

So, if you are in the cleanroom, you cannot wear makeup or you can not wear sandals, you are not allowed to bring coats, hats, backpacks, bags. All these items should be stored in the office or the lockers outside the cleanroom, you cannot wear dirty clothes, particularly muddy boots or shoes. Never unzip a cleanroom gown to retrieve an item from the underlying garment. Always follow the lab protocol and safety is very important.

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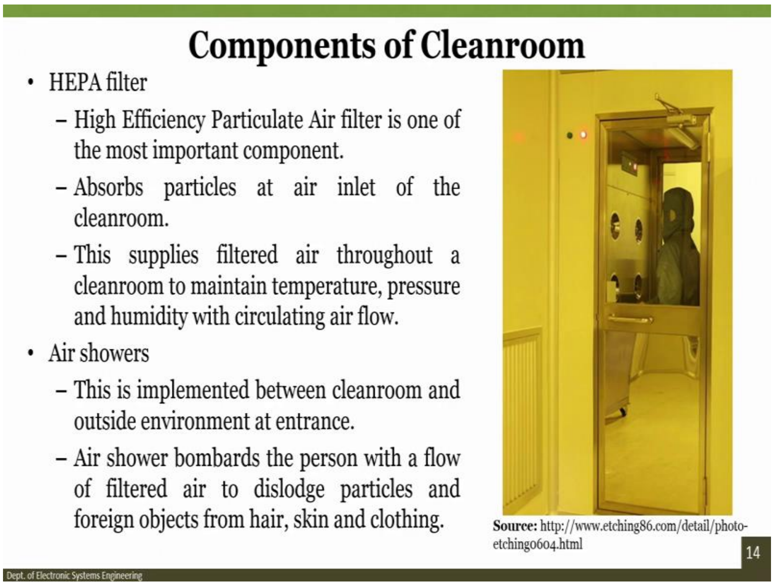

Now if you want to create a cleanroom the question should be how can one create a cleanroom or class 10 or class 100 kind of cleanroom facility. So, the answer to the question is by using a filter called HEPA. HEPA stands for High Energy or High Efficiency Particulate Air Filter, and is one of the most important component of the cleanroom and the way the HEPA filter works is by absorbing the particles at the air inlet of the cleanroom and this applies the filter air through the cleanroom to maintain temperature, pressure, humidity.

Another thing is very important the cleanroom if you see it is an air shower, when you enter the cleanroom, the air shower will help to bombard the person with a flow of filtered air and this, in this bombardment will result in dislodging the particles, it can be dislodged also foreign objects, it can dislodge skins and clothing and so on and so forth.

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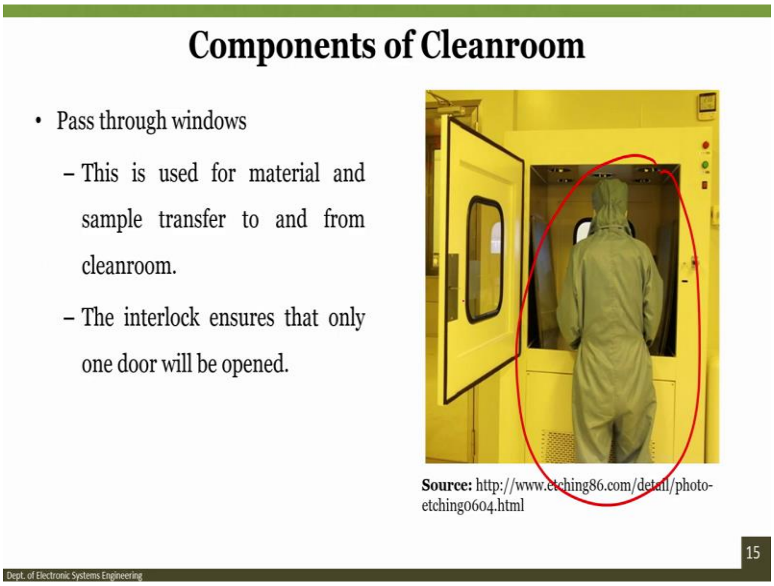

Then another thing that when you see the cleanroom I think I will just send you a video of how the cleanroom looks like how to enter the cleanroom, what are the protocols within a cleanroom, how the pass box works and everything. So for now, just understand that when there is a pass box is used for passing the material from one side of the cleanroom into other side of the cleanroom.

So, if you wear all these gowns, the whole cleanroom hood and then you do not have to, if you do not want to go inside, you can open the pass box put your close this door led the person inside open the other door and that person can retrieve the material. So, it ensures the that only one door will be open at one time and thus the passing of the material is possible.

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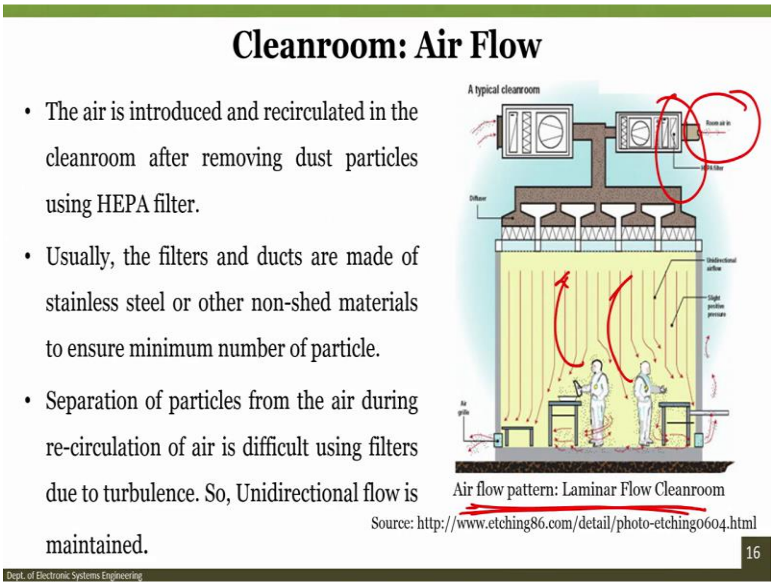

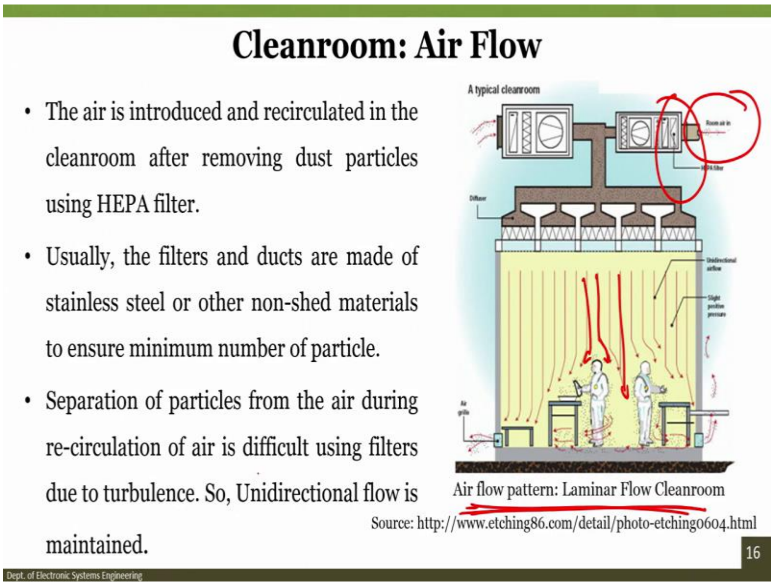

Next one is about the airflow and you can see in this particular schematic that airflow which is a laminar cleanroom flow is very important. In this case the air is introduced and re-circulated in cleanroom after removing dust from the HEPA filters, you can see here the air comes from here it passes through the HEPA filters and usually the filters and docks are made out of stainless steel and to ensure minimum number of particles.

Also, separation particles from the air during recirculation of air is difficult and that is why it will, due to the turbulence because if you send it back it will create a turbulence. So, to avoid that, it is only unidirectional flow is allowed and multi directional flow is not allowed. So, if you see the unidirectional flow is shown here to avoid the turbulence.

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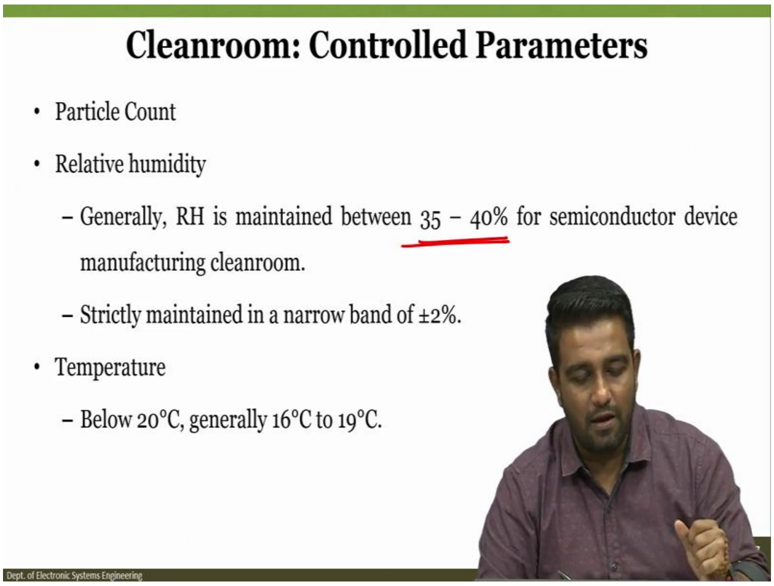

And the next slide when you see that, what are the cleanroom parameters, you will see that the particle count is one of the very important parameter along with the relative humidity which generally lies between 30 to 40 percent, we also have the narrowband or plus minus 2 percent that means, it can go to 33 percent it will go to 42 percent or 38 percent or somewhere in that range. So, plus minus 2 percent is allowed. So, the point is 35 plus minus 2 40 plus minus 2 and the important factor is that you have to strictly maintain the temperature also, generally it is below 20 degrees centigrade in between 16 and 19 degrees centigrade.

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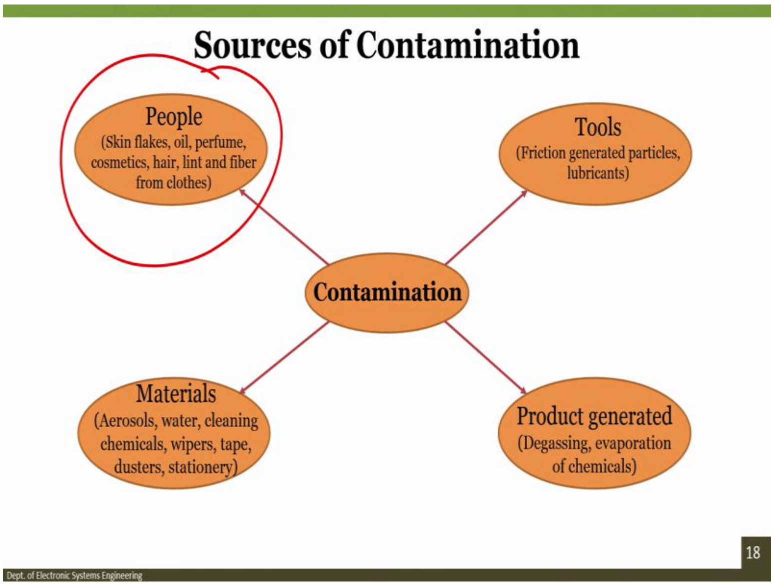

Now, if you talk about sources of contamination, there are several sources of contamination, the biggest source is the person working inside the cleanroom. So, and this contamination generates from several things right from the materials that we use in the cleanroom which can be aerosols, which can be water, it can be cleaning chemicals, wipers, tape, dusters, stationery and many more things it can generate out of degassing evaporation of chemicals, when we use wet benches, when we go for a physical vapour deposition like sputtering, EBM thermal evaporation, we will see and understand some of those in this particular course as well.

Finally, the tools that generates because of the friction generation particles lubricants and finally, the people that are working inside the cleanroom, because of the oil, perfume, cosmetics, hair lint and fibre from clothes, these all are the sources of contamination inside the cleanroom.

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So, as I told you earlier, the restricted materials within the cleanroom are right from the paper pencil fabrics, wet and dirty clothes, loose clothes, dangling jewellery, everything is not allowed within the cleanroom.

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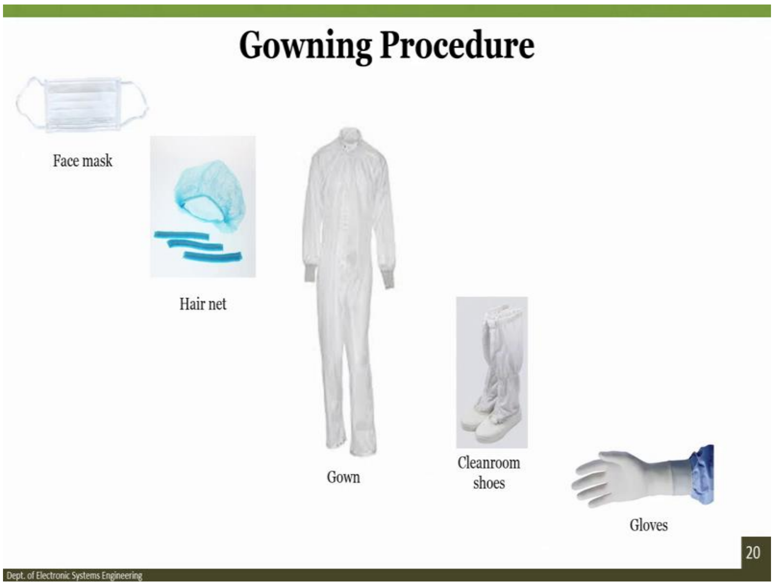

The gowning procedure, I will send you the video just you look at here. Now I am sure that most of us we know how to wear a mask it should be above the nose, not covering your eyes of course and it should cover your mouth. Then you have a hairnet and then you have gloves, you also have a safety glasses, a cleanroom shoes and a gown.

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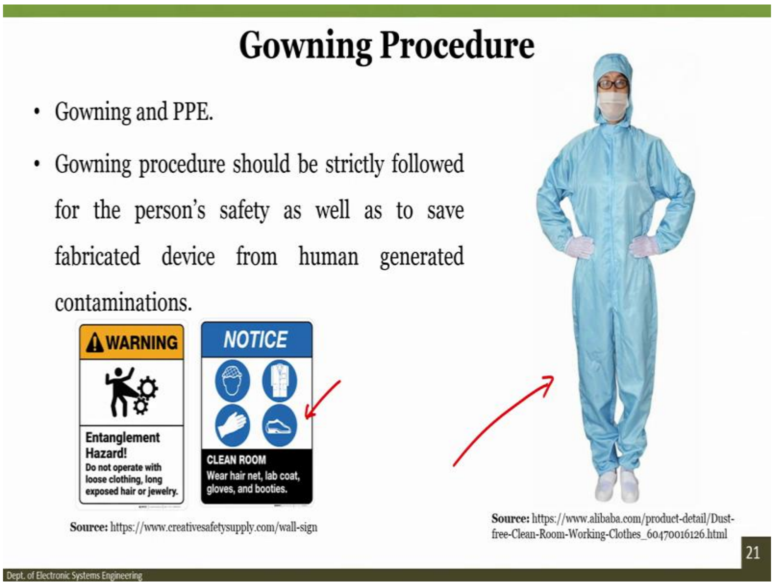

So, this accounting procedure gowning and PPE, PPE stands as I told you earlier, it stands for personal protective equipment. So, gowning procedure should be strictly followed for the person safety as well as to save the fabricated device from human generated contaminations. You understand that there is a loose clothing, there is an entanglement hazard. Secondly, wet hair net, lab coat, gloves and booties you can see that this all these things would be there in the cleanroom and once you were everything more or less, this is how the person should look like when he or she is wearing cleanroom gowns and along with the PPEs.

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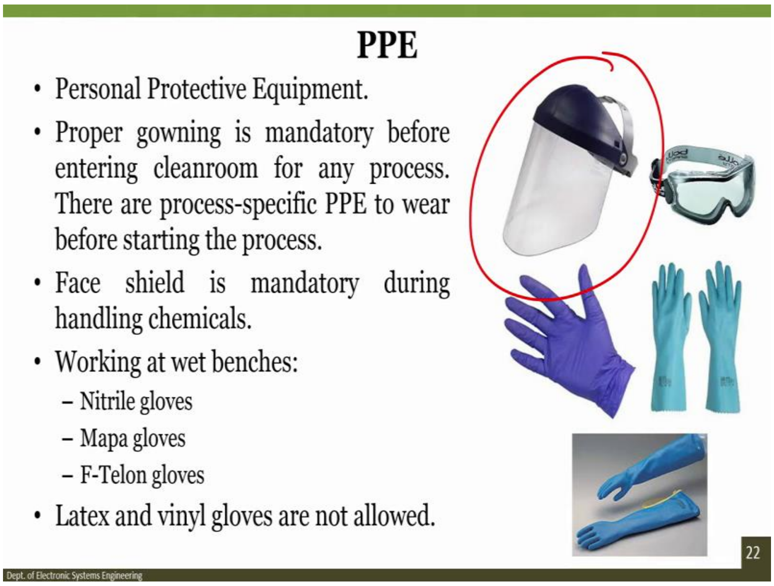

So, further in PPE, we have to also understand the face shield, we have do understand the mask, gloves, safety glasses and the face shield is used when we go for the wet etching, then generally when there is a acid bench, there is extra protection that we go, have to take. Same thing we had to wear different kind of gloves, particularly when we work in the acid band environment and another thing that we need to understand is that working at wet benches, you have three different kinds of gloves. One is nitrile gloves, another is Mapa gloves and last one is the F-Teflon gloves while the latex and vinyl gloves are not allowed inside the cleanroom.

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So, the few more slides or understanding the safety issues, because it is very important whenever you understand about biomedical system you should understand what are the safety hazards and it starts from the MSDS, which stands for Material Safety Data Sheet all the chemicals that used, all the materials that used within the cleanroom or even in the lab would have MSDS data sheet, you can see it, you can see the temperature boiling point, melting point depending on the material of course and you have to be careful when it is explosive or not whether it is corrosive or not, whether it is flammable or not, if it is a gas cylinder, if it is an environment that is aquatic toxicity, when there is acute toxicity, you will see a symbol skull or crossbones, when there is an exclamation mark that means that there is a skin sanitizers sensitizer acute toxicity is there.

The respiratory track irritant can be there, hazard to ozone layer can be there, is the exclamation mark, then the another symbol that you see health hazard which is right here that will, when there is a carcinogen material inside, when there is a mutagenicity, when there is a reproductive toxicity, respiratory sensitizers, target organ toxicity, aspiration toxicity, then you have this kind of symbol and finally, this symbol very well is a flammable, it is a flame.

Flame symbol stands for flammables, it stands for self-heating, emits flammable gas self-reactive organic peroxide. So, these are all the symbols that more or less, when you see in the lab, you will know that this is for that particular, the lab has that those particular you know materials with that particular explosives or corrosive or flammable materials inside the ecosystem and then you need to take care accordingly and wear the PPEs accordingly.

Now, you have four blocks here as you can see on the screen, right the leftmost block which is a blue one, the blue one shows that it is a health hazard and it can be deadly extremely dangerous hazardous it can be slightly or it can be normal material, if it is deadly, you give a point 4, if it is extremely hazardous, extremely dangerous material, you can give 3, if it hazardous 2, slightly hazardous 1 and normal material then you can say 0, if it is red it stands for fire, fire hazard.

If it is below 70 degree then you say that is 4, if it is below 100 degree Fahrenheit then 3, below 200 Fahrenheit 2, above 200 degree 1 and will not burn it is 0 instability the yellow one shows instability, whether it is detonate then it is 4, shock plus heat 3, violent chemical 2, unstable if heated is 1 and stable is 0. This 4, 3, 2, 1, 0 that I am talking about is all the corresponding right from deadly to normal.

So, 4 is extremely deadly and then 0 is normal. But in case of fire we have seen that what are the flash points that if it is 200 degrees that means that before that it will not catch the flash and that is why we have numbering like that. So, having said that the last one that we have left here is a specific hazard which is a white colour box and here you can see that it can be for oxidizers, alkaline materials or you should not use any water or simple asphyxiate or it can be acid, it can be corrosive, it can be radioactive. So, then we use a white colour box.

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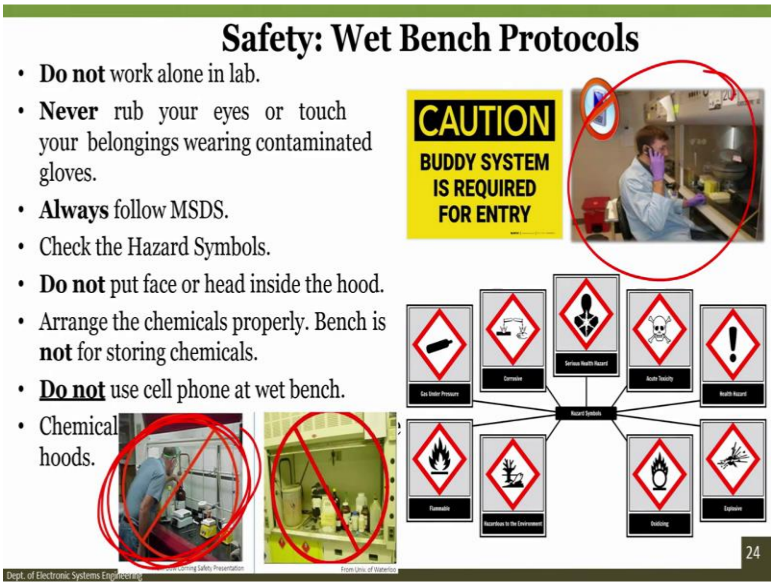

Excuse me. Now, we can talk to wet bench protocols. So, the most important thing is that in the wet labs as you can see in this screen, you are not allowed to do this. You cannot wear the PPEs and work in the wet bench with mobile in hand and talking to someone. Next thing is you can, you should not never put your head within the wet bench, because what happens is that, there is of vapour that because of the boiling of the chemical that vapours we will breathe in if you will have the head within the wet bench.

So, you had to take care of these issues when while working in the wet benches. You see these should not, it is not a storage area, it is a wet bench to perform the experiment, you should not store the chemicals like this, it is not allowed at all. So, and finally, you should never rub your eyes or touch your belongings wearing contaminated gloves. You always follow the MSDS data sheet. Do not pull your, do not put face or head inside the hood very, very important. You should never do this never. Do not use cell phone and be cautious when you use chemical hoods.

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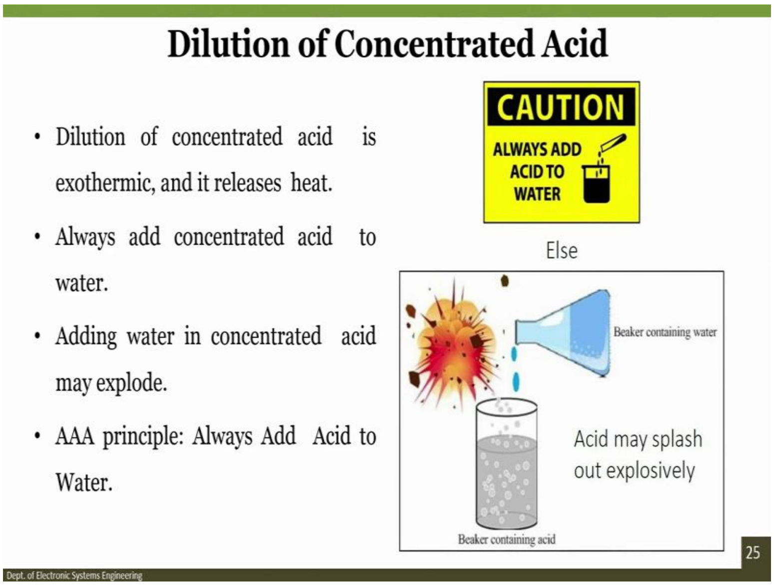

These are something that is very easy to understand that we have studied in chemistry. Dilution of concentrated acid is exothermic and it releases heat. That means you should always add concentrated acid to water, do not add water into concentrated acid otherwise it may explode and always I remember that AAA principle that means that always add acid, AAA to water. You should be careful while you are using the cleanroom environment.

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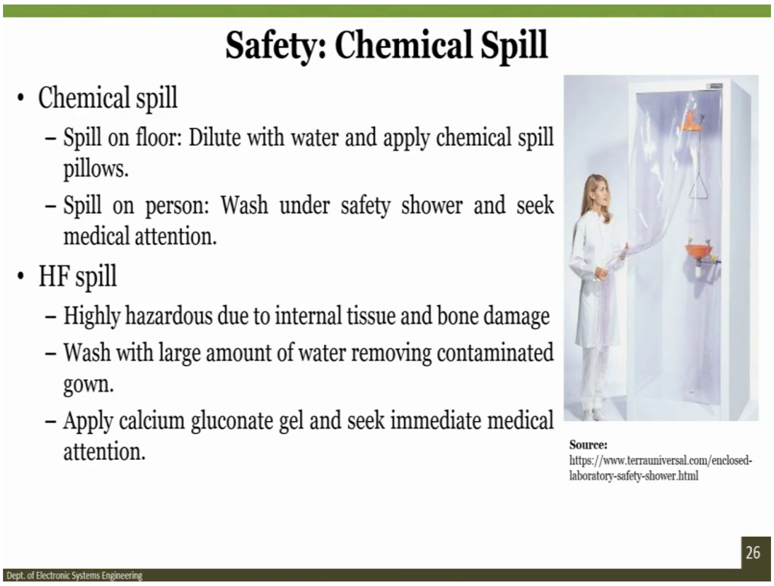

Finally, if there is a chemical spill, then there is a split on floor or spill on person, if the spill is on floor, then you have to use a dilute with water and supply chemicals, chemical spill pillows which are already available in the cleanroom, if there is spill on person, then wash under safety shower and seek medical attention.

The most important or dangerous spill is HF spill, HF stands for hydrofluoric acid and this spill is highly dangerous due to a internal tissue and bone damage, you had to wash with large amount of water removing contaminated gown and then finally, apply calcium gluconate gel and seek immediate medical attention.

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So, the last safety that we have to see is electrical safety. Now, I really want you to understand this thing because when you, when we will look at the cleanroom protocols and the fabrication process to for several devices. This all things comes at a later stage, first is how to work inside a cleanroom, what are the cleanroom protocols, what are the safety issues and what kind of safety that we need to take care of before we start looking at the experiments.

So, very important it is not only for this course, it can be applied for many, many courses. In fact, wherever you are working in your lab environment, make sure that all the safety issues are taken care of. So, you can see that as many of the tools use high voltage supply, practicing the electrical safety is extremely important.

This is absolutely not allowed what you see here, wet hand is there and we are using the power and then you can see there is a dangling wire, absolutely not allowed, cut wire not allowed, we generally try to do this things often we have seen, you may have seen, but this is not a good practice to use the multiple things from one single source. Particularly when it is like this broken, it is hanging it is not correct.

So, there can be danger when it says voltage you will see this kind of symbol, if it is electrical hazard, you will say this, if it is you have to keep out from electrical hazard then this is the symbol, then severe shock hazard is this one high voltage is this. No loose connection and then you have a hazard voltage. So, this is the symbol. So, the point is learning electrical safety and of course the all the other safety that we are discussing now is very important part of this particular cleanroom protocol. So, we had to learn that.

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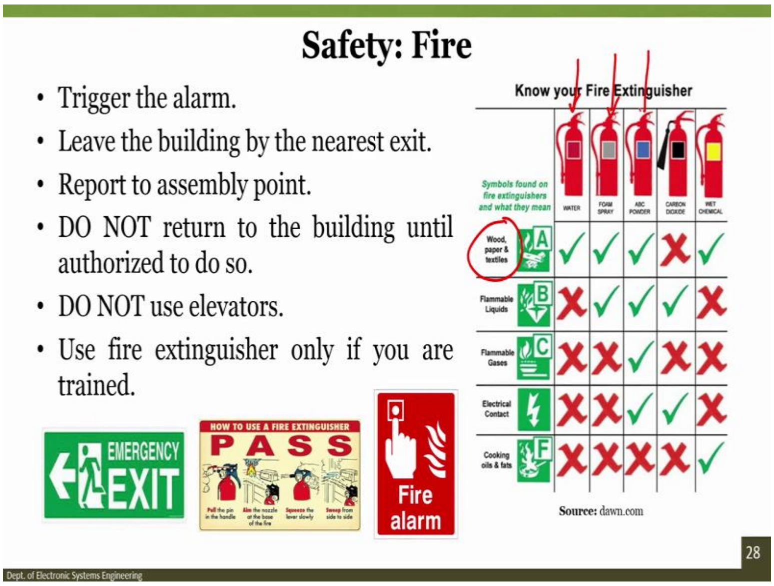

Fire safety all of you now, I am sure that you know it for those who do not know it, we cannot use the any kind of fire extinguisher to remove the fire to extinguish the fire. So, the point is, if there is a fire you have to trigger the alarm leave the building immediately, do not return to the building until authorized, do not use elevators, use fire extinguishers and in particular symbols found on the fire extinguisher and what they mean.

So, if you have a wood paper and textile kind of material that is on fire, then you can use the fire extinguisher which is your water, you can use the foam spray, you can use the ABC powder and you can use the wet chemical, you cannot use carbon dioxide, if it is wood paper and textile. Same thing, if I go for the flammable liquids, if flammable liquids catch fires, then I cannot use water, water is not allowed. I can use foam spray, ABC powder, carbon dioxide and wet chemical is not allowed.

Same way for flammable gases electrical safety and cooking oils and fats. So, all things are on the slide you can easily see, you can go back and look at the lectures and understand that how the things are done. Now when you use a fire extinguisher always understand this term called pass, P A S S, pass stands for pull the pin, then aim the nozzle and squeeze the lever slowly and sweep from side to side. So, this is how it is written pass P A S S.

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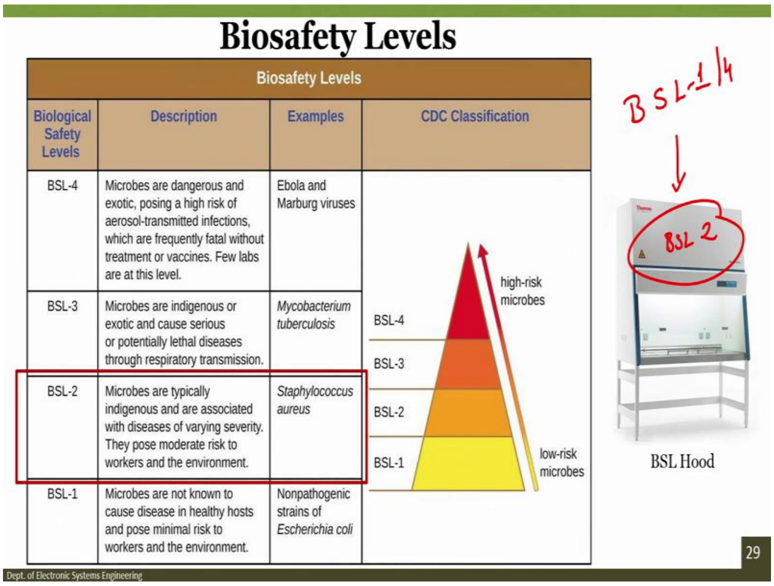

And then the very important point is biosafety hazards. So, when you work in a cleanroom, you see, you will see biosafety hoods. These are called biosafety hoods and its safety level is biosafety level 1, to biosafety level 4. So, you can see here, depending on the experiments that we will perform, we will show it to you how biosafety level, biosafety hood looks like. But it sends from BSL 1 to all the way to BSL 4, we what we will show you is BSL 2. BSL 2 hoods, we will show it to you as a part of this course.

And you can see that BSL 2 are microbes that are typically indigenous and associated with diseases vary in severity, for example, staphylococcus. If I have BSL 1, then I can use some strains of E. coli. But if I have a tuberculosis bacterium or it is called Mycobacterium or if I have if I am working with Ebola or Marburg viruses, then I had to go for BSL 3 and BSL 4 accordingly. If you want to use tissues, whether it is hard tissue or it is a brain tissue, you can use BSL 2.

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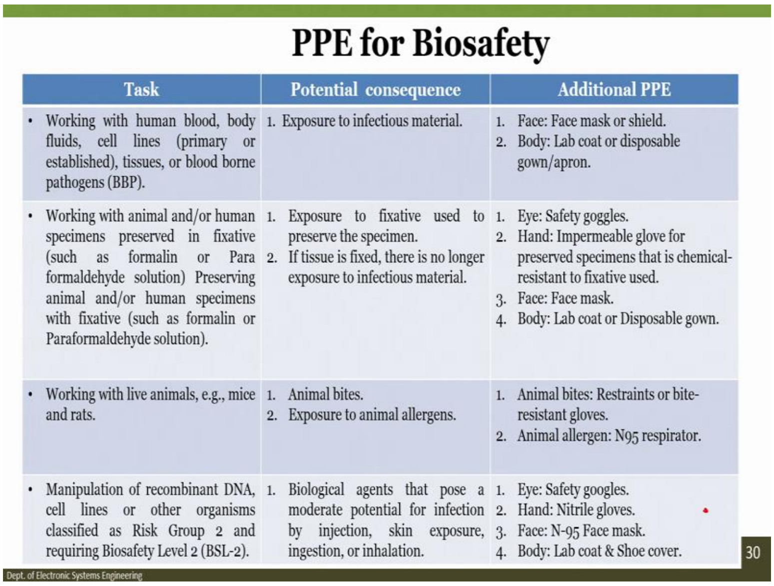

PPE for Biosafety

Task	Potential consequence	Additional PPE
• Working with human blood, body fluids, cell lines (primary or established), tissues, or blood borne pathogens (BBP).	1. Exposure to infectious material.	1. Face: Face mask or shield. 2. Body: Lab coat or disposable gown/apron.
• Working with animal and/or human specimens preserved in fixative (such as formalin or Para formaldehyde solution) Preserving animal and/or human specimens with fixative (such as formalin or Paraformaldehyde solution).	1. Exposure to fixative used to preserve the specimen. 2. If tissue is fixed, there is no longer exposure to infectious material.	1. Eye: Safety goggles. 2. Hand: Impermeable glove for preserved specimens that is chemical-resistant to fixative used. 3. Face: Face mask. 4. Body: Lab coat or Disposable gown.
• Working with live animals, e.g., mice and rats.	1. Animal bites. 2. Exposure to animal allergens.	1. Animal bites: Restraints or bite-resistant gloves. 2. Animal allergen: N95 respirator.
• Manipulation of recombinant DNA, cell lines or other organisms classified as Risk Group 2 and requiring Biosafety Level 2 (BSL-2).	1. Biological agents that pose a moderate potential for infection by injection, skin exposure, ingestion, or inhalation.	1. Eye: Safety goggles. 2. Hand: Nitrile gloves. 3. Face: N-95 Face mask. 4. Body: Lab coat & Shoe cover.

PPE is for biosafety. If you see that task was it potential consequence for these additional PPE, you will understand that what are the task and what are the potential consequence for which you require the additional PPEs? It makes no sense for me to read line by line, because it is very clear from here that you have to understand what are the tasks and what are the consequence and depending on that, whether you would like to have the additional personal protective equipment or not.

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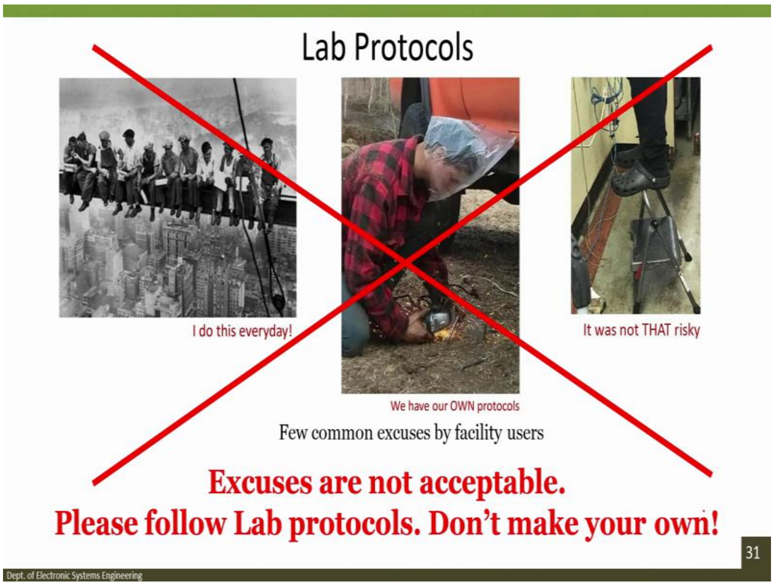

Of course, excuses are not acceptable, you have to follow that protocol and you should never make your own protocol. Some of the photos just to show that this is not a way to work.

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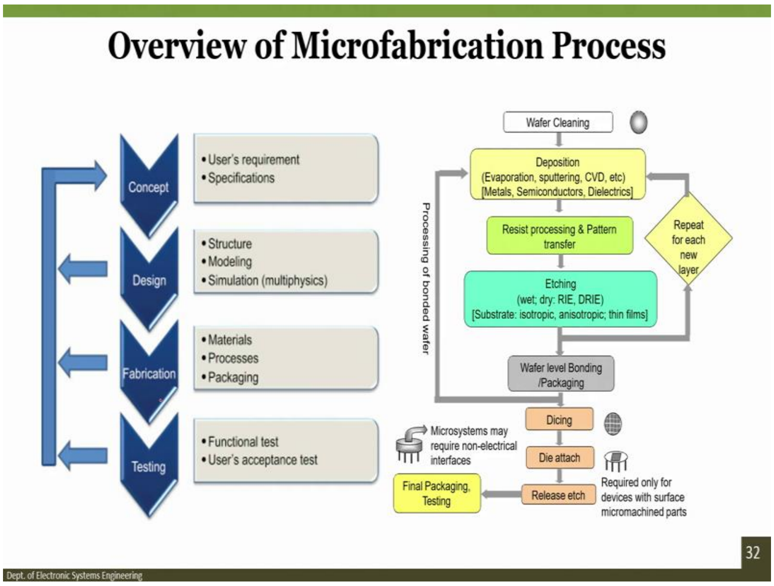

Finally, when we talk about microfabrication process, we will see several things right from wafer cleaning to the oxidation process, which is thermal oxidation process, then we will look at the deposition techniques. The photolithography technique, we will look at the etching, RIE DRIE and then by bonding, dicing, releasing and also we will understand right from concept to the fabrication to the testing and then once you have the device and use the device for certain application, let us say we want to understand the electrical, mechanical and thermal property of tissue, then what are the mathematical models that can be used for fitting the data, fitting the curve and those things we will take it at a certain point of time.

So, we will try to cover most of the things which are related to microfabrication process that are used to fabricate your devices and having said that, this is the last slide of this particular class. In the next class, we will actually start to use the silicon wafer and I will show you how we can, what are the process to fabricate those silicon wafers and also we will take the concept of photolithography and elect and the deposition techniques for metal deposition semiconductor division and insulator deposition and we will see how we can pattern different materials onto silicon substrate.

So, as to realize either sensors or transducers in detail. So till then you take care, look at this class, this is (more) mostly like introduction to the cleanroom protocol, cleanroom safety and the micro fabrication process. So, till then you take care. I will see you next class. Bye.