Electronic Materials, Devices and Fabrication
Prof. Dr. S. Parasuraman
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Madras

Lecture - 38
Clean Room Design and Contamination Control

Last class we looked at semi conductor process yield. Yield was essentially defined as the total number of wafers that come out divided by the total number of wafers that went in. The number of wafers that went in are of course the blank wafers. The wafers that come out are the finished or the processed wafers, we saw that they were three main kinds of yield. One was the wafer fabrication yield or fab yield. The next was the sork yield, which related to the number of good or functioning dies in a given wafer. Then, finally you had your packing yield, the overall yield is related to those of product of all three of the individual yields.

We also saw something about the total cost of manufacturing of a semi conductor and we found that yield is one of the important parameters that affects the variable cost of manufacturing. Lower the yield, which means lower the number good chips or good dies, then higher is the cost of an individual chip. So, today we are going to look at how the clean room design and contamination control is done in order to maximize the yield and minimize the cost.

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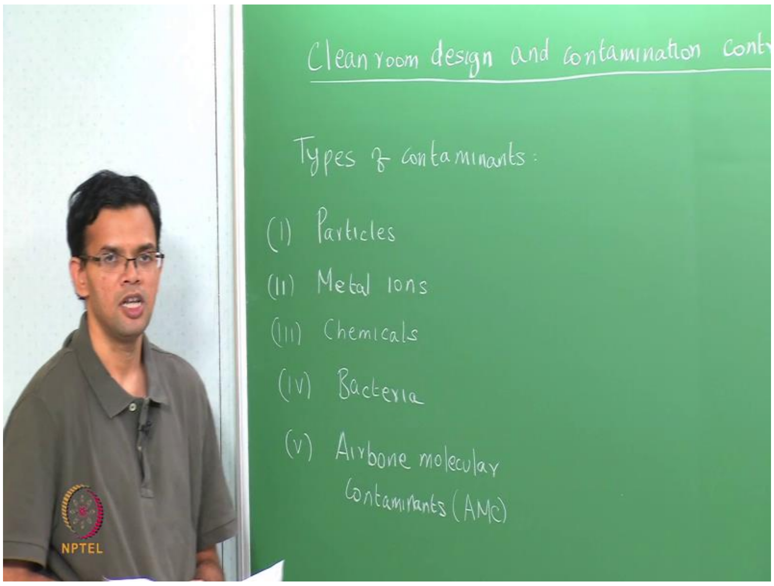

So, one of the most important factors that affects the yield in a fab is the wafer contamination, which is why we essentially go for a clean room. Now, this is especially important because we see the devised dimensions are essentially shrinking. So, when the IC's were introduced in the late 1960s, a typical device dimension was of the order of micrometers or even 100s of nanometers. Now, we have devices that are only a few nanometers across so that even contamination of the order of nanometers can essentially affect the device. So, in such cases, the design of the clean room and minimizing contamination in it is critical in order to make sure we have good functioning devices and to also increase the yield.

So, we look at clean room contamination, contaminants can be divided in to five main categories. So, the one is particles, then we have metal ions and we will see the role of each of them briefly, then we have chemicals. So, the process chemicals that are used bacteria and then finally something called airborne molecular contaminants or a MC's. These are essentially the five main categories under which contaminants are classified in, all of this has a potential for affecting the device performance, so let us one look at particles.

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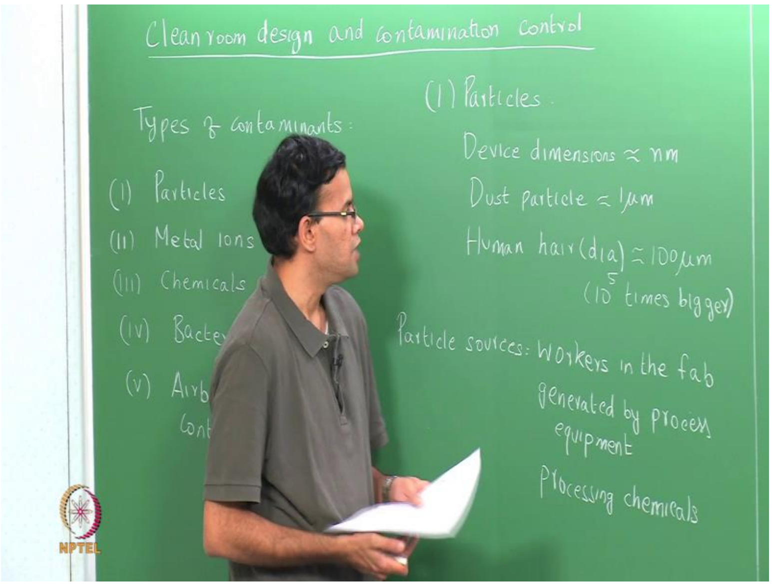

So, we saw that in the case of semiconductors, we have devised dimensions that are of the order of nanometers. So, we can compare that to the size of a typical dust particle. For example, if you have a dust particle, a typical size is approximately 1 micro meters, so already a dust is more than 100 time larger than the size of the divide. If you look at the size of the human hair, if you look at the diameter, this is approximately 100 micro meters which is 10 to 5 times bigger. So, the idea being that even small dust particles have essentially sizes that have much larger than the device dimensions. So, any of these contaminants can essentially affect a device, so what are some of the sources of particles in the case of fab?

So, the main source of particles is the people who actually work in the fab, so these are the workers this is one of the reason the special suits are owned by people working in the fab in order to minimize any particle sources. You can also have particles, they are generated by the equipment, so most process equipment essentially has metallic components. So, even a small thing like a metal screw that is rubbing against another surface can generate metal particles and these particles again will be of a size usually of few microns, which can again affect your device.

You could also have processing chemicals contributing particles, for example, if a chemical has some sort impurity or some sort of dust. So, this again can deposit on to the wafer and again contaminate the wafer.

This is one of the reasons why measurement in the case of a fab defect is really important using defect measurement. We can track down the density of the defects and also the size shape and chemical composition of the defect. So, this in turn will be used in order to find out the source of the defect. So, for example, if you have a metallic defect in the case of wafers then one particular source of the metallic defect can be the process equipment.

This is something that can be used in order to trouble should the equipment and to remove the source of the defect. So, generally when we look in the case of semiconductors, we said that the devised dimension is of the order of nanometers, which means particle levels show or particle sizes should also be smaller or of the order of nanometer.

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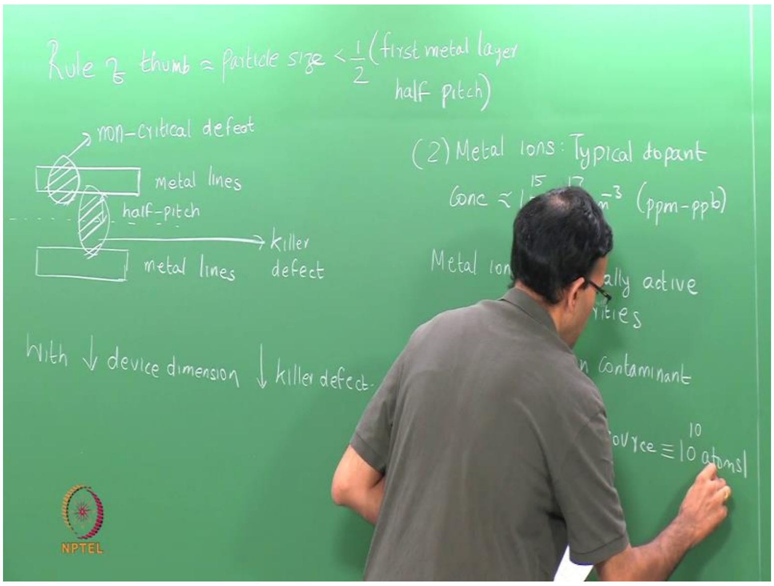

A rule of thumb states that the acceptable particle size must be less than half, the one metal layer half page. So, this sort of gives you the minimize size of the particles that have to be detected and have to be controlled, we can show the space small schematic. So, in the case of a semiconductor, we have seen that there are different levels of metallization the case of some of the newer technologies. For example, the 302 nanometers or 208 or even 40 nanometers, there are up to 11 layers of metallization, so the one layer metallization is what we used.

So, this represents the metal lines, the one layer of metallization is usually the highest density and as we go up the density of the metal lines reduces and the size of the individual metal lines will also increased. So, the distance between the center of the metal lines and the metal line itself it is your half page, so the size of particle should be less than half of the half page. So, this makes sure that the particles do not cause any shorting in the case of metal lines and performance of the device. If we have a defect particle here, this is essentially a noncritical defect because it does not cause any shorting.

So, these kinds of defects are, but the defect that essentially bridges, two particles can cause an electrical short, so this becomes your killer defect, so not only the defect size maters, but also the location of the defects. So, reducing future size or reducing device dimension, the size, if the defect or the size of the killer defect will also reduce, which means we should be able to detect and control these small defects. We will look at particles the next type of contaminants is you metal ions, so why are metal ions bad? The reason being off course their metals, so they have some sought of an electrical property, which can affect the electrical property of the device because you essentially building and electronic device.

We saw that the typical dopant concentration is of the order of 10 to the power 15 or 10 to the 17 per centimeter cube, this is in the parts per million or parts per billion range. So, any metallic defects with the concentration in the order of parts per million or billion or even higher in affect the electrical properties of the device and once again destroy our entire die. So, metal ions are essentially electrically active impurities, another name for them is a mobile ion contaminant or MIC. So, these usually have high mobility within semi conductor, so they can basically bury deep into semi conductor and affect the properties.

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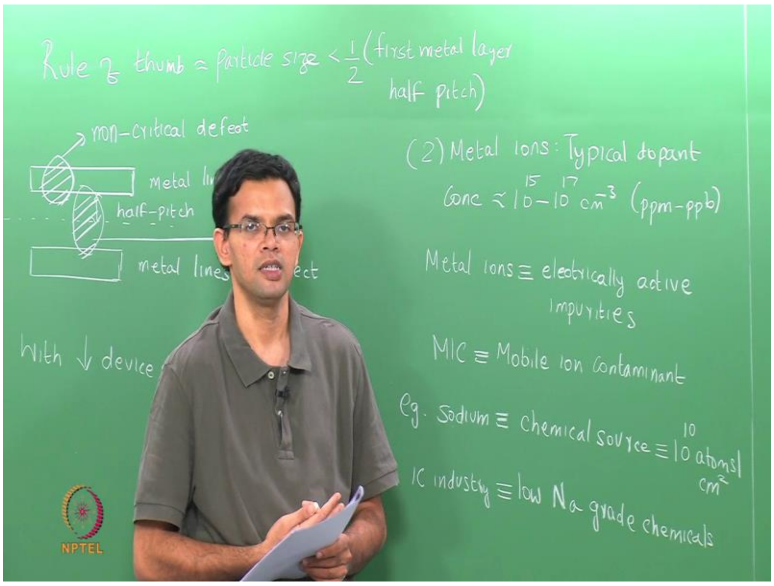

So, a most common form of a mobile ion contaminant is sodium, sodium is usually present in some of the process chemicals that are used for IC fabrication. So, the essentially have a chemical source and even a sodium concentration as low as 10 to the 10 atoms per unit area can affect your device and cause its electrical performance to degrade. So, for example for use in the IC industry, you have to essentially develop low sodium grade chemicals.

So, the regular purity of chemicals there are routinely used in other areas is actually not sufficient for the IC industry. So, we specifically in need chemicals that have low concentration of metal ions in order to reduce any contamination due to the metal ions, so the next classification of contaminants is your process chemicals.

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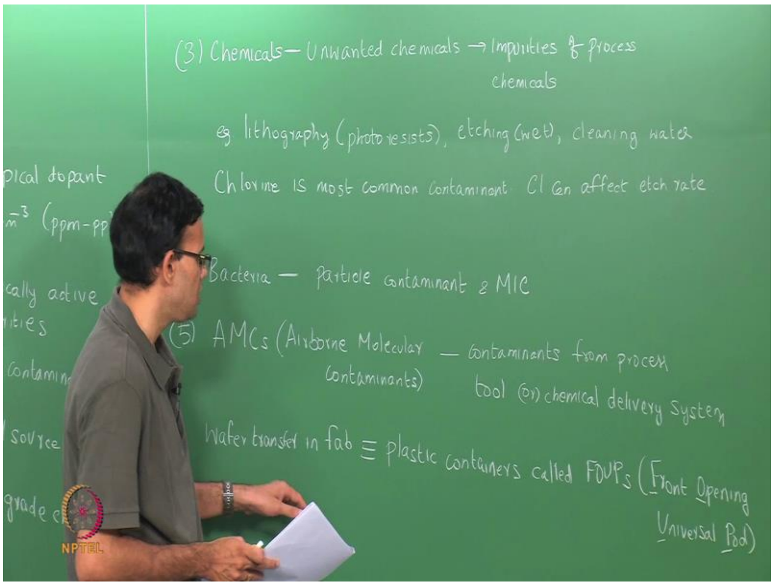

So, these are essentially unwanted additions or unwanted chemicals that add on to the regular chemical that you are using. So, these essentially act as impurities to the chemicals that are used in the IC fabrication. So, some of the common areas were chemicals are used are in lithography, where we used photo resist we also used chemical for etching. So, etching is to either remove layer of silicon or to remove any metal layer that is there in your sample. So, in etching, this is typically in wet etching, we also used water usually some sort of deionizer water is used for cleaning.

So, in all of these areas, any impurities the chemicals that are used can again affect the quality of the device and can again degrade the device performance and affect the yield in the case of chemicals chlorine is usually the most common contaminant. So, of you using a chemical for etching, chlorine can essentially affect the etch rate. Bacteria is another type of contaminant, so this essentially acts as a particle contaminant because typical bacteria sizes are again of the order of nanometers or more bacteria are also the shows of metallic ions something like sodium or potassium. So, they can also act as a mobile ionic contaminant, so MIC's the last is your airborne molecular contaminant or

AMC's.

So, as the name implies these are essentially airborne contaminants, so the component need not essentially come in contact with the wafer, but through the mini environment will see what mini environment is.

Later on, it can essentially contaminant the wafer, so these are contaminants that come from say the process tool they could be from the chemical delivery system. So, even the simple process of transferring wafers in a fab cause airborne molecular contaminants. So, wafer transfer in the fab, so in most commercial fab's wafers are not transferred by hand, so because these are essentially 12 inch wafers and they are typically transported in boxes of 205. So, these are transported in special plastic containers called foups, a foups stands for front opening universal pod.

So, it is an acronym for a front opening universal pod, so wafers are essentially stood and transported in these FOUPS, but once again these are plastic containers. So, any out gassing in them, it can cause airborne contaminants, so which can again affect the wafers. So, wafers are stood for a long time in this FOUPS when we will that they will be some sought of contaminants on this surface not all of these will be killer defects circular contaminants, but some of them have the potential to be killer defects.

So, usually some sort of nitrogen purging is done in order to minimize contamination, but this can cause additional issues with the purity of nitrogen. So, the point is there are different types of contaminants for wafers in the fab and all of these have to be minimized in order to improve the yield of the wafers. So, what does contamination essentially effect? So, we will look at some of the issues of contamination.

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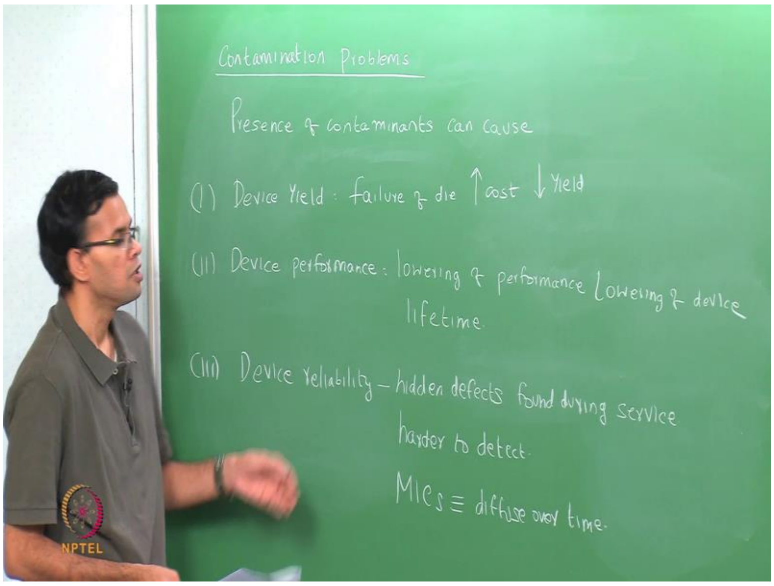

So, we will look at contamination problems or why is it essentially bad, so the presence of contaminants in your device can have three major effects. So, the one is, it can affect device yield this is straight forward, it can lead to the failure of the die and an increase in cost accompanied by a lowering of the yield, it can also affect the device performance. So, in this case, it leads to a lowering of the performance of the device, this is essentially bad when it happens over a time frame because it leads to a lowering of the device life time.

So, this is harder to detect then device yield, because failure does not occur, but the device does not perform at its optimum value. So, usually some sought of electrical testing can be done in order to device performance. So, this also can be measured and taken into account, but the most pernicious problem due to contamination is when it affects device reliability. So, these are essentially hidden defects, which are known only during the service of the device, they are much harder to detect because the device is still works.

So, yield is not an issue and the same time any electrical testing will also not show up these kinds of contaminants, but during the service of the device when the device is in operation can essentially cause failure. A common example of a defect that causes a device reliability failure is the mobile ionic contaminant MIC's. So, these can essentially defuse in to the device over time and can affect the properties. So, we have seen the types of contaminants we have also seen the typical problems that arise due to contaminants, so next we need to look at some of the sources of contaminants and how to eliminate this.

So, this is one of the reason by work in the fab is all carried out in a clean room in order to minimize the various sources of contamination. So, what are some of the general sources of contamination in the fab?

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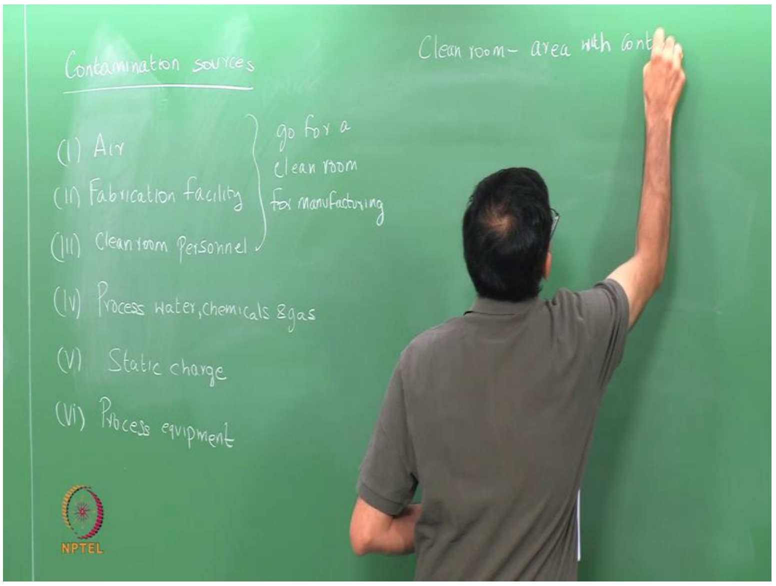

The first of course is the fab air or the fab atmosphere the fabrication facility itself can be source of contamination the clean room personal. So, people who work in the clean room would be source of contamination. The process chemicals and the process gas even the process water that is used is the source of contamination.

So, process water chemicals and gas static charge, so this is because most of the surfaces are essentially insulating were the rub against each other can cause a static charge which can again affects device performance off course process equipments. So, to minimize the contamination due to the one, three, which is the fab add or the fab atmosphere the fabrication facility and the clean room personal, we essentially go for a clean room for semiconductor manufacturing.

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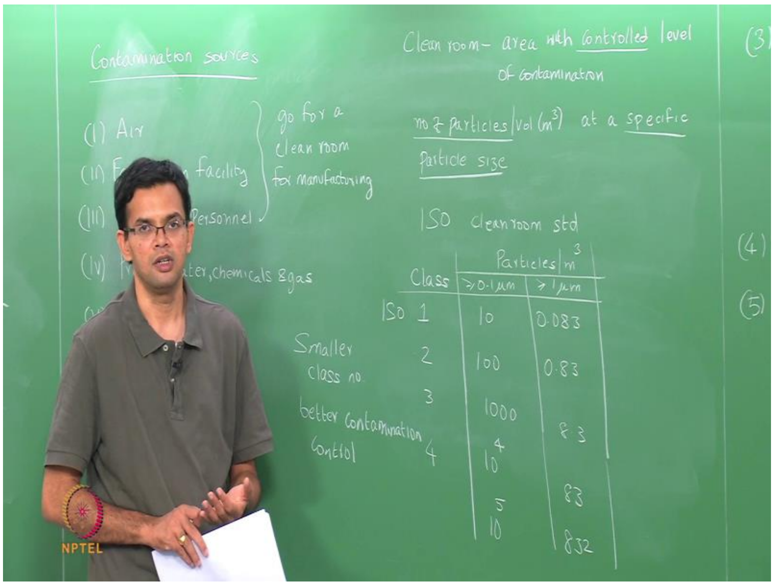

So, what exactly is a clean room, so a clean room is defined as in area with a controlled amount of contamination or a control level of contamination? The operative word here off course is controlled, so this is usually specified by telling the number of particles your number of contaminants per unit volume. So, this could be meeting a cube or feet cube at a specific particle size, so we not only mention the number of particles, but we also specify the size of the particles.

So, remember with increase in IC technology, we have smaller and smaller particles because we have smaller and smaller device dimensions. So, we need to have contamination or the defect sizes should be of the order of nanometers there are different standards the most stand common standard is the ISO clean room standard, which mentions the size of the particles. Based upon this, we have different classes of clean rooms we will talk about class, so talk about particles per unit volume. So, particles per meter cube and we also said that we need to specify the size, so greater than 0.1 micrometers which is 100 nanometers and then greater than 1 nanometer.

So, you can specify the class of your clean room either using a point 1 micro meter size particles or 1 micro meter size particles. Based upon this a class 1 clean room can have 10 particles whose size is greater than 100 nanometers and 0.83 greater than 1 micron a class 2 can have 100. So, this is essentially a log scale point 83, a class 3 can have a 1000 or 8.3 a class 4 can have10,000 or 83 and the class 5, this 10 to the power 5.

So, smaller the class number, smaller the class number, better your clean room cleanliness because the number of particles is smaller off course to achieve a smaller class number, we need better contamination control. So, different sections of the fab would essentially have different classes, so the section where the wafers are essentially exposed will have the smallest class number or the highest cleanliness. So, their different designs for the clean room in order to achieve these different contamination levels. So, there are different designs for the clean room.

The earliest design as called ball rooms design, so in this case, the wafer fabrication was done in chemical hoods, which was separated by clean room filters. So, hoods were used for fabrication and essentially wafers were transported from one hood when the processing is done to the next hood and this was typically done by hand because the wafer size is also small. So, within the hood HEPA filters and HEPA stands for high efficiency particle attenuations. So, HEPA filters were used within the hoods in order to minimize contamination, but usually the device dimensions in this case were of the order of micrometers.

So, contaminants sizes were also of the order of micrometers, so the ball room design basically gave way to the tunnel and bay concept, so in the case of the tunnel and bay concept physically different sections of the fab were physically separate by walls. So, the bay represents the clean areas of the fab and the tunnel represents the area between the base. So, within the tunnel were all the areas for doing any sought of maintenance work on the fab equipment, while the wafers themselves were only exposing to the bay.

So, this way the wafers were kept clean and contamination was minimized, so this in turn gave rise to the bay and chase concept. This is again based on the ballroom design, but instead of having a physically separate tunnel and bay were they were essentially walls the problem with walls is they would occupy space the fab was virtually divided into a bay and a chase. So, a bay again represents a clean area, while the chase represents the area that is not clean. So, based upon this we can look at it cross section of the fab still start from the bottom.

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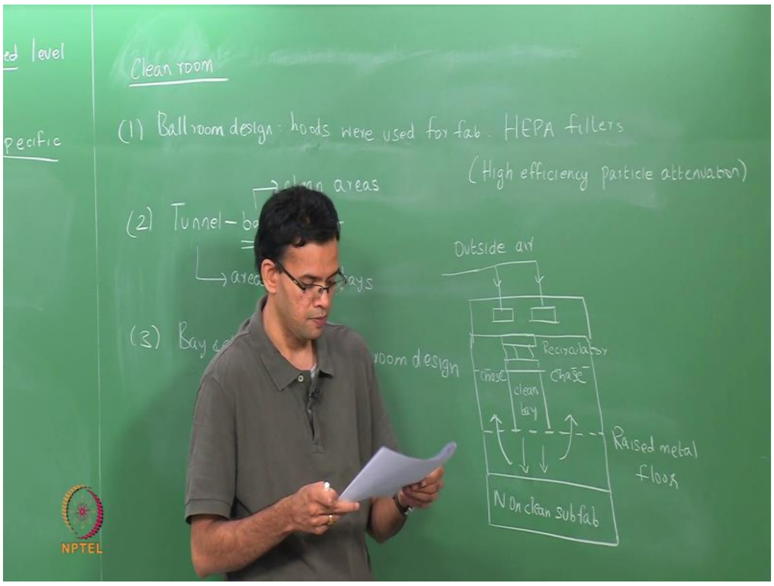

So, below the fab is a no clean area which called the sub fab. So, the sub fab usually has all the areas for the process chemicals that are stood all the cylinders for gas injection or gas supply. All of that is stood in the sub fab, there is a raised metal floor on which the fab is housed. So, this not a solid surface, but usually has some out of openings, so within the raised metal floor or above it, you have the clean bay and then you have the chase that is surrounding the clean bay right above the clean bay.

You have provision for flowing air through the fab and then there is recirculation for cleaning the air this is the recirculation and then outside air is entered in to the fab. So, the air essentially force down through the clean bay area, so the air goes down and then gets re circulated through the chase. So, the air flows down through the clean bay, so any contaminants are essentially blown down through the raised metal floor and then they go back up through the chase and are they taken out through the fab.

So, this way without having a physical wall, it is possible to maintain the cleanliness in the fab. So, we were having a bay and a chase concept it is possible to minimize the contamination due to the air and the fabrication facility. For fabrication facility and clean room personal, the wafers are not exposed within the fab, they are exposed in a region that is called a mini environment, which is usually an enclosed region which is just before the process equipment.

So, wafers are transported through FOUPS and this is done overhead and then there are

Roberts, who basically grab the FOUPS, then take it into the mini environment where the wafers are opened. So, this way the wafers are not exposing to the fab air or to the clean room personal and that way contamination.

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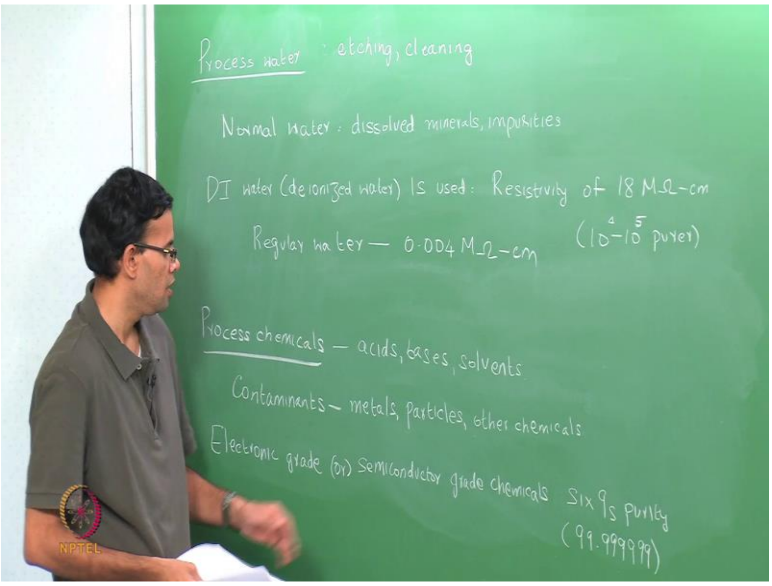

In the way one is minimized, another contamination source that we saw was the process water it is also related to the process chemicals. So, water is basically used for etching for cleaning etc and typically wafers arranged many times. So, a normal water source will have dissolved minerals and impurities. So, for clean room work de ionized water or DI water is used. So, this is water that has been removed of all of dissolved minerals or impurities and DI water is usually measured by its resistance. So, higher the resistance of the water, purer the value is de ionized water has a resistivity of 18 mega ohms per centimeter.

If we compare regular water has a resistivity of 0.004 mega ohms per centimeter, so de ionized water is typically 10 to the power 4 or 10 to the power 5 times purer. We also have process chemicals and we said that any contaminants in the chemicals can lead to contamination of the wafer. So, chemicals there are typically used are acids bases solvents like acetone or ethanol, IPA just isopropyl alcohol all of these are used typical contaminants in them can be metals can be particles can even be other chemicals. So, there are essentially established standards for process chemicals these are called electronic grade or semiconductor grade chemicals.

So, these are essentially chemicals with 69 is purity when we say 69 is 99 by followed by 69. So, we essentially need high purity chemicals not only chemicals, but also gases. In order to make sure that there is no contamination due to the process chemicals, not only the chemicals must be pure, but the chemical delivery system must also be pure. So, usually there is some sought of a bulk chemical delivery system called BCD that is set up in order to make sure that the chemicals they deliver to the various process equipments or all pure. So, we also have to look at cleaning of the wafer surface because these can also be a source of contamination.

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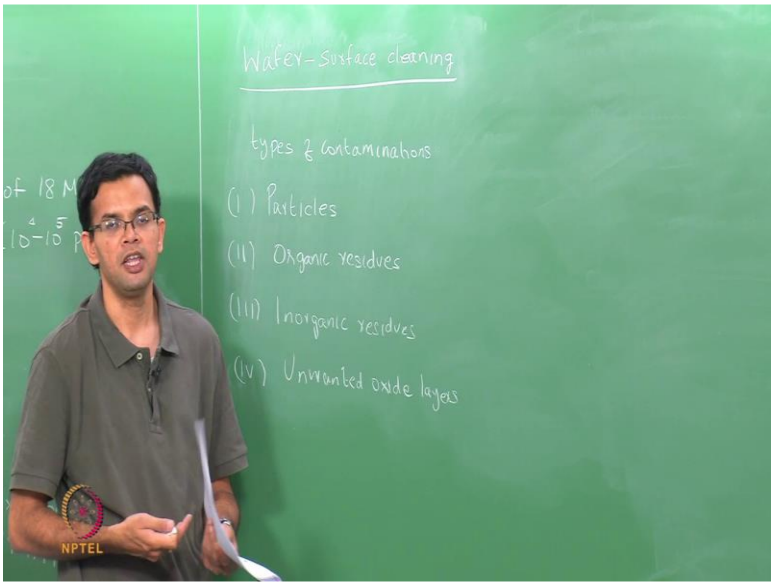

So, clean wafers are essentially needed for each and every step, so the wafer surface has to be clean at every step this again make sure that the contaminants to the surface are essentially minimum.

So, some of the types of contaminations can be particles organic residues, these essentially come from the chemicals that are used we can also have inorganic residues and unwanted oxide layers. So, typically these are silicon dioxide layers, so we have different cleaning strategies depending upon whether the wafer is located in the front end of the line FEOL, which is your front end.

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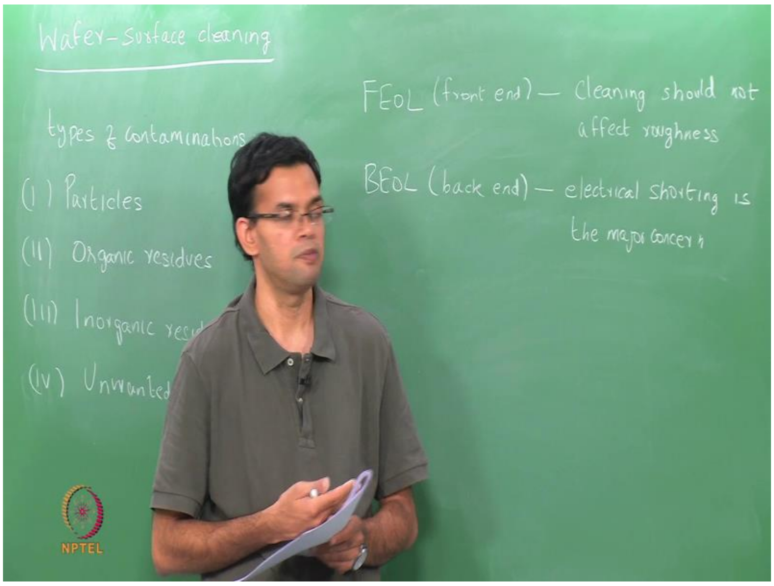

You also have the back end of the line, so we have different cleaning strategies for these different areas. So, in the front end the cleaning should not affect the surface roughness the front end of the line is where the various elements like transistors and diodes are defined, so that the cleaning should not affect the electrical characteristics of this in the back end. This is where the electrical and the metal lines are found, so electrical shorting is the major concern. So, wafer cleaning essentially involves some sought of particle removal usually by blowing air and then chemically cleaning the surface with mixture of acids.

Usually, sulfuric acid and hydrogen peroxide is used this is to remove any unwanted oxides sometimes h f is also used and then the wafers are again cleaned with DI water and then blow dried in order to remove any particles in other contamination. So, usually after some sought of chemical processes like say lithography or etching usually a cleaning operation is performed in order to remove the contaminants and make sure the wafer is clean before it goes on to the next step.

So, today we have looked at the various ways we can maintain the cleanliness in the fab. So, one way this is achieved is by choosing the appropriate fab design, but it is also done by making sure that we have three in process chemicals clean gases clean DI water and also by periodically cleaning the wafers during the fabrication process. So, in the next class, we are going to look at the various components of your integrated circuits. We saw that the integrated circuits essentially formed from various devices like diodes and transistors. So, we going to see how all these are fabricated and how they come together to form the IC circuit.