Particle Characterization
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Module No. # 6
Lecture No. # 17
Surface Adhesion:
Adhesion Force Measurement.

In the last lecture, we continued our discussion of particle adhesion forces. Previously, we had looked at van der Waals force of adhesion. In the last lecture, we looked at electrostatic forces of adhesion between particles, and between a particle and a surface, looked at the electronic double layer forces that result from contact potential. Also looked at the ionic double layer forces that apply for the particles that are suspended in solutions, where the zeta potential is what drives the forces of attraction and repulsion. And finally, we discussed surface tension based forces as well as hydrophobic, hydrophilic forces.

Since we have so many different adhesion forces that can prevail at any time, it is important for us to be able to measure the adhesion force. In order to, validate some of our theories, on particle adhesion and also obtain data; that is practically useful to us. Now, when we talk about measurement of particle adhesion forces, two ways - you can do it one is at a single particle level and the other is for a population of particles, that maybe decorating a surface for example.

So, our techniques for adhesion force measurement will clearly be different for the two cases, when we need to examine single particle adhesion forces. The first requirement is that we have to be able to visualize that single particle; we have to be able to zoom in on a particle and characterize, what force is required to make it move a way to look at adhesion force, is that it is equal to the first removal force, that is, able to dislodge the particle from the surface.

Therefore, essentially, instead of trying to measure the actual force of adhesion between the surface and the particle are between two particles, or between two surfaces. Instead, what we try to measure is? What is the minimum force that is required to overcome this force of adhesion, because you have to have perfect balance between the removal force and the adhesion force. In order to, reach that quasi steady state where the particle is essentially just bouncing on the surface; so that if the if the removal forces are even slightly exceeds the adhesion force, it will immediately dislodge the particle.

So, that gives us a convenient way of measuring particle adhesion force, because the force of removal is something that we can quantify, fairly, precisely and so without having to do molecular level measurements of forces that are binding two surfaces together. We can more conveniently measure the force that is required to drive them apart and thereby estimate the force of adhesion.

Now, in order to do this, you still have to develop a system in which the particle adhesion process itself can be controlled and simulated in a reproducible manner. In other words, you have to have a way of causing a particle to adhere to a surface in a manner, which is very predictable. The force of adhesion should be something, that is, repeatable and reproducible for multiple experiments and similarly, the force that you apply to remove the particle form the surface.

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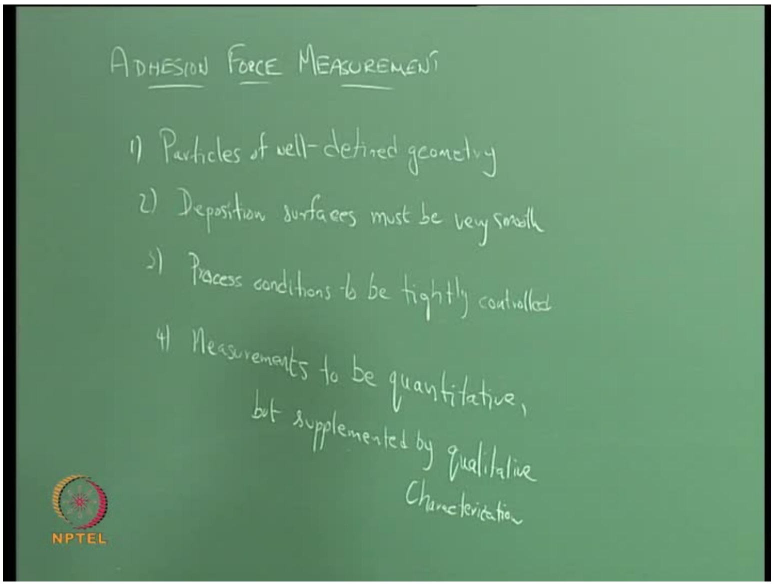

You must also be able to apply it in a very repeatable and reproducible manner. In order to achieve both of them, you have to really develop a set of requirements; that the surface as well as the entire system must satisfy, in order to quantify particle adhesion forces reasonably, precisely. Some of the minimum requirements for such a system are the following: the first thing is you need to be able to produce particles of well-defined geometry, as we have seen, before the shape of a particle has a distinct influence on its adhesion characteristics.

So, in order to characterize the adhesion force of a set of particles to a surface, you need to have reasonably good control over the shapes of the particles that are contained in the population. If you have wide variety of shapes, present in the particle population, then the distribution in the corresponding adhesion forces is going to be so much that you are never going to be able to really characterize a uniform adhesion force for that entire set of particles. So, well defined geometry is important and usually spherical particles are chosen. Because, it is a more convenient to obtain spherical particles and also the adhesion between a spherical particle and a surface does not depend on the direction of approach or the angle of approach whereas, if have a particle that is elliptical for example, you can easily imagine that depending on, whether the particle approach a surface end on or side on the adhesion forces are going to be very different.

So, some of those variables can be eliminated by using spherical particles, as your test particles. The second requirement is that - the deposition the surface on which you are going to study the adhesion characteristics must be very smooth. Again the reason for this is that as we have seen before surface roughness can have a significant influence on adhesion characteristics.

So, you really have two choices, you start with an highly polished surface that you eliminate surface asperity as a variable or try to produce very controlled surface distributions of roughness, in order that you can study the effect of surface roughness on particle adhesion, but in general to study adhesion characteristics of a particle to surface, it is preferable to start with a highly polished and smooth surface, so that you can eliminate the surface roughness as one of the variables.

The third requirement is that - all process conditions must be tightly controlled, what we mean by that is, that once you have prepared the particles and you have prepared the surface on which you are going to study the adhesion characteristic, you still have to deposit the particle on the surface, in order for the adhesion to happened and you can then study the force of adhesion.

Now, you will be using some transport mechanism. In order to convey the particles from the source to the surface on which you are going to study the adhesion characteristics that transport mechanism or process must again be very tightly controlled cannot be allowed to vary from run to run, so your flow paths that convey the particle to the surface must be maintain the same. The flow velocities must be maintained the same, if you have designed the system to have no thermal gradients then, you have to ensure that all experiments are done in the absence of thermal gradients. So, all these process conditions that can affect the delivery of the particle to the surface and the adhesion of the particle to the surface must be tightly controlled.

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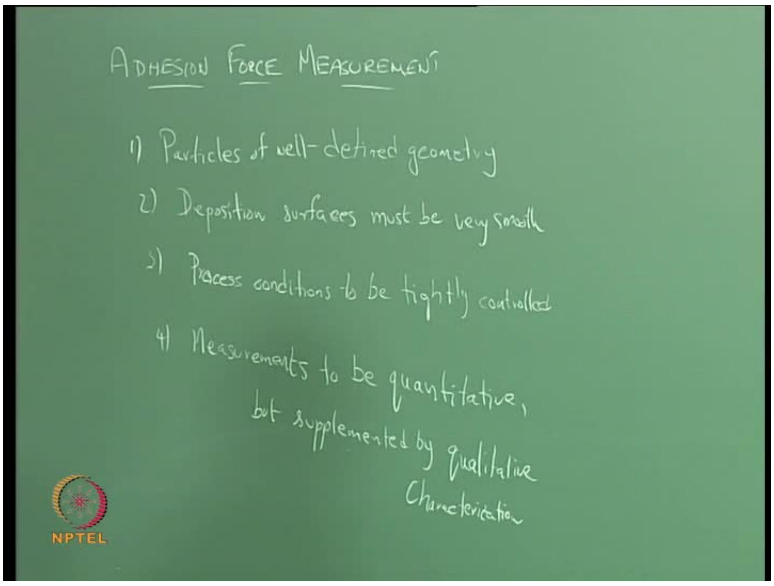

The forth requirement is that - measurements must be quantitative, but supplemented by qualitative characterization. As you can imagine, the simplest way to study particle adhesion forces would be to deposit a known number of particles of a known size distribution on a surface, count the numbers of particles on the surface; apply a certain force, see how many particles are removed, keep increasing the force until all particles are removed from the surface. Now, that is essentially, a quantitative method, what you are really doing is for every application of force you are counting the particles before and after and the removal efficiency of the particles and the corresponding force that has been applied, gives you an indicator of what is the adhesion force binding the particle to the surface. But sometimes, you can fool yourself, if you just look at quantitative data, because there can be many artifacts, when you are doing purely quantitative analysis, because what you may be counting as a particle on a surface may actually be a defect on the surface you know simple dimple on the surface you may be counting as a particle. Sometimes, it is important to not relay entirely on quantitative measurements but, actually do some analysis. Make sure that what you are counting as a particle is really a particle and not just a feature of the surface or material, that is part of the surface which has broken off or a simple hole in the surface, because all of these can fool a particle size analyzer or even a particle counter into thinking that these are particles. So, it is a very important to be open to doing auxiliary measurements that can conform your quantitative data.

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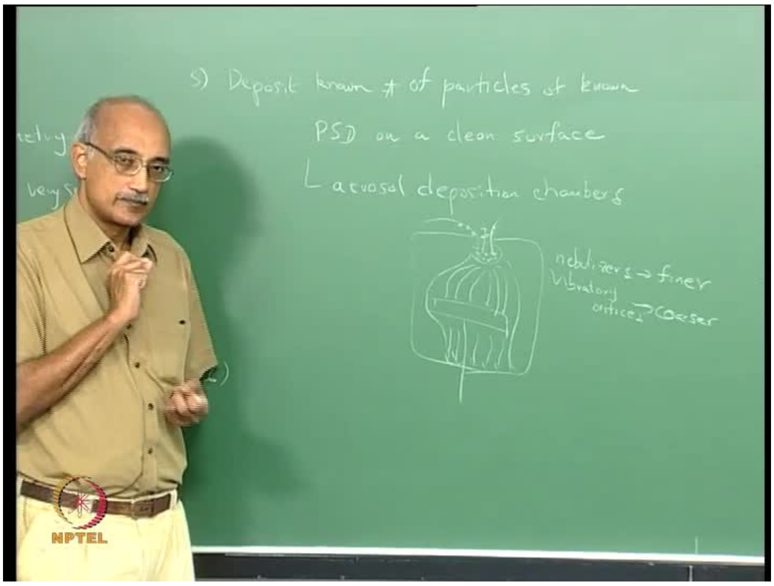

What are some of other requirements, you have to be able to deposit known number of particles of known particle size distribution, on a cleaned surface. So, before, you even begin your measurements, you have to ensure that the surface on which you are doing the adhesion tests very well cleaned, preferably to monolayer levels of surface films and particles and so on.

Because any contaminants or impurities that are present on the surface will interfere with your measurements and give you spurious data. So, it is very important to start with a very cleaned surface, for example, if you are conducting experiments on silicon wafers, you have to ensure that the silicon wafers is chemically cleaned and hatched. So, that it is perfectly cleaned before you start the experiments. And then, you have to deposit a known number of particles of known sized distribution. Now, that is not easy to accomplish, because a requires a supply of particles of a known size and known count. And as we saw earlier, when we were discussing particle counters there are certain materials like polyester in latex which can be prepared, in such a way you can either get mono dispersed materials or you can even get poly dispersed materials of the a cell.

But even if you have the supply, how do you again transport it and put it on the surface in a repeatable manner every time, because as you can imagine as particles become smaller and smaller their motion can become more and more difficult to control. So, you have to have fairly good flow system designs, in order to be able to deposit the same number and size distributions of particles on the surface every time. And in fact there are specialized equipment that have been manufactured for this purpose; which are essentially aerosol deposition chambers. So, these are specially designed and fabricated to ensure that particles are generated at a particular source and then they are transported and deposited on substrates that are mounted in the chamber, in an extremely repeatable and reproducible manner.

So, typically they would look like this, with a substrate being mounted at the bottom and there will be an inlet at the top, where the particles that you are actually planning to deposit on the wafer are introduced. The generation of these particles can actually be done in two ways - the particles can be generated externally and introduced into the chamber as a fine distribution of the particles along with some carrier gas or carrier fluid. The other way is to actually generate the particles here inside the chamber again in terms of control over the process the latter is actually preferable you actually want the particles or droplets to be nucleated within the chamber. Now, there are again specialized techniques to be able to do that nebulizers are used for this purpose, vibratory orifices essentially, the way these work, if you take a continuous film of liquid and you pass it through either a vibratory screen or a nebulizer typically uses an ultrasonic horn, they make the film vibrated very high frequencies. As they do the film breaks up into fine droplets in the case of a nebulizer, by changing the frequency of the ultrasound, you can change the size distribution of the droplet that you generate. And similarly, in vibratory orifices by changing the vibration frequency, you can generate droplets of the size that you are looking for typically the nebulizers are used to get finer particles compare to vibratory techniques, which are used to get coarser materials.

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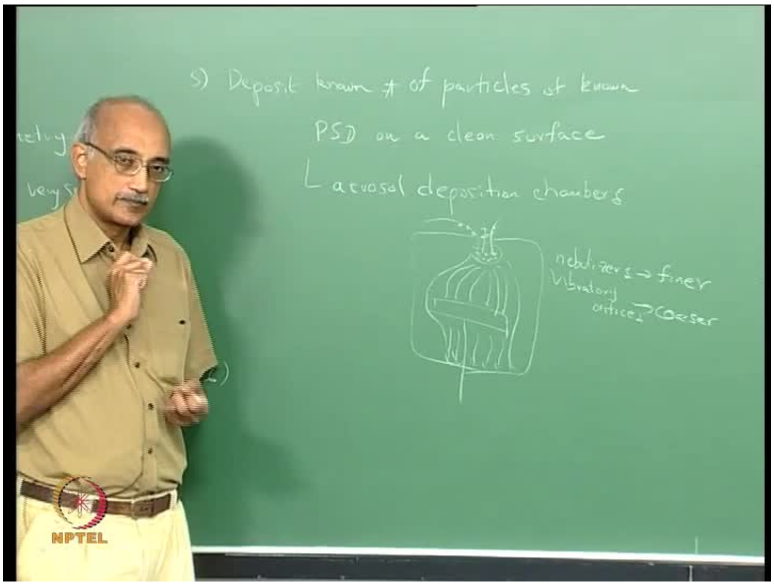

Now, in these chambers, it is what they do is they pay a lot of attention to how these particles are then transported to the wafer, on which you are trying to deposit them. So, the flow will be designed. So that it is laminar and it follows the same path every time so, that there is no intermixing of the stream lines, there is no turbulence, there is no recirculation there is no stagnation. Because, it is very important that establishes table flow in this chamber and we convey the same number and size distribution of particles every time to this substrate. Now, stream lines are good for transporting particles that are in intermediate size range, which follow the stream lines but, as we know particles that are much larger will not follow stream lines they will inertially impact if the strokes number is high enough.

And similarly, particles that are very very fine will not follow the stream lines, either because they will essentially follow a diffusional part; so they are very lightly to deviate from the stream lines. So, this strategy of using essentially a unidirectional laminar flow works well for the particles that are roughly in the point one to ten micron size range, but for particles that are smaller than point one microns are larger than one micron. Simply, relying on flow stream lines is not sufficient. So, you have to control not only the flow stream lines in those case. But, anything in the design of the chamber that can effect diffusional paths for example, when you talk about diffusion, even slight temperature non-uniformities can be sufficient to cause significant thermal diffusion to set in. Similarly, pressure controls are very important, if you are running the deposition chamber at a particular pressure, you have to maintain the pressure as precisely as possible. Because even small exclusions in pressure can impact both diffusional velocities, as well as inertial effects also, you have to ensure that particles when they leave the orifices are being delivered at a constant velocity, because especially in the case of larger particles, the velocity determines the impact potential to the surface. So, the output from the nozzles should be tightly controlled in such systems.

In order to ensure that the particles are delivered to the deposition surface in a repeatable and reproducible way, so, the sixth requirement is that in order for you to estimate the prevailing adhesion force, as I mentioned you can do it in two ways, you can look at individual particles and look at their. The kinetics of how they get dislodge from the surface or you can take a set of particles and define a mean adhesion force for the set of particles in the latter case what you do is you initially you clean the wafer you deposit a certain number of particles on the surface of known size and count.

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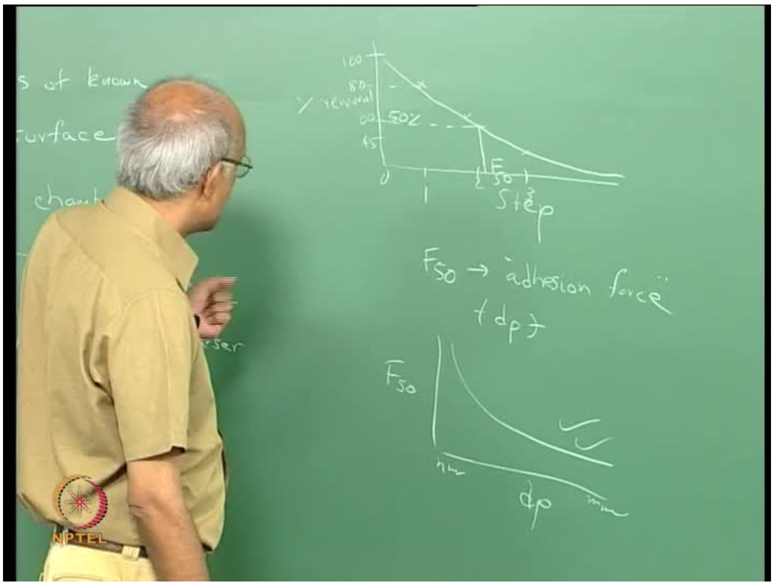

And then, you apply the removal force and you look at what percent of particles are removed. So, when you follow that technique essentially, what you will be doing is this will be your step in the process and this is percent removal. So, let us say that at time zero y start with some hundred particles on the surface. You apply your particle removal force, one time it may be something as simple as blowing air will talk about particle removal forces in more detail, later in this lecture in and in the next lecture, but you can imagine that if you are trying to remove a particle from a surface and you want to do it in again in a measurable and controllable way, you can just have an air nozzle and blow air across the surface at some velocity. So, let us say that is a removal step specific after step one you would have removed some particles.

And let us say, that now you are at 80, you take one more step and now you are at let us say 60 and you apply one more adhesion force now you are at 45 and so on so essentially you will follow some curve like this whereas, certain number of particles will be removed every time and this will typically have an acentrodic behavior typically, when you are trying to remove a particles from a surface, the efficiency of removal will be very high in the first stage of extraction and then it will quickly drop, because the particles that are easy to move would have been removed in the first stage of extraction or the particle removal. The particles are still left are going to be increasingly difficult to remove.

So, you will take something like this and then what you do is estimate, where this curve intercepts at fifty percent removal efficiency and you calculate the force required to remove fifty percent of the particles. Now, corresponding to each of these stages of particle removal you can estimate the amount of force that has been supplied to the surface. So, corresponding to the time that it takes to remove fifty percent of the particles of a certain size, you can estimate the corresponding force f fifty. Now, by convention f fifty is taken as a representation of adhesion force.

Now, obviously in terms of absolutely magnitude, this is not realistic, because when you apply this force, your are still leaving fifty percent of the particles, on the surface. So, consider it more like a half life definition this is what it takes to remove fifty percent of the material. The reason that we do not define f hundred as the adhesion force is that it might take a long time to get hundred percent removal and it is not practical to wait until you have removed all the particles in order to define a corresponding adhesion force. So, for practical purposes by convention by tradition, we take f fifty to be a representation of adhesion force. Of course, f fifty is very much of function of dp, as we were discussing in earlier lectures the finer the particle the more difficult, it will be to dislodge it from a surface even though adhesion force scales as particle size, but we know from empirical evidence that finer particles are more difficult to remove compared to coarser particles.

So, actually, if we take this parameters f fifty and you plot that against dp, what kind of curve would you expect, as the particle size get smaller, the force to remove it becomes larger. In fact this is the kind of curve, you will except the force to remove fifty percent of the particles will increase exponentially as particle size drops.

So, in our nanometer sized particle compare to, let us say, a millimeter sized particle will be almost infinitely more difficult to remove from a surface. Hence, the challenge of particle removal from surfaces many of the techniques that we normally use like wiping or vacuuming or dusting or blowing with air all of that works well for particles, that are in this size range. Where it is reasonably easy to remove particles from a surface, but many of these methods will not even be slightly effective, when you talk about particles in the nanometer or even micrometer size range. So, this is how we characterize adhesion of particles on a surface. Now, one of the questions is how do you estimate this percent removal.

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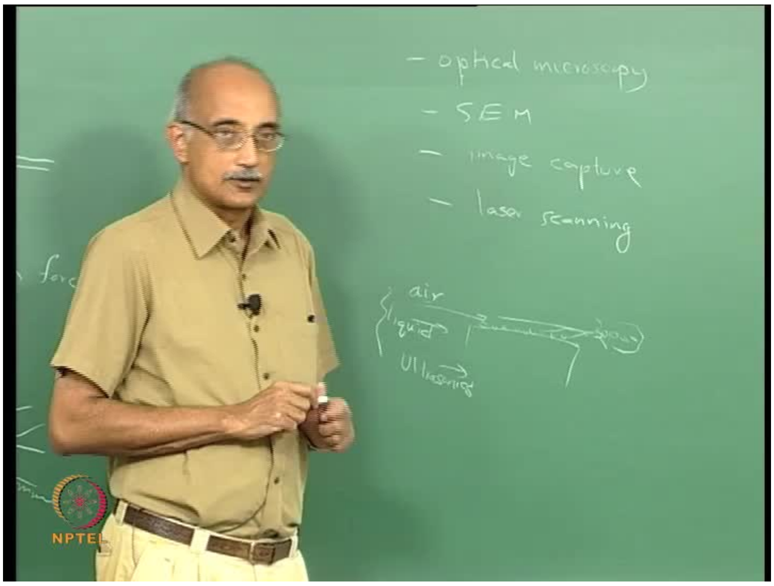

What techniques are available for you to do that, well we have examine some of these techniques earlier. So, for example, optical microscopy, scanning electron microscopy, image capture techniques, laser scanning. Some of these techniques work well for single particles and some of them work well for assemblies of particles for example, an optical microscope is very conveniently used to look at a a fairly large surface for example, you know, if you are looking at particles that are coating this entire substrate and then you wash it with water right and you want to know, how many particles are still left, how would you do it by you can just look at it, if the particles are big enough, but if you want to be able to tell whether even they are finer particles have been removed, you will probably take a magnifying glass right and just go over the surface.

So, for a large surface and for course particles an optical microscope would do fine scanning electron microscope. On the other hand, would be required, if you are looking at how individual particles are getting dislodged from a surface or if you want to know, how particles in the one micron size range or getting remove from a surface.

So for example, if you again have a semiconductor wafer and you are worried about impurity particles on the wafer, and your critical dimensions are of the order of point one microns. Then you really need to know how well the particles in the point one micron size range or adhering to the surface. So, in that case, you will have to use a scanning electron microscope to do the characterization. Image capture and laser scanning, we talked about earlier as two essentially alternative techniques to look at particles on a surface. In image capture it works very well when you are trying to do this experiment on particle adhesion, because essentially you take a surface you will deposit particles on it take a photo right and that is your reference.

When you apply a certain force to the surface and after the force has been applied, take another photo or image and then do an image compression. There are software that can do this, you know automatically for you and they will quickly tell you it is based on comparison of subsequent images; what percent of particle that where present, initially still the main after the cleaning process has been applied.

So, image analysis, image capture and analysis gives you a very convenient way to characterize particle adhesion. Laser scanning, on the other hand is certainly improves a sensitivity and the resolution of the method, but it does require that you look at light scattering characteristics form a surface again before and after application of the cleaning step, so laser scanning works well when you have a highly polished and smooth surface, where the surface itself is not going to interfere with your measurements. But it does not works, so well when you have for example, a silicon wafer on which you have already put down a pattern, you know some circuits, some conductive paths, some semiconducting paths, and so on because once you have put down these features on the surface they act as noise in the measurement and they actually interfere with your ability to measure the signal, which is the particles that have been deposited and removed from the surface. So, all these techniques are semi qualitative, because they can also give you a pictorial or visual representation of how particles adhere to a surface and how they are removed from the surface.

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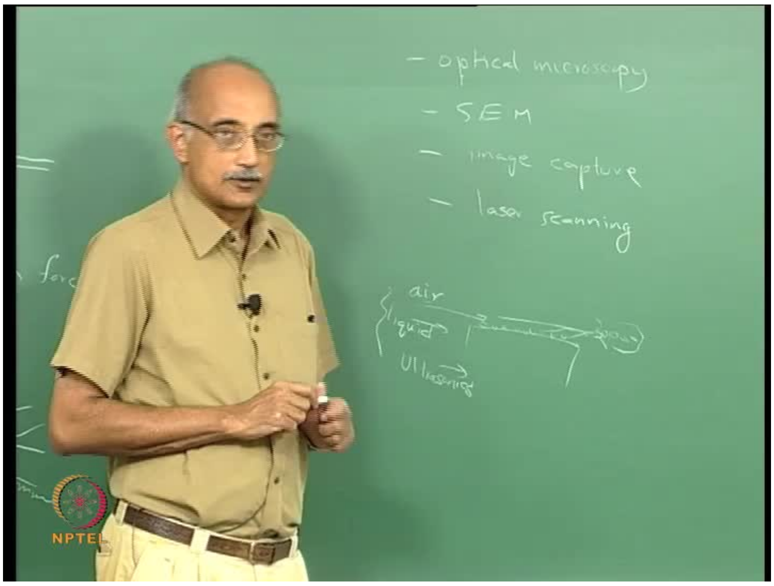

They are also quantitative in the sense that they will enable you to count and obtain removal efficiencies but, there are other techniques which are much most conveniently used if you are only interested in doing counting for example, once you have let us say that this is your wafer and on this you have deposited a known number of particles of a you know known size distribution. And now, you want to apply a force to remove the particles right let us say, that what you doing is just taking compressed air and blowing it have blown air for a certain period of time. Now, in order to look at the extraction efficiency there are two ways in which in which you can do it you can look at the surface before and after or what you can do is the air that comes out after it is pass through over the surface, you can count particles in the air right. So, it is a much more direct measure. So, some of these particles would have become air bond and now they will be suspended in the air stream. So, you can actually compare the count of particles that have become air bond to the counter particles that were on the surface to begin with.

Obviously to the ratio between these two is related to the adhesion force the stronger the force of adhesion the fewer will be the particles that become air bond for a certain pressure and velocity of air passing over the surface. Alternatively, you can do this with for example, liquid spray, you can imagine again a surface like this and you want to know how many particles there are, instead of trying to measure the particles on the surface before and after, you clean it with a liquid and then collect a sample of the liquid and count particles in the liquid. Now, the requirement here is the fluid itself must be pure before you blow it on the surface or you spray the surface with it because what you are looking at is the delta.

How many particles were in the fluid to begin with, and how many particles are there in the fluid after you have used it to remove particles from the surface but, if you have the ability to do that if you have the ability to supply clean fluid and actually quantify particles that have been entrained into this fluid, then the delta will tell you how many particles have been loosened from the surface and entrained in the fluid and that would be an indirect measure of the adhesion force of the particle to the surface.

Another extension of this and again we will talk about this in more detail later on is ultrasonic’s. As we will discuss later ultra sound is a way of removing virtually hundred percent of the particles from a surface regardless of their size. Ultrasound is the only mechanism that can remove particles that are as large as the particles that are small as a nanometer. So, here again essentially, the way you do this is take the surface immerse it in an ultrasonic medium remove particles from it by turning on the ultrasonic’s and then look at particles that have become entrained in the liquid.

And that gives you a measure of how strongly they where adhere to the surface to begin with. So, there are many different ways to measure particle adhesion forces to a surface and you can be as basic and fundamental, as you like or you can be as apply them practical, as you like the way that you actually measure particle adhesion force to a surface to large extent depends on your own application what are you trying to achieve by measuring the adhesion force.

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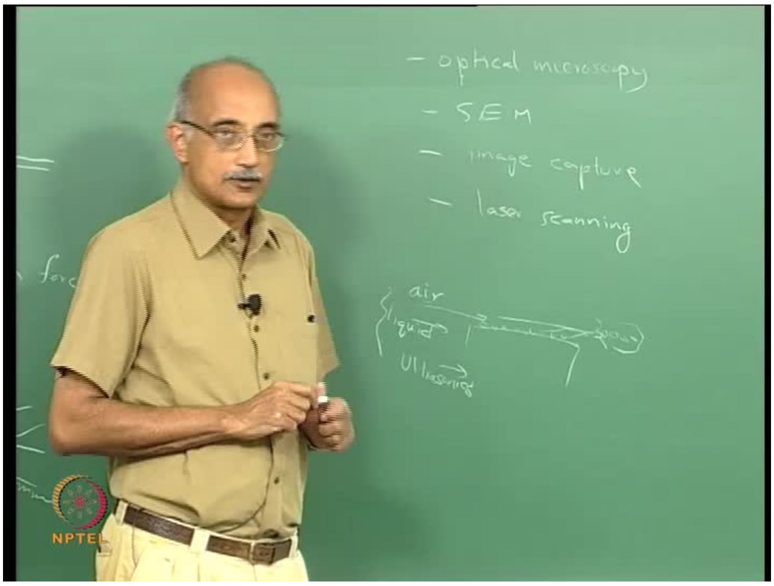

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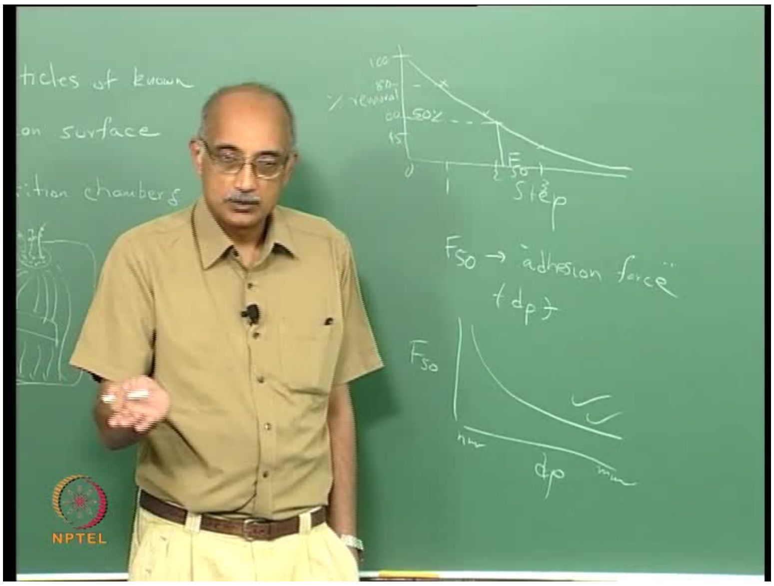

What level of information do you need you need to know how every individual particle sticks to the substrate that you are interested in or you just want to have a feeling for the overall adhesive nature of the particulate assembly or powder that you are dealing with, so depending on your needs you can essentially customize your method of measuring. The adhesion force now one of the things that is obviously central to our discussion is the removal force itself because the you know going back this curve where we have plotted the percent removal as the function of removal force, you can imagine that depending on how you apply the force the results may be very different.

For example, the same magnitude of force can be applied by scrubbing the surface with the brush or by directing pressurized air on to the surface or by doing sonication you can, you can, tune these so that you get the same magnitude of force, however what you will find is that the particle removal characteristics are very difference in these cases because they all act differently on particles of various sizes.

So, one of the things to keep in mind is this definition of adhesion force by measuring the force required to remove the particles is also dependent on the technique that you use to remove the particles from the surface. So, this f fifty that you have estimated at your adhesion force is not a unique number, it will actually depend on the method that you have used to remove the particles from the surface. So, clearly the particle removal method also play as a significant role in determining the adhesion force of the particle to the surface but, also in a in a practical sense.

If you have a critical application in which you cannot tolerate particle on a surface and you have remove the particles completely, what type of cleaning method do you apply what particle removal method would you apply the selection of the particle removal technique depends on many factors the nature of the surface is very important for example, if you have a surface that is very delicate you really cannot apply excessive force to it.

So, you have to be very gentle in your cleaning process, on the other hand if you have a metal and which can withstand fairly high forces, then you can imagine doing high pressure spray cleaning or brushing with a metal brizzles or using ultrasonic cleaning. So, these are aggressive cleaning methods to remove particles from surfaces, which you cannot apply.

For example, if you have a plastic or a rubber or paper you know, if you are trying to remove dirt from paper would be able to spray it with water, no because it will totally destroy the paper right. So, you have to match it, you have match your particle removal method to the substrate from which you are trying to remove the particles the geometry also becomes important, if you have a flat surface the way you would remove the particles from that would be very different compared to the methods you would come up with to remove particles from more complex surfaces.

If you have a lot of hidden features or recesses in the in the material then for example, as simple air blow off might not work because, it may remove particles from the flat portions but, it probably would not enter into let us say you have screw holes, you really cannot remove debris from screw holes just using compressed air, we have to come up with the different technique to be able to do that. So, the material, the physical characteristics; as well as the geometrical features and of course, the chemical characteristics as well if you have a substrate that reacts with a certain solvent when you cannot use that solvent to remove dirt from that surface, right for example, if some if you have a material, which oxidizes in water, let us say magnesium or aluminum, you cannot use clean magnesium surface, using water because, you will immediately form magnesium oxide, which is almost an explosive reaction same thing with aluminum, if you run water over aluminum, it will immediately oxidize and form aluminum oxide and if you do not want that then you really cannot wash aluminum with water, right.

So, all these aspects of the substrate have to be taken into account, when you are trying to define a method for removing particles form a surface and similarly, the nature of the contaminant must also be taken into account is the contaminant we are trying to remove something that is native to the material or it is something that is external.

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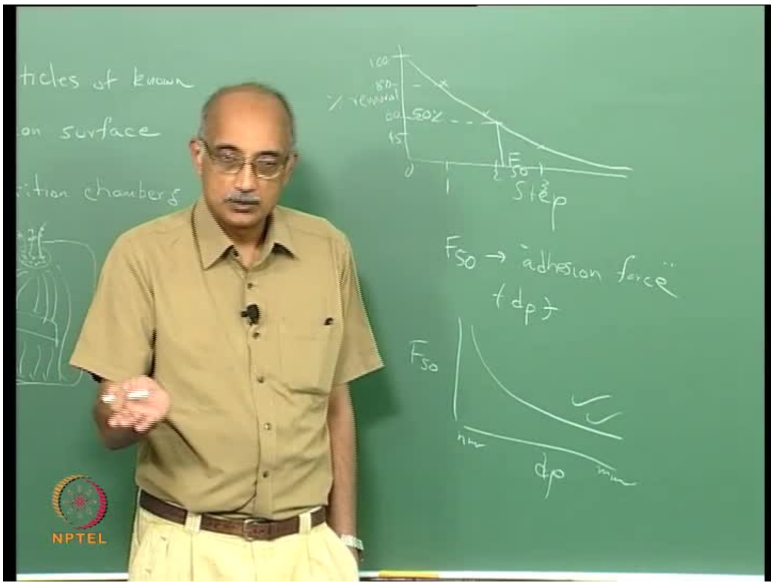

For example, again if you have a metal surface, the metal particles that are left over from when that metal surface was fabricated, themselves act as an impurity that you can remove but, that would it take a very different process compare to if you are more concerned about removing dust and debris that has collected on this metal surface as an external contaminant or impurity.

So, depending on the nature of the particle that you are trying to remove you have to customize your removal method and this again goes back to the adhesion force. The particles that are native to the metal or material or likely to be more strongly adhere to the surface. Because these particles were probably generated during the original manufacturing process of that component, whatever it is. Whereas, particles that are external, which are deposited or likely to be loser I mean dust for example, when it accumulates on a surface it is very easy to clean, right, but if the particle is something that was on the surface to begin with from the time, it was molded or machined then it is very strongly adhered to the surface and it is going to be very difficult to remove.

So, the particle removal technique that you choose must match not only the substrate from which you are trying to remove the particle but, it must also reflect the nature of the particle that you are trying to remove from the surface. So, these are two important considerations. The third important consideration is how clean is clean, you know when we talk about particle removal from a surface cleanliness is not an absolute value I mean I am sure you have heard the saying that cleanliness is in the eyes of the beholder, right, more functional representation of that is to say that a surface must be as clean as it needs to be you can never achieve zero particle levels on any surface, because nature is against you.

Let’s say that you take the surface and you clean it and you clean it and you actually achieve zero level of particle down to let us say .001 one nanometers, right. How long is it going to stay that way not even for a nanosecond, because as soon as you have completed your cleaning process nature is constantly depositing more material there, so you will never achieve a perfectly clean or zero particles substrate. So, you have to determine what do you need for your product you know if you are making a hard drive may be you need to have a surface that is very pristine, on the other hand if you are supplying chairs to a classroom, how clean does it needs to be, right, it needs to be clean enough that people are not going to look at it and see lots of junk on it.

But as long as you get rid of the visible contaminants you are happy. Right. So, the definition of how clean you need to get the surface again determines the nature of the cleaning process that you apply to achieve the cleanliness level and the forth aspect is you have to have a quantitative measure of cleanliness, you cannot base it on subjective evaluations again there is a saying by lord kelvin that you cannot control what you do not measure.

So, if you have no way of quantifying particulate levels on a substrate or in a fluid then you really cannot control the particulate level either, so control optimization elimination all of these requires the ability to measure quantitatively. So, even before you start developing a process to remove particles form a surface, you have to decide how are you going to measure the residual particles on a surface, what technique are you going to use because a technique that you choose will again decide the method that you choose to remove particles if you are going to be using a scanning electron microscope to identify whether or not there are particles on a surface.

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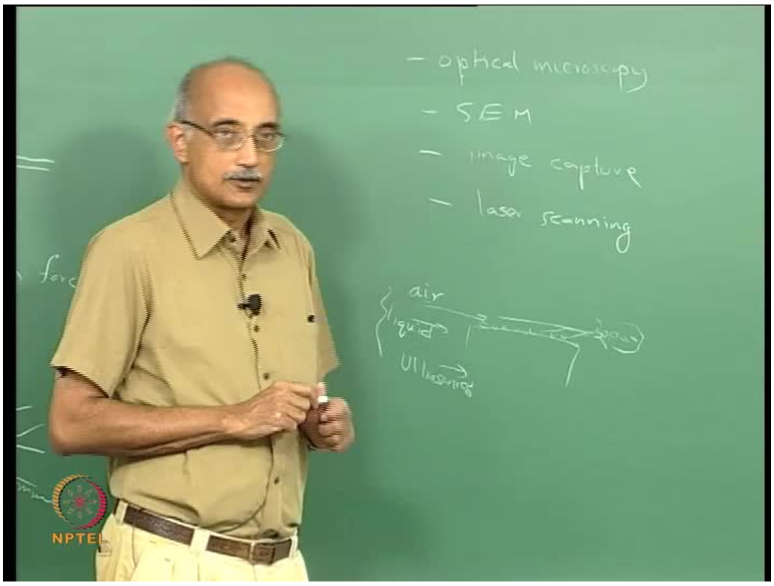

Then you have to use a very aggressive cleaning process, like ultrasonic's in order to get the surface to be clean enough for s e m inspections. On the other hand, if i just going to do a magnifying lens or naked eye inspection, then just doing something air blow off or wiping or vacuuming may be sufficient. So, these are all considerations that you have to take into account when designing a process to remove particles from a surface. The other thing to keep in mind is there are essentially, two classes of particle removal methods dry and wet. A dry process for removing particles is simply to take a dry wipe and just wipe the surface you know for example, when you take this duster and I remove the chock writing from the blackboard that is a dry cleaning process, right. Because the particles from the chock have been transported and they are adhering to this blackboard and when I just use a wiper all i am doing is just applying a dry force to remove the particles from a surface and this can easily see dry removal is never a hundred percent - right - it is not it is not a very efficient process.

Now, if i had a wet wipe and i had done the same thing the surface would be much cleaner after i am done with it. so, in general wet cleaning processes tend to be a lot more aggressive and much more complete compare to dry cleaning processes but, what is a negative why wouldn’t you just use wet cleaning everywhere.

Well, the biggest problem is drying because by definition, when you use a wet process you have to then dry the surface you have to somehow remove the residual liquid from the surface. Now, in a case like this, we can just wait for ten minutes and the water will be completely gone but, when you are running a manufacturing process and you are pushing out product on a twenty four by seven schedule you cannot afford to wait.

So, the drying step can become a rate limiting step for your production. So, you have to be very careful with it and that is why even though people are aware that wet cleaning works much better than dry cleaning, if a dry cleaning option can be made to work for your process and your application. It is much more preferable than investing in a wet cleaning process plus there are lot of issues about chemical compatibility and so on. Which you can avoid if you use strictly mechanical processes and dry methods of particle removal, now even when we talk about dry methods of removing particles that is of huge variety to choose from you know simplest you can imagine is scrubbing with a brush or vacuuming a surface or wiping with a dry wipe or blowing air on a surface or blowing nitrogen or some compressed gas is another method to do it there are also more sophisticated techniques of dry cleaning.

Such as laser cleaning, plasma cleaning, and so on in terms of wet cleaning, again you have a huge variety of methods, you have everything ranging from simple wet wiping to soaking in water use of surfactants and detergents spraying with water and other liquids and techniques, finally, such as ultrasonic's and megasonic's and so on.

Each has different characteristics each has its own strengths and weaknesses, what we will do in the next lecture is talk in the little more detail about, dry methods of particle removal from surfaces and wet methods of particle removal from surfaces. And we will try to point out the advantages and disadvantages of these techniques for removing particles over a very wide size range, you know there are applications that are required to remove millimeter size particles and there are applications that are required to remove nanometer sized particles and you have to customize the or particle removal technique to what the demands are.

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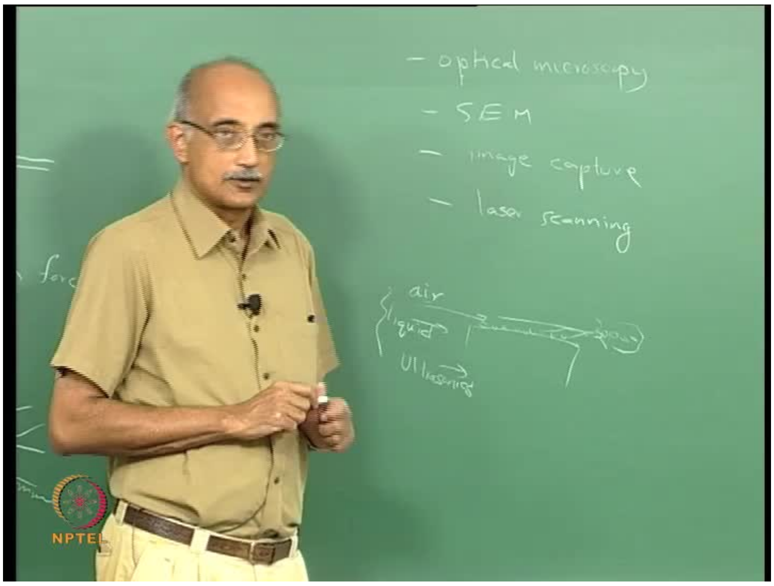

So, we will discuss that more detail in the next class. Any question on what we have talked about today?

Yes sir, plasma cleaning is the same you charge the particles (( )).

You know actually charge the gas, when you expose the surface to the gas the plasma interacts with the impurities on the surface it typically vaporizes it, for example, if you have a hydrocarbon on the surface, when you expose to a plasma it converts a hydrocarbon into CO_2 and $H_2 0$ the CO_2 goes off the water is removed from the surface, see you at the next lecture then.