Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology – Part- 2

Module- 08
Introduction to Dry Etching Techniques

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Hello and welcome to this manufacturing process technology part to module 8.

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We were talking about plasma systems and particularly concerned with the DC glow discharge system where we already discussed about how this glow discharge is carried out inside a chamber with evacuation followed by the injection ata controlled data for by molecular gas.

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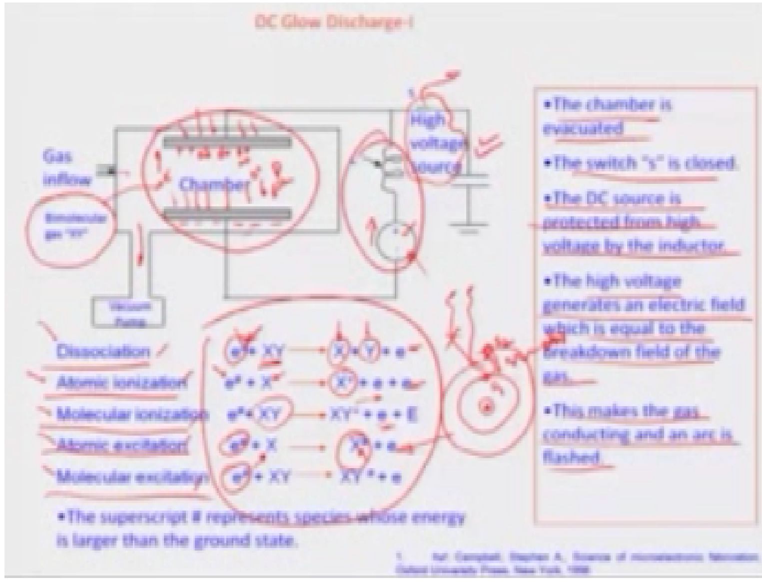

And there by breaking down or reaching the breakdown field of the gas so that these following events could happen dissociation atomic ionization molecular ionization Tomic Oxitec station and molecular excitation so we had given details about what all these processes would typically mean and then the question was how to sustain the plasma once the ions and electrons have been formulated within the chair.

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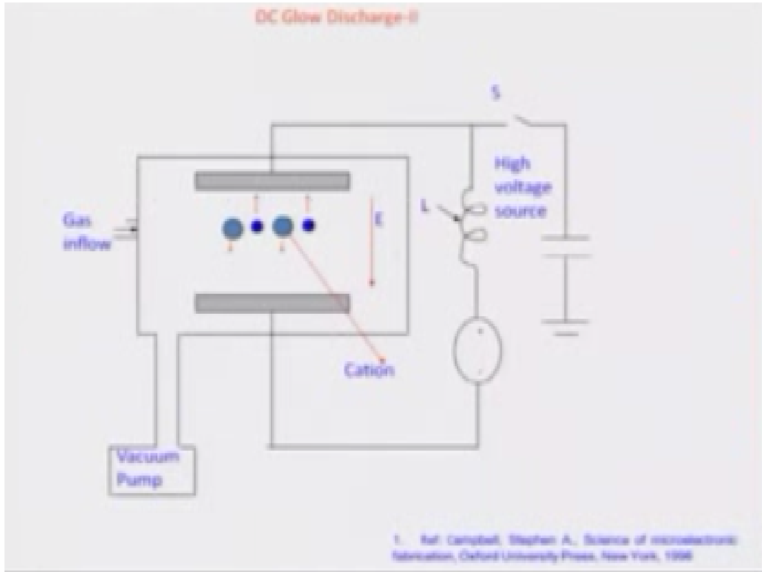

So as we see here there is a DC source for doing the sustenance of the plasma and the way that this sustenance would happen is that typically when the DC source applies a potential and makes one of the electrodes positively charged an anode the other one cathode so obviously the electrons would now start going towards the positive electrode as shown by these bright blue balls and the dull bluebells.

Which are actually bigger in size are the ions they are going to go towards the cathode because the captions and they can actually go and bombard at certain velocity which is also dependent on the biasing voltage that has been provided to carry these along the plates. And the movement there is bombardment of this heavy ions on to the metallic cathode there is a production of secondary electrons as can be seen here.

And so therefore the cationic head would result in the generation of secondary electrons and the electrons again will retain a momentum in the opposite direction because obviously they are being pulled by the field towards the anode okay and so there rush back and while rushing back they hit further you know named neutral ions or neutral atoms which are available or neutral molecules which are available in the chamber and try to ionize them further.

So basically the secondary electrons which are getting generated here create a sheath of plasma a sheet of ions and electrons very close by the to the cathode plate and this kind of make sure that the plasma is sustained okay so more ions which are created here would again rush towards the negative voltage negative electrode to the cathode and again produce more second reason this secondary would again in GA sort of induced more ionization effect near the catholic region.

So there is a sheath of captions which would come because of this secondary electron release process and you know bombardment near the cathode to the otherwise neutral gas molecules which would turn into becoming ions and designs would again you know sort of a in a chain reaction manner would again pump out more electrons.

So this leads to the sustenance of the plasma even though the high voltage source has been excluded from the circuitry and the power which is consumed by this DC volt you know this voltage source is really the power which is needed for sustaining the activity of the plasma for long amount of time so that is how DC glow discharge takes. So let us look at what are the kind of you know zones which are formulated in such a glow discharge so typically in a glow discharge tube you have some portions which are very bright okay.

As you can scene here by the dark blue globe and some portions are near electrodes for example the cathode and anode which are exceptionally dark and then also some dark fringes or dark spaces in between this bright zone and based on that these different areas are characterized or are as named or classified as the crooks dark space which is typically at the cathode obviously the electrons which are coming out of the cathode are highly energized.

And they are responsible for creating ions rather than moderate energy species as I told you earlier that the moderate energy species because of atomic or molecular excitation are really responsible for creating the brightness the globe because there is a short lasting electron in a higher state which generally jumps back and creates some kind of a you know discharge or light discharge of photonic discharge because of change of state.

So and from excited state to the ground state there is a transition process which is accompanied by this glow discharge so the Krug stock space is basically because all the available species are now in ionic State close to the cathode which is also responsible for the sustenance that I'd sort of spoken in the last slide on the other side on the anodic side not really is an electron sink so whatever comes in is actually pulled in and there is no scope for any positive ion because the positive ions are all repelled back into towards the cathode region.

And so therefore you know you have a dark space here the Nordic dark space and in between there is obviously an area where the momentum electrons momentum of the electrons which are going to create additional secondary’s are such that they would knock off the electrons from the atomic species rather than mildly or moderately excite them so there is a region where this knocking off tendency would happen where the electron energy is completely absorbed beyond which the electron again starts you know to go by and so therefore there is a space which incompletely filled with ionized species again in between the two cathodes and anodes.

And the remaining area is allowing region where there are these mild energy species or mild energy electrons which would Tomicly excite or excite the molecules which are presenting the plasma chamber so you have reduction in electron density on one side space use for micro systems and microelectronic favor normally which is the cathode side of electrons gained electrons that have gained sufficient energy to primarily ionize the gas in the molecule creating Faraday stack space and then you have a high kinetic energy of the electrons and anode.

Acting is electron sink responsible for the anodic dark space and the glow comes normally from the moderate energy species in a plasma source so incidentally our focus also would be on this group stack space which is used mostly for microelectronic fabrication because their ions and there is bombardment of the ion so if there is a material which is kept there would be a influence over the material by the ion striking the material data certain velocity and you could actually tailor the pressure and power regimes of the plasma in a manner.

So that the mean free path can be controlled and therefore you can have a case where there is a high impact which dislodges the material or another case very low impact with just some kind of surface chemical reaction on the on the surface of the substrate which is kept in such a such a space so having said that let us look at the potential problem which would happen in such aglow discharge particularly when we are using insulating materials and as I had earlier Illustrated that when we are talking about a DC glow discharge obviously the cathode and anode polarities do not change it is a direct current signal.

That is being fed into the system and so think of it that if I had an insulating substrate on the cathode side beyond a certain level of you know creation of let us say electrons the sustenance part of the plasma becomes very difficult because it will not generate enough secondary is to produce that sheet of captions which is really the driving force behind the sustenance of the plasma so therefore people have looked into alternate you know alternately engineered systems.

Where this DC effect does not have to bother even though there is an insulating substrate on one of the electrode and one of the initiatives that have been taken is it towards.

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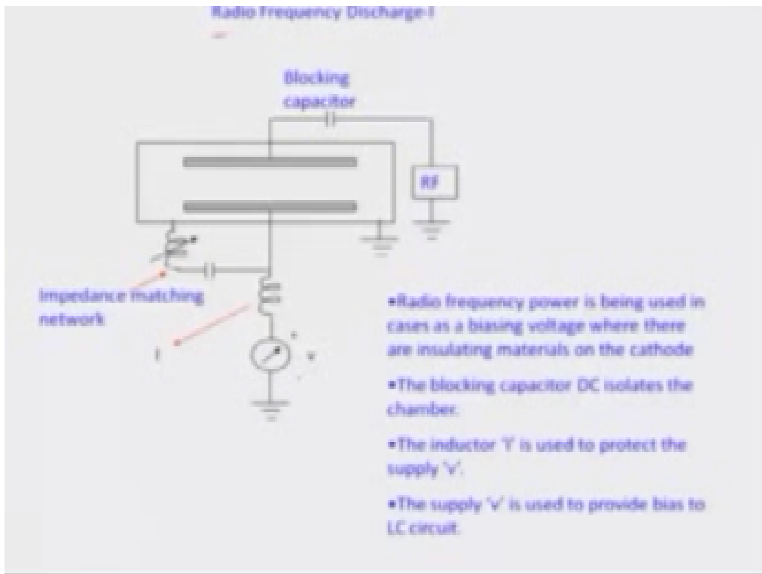

This radio frequency discharger an RF discharge system so typically there is a radio frequency signal which is now sent into the plates and there is a blocking capacitor which kind of filters all the DC component only generating the sinusoidal signal to these plates and obviously there is a something called an impedance matching Network which I am just coming in a little bit why it is needed and then there is a bias voltage which is given here through an inductor coil.

So the way that this system works is that the blocking capacitor DC isolates the chamber inductor eyes used to protect the supply V which would be used later on for the purpose of giving a bias tote LC circuit has suggested here in this particular drawing and using basically a radio frequency power to actuate the plasma process in this particular chamber.

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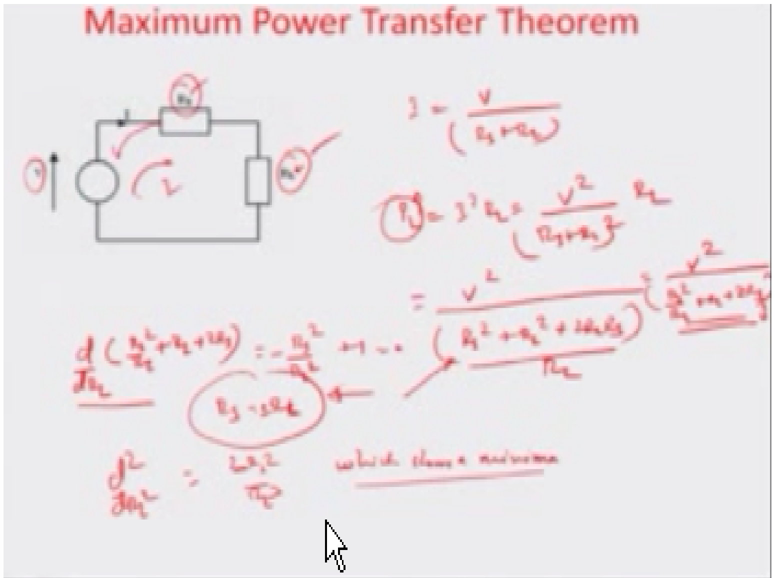

So let us look at why it is needed to balance the resistance of the source so that there would be maximum power transfer between the source and the electrode so let us suppose in a conventional case if there is a source resistance which is associated with any power source and a load resistance RL there is a way to sort of formulate a maximum power transmission or transfer condition from the source voltage to the load resistor and let us look at how we do it.

So supposing we had a current I in the particular circuit so I basically can be written simply by catopsa law as Divided by RS + RL and power as we know across the load resistor is nothing but I square RL so you have square of VRS + RL whole square times of RL another words I can actually write this down further as RS square + RL square + twice RL RS and divide the whole thing by RL which brings us to a sort of condition namely v square by RS square by RL + RL + twice RS.

So in order to maximize the power the resistance here or the denominator here needs to be minimized and for minimization would simply sort of differentiate this expression RS square by RL + RL + twice RS with respect to RL and this would yield typically RS square by r l square the _ sign + one ok and then equate this to zero so therefore the condition for the maximum power transfer to happen would really be at the source and the load resistors are equal to each other.

So obviously if I do a second derivative here with respect to RL we are able to see that what results is actually appositive term to RS square by r l cube which shows that we are treating a minima ok are we the dealing with a minimum point so for the minimization of the denominator term here the power obviously is the highest and the power transfer which is the highest power transfer takes place for this conditioners equal to + _ RL.

So therefore let us come back to the plasma source as we is explaining and trying to see what try to see what we meaning here so this set of network is a sort of a matching Network which would be able to sustain the maximum power transfer between let us say the RF source and the internal resistance that the source would have with respect to this variable load you have to remember that there is a medium here which is a by molecular gas.

And then also it has a ionic discharge and electrons which are there and the density is not in our control so therefore the impedance that this capacitor plate set would occur to happen to our give offer to an AC signaler RF signal would be really varying so therefore we need to keep changing the overall impedance in this whole regions that this l or the load resistance could be made always equal to the source resistance of the RF power right here for the maximum power transfer from the RF voltage source into the system .

So that is the reason why we have a impedance matching Network as you can see particularly here just going to rub off all these different lines to sort of avoid any confusion so that is how you can think of the reason for having a impedance matching Network so having said that now let us look into another different aspect that how this RF driven plasma really works out so let us look at what would be the sequence of events when ions and electrons are formulated within the plasma chamber so in one go when let us say the first half of the cycle this particular you know plate is positive and let us say the other plate here is negative.

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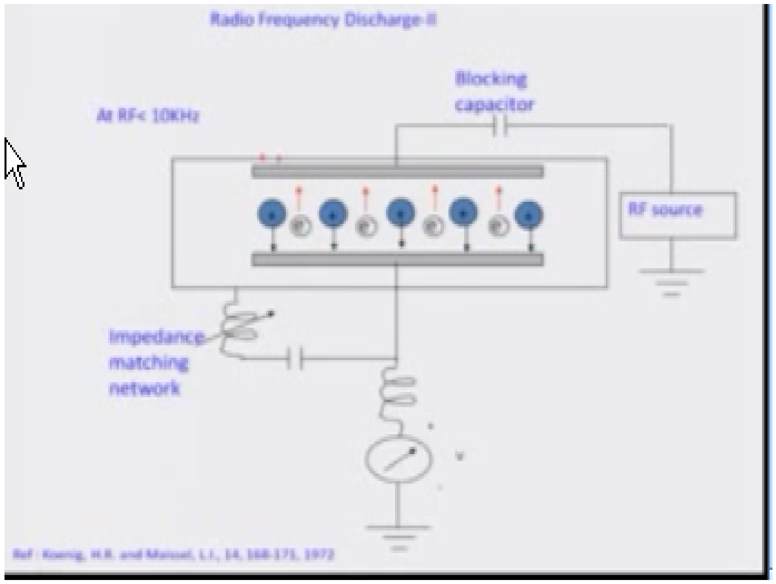

So obviously the ions would start moving towards the cathode and the electrons would start moving towards the anode and supposing we were to change the RF signal by reversing the polarity so obviously the ions now would start moving towards the upper plate and electrons would move towards the lower plate and this keeps on happening at a certain you know frequency okay so in one instance for example there is a electron moving up I am moving down other ants trances the other way round.

And this keeps on happening based on the frequency of the RF source that is being formulated now there is a situation beyond a certain critical frequency which is in the range of about ten thousand Hertz or ten kilo Hertz where we can actually see that it is only the ions are too heavy you know and so they are not able to follow the field anymore as the electrons which are going to go to the plates.

So therefore the ions kind of confine themselves to the bulk of the plasma whereas the electrons travel from n to n making the plates relatively negatively charged to with respect to the bulk of the plasma so and RF frequency of greater than about ten thousand Hertz or 10 kilohertz this additional effect comes in where only the electrons move and create negative polarities on both the plates with respect to the bulk of the plasma which actually has bunch of different positive ions okay.

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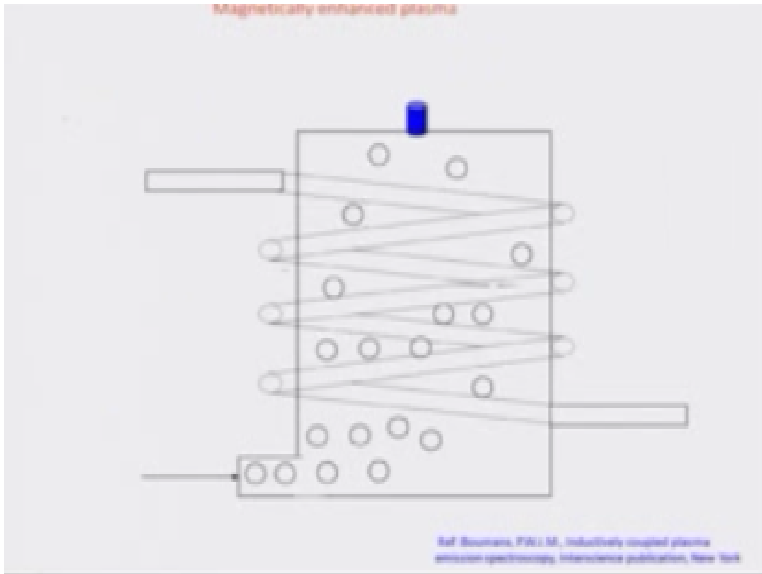

So this is what is going to happen even if there is a pulsating signal okay so the electrons are the on which are moving in the ions do not move anymore because of the high level of the frequency so having said that now let us look at the slightly different form of plasma which is actually the magnetically enhanced plasma and basically these are plasma systems which are supposed to produce one of the highest plasma density levels let's look at the basic principle it is based on-again and the factor.

That there is a magnetic field associated with the circular circularly flowing current in a loop so supposing there is a gas there is a you know chamber here as you can see and there is a evacuation process and also a gas released where a diatomic gas has been flown into a chamber and supposing there is an RF coil which is surrounding this particular chamber and at first instance what we do is create some kind of a spark to generate the plasma process okay.

So at this instance what we are trying to do is that we have a Tesla coil right here which is going to generate a small spark and the spark would thereby ionize some of the gas molecules in the near vicinity of thistles coil creating some ions and some electrons at this instance if we apply a current let's say in the coil around thethe chamber there is obviously going to be a magnetic field associated with the direction of the current given by the biot-savart theorem where you know because of the given by the right handgrip rule where can see that if supposing the current is going in a clockwise direction the magnetic field would be always based on the you know the direction of the thumb.

And so they are going to be if the current is from top to bottom a magnetic field given in this particular direction okay so the electrons and the ions which are again moving with respect to the medium around this place would obviously face certain forces Lawrence forces which are given by which are proportional to the charge which are proportional also the product between the velocity of the charge and the magnetic field which is the ambient magnetic field generated by the coil

So supposing now if we add an additional constraint that this is an RF coil and therefore there is a change in the way that we are flowing the current so in one instance the current is flowing let us say from the top here to the bottom and in the other instance the other way around that the current starts from the bottom and goes all the way to the top so obviously the magnetic field in this case would keep on oscillating okay.

So in one case the magnetic field goes or points down another K is the magnetic field points up and there are going to be a different directional forces which are applied by the changing direction of the magnetic will remember the force is actually proportional to V cross P or velocity of the charge cross the magnetic field direction and so that if the field direction is reversed the force would be reversed.

So there is critical situation where this frequency would generate a condition where the ions would start moving in circles and mind you that if I wanted to calculate what is going to be the radius of such circle and if we assume let us say in what particular case that the velocity and the magnetic field are perfectly perpendicular to each other since 90 being one so we can have the Lorentz force F equal to the charge value Q times of VB and you know the centrifugal force.

Which is needed foursome iron to keep at a certain radius with mass velocity V is given by MV square by r so already when there are when these two forces get balanced to each other would-be a condition when the Ironwood or the mass of the ion would start executing a circular path of radius R so in this particular case the radius R then would be known by simply calculating the MV by QB and if I have to look at the kind of magnitudes that this radius would have.

So obviously the charges on a iron and an electron are more or less similar because if one electron is lost by the eye on the Iron wood at the most have +1 or 1 proton okay but what is different though is the mass so that I am being much heavier in comparison to the electron would actually go at similar velocities for a higher radius so the ions radius typically would be very high whereas the electrons would have smaller radius and this condition is a very strange condition that the ion takes big loops or big circles.

And finds that many electrons in its path you know across this radius radial motion are actually executing small circular motions so they have more hits which would start ionizing the material and there would be a high density plasma which would result from all this magnetically enhanced system of class mass so in fact this magnetically enhanced plasmas are known to be one of the highest plasma density levels that any system can offer.

So just like to take you through some of maybe abit classified information about how do you perform plasma assisted etching?

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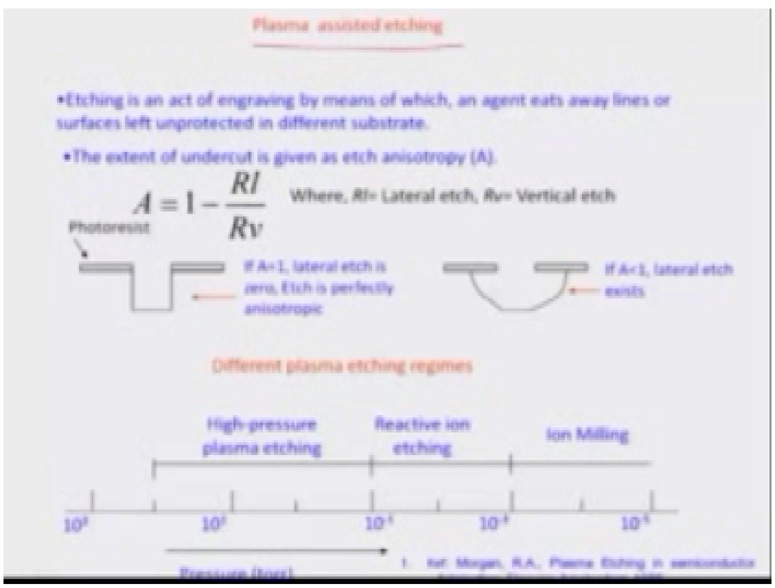

And as we had already learned in wet etching is that it is an act of engraving by means of which an agent eats away lines or surfaces left unprotected indifferent substrates there is also something called an undercut which we had found earlier you know in one of the modules where we were talking about lateral etch with respect to a vertical etch because of the homogeneity or the isotropy city of the etching process and the extent of that undercut is really determinant of how an isotropic the Would be in here is something called a NH is anisotropy factor a which is related tone _ lateral by vertical edge.

In a case where r l and r v are equal to each other this a becomes zero so it incompletely homogeneous or isotropic and if it's a case where there is more vertical in comparison to the later latching it becomes more and more anisotropic and you can think of this anisotropic etching process to be something which you know you Dahlia seen in the case of hydroxide etches but in this case it would be talking mostly about plasma assisted etching processes.

So different plasma etching regimes have been classified based on the chamber pressure which is existent within plasma systems obviously chamber pressure is an indication of how small or big would be the mean free path between the different ions the mean free path is higher than there is a tendency of the ion to sort of go and bombard so we have now classified into three different kinds one is the high pressure plasma etching system which is typically a small few layers of chemical reaction of the species in the plasma with respect to the substrate surface reactive ion etching.

Where you have physico-chemical kind of behavior so there is some kind of a bombardment because of the biasing voltage of the plasma and there is some kind of a chemical etching process which is existing in parallel to each other and again you know the ion milling which is are extremely low pressure corresponding to about 10 to the _ [32] _5 tours and this typically means bombardment and knockout of the atom.

So it is something like Avery low means free path because of which high energy species can be bombarding the surface on a continuity thus removing the material from the surfaces that is how plasma assisted etching is classified or you can have different later latching regimes as shown here.

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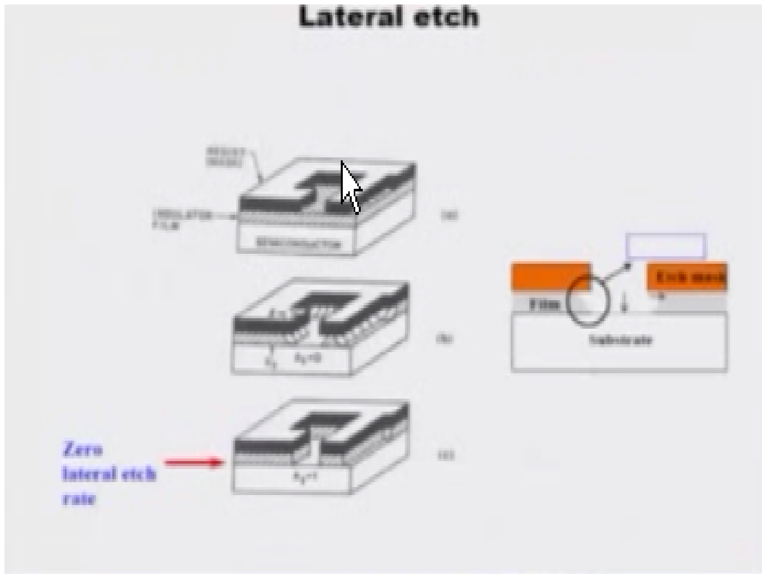

All these half cases of little etching thesis for example a very good an isotropy sorry isotropic etch where AF is close to a one and there is no later latch which is there an only vertical edge so typically the etching would always be having an undercut for which there is always a over design of the masking system the H mask is made in way so that you can take care or accommodate for this undercutting action of the etchant that you are trying to develop okay.

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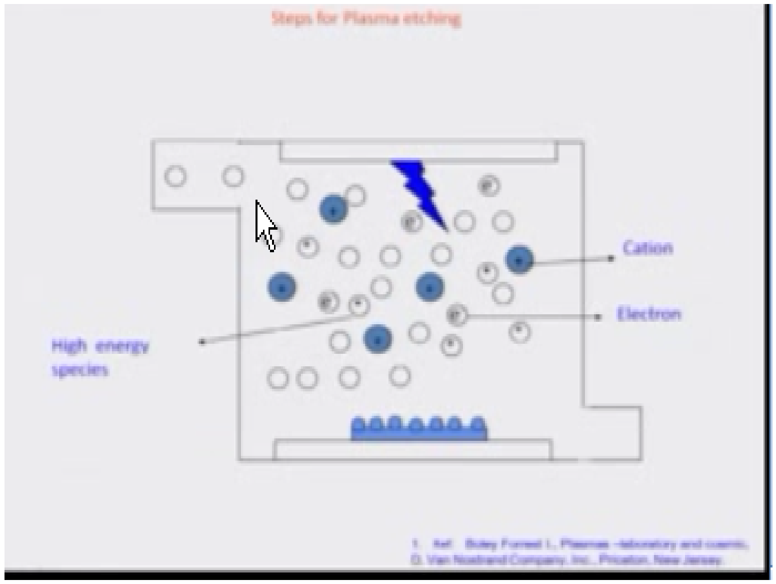

So the following of the steps of the plasma etching process so there are high energy species and free radicals which are available in a plasma chamber as given by these species marked with stars so typically such free radicals would graze on the surface of the substrate and try to find out a tone where it would have dangling bonds and they would try to get associated with some of the substrate atoms so if such an association is possible it would take away now the atom is a gas phase and it would get pumped out of the system.

So therefore the reactive species of a plasma are able to take off the atom in this manner and there are many such illustrations where either small chemical changes would happen on surfaces or the atoms would go totally out by chemical reaction and then going in gas phase and getting pulled out of the of the plasma chamber and based on that you again have the three different regimes of high pressure moderate pressure and extremely low-pressure of plasma etching so in this particular slide I would like to share some of the real results which came in one of the experiments when we were trying to do plasma etching.

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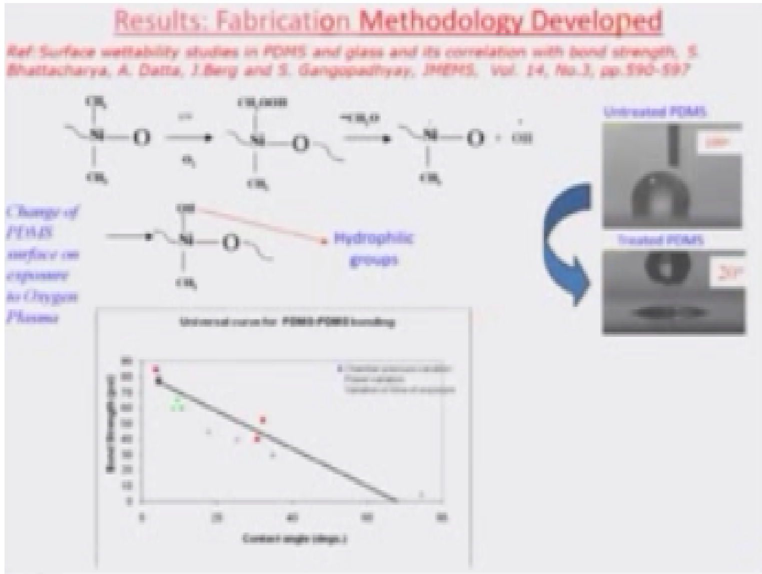

Where we would actually take a pdms surface and try to expose the surface to oxygen plasma and there would be an immediate change in the surface groups because of the high pressure low power regime which would consider here so there would be a conversion of the ch3 in 20 h of polymer called PDMS which we have been talking about in great details in the earlier slides and this would result in the formation of hydro fit o.h based hydrophilic surfaces.

Before treatment the pdms surface as a contact angle of about 109 degrees because of the abundance of these non polar groups or you know ch3 groups on the surface betas soon as the surface treatment of the oxygen plasma is done there is a small layer again because of the high pressure and low power gene which gets formulated and chemical layer of SI which on the surface which results in lowering of the contact angle.

So if I were to actually plot the bond strength that okay so basically the idea here is that if supposing I had to such layers of surfaces which I would bring in close proximity or hold in close proximity of each other for some time there is going to be a tendency of h2o group to get generated and a irreversible bondage getting formulated between the SI on both the upper surface as well as lower surface.

So there is a colon all linkage which happens is o SI linkage which happens at the behest of the water molecule which gets escaped from the from the intermediate region so the two surfaces which are now exposed to plasma ask and brought can be brought close teach other to have an irreversible linkage with respect to each other and we were trying to test the bond strength of such a surface.

So we had in fact generated a test for this which is known as a blister test I am just going to refer to this just a little letter a little bit later but the idea here is that the we found out that with the contact angle after the plasma exposure surface there is a changeover of the bond strength as well and it can be correlated to the density of the you know the SiO HR the slick and hydroxide groups on the surface as a function of different parameters of the plasma which would eventually result in a variable bond strength.

And what we see is that if the contact angle is below a certain value the bond strength is going to be sort of maximum in this particulars ration the way we did the bond strength studies are through the standardized blister tests so we generate a pattern and withmicrofabrication generate a small pistol pocket and connected through compressed here and under a microscope we shoot in the compressed air and try to see what is the expansion of this of this blister and you know there is sort of a instance when you can see the surface is getting separated under the microscope.

And that is the pressure corresponding to which the bond strength fails or the bond fails between the two surfaces that are that are in question so this way you can find out that due to the oxygen plasma exposure there is a surface transformation chemical surface transformation limited to only a few layers of the surface okay and so the various schemes to point this out one scheme you know through a UV and o2plasma you have a ch2oh which changes into again a dangling bond here and there is a which already existing through the water vapor in the plasma chamber.

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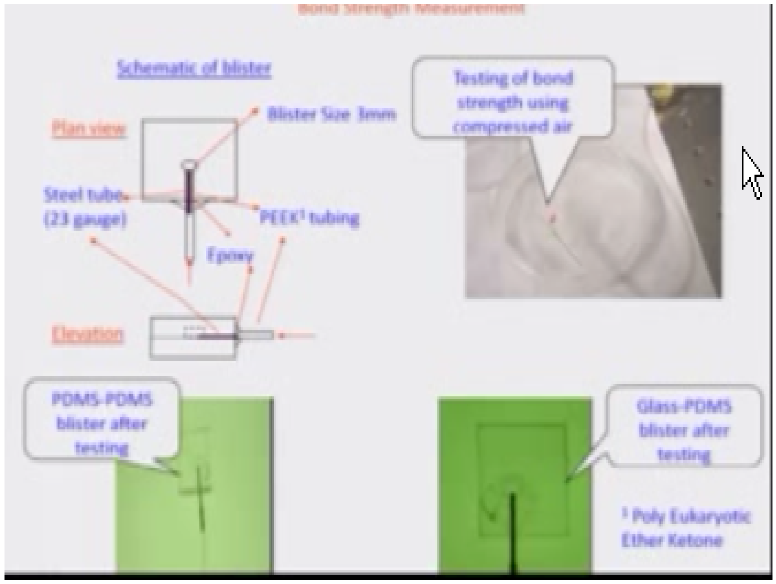

Which comes and sits on the top of this dangling bond and the scheme again you know you have several different intermediate steps here as illustrated to finally formulate this you know SI o H at the top of such surface so the many such schemes which have been studied earlier by people but you know the exact window of operation of the in terms of the pressure and the power of the plasma system would come out by this contact angle analysis which is a sort of an universal scale to gauge.

Whether you would get good bonding strength between the different surfaces which are participating and in this particular process the many such phenomena of any other phenomena which happen because of the exposure to oxygen plasma one of them is chain scission because of which there is a molecular reorientation and there is always a formation of a sort of crack you know on the surface so infect if you look at this kind of unexposed layer of plasma because of the huge amount of the silo H present there is always molecular V orientation and the surfaces a very dynamic surface of you know.

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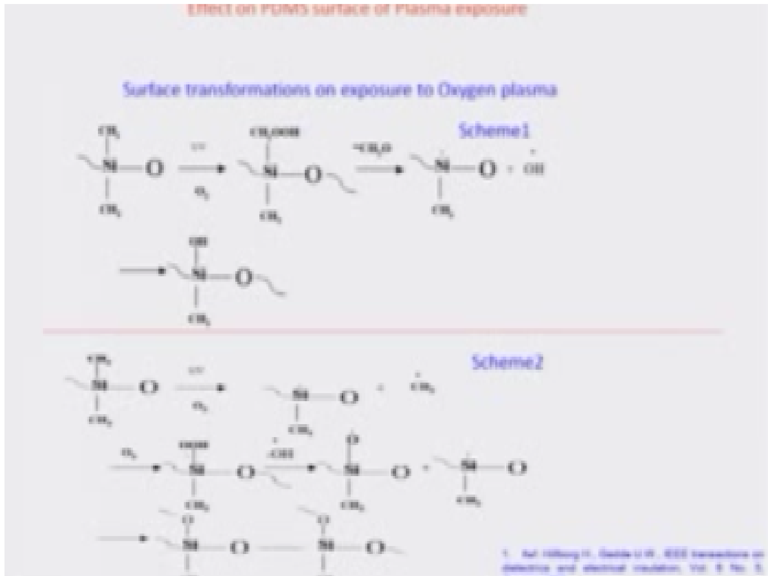

So therefore what we have typically observed as this that the cracks are responsible again for shooting up the long chain and the short-chain oligomerswhich are there in the bulk of the material and after a while you see that the contact angle kind of relax fastback to the normal and it becomes more hydrophobic with time as we leave it alone after a plasma exposure so these kind of studies have been done in view of what was represented in the last two slides.

So I think I would like to conclude here this particular module in the interest of time but we have other things on board particularly related to the additive processes which I would like to highlight in the next module and also summarized on to the various regimes of the pressure based etching that have already described in great details in this module thank you so much for attending to this module thank you.

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