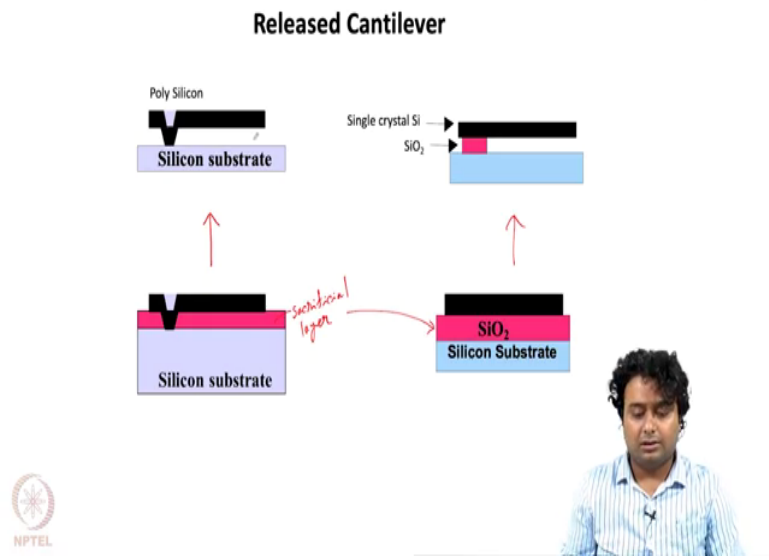
A Brief Introduction to Micro Sensors
Dr. Santanu Talukder
Department of Electrical Engineering and Computer Science
Indian Institute of Science Education and Research, Bhopal

Lecture – 10
Stiction

So, today we are going to talk about Stiction. Now, what is stiction as the name suggests that it is about sticking up some structure to it is base or structure.

(Refer Slide Time: 00:43)



Now, let us see, how a released cantilever may look like. There are two different kind of cantilevers I have drawn here, one is like here you can see this whole material is of polysilicon ok. So, polysilicon itself is sticking to the silicon substrate. And, what is the difference between this silicon and this silicon? So, this is this substrate is like single crystal

silicon ok. And, this has a particular crystal arrangement whereas, this silicon you can consider it like amorphous or polycrystalline.

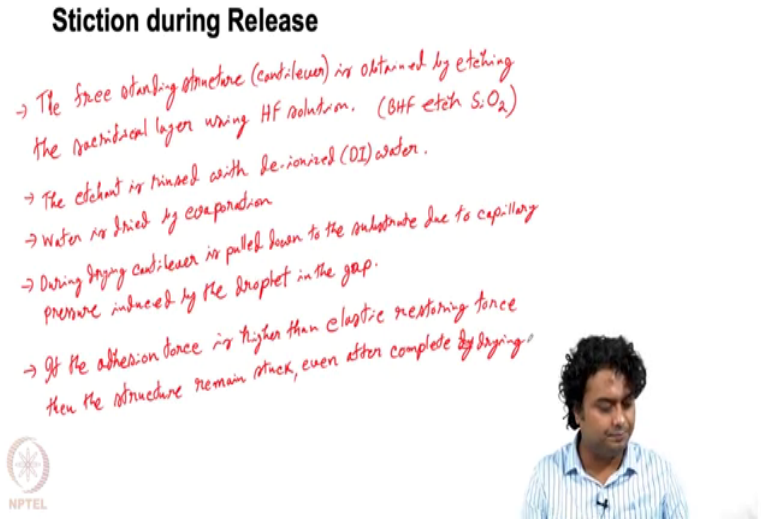
So, here the crystal, it is not a single crystal or the crystal arrangement for the whole structure is not same. Now, here the polycrystal cantilever is itself attached to the silicon substrate. Now, in the second case as you can see this is a single crystal silicon cantilever. And, in between that cantilever and the substrate, which also is a let us say a single crystal silicon substrate, in between there is a S i O 2 or Silicon Dioxide. Now, this Silicon Dioxide actually act as anchor.

So, this is connected to both the silicon like the top silicon and also the substrate. And, then this cantilever is attached here or sticked here to the substrate and this cantilever is attached here and then the cantilever can vibrate. Now, how we can make them that we will discuss in like in the next module, while discussing about the fabrication, but for discussing the stiction we need to know how it is coming. And, for that as I have drawn here, that before we get this cantilever there is this step where we put a put let us say sacrificial layer in between the cantilever and the substrate.

So, there is actually before we get this stuff actually we have this kind of structures So, ultimately. So, the process flow is actually in the opposite direction, I mean that you have first this kind this structure with the sacrificial layer. And, in both the cases we have the same sacrificial layer let us say S i O 2, but in this case the S i O 2 is not removed completely.

So, there is some S i O 2 left at the anchor whereas, in this case S i O 2 is released completely. So, we have we get this kind of polycrystalline silicon cantilever. Now so, to release the cantilever; to release the cantilever we need to remove this layer, then it will be like floating in that vacuum right. So, how we can do that?

(Refer Slide Time: 04:00)



So, for doing that, what do we need to do? We need to etch or remove that layer using HF solution. HF means, actually hydrofluoric acid solution. So, in a freestanding structure that is our cantilever. I am writing the freestanding structure because it can be membrane also in a different kind of geometry. So, in this case this is a cantilever sacrificial layer using HF solution. So, HF is hydrofluoric acid.

So you call it HF solution or a also a BHF or buffer HF, which is used to etch a silicon dioxide sorry buffer HF is used 2 etch S i O 2. So, if we have a sample with S i O 2 layer on top of it if we put it in 2 HF solution, then the etch that S i O 2 clear get dissolved and get removed from the sample. Then, after etching that we directly do not take out the sample from the HF solution, we actually rinse it.

So, then we rinsed it we rinse it with water and that is not a normal water because it has many like a metal ions in usual water. So, we use deionized water or D I water, because if we have; if we use normal water then, those ions metal ions can go to your device and that can damage the device, because that has like static charges. So, we use de ionized water or D I water in short, then water is dried by evaporation it is dried by evaporation. Now, let us go back to the previous structure.

So, what I am saying is so, you put this sample in to a in a BHF solution first and then they re replaced the BHF solution with a D I water and then this region get removed, but there is water everywhere, because this total sample is dipped into it ok. So, by the way this is all are cross sectional images. So, cross sectional images of the cantilever. So, now, you see that the water will be everywhere, in the around like in the gap also and around the gap around the cantilever around a sample everyone, everywhere there will be water.

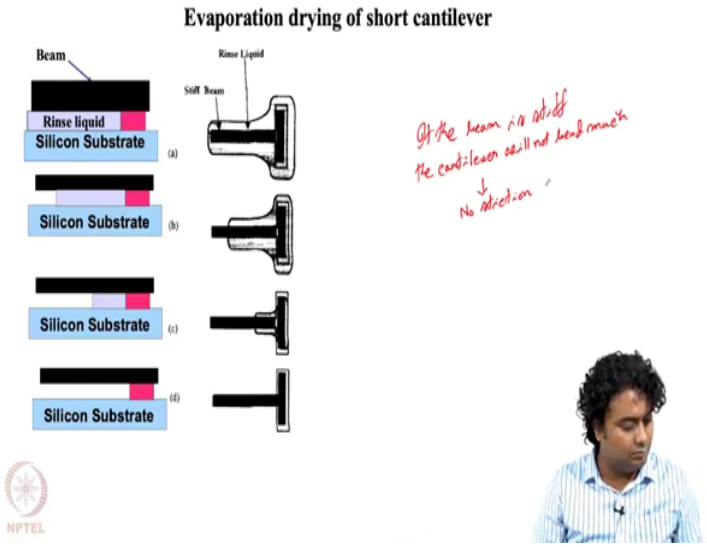
Now, when we start actually evaporation drying then there will be in water droplet, which will be trapped in between the cantilever and the in between the in between the cantilever and the substrate.

So, there will be some water trapped in between this gap ok. That will form a water droplet and because of the capillary pressure or surface tension, this will try to pull the silicon cantilever towards the substrate ok. So, this water droplet as it becomes smaller and smaller while drying up so, that we will try to pull the cantilever towards the silicon substrate. Now, if the cantilever is not stubby enough I mean, if it is long and thin then there is a chance that it will stick to the substrate; it will get stuck to the substrate. So, that is called stiction.

So, during drying cantilever is pulled down to the substrate due to the capillary pressure induced by the droplet in the gap or trapped in the gap. And, if the adhesion force, adhesion force means, which is actually like pulling them together like while it is stuck. So, the cantilever get get pulled down on the substrate then, there is an adhesion force in between the cantilever and the substrate. And, if that adhesion force is higher than the restoring force, because the cantilever will trying to come back to it is normal position.

So, if the adhesion force is higher than elastic force means mechanical force, elastic restoring force, because this is the force, which is trying to restore the cantilever to it is normal position the structure remain stuck. So, this is called stiction stuck, even after complete drying even after complete drying ok.

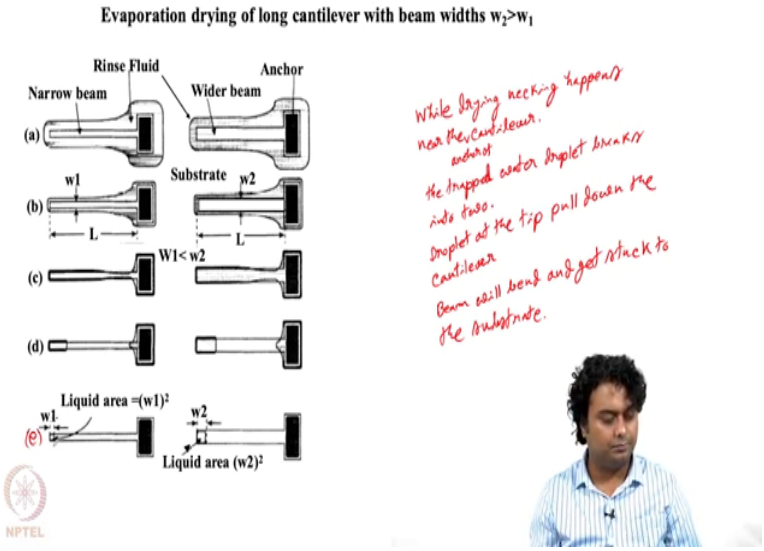
(Refer Slide Time: 13:27)



Now, we will see two different cases. The first case is of short cantilever. Now, what happens in case of a short cantilever, which is also we can call it a stubby, this is the liquid trapped inside the gap right between the cantilever and the silicon substrate. Now, this liquid starts to get dried up. And, this happens from the tip site to the anchor site. And, as you can see that slowly this liquid proceeds to the towards the anchor though this liquid is pulling the cantilever down, but as this is a short cantilever the restoring force is also a much higher than the like the surface tension the capillary force.

So, because of that it is not able to pull it down. So, much that it will get stuck here, rather the liquid start drying up and it will ultimately get completely dried and without even pulling, without any stiction. So, if the beam is stiff; if the beam is stiff than the cantilever will not bend much and no stiction, no stiction.

(Refer Slide Time: 15:32)



Now, let us take these two cases where we are taking a longer beam much longer and thinner beam and we have two different width ok, we have two different width. So, we will see that how the drying happens for this two beam. So, as you can see as it starts to get drying up then it forms a kind of neck here. So, in between the tip and the anchor towards mostly towards the anchor it forms a neck like this.

So, this because of this neck the water droplet actually gets separated. So, one water droplet forms at the towards the tip site and one water droplet forms at the like the anchor site. Now,

that anchor site droplet get dried up and the cantilever is very stiff here at the near the anchor right. So, it will not it will not be able to pull the cantilever down, but the dip site water droplet, here the force required is much smaller than the force required here.

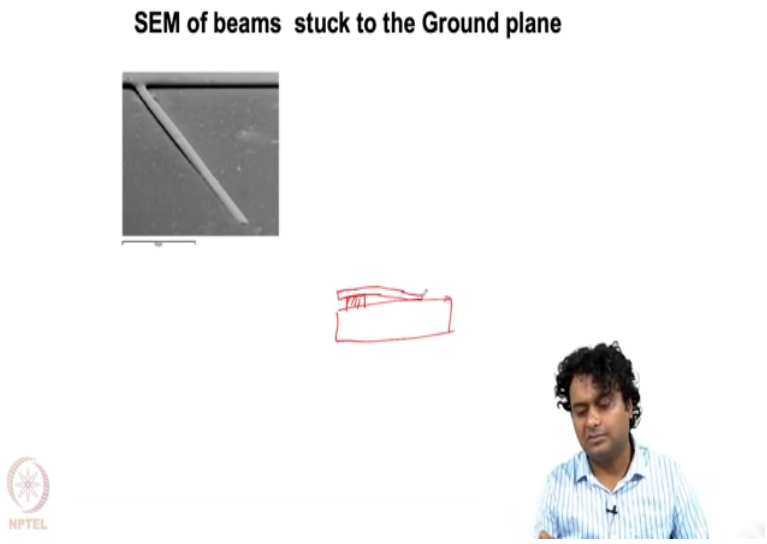
So, the cantilever this water droplet actually will be able to pull the cantilever down and then it can get stuck towards the it can get stuck to the to the substrate. And, as you can see here this droplet, how much will be the area of the droplet that also depends on the width, because this is ultimately width square.

So, W 1 square or W 2 square and so, the it will be almost because it usually the droplet us starts to form in like spherical shape and then it will try to take the shape of the cantilever symmetrically. So, it will be almost like square shape and then the it will depend on the width of the cantilever, that how much will be the contact area. Along that contact area actually the adhesion force also is dependent.

So, while drying it is near the anchor of the cantilever, trapped water droplet breaks into breaks into two. Droplet at the tip pull down the and we write beam will bend and get stuck to the substrate ok.

So, this trapped water droplet near the tip will actually pull down the cantilever to bend and stiction will happen.

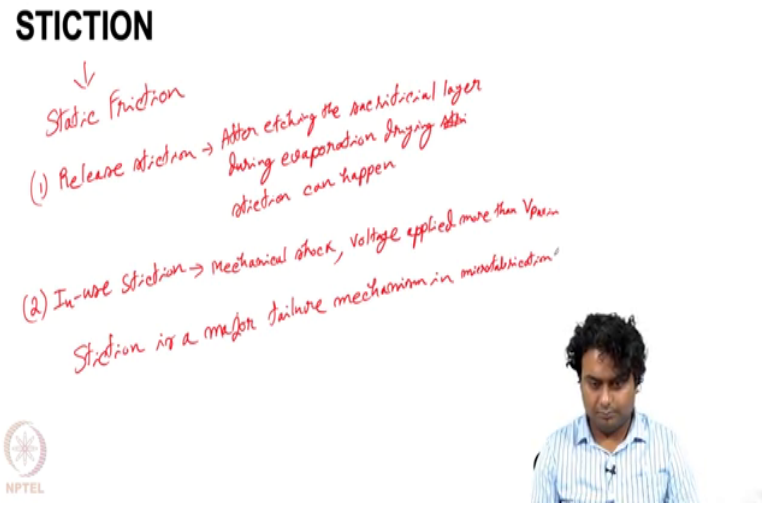
(Refer Slide Time: 19:56)



So, here I am showing one of the SEM image of a stuck beam. So, here you can see that the anchor site it is you can see the shadow, where it is like there is a gap in between the cantilever and the substrate, but at the tip site it is stuck. So, it is like stuck to the substrate. So, that is why you cannot see any shadow? So, this is one of the real image of the stuck beam and if you see it cross section wise, then how will it look?

So, let us say this is the substrate and then you have the anchor here, here it will be not only stuck, but then at the tip site it will try to come down ok.

(Refer Slide Time: 20:58)



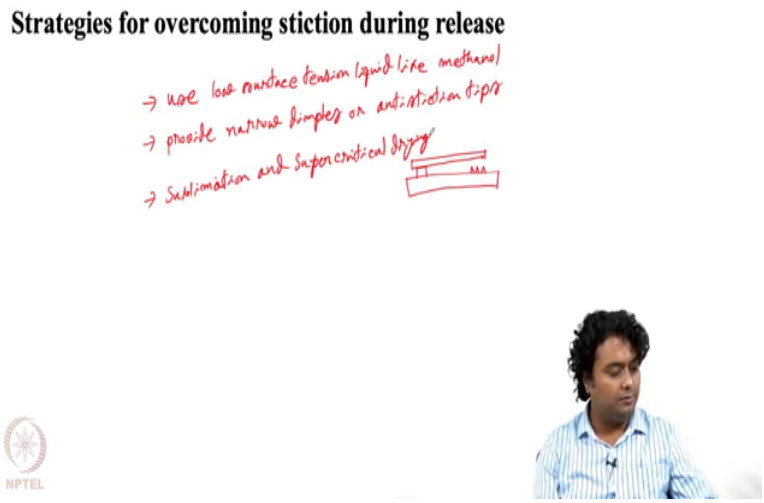
Now, what is stiction? Actually, by name it is it does mean that static friction. So, friction force we are all aware of and this is kind of static friction force. Now, what can be a different reason for a stiction? So, one is like release stiction. So, that we have already discussed right, while drying after etching the sacrificial layer, after etching the sacrificial layer, then during evaporation drying, while we are evaporating the water right. So, during evaporation drying stiction can happen.

Another type of a reason maybe in use stiction; so, in use stiction let us say, so, you are you have a now release cantilever. Now, it is vibrating right it is always like your application is such that there is need it needs to vibrate. Now, while you are electro statically vibrating one cantilever.

Let us say, somewhere we are we apply some higher voltage and because of that it gets pulled in more than more than that like the critical gap, what it should not be right. So, if it is more than that and if it once it touches the once it touches the substrate, then in that case if the adhesion forces are higher than the restoring force. Like more than let us say pulling voltage the volt no more than the pulling voltage, the voltage is applied. Then, once it get once it contact the substrate if the adhesion forces are higher than the restoring force, then it can get stuck. So, this can happen during because of some higher voltage also or let us say it suddenly get some kind of shock and then it gets stuck to the substrate. So, that is also possible.

So, that can be because of mechanical shock and voltage applied more than V p V p minus V pulling, more than pulling voltage if you apply more than pulling voltage, if you apply voltage then also it can happen. And, what we need to understand in this context is the stiction is a major failure mechanism in micro fabrication, this is a major failure mechanism in micro fabrication.

(Refer Slide Time: 26:02)



Now, the question is that how we can avoid or overcome stiction?

So, during release mostly. So, in use is we have to be careful we should not give any mechanical shock or you should not put more like a more voltage that we need to be taken care of, but during release how we can get rid off, because this is an unavoidable situation right. While we are making these kind of devices we need to go the sacrificial layer etching and then washing the sample with water and then drying the water.

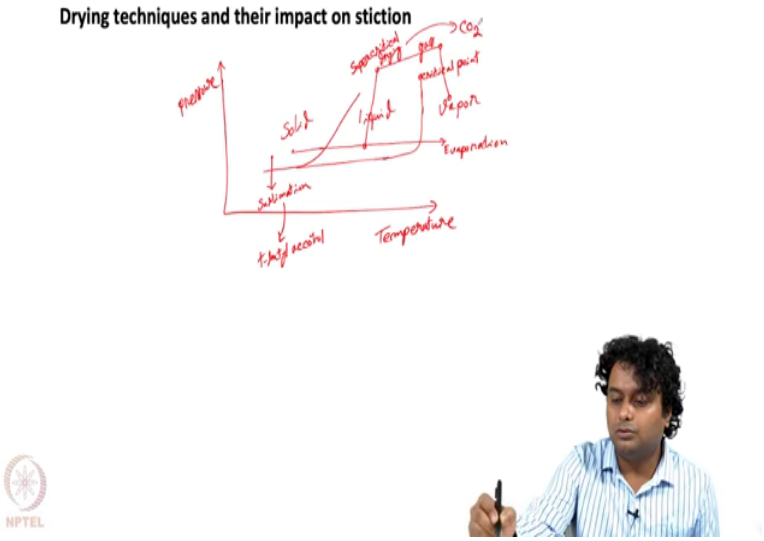
So, we need to do that, but how what kind of strategy we can take so, that the stiction will not happen. So, one is use 1 point is use low surface tension material, low surface tension liquid like methanol.

So, if you other than water, if we use actually in the final stage, we use methanol to wash it then the chances of stiction will be lesser, because ultimately the water droplet is what it is pulling the cantilever down right, but if it is methanol droplet in place of water, then what will happen the pulling force will be lesser, because the surface tension of methanol is lesser than water. So, it will pull with lesser amount of force. Another option is provide narrow dimples or anti stiction tips. So, what is that let us say this is as I was drawing this is a substrate and on top of that you have the cantilever and then here near the tip or so you can put some narrow dimples or anti stiction tips.

So, even if it gets pulled in the contact area will be very less because this is just like anti stiction tips. So, like a very sharp tip so, the contact will be lesser and the adhesion force will be never higher than the restoring force. So, it will not get permanently stuck to the substrate. Other two techniques are super critical drying.

So, sublimation and supercritical drying are two different techniques, where we do not form actually liquid gas interface. Because in sublimation actually the solid material itself directly evaporated, directly evaporates without going through the liquid phase. And, super critical drying also is a similar technique, where we have some kind of liquid going to gas space directly without going to the vapour space. So, we will discuss about sublimation and super critical drying later in a little bit of detail.

(Refer Slide Time: 30:12)



Let us talk about different kind of drying technique.

So, this is your phase diagram many of you are already aware of that. So, there is this pressure and temperature. And, depending on different pressure and temperature, what are the; what will be the phase of the material like, whether it will be in solid phase, liquid phase or vapor phase right. So, as you can see that as we were increasing the temperature it is going from solid space to liquid to vapor. And, that is the usual like you are familiar with these phenomena right, while you heat up the ice it becomes water and then you heat up the water it becomes vapor.

Now, usual drying technique or the evaporation drying technique goes from solid to liquid to vapor. So, you have solid, then it goes to liquid and then it goes to vapor in so, this is evaporation. And, in this case the usual technique the water is in liquid phase.

So, it is in liquid phase and then it goes to vapor evaporation, it goes to vapor phase by evaporation, just by heating it or like the normal evaporation. As, I was discussing the sublimation, sublimation there are these materials which can go from solid phase to vapor phase directly. So, these all this phase is vapor phase. So, sublimation happens from solid phase to vapor phase directly, without going to the liquid ok.

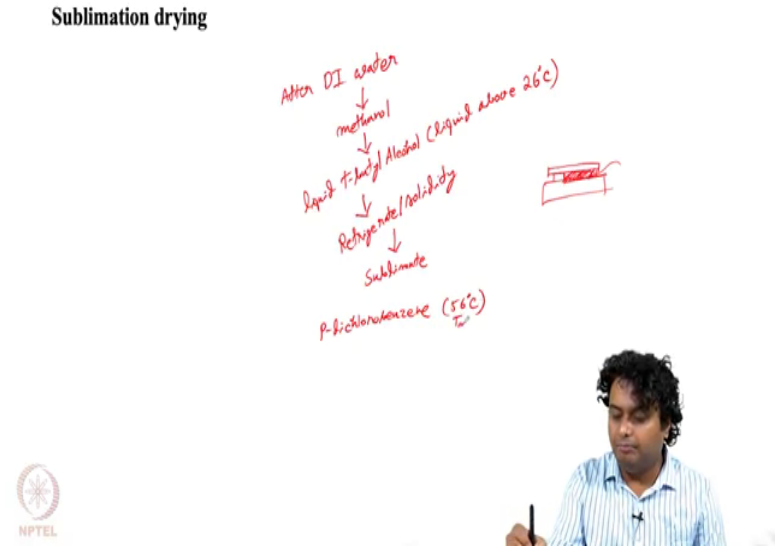
So, there is no formation of liquid or liquid droplet or no surface tension at the liquid air interface. So, stiction will not happen there. So, there is certain pressure and temperature above which the material can be considered or the fluid can be considered at gas.

So, so, above this point that is at some particular pressure and temperature, which is called critical point the fluid will be called gas and what is the difference between gas and vapor? So, there is a this property that, if we if we apply higher and higher pressure than the vapor can be again converted into liquid, but a gas cannot be. So, gas and fluid vapor are two different kind of phases.

Now, there is some technique called super critical drying where from the liquid phase, by going into higher temperature and pressure it can go to the gas phase above the can go over the critical point. So, we increase the pressure, we increase the temperature, we increase the pressure, then we increase the temperature and then again we decrease the pressure to come back to the vapor phase. So, totally avoid the liquid vapor interface.

So, this is called super critical drying. Now, for sublimation we can use tertiary butyl alcohol can use tertiary butyl alcohol or it is called t butyl alcohol and super critical drying can happen with CO 2.

(Refer Slide Time: 34:35)



So, sublimation drying how we do we after D I water, D I water, we replace the D I water with methanol, anyway it has low surface tension. Then, we replace the methanol with this tertiary butyl alcohol t-butyl alcohol. And, this is in liquid phase above 26 degree centigrade.

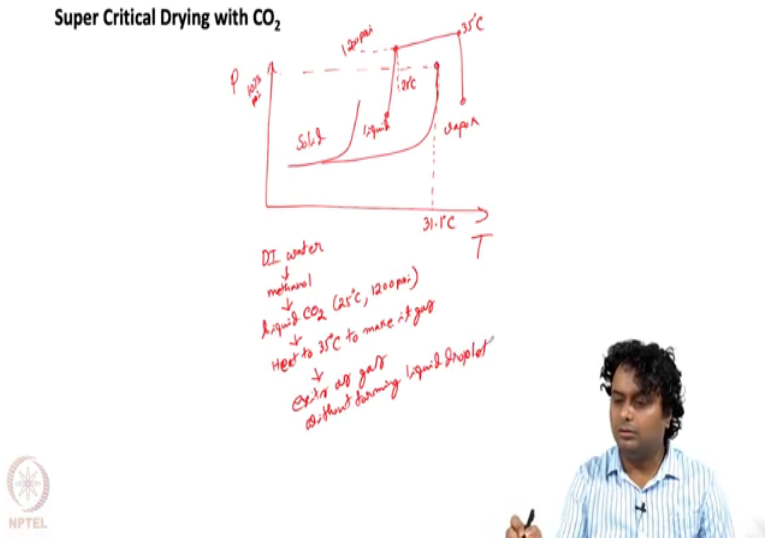
So, it means that 26 degrees centigrade and we put liquid tertiary butyl alcohol. So, this is liquid and then we refrigerate it. Hence, we put it in a freezer solidify. So, we solidify it inside the freezer and then it will sublimate. So, in this step there is a solid tertiary butyl alcohol or t butyl alcohol in the gap.

So, as I was saying that this is the substrate and then on top we have we have the cantilever and in between the gap this is the region, where the water was forming a droplet. Now, this is t butyl alcohol solid t butyl alcohol and that automatically evaporates like from the solid

phase itself, it evaporates to the vapor phase. So, we do not have any liquid droplet forming or no stiction.

And, another option or another material you can use is t dichlorobenzene, this is also this also can sublimate. And, for that we need to use 56 degree centigrade like, it melts above 56 degree centigrade it is T m melting temperature.

(Refer Slide Time: 37:28)



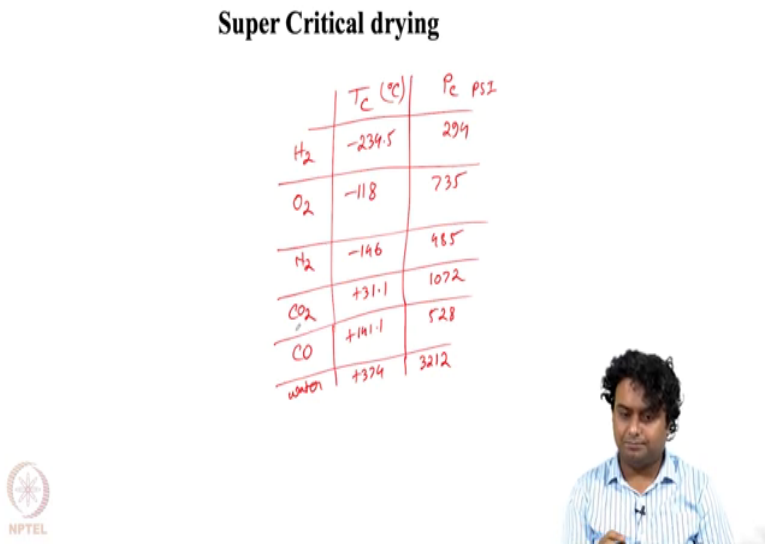
Now, for CO 2 like super critical drying we will do with liquid CO 2. So, again let us draw the pressure temperature diagram. So, this is pressure and this is temperature and then we have this is graph. So, let us say this is the critical point ok. This is solid, this is liquid, this is vapor and above the critical part it is gas. So, and for CO 2 this point this critical point is somewhere at 1 0 7 3 p s i. This is 31.1 degree centigrade. So, what do we do is first we take

the CO 2 in normal temperature and pressure and then apply high pressure to make it, high pressure.

So, it will be at high pressure liquid and then we apply high temperature also to go over the critical point and then again it comes back to vapor phase ok. After D I water. So, the sample was in D I water that we replace by methanol initially methanol. So, that is that low surface tension liquid and then this is replaced by liquid CO 2, liquid CO 2 at 1200 psi and 25 degree centigrade. So, it is at 25 degree centigrade and 1200 p s i ok.

So, this point, this point is this is 1200. So, these are 1073, which is it is critical pressure and temperature and this is we go above that pressure wise this is 1200 and this temperature maybe about let us say 25 degree centigrade. And, then we increase the temperature to 35 degree centigrade heat to 35 degree centigrade to make it gas and it actually exits as gas without forming liquid droplet.

(Refer Slide Time: 41:49)



So, as we have seen now that we have used here CO 2 right, liquid CO 2, because it has like critical pressure and temperature is in our reachable domain like it is 31 degree centigrade and 1200 psi means about let us say. So, we are using as CO 2, because it is critical temperature and pressure, we can achieve easily like temperatures critical temperature is 31 degree centigrade you can definitely go above that and 1200 p s i means above 73 ATM pressure we can also achieve that. So, liquid CO 2 is used, but there are other materials also so, that we will now discuss like.

So, if I this is let us say T c and this is P c. So, these is critical temperature and critical pressure and let us say, we take different material like different-different gas let us say, hydrogen is about minus 234. 5 and this is in degree centigrade. So, it is in PSI 294 ok, then

O 2 is minus 118 and 735, N 2 is minus 146 and 485. CO 2 is plus 31.1 1072. And, we have carbon monoxide also like plus 141.1 528 and water is plus 374 and 32.2.

So, if you see here CO 2 is most achievable, because the temperature is almost in the our room temperature area, where as for the other all the other cases, it is either very high or very low. So, which is difficult for us to get because initially you have to start below critical point right, because we need liquid CO 2 like that we need here, we need liquid N 2 liquid N 2 also can be used and it is very frequently used for different-different purpose, but here liquid CO 2 is more preferred.