Nature and Properties of Materials

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Lecture 32

Materials Selection: Probe for Scanning Probe Microscope

Today we are going to do one more case studies on the design of a probe for scanning probe microscope, so essentially is only the probe part of a scanning probe microscope we have selectively chosen and we will see that how we can select the material for this type of a probe.

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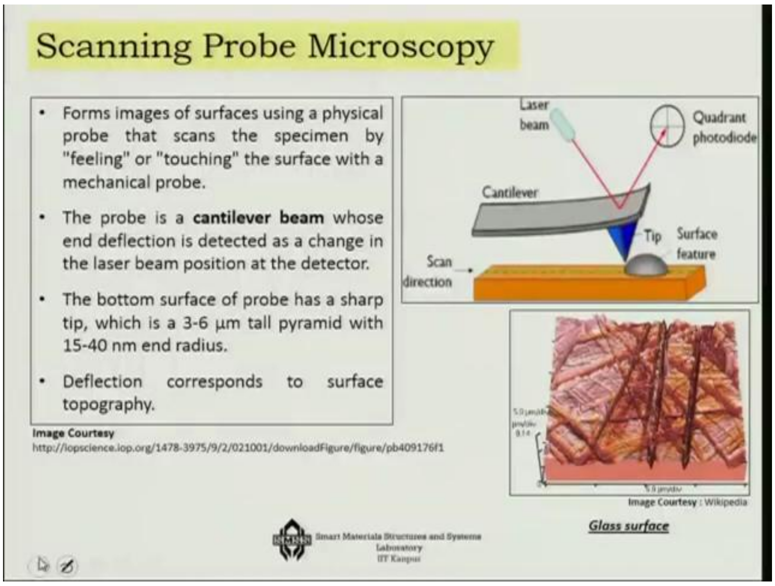

Now, scanning probe microscope is one of the most powerful imaging technology that is available today and it is used for imaging of surfaces using a physical probe that actually scans the specimen by something like touching the surface with a mechanical probe okay, so this is like a cantilever probe as you can see here and it has a sharp teeth and it is going to touch, so a material has many kind of undulations if you look at it so what is it going to do, it is going to touch it and as it is touching, its deflection is changing which is picked by the laser beam and then from the laser beam the light that is coming is to the quadrant photodiode very highly sensitive and from that it actually from the deflection it actually find out that what is the nature of the surface of the sample like this type of a surface.

So a very important tool in case of a scanning probe microscopy is actually a cantilever beam whose end deflection is what we detect and put it as a change in the form of a laser beam position changer and the detector. The bottom surface of the probe has a sharp tooth, which is just 3 to 6 micron meter tall pyramid with 15 to 40 nanometer end radius, it is very-very challenging. In fact, this is the part which is you can say it like a MEMS or a MEMS device on its own that bottom part of the system; it is a micro electromechanical or a nano electromechanical system.

And naturally the deflection corresponds to the surface topography. So, our tip has to be very fine and then whatever little deflection will be produced that is to be interpreted in terms of the surface roughness that is the idea for scanning probe microscopy probe.

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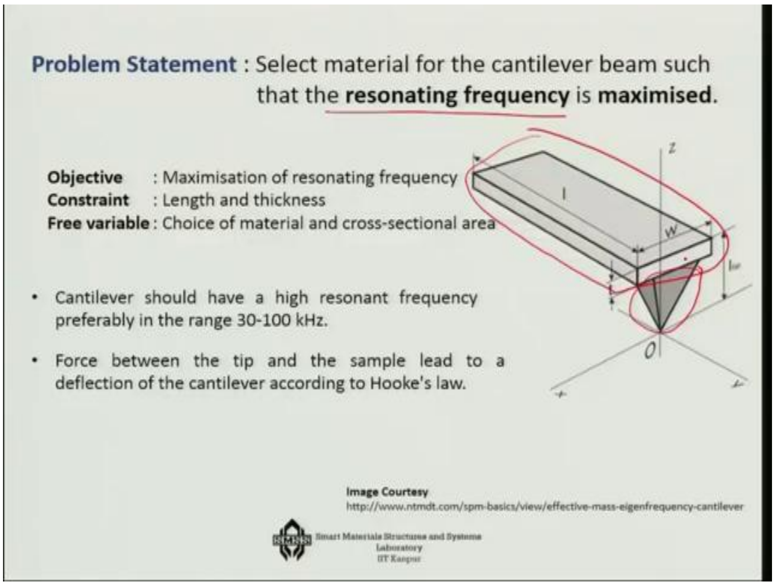

Now, what is the problem statement for us? That select material for the cantilever beam because you see that we are doing it from the resonating frequency point of view okay and we have to maximise the resonating frequency so we have to select material for that probe. This part is very-very small so that is why is not important from the resonating frequency point of view; its contribution to the resonating frequency will be very small.

Now the point is, why are we interested on the resonating frequency? It is because many times we use this probe in terms of tapping the surface, so we tap the surface at various points. While tapping suppose if it is very flexible, then its natural frequency will get actually coupled with this tapping frequency, so that means this particular beam will start to have resonance, we want to avoid that.

To avoid this, we want to keep the cantilever’s natural frequency so high something like 30 to 100 kilo hertz, so that it never interferes with the scanning frequency, so that is what is the idea that how can we maximise the resonating frequency of the system. Now let us go to the board and try to see that how we can do the same thing with the help of the Ashby technique okay, so let us try to solve this problem.

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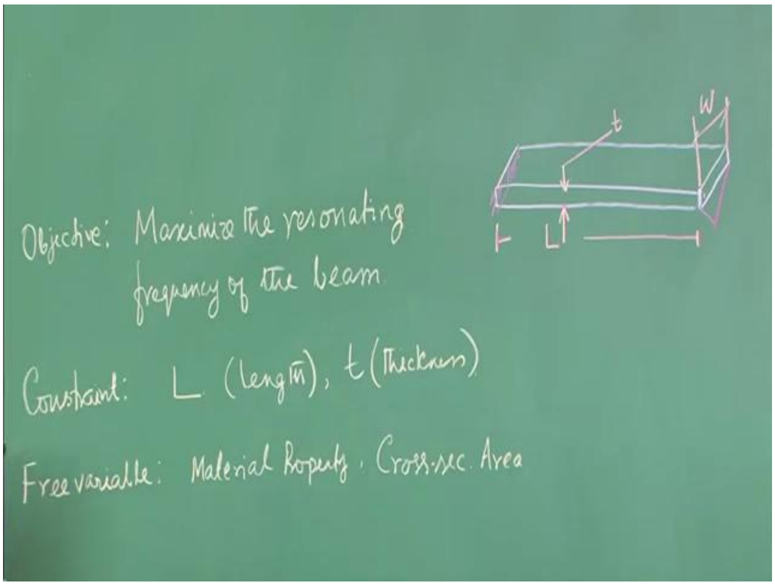

We have a cantilever beam let us say; I will just draw the beam first and let us say that the beam is of uniform thickness although in practice it is not like that exactly, but let us say that the beam is having uniform thickness. And one edge, this is the fixed edge of the beam right, suppose this is the fixed edge of the beam. The beam has the probe has a length L, the probe has a width say W and the probe has a thickness say this is T okay. And there is a tip here, but we are right now currently neglecting that that tip effect, etcetera. Now, so let us write it down that what are the objectives of our analysis.

Let us try to put this thickness T, let us put this as length L, I hope it is clear up till now and I am applying this colour that is the length L that is very important and also the last parameter that is the width of the system okay width of the beam. So with this now what is the objective first? Objective is that maximise the resonating frequency of the beam okay. And what are the constraints for us? Well, length is of course a constraint, so this is length and we may put thickness also as a constraint because if it is too thick then it is difficult in any solution if you have that, it is difficult to really use this probe in terms of scanning a system.

So what is the free variable for us then? Free variable is of course material property, so selection of material and cross-sectional area. Okay we can we are free to choose the cross-section area of the system. Now, in order to know the resonating frequency what we are going to do, see this is a continuous system so as a result for a continuous system it is actually consisting of infinite lump masses, so that they do not have one natural frequency but many natural frequencies. However, when I am telling the resonating frequency we are actually implying that it is the fundamental frequency, so this is basically nothing but the fundamental frequency.

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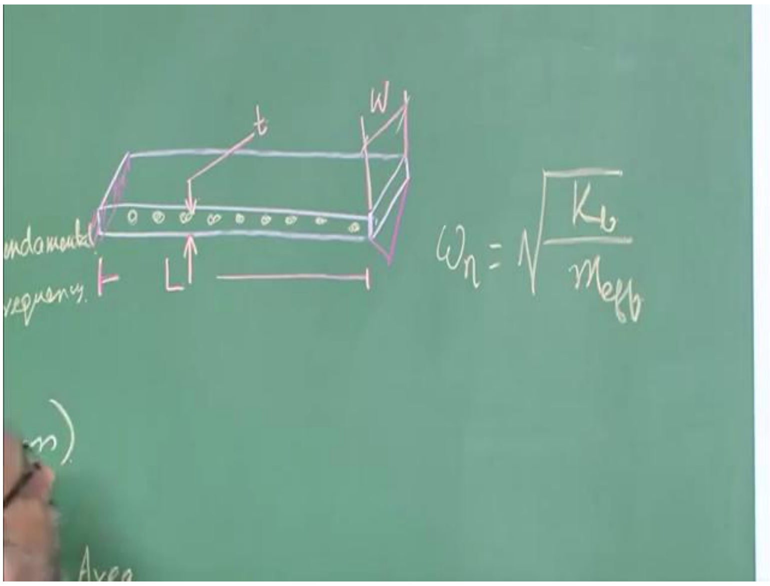

And one way to obtain this fundamental frequency is that we actually consider this Omega n as square root of K that is the stiffness the bending stiffness the bending mode, so you may put it as K b over effective mass okay. So corresponding to the 1st mode shape which is somewhat like this if I draw it that is the 1st mode shape if you actually excite such a system that is the way it is going to vibrate. So between that systems, the natural frequency is square root of K b over M effective. The question is what the K b is and what if the M effective, so how can we find it out? Okay, what is the N deflection?

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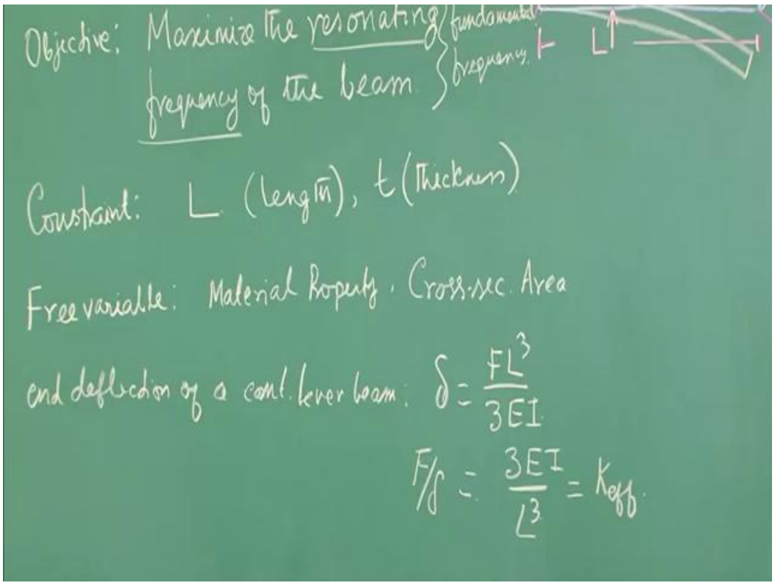

N deflection of a cantilever beam we know that it is delta = F L cube over 3 E I. In other words, I can write that F over Delta is actually 3 E I over L cube in fact, that is the K effective for us okay, is very close to the static deflection of the system corresponding to that stiffness we can consider it to be a good you know K b for us okay, so we can consider this to be an effective stiffness of the system, let us call it as the bending stiffness of the system K b. Now we also have to know what the M effective for the system is.

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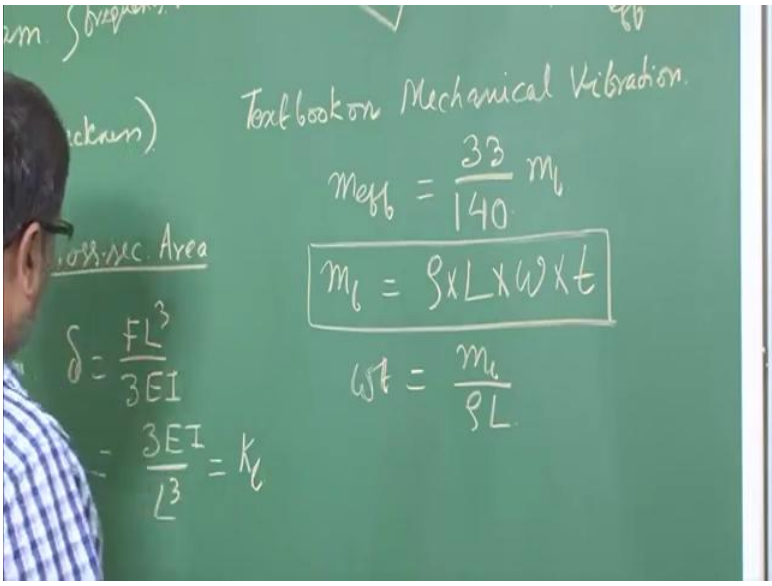

Now I will not go into the details, but if you look at any textbook on mechanical vibration, you will see that for this type of case the M effective will come out to be 33 over 140 times the mass of the beam, 33 over 140 times M b. Now the question has come for us that what is

M b? M b, we can write it as Rho times length times W Times T right, Rho L W T that is what is the M b the mass of the beam. Now in this case we have to keep in mind that the cross-sectional area is considered as the free variable. In other words, W T is nothing but M b over Rho L okay and that is our W T.

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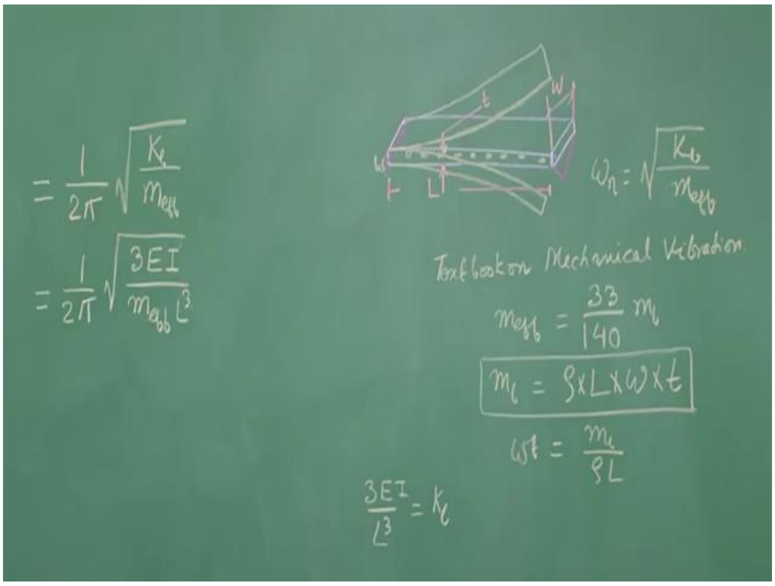

So if you look at the expression of Omega n, so let us try to write down the expression of Omega n here if and we use the expression of Omega n, let us try to now erase this part and try to work on the system, this part you already know I am just keeping the expression of K b okay and the expression of W M effective okay.

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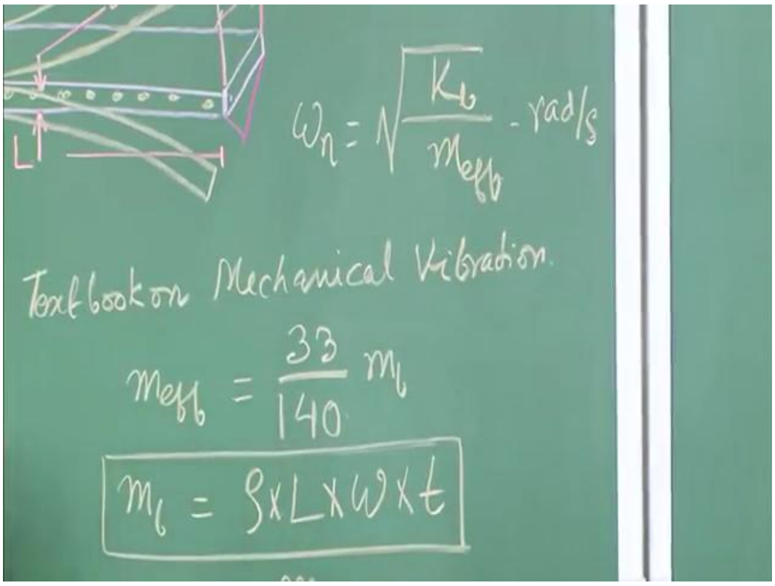

Omega n here is actually as radial per second, right. And here let us put a different variable then because we have divided it by 2 pie, so let us put it as 1 over 2 pie square root over K b over M effective. So if I now work further, what we will find out is that this will become now also we have to keep in our mind that I which is the I of the beam is actually W T cube divided by 12 okay.

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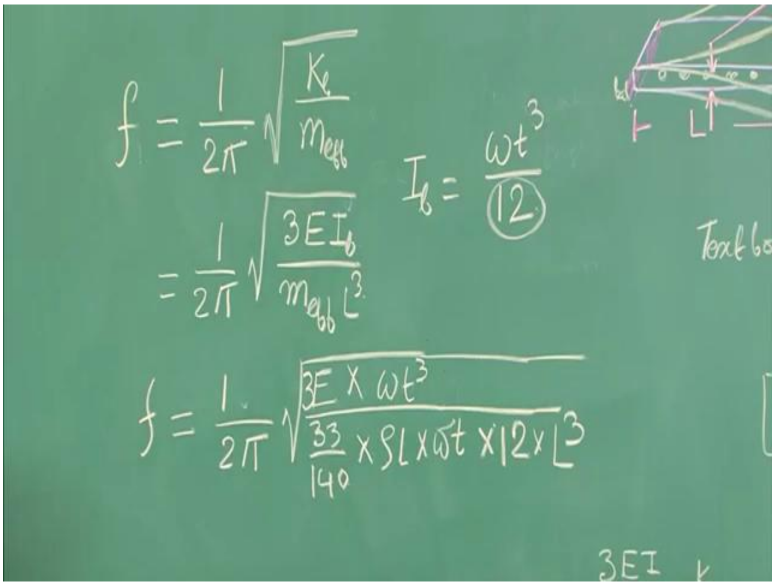

And so I can put that expression also here, so F will be 1 points 03 divided by 2 pie that is the 3 square root we have kept it out okay and then what is it that we have inside, let us try to keep all the parameters now here, E okay and then we have from I b we are getting basically, so 3 E is coming here that is our 3 E term okay, then we have W T cube, then we have our M effective, which is 33 over 140 and M b, M b is I can write it as M b here that is W T is this thing, so I can write M b as Rho L times W T, right.

So 33 over 140 times M b as Rho, let us just keep it as one for the time being okay, so 1 let us keep it right now. So however, this we need to really look into now that this M b itself is giving us what Rho L times W T that is 1 we are getting okay and then that is our M effective and what else are we getting from here? We are getting okay 33 over 140 that is the M effective. We have that 12 term here, this 12 term we have to keep so we have the 12 term here. And also we are going to have let us see 3 is there, I b is W T cube that is fine, M effective is there, yes L cube, L cube we are missing right, so that is all these are the terms that we have.

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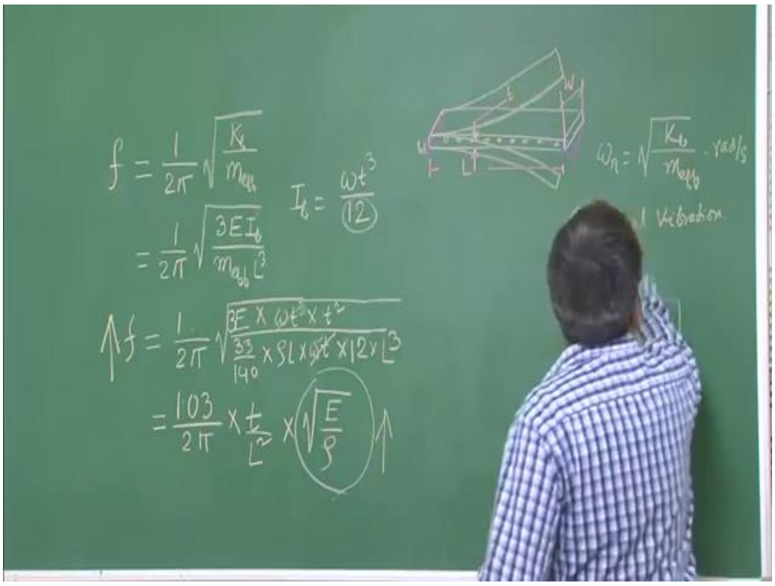

Now, as has been already solved by this particular part, so this is coming out to be 1 points 03 over 2 pie, so as been solved already by our T and multiplied by let us look at this part now very carefully. So I can write this W T cube as W T times T square okay. So if I write like that, so then I have no problem, I am actually getting the T out okay. And then the W T of course it is a free variable, but it is cancelling in this case so that is also fine with us and what we are, L to the power 4 is there so we can actually bring L square here, T over L square and we do not want to touch them either and finally we have square root of E over Rho that is the material property index.

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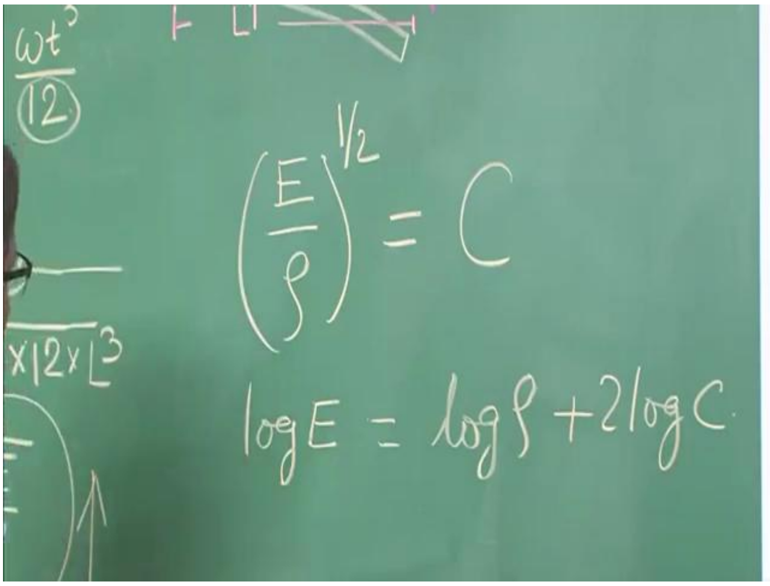

If you want to maximise this frequency, you have to maximise the square root of E by Rho that is the point that we are getting as a take home exercise result from this system. So let us write it down that E over Rho to the power half if I keep a (())(17:42) minimum value for it for the design, then this will become in the log-log plot as Log E = log Rho plus 2 log C. In other words, as you can see that in a log-log plot between the 2, the slope is one that is 45 degree okay.

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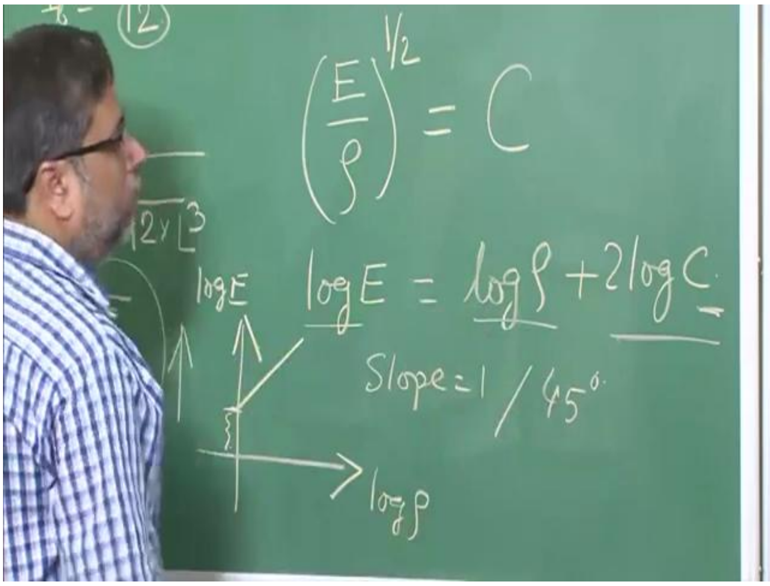

And this depending on the value of C, we get the intercept part of the line so that means in the property index of log E versus log Rho, the slope is unity but it starts with a minimum value, so that value is what we do know C ones we determine the 2 logs, you will say what exactly is this value, but this is what will be the nature of the line. And that we are going to get provided we keep area as the free variable. Now suppose, we do not want to keep area as the free variable, if we want to keep suppose anything else. Suppose if thickness becomes a free variable, what happens?

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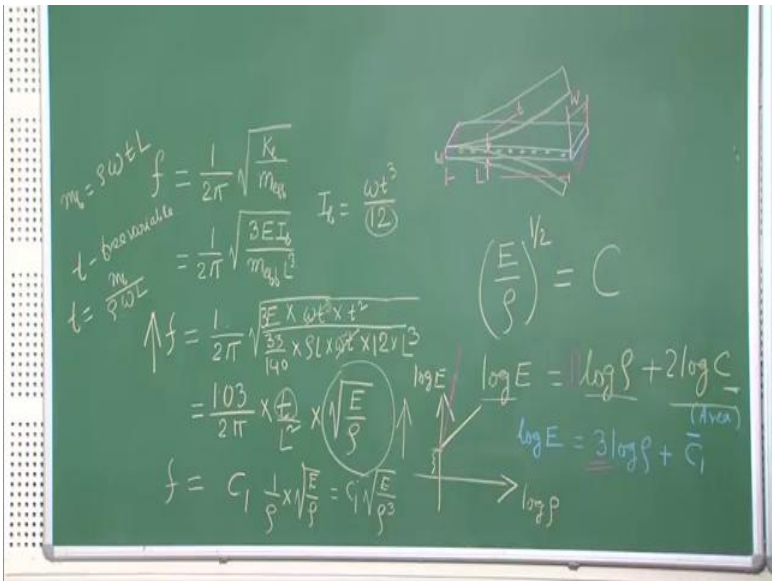

So suppose there is one such system which is not a probe, in case of probe you need that where thickness is a free variable, then we know that in our final expression there will be a T term and we know also that this T we can actually replace it if we remember that mass of the beam was nothing but Rho W T okay times the length of the beam, so T is nothing but M b over Rho W L. So even if I take everything out, but still we have a Rho term here, so that means our constant F will be a new constant now, let us call it sometimes as constant C 1 and then there is a Rho term here so it will become 1 over Rho times square root of E over Rho.

In other words, this will look like C 1 and square root of E over Rho cube. In other words, in such a case suppose I use you know, so this is what for us as area free variable, let us call it area and let us just put just below this line put this new one, then this new one would look like we have F as C 1 square root over E cube, so we can write it as log of E = 3 log Rho plus some constant, correct. You can evaluate it, but the important thing for me is that here it was unity, here it was unity and here it is 3 that mean the slope changes.

The slope which is 45 degree for us that slope changes in the next place, so this changes the nature of the solution. We will see that how all these things affect our choice of the material. So the choice of essentially I want to actually impress on you that the selection of the free variable T can qualitatively… The selection of the free variables so to say can qualitatively change the nature of the solution very-very dramatically very significantly. Let us go back and see that what material we may choose in such a case.

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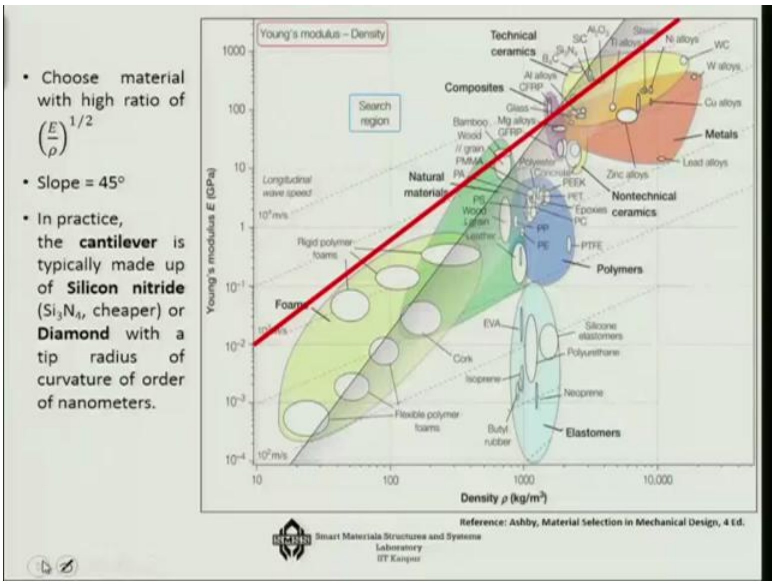

This is what is our the diagram of E versus Rho as you can see, X axis is our density, Y axis is our Young's modulus E and here we have the plot of all the materials from Ashby's material selection in mechanical design. And as you can see that this is the line that is for E by Rho = 1 subjected to the initial value of our own choice, we will see that what are the materials that we can get, we can either get something like silicon nitride, etcetera, those which are above this level or we can get something like suppose if you want to choose something which is also equally hard, you can actually choose ceramics, you can actually choose things like diamond also here.

So, which will be somewhere in the technical ceramics range, you will see the diamond also is a good solution you can find it out okay, it will be somewhat higher than the silicon nitride, but silicon nitride is a cheaper solution in terms of the cost, hence that is what is actually much more preferred solution. Depending on the application one may go for some or the other advanced versions of metallic alloys in this region, but generally it is silicon nitride, which is used in this particular type of a situation.

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So thus you know, we have demonstrated again for another typical application that how you can use the Ashby chart will selectively and your knowledge of materials in order to select a proper material for something which is as complex as the probe of a scanning electronic microscope. So this is where I am going to end today and in the next lecture I am going to now cover other non-mechanical properties like optical properties, electrical, magnetic and thermal properties. Thank you.