Electronic Packaging and Manufacturing
Prof. Anandaroop Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 40
Special Topics

Hi welcome back to what is the last lecture of this course on Electronics Packaging and Manufacturing ok. So, as part of this last lecture we are going to look at some Special Topics. It is not a one particular topic which we have typically followed before or one subtopic, what I am going to do in this last lecture is talk about a few subjects which is very relevant today. And, where there is in some of the newer advances where people are in the last in the last few years or within the last decade at least there has been a lot of concentrated research going on ok.

So, the first one we are going to talk about lead free solder, then we are going to talk a little about carbon nanotubes and then 3D printed electronics ok. So, we will talk about each of these one by one and finally, we will close with a small video.

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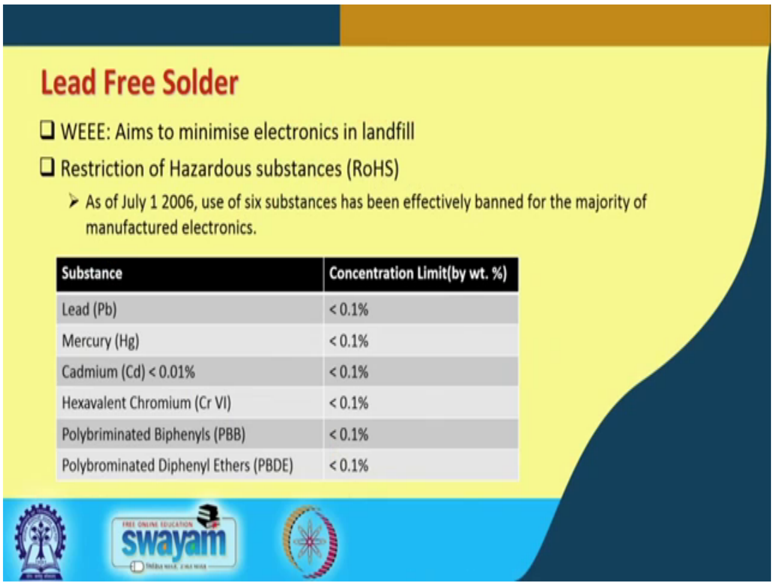

So, lead free solder, what does this mean? So, see all this file whatever solder traditionally we have used since we started using electronics and making electronic components, the solder has primarily been lead tin solder ok; lead and tin where the primary components. But however, what happened is RoHS which is Restriction of

Hazardous Substances; so, they this organization came up with mandate where they identified six substances that should be effectively banned for the majority of manufactured electronics ok.

So, that is and they gave enough notice. So, I remember I was working on lead free solder at Intel in the year 2003 this was whereas, this effect was supposed to come from 2006. So, companies had started taking preparations because this meant a major change remember; solder is almost ubiquitous we saw that we will again see today one slide where. So, solder is so, widely used in the electronic industry and certainly if you and say that you know everything has to change and you have to move to a new material that change is not going to be easy. So, it takes lead time and companies did well and today its almost effectively banned.

So, what RoHS said is these are the six hazardous substances and so, in electronics the concentration limit by weight must be less than 0.1 percent for each of these. And, the first one and this list is lead alright. So, actually cadmium is 0.01 percent not 0.1 percent. So therefore, the question is that what are we supposed to do in this case.

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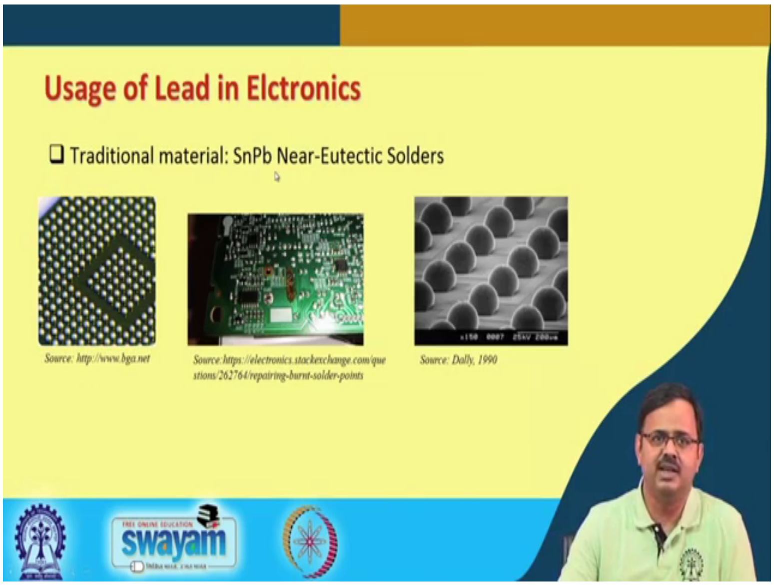

Because use of lead in electronics through the use of lead tin solder near eutectic solders are everywhere. I mean we have talked about solder balls extensively right, we have also talked about interconnections by soldering techniques from the package to the chip carrier from the chip carrier to the motherboard ball grid arrays all solder balls ok.

So, you see that solder was is almost omnipresent in electronic products alright. So, there was this push that you know you cannot use this solder anymore you have been using it for so, many years that is fine, but let tin near eutectic solders can no longer be used.

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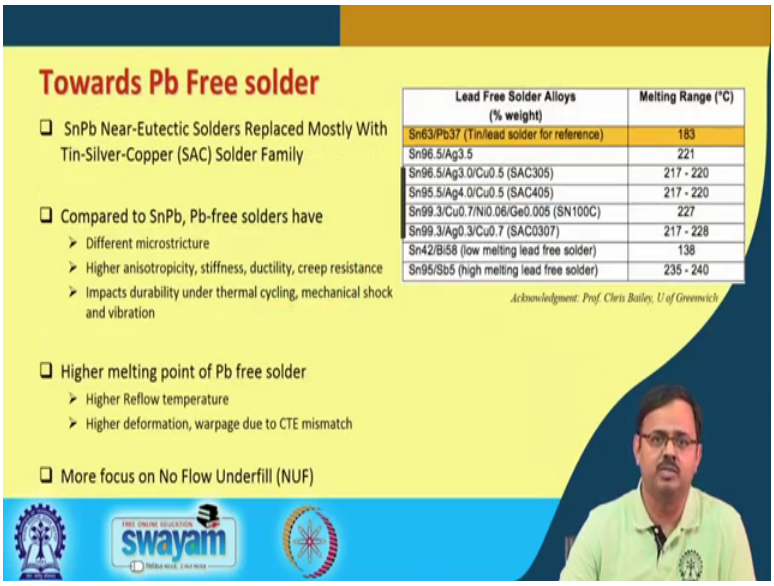

So now, we have to move towards lead free solder. So, what has done is there is an extensive research across the world in different companies, different labs where people have and universities; labs means both university labs as well as research labs. Where, people have looked at various compositions in order to replace or in various compositions to come up with an alternative solder which can replace the lead tin solder ok. So, some of these are shown there and so, the first one is lead tin lead is 37 percent, tin is 63 percent and that melting range is around 183 degrees C. But, what has happened is most of these what has been found is that sack or SAC which is a composition of tin silver and copper ok.

Say tin the chemical formula is Sn, silver is argentine Ag and copper is Cu ok. So, that is where SAC if you take just the chemical names and take the initials that is where SAC come from. So, this tin silver copper solder family which is going to replace tin lead solder. So, various compositions have been tried some of which are shown over here. And, these are primarily the difference is primarily in the concentrations by weight alright. So, as you can see tin is the major is the major is a major contributor; major composition is tin for most of these you see 96.5 percent 99.3 percent. And then there is also some tin bismuth and some other formulations, but what you see is most of the SAC family which is most popular which is listed here. The first thing that we notice is the melting range is higher alright.

So, will come to this, but that is something that we see right away from the table that strikes our eye. Now, compared to the lead tin solder the lead free solders have different microstructure of course, different composition, different microstructures. These have higher anisotropicity, stiffness, ductility and creep resistance. So, some of these are good right higher creep resistance of course, is good higher stiffness is good ok; ductility also fine. But what this does is this impacts a durability under these stress conditions that we talked about under thermal cycling mechanical shock vibrations and most of them are favourable property changes.

But what we also see is the melting point of this lead free solder is higher. So, what does that mean? That also means that the reflow temperature when it is reflowed and pass through the reflow oven or wave soldering the temperatures that we need to reach are higher because the solder has to melt. So, now if you have to heat it to higher temperatures what happened, we have seen enough about CTE mismatch about warp age before. That is because of CTE mismatch between silicon and organic laminates and now we are saying that in order to have this reflow process the temperatures have to be higher.

So, which means that delta t is higher therefore, the plastic strain is higher and therefore, the life is going to be impacted right. The life the cycles to failure which we saw as part of our you know the reliability discussions that is going to go down right. So, there are some positive side negative sides and the whole thing as to how this new composition is going to behave under fatigue, cyclic loading, what will be the crack formation, will there be a crack formation, how will it propagate. So, all these are going to be different and so, there is a whole lot of new characterization that needs to be done. (Refer Time: 08:01) is exactly is just an example what about vibrations, what about drop test impact test ok.

And, the other thing that has happened is remember no flow under fill. When we are talking about under fill under fill epoxy the first thing was you first bond it and then you dispense the epoxy and then through capillary action it kind of squeezes into the spaces between the solder balls in a flip chip arrangement. The other one was a no flow under fill where, you first dispensed the under fill on the substrate and then bring the dye with the solder balls. And, it comes and it squeezes out the; it squeezes out the under fill material and the bonding happens under pressure and a little bit of temperature. So, lead free solder therefore, goes towards no flow under fill ok; (Refer Time: 08:54) that is what is called.

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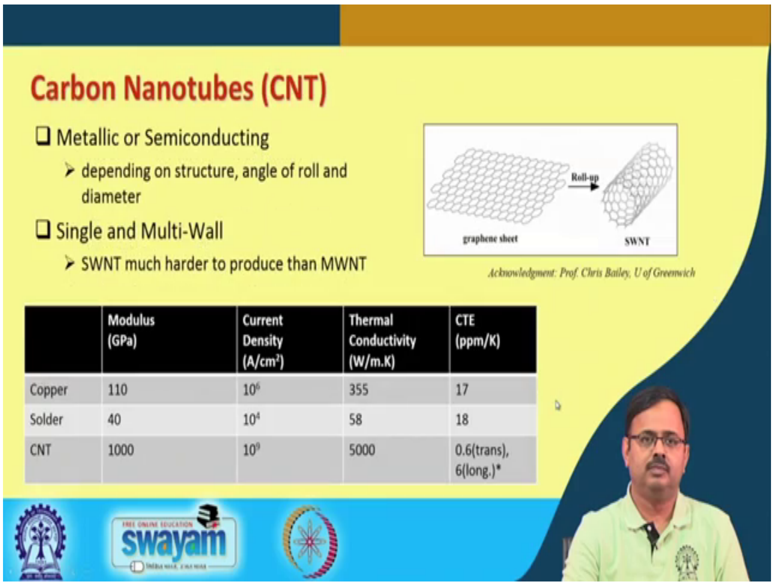

So, lead free solder has been a big there has been a big push towards first of all coming up with new materials and characterizing them under different applications alright. The second special topic we wanted to discuss is carbon nanotubes. What is carbon nanotubes? Carbon nanotubes is if you take what is called a graphene sheet which is a 2D carbon a allotrope; primarily from graphite what is graphene and then if you can roll it up in this manner what you get is a carbon nanotube ok.

So, this carbon nanotubes this has been a field of research for almost 10-15 years now. These have got some amazing properties first of these the anisotropic definitely, but if you look at it these are if you and you consider; so, copper solder and CNT just in terms of properties. The elastic modulus for carbon nanotubes is 1000 1 order of magnitude higher than that of copper and even more almost for 20 times higher than that of solder right. Current density you can see this 3 orders of magnitude higher than copper, 5 orders of magnitude higher than solder. Electrical conductivity the amount of current it can flow of course, it is directional property. But, you see this thermal conductivity 5000 copper is 400 ok, 355 solder is around the 50's or 60's 58; I mean some formulation.

Carbon nanotubes 5000 higher than higher than diamond ok. CTE: Coefficient Thermal Expansion way low right in the transverse direction very low in the longitudinal direction somewhat higher, but still definitely several times lower than that of copper or solder. So, can you look at carbon nanotubes as an interconnect material right; seems to be having all the favourable properties right. So, that is one so, carbon nanotubes therefore, has gained importance. So, has graphene if you look at this 2D structure, if you have a conductivity a planar conductivity of 5000 you can understand it will be what a wonderful heat spreader is going to be graphene sheets right; so, excellent.

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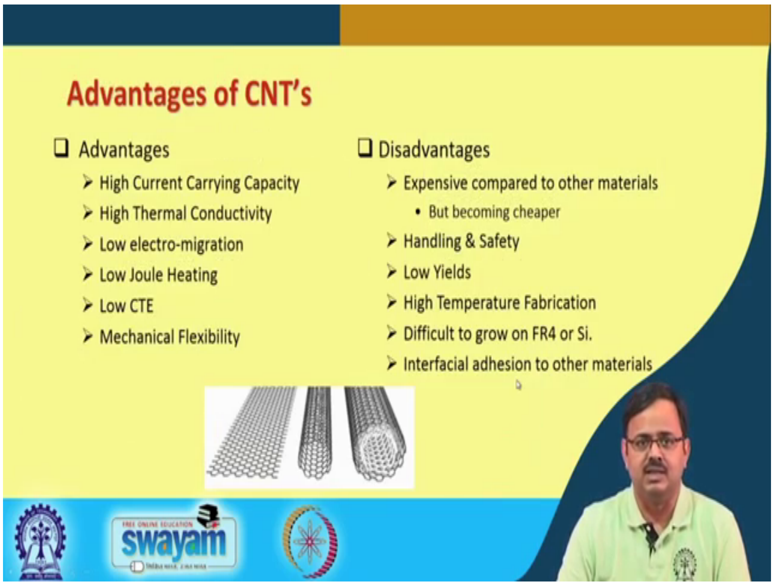

So, the advantage of CNTs you see here high current carrying capacity, high thermal conductivity, low electro migration, low joule heating because i squared r is less; net mechanical flexibility higher modulus of rigidity as we saw. So, all these are very good properties. Disadvantages: extremely expensive ok; there are few methods by which carbon nanotubes can be made, but extremely expensive especially single walled carbon nanotubes. But, again this is something that is advancing and therefore, with more and more newer techniques and innovations its becoming cheaper. It is still way more expensive compared to other materials, but the trend is towards cost reduction right.

Handling and safety ok; you do not want to these are so, tiny things and if you do not I mean handling and safety is a concern, it is delicate. Low yields in the sense I mean its it is a complex manufacturing process that is why, it is expensive. You cannot really make it in large numbers in high volumes at a very fast rate. High temperature fabrication because, when you want to want to manufacture these the process occurs only at very high temperatures. I have intentionally not talked about the processes, you can you can look up on the internet. The other thing is its difficult to grow so, these are these are like tubular structures like nanotubes right where, can you grow right. It is difficult to grow on FR4 or silicon that is the disadvantage.

If you want to view it as interconnect materials and you want to replace let us say the solder balls in flip chip technology with this carbon nanotubes, then you should be able to grow it either on the board side or on the right side. So, either on FR4 or silicon it is not easy ok. And, interfacial addition to other materials there is one property which can be you know harmful or not harmful; I would say which can impact us adversely. Some people also use it to that to an advantage, you can have a carbon nanotube and it can be it will stick very easily and you can remove it like a Velcro; I have seen applications like these ok. So, depending on the applications, but here I mean it can be both an advantage or a disadvantage, but primarily we have to be careful about this ok. It should not adhere to a surface which where we do not want it to it here clear.

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So, what can be the applications in electronics industry? So, we already talked about on chip interconnects, vertical via interconnections horizontal wires; you can think about all of these. Off chip interconnections so, flip chip bumps through silicon via clear and thermal management; can it be very good I mean can it be used as a thermal interface material. You imagine right this is such high conductivity, if you grow it densely why not if you and align it properly so, that the conduction happens only the vertical direction from the chip to the heat sink; why not. You have a grease and have this carbon nanotubes dispersed and somehow come up with some method to align them ok.

So, these are all examples where carbon nanotubes can be used and graphene again as I talked about if you do not roll it up into a nanotube and just have the graphene sheet that again has lots and lots of advantages even from the thermal point of view; that would be a wonderful heat spreader alright. So, carbon nanotubes again a very hot area of research especially in the materials world, but also in the applications world. It is a wonderful way where material scientist its wonderful avenue for multidisciplinary research; where whether if you are an electrical engineer focus on the first two applications. If you are thermal engineer you focus on the last application and work closely with the material scientist who will develop these materials for you wonderful alright.

So, we have talked about lead free solder, we have talked about carbon nanotubes two very relevant and current topics of interest and research in the field of electronic packaging.

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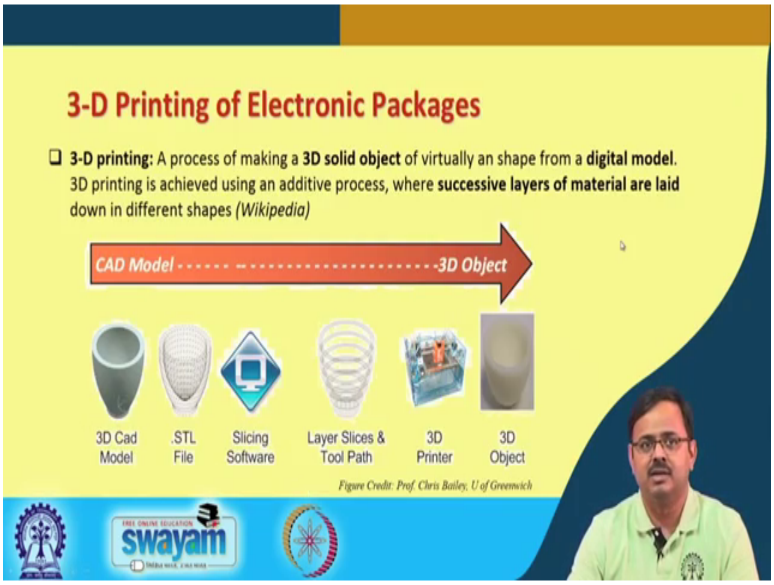

The third one is probably the newest and that is 3D printing. We see this entire push towards additive manufacturing and 3D printing is one of those techniques. So, what is the additive manufacturing? alright. So, additive manufacturing what it means is you grow a substance; you grow a structure or a pattern or whatever you want to want to make you actually grow it layer by layer by adding materials ok. What do I mean by that? See till now, let us say you had to I had to make something I have to make a structure made out of aluminium. What was the method? I take a block of aluminium and then use various machining techniques.

Let us say I want to have some channels on an aluminium plate, I will take an aluminium block and then use maybe an end milling machine to mill off the channels right. If I had to drill a hole I would take a solid surface use a drilling machine with a drill bit and drill through correct. So, it was all about subtractive, you start with a mass of material and then you remove the material where you do not need where you do not need it and then give rise to the structure. Additive on the other hand is I do not remove material, I take material may be in the form of powder and deposit it and make the structure out of this. You know wonderful example is play dough that kids use; play dough right it comes in the form of a dough of different colours and they will take small pieces and you let us say they want to make a shape of a face. So, they take one colour make a circular disc then they take maybe another colour make the eye, make the nose, make the smiley face ok.

So, what have what have we done there or what has this child done? He has actually made this and grown this layer by layer ok. Now, make it even more complex; let us say this was the face on which there was this eye and eye and nose and the face. Let us it has to be very knit, it has to be a flat structure. So, then what do we do? Right, we will put will keep these holes out and then fall for the eye, for the nose, for the face and then put this other coloured cradle in those holes and you get this planar structure. Now, on top of that you want to have some other face right. So, let us say when you invert it, you want one phase maybe the man's face, you invert you look at the other way it is a woman's face then I will do the same thing on top of that clear. So, what have we done? I have made a structure layer by layer.

Now, bring it down and scale it down; I will take this powdered materials and deposit it layer by layer ok. When we print a colour photograph what do we do? On a piece of paper if you take a colour print out it will print with black ink where it has to be black it is going to dispense RGB or combinations of those for the different other the colours right; where it is red it will be red, where is blue it is blue, where it is yellow it is yellow right. So, 3D printing is similar; I am going to deposit these powders of the material that I want layer by layer and grow it. So, 3D printing is a process of making this is a Wikipedia definition, Wikipedia always we do not trust ok.

Because there is no sanity check of what people put up, but that being said this one is the most in I would say majority of cases they are good, they are correct and in this case it is correct. A process of making a 3D solid object of virtually any shape, I am going to come to this virtually any shape from a digital model. It is achieved using an additive process where successive layers of materials are laid down in different shapes. So, for example, this is a 3D CAD model I probably want to make this. So, in a CAD software I will put this I will I will get a STL file, then I will have a slicing software where it is going to break it up into slices of anything dimensions. So, each of these are you can think of it you are taking multiple printouts on the same piece of paper; one above the other and that paper allows you to do that. So, it is similar.

So, first I will deposit the powdered metal the 3D printer will deposit the first layer in the form of this solid circle then in the form of a ring with a certain slightly higher diameter again a slightly higher diameter and so on and so forth. And finally, I find get this 3D object. Now, this is all white it is the same material, but could it have been different materials could the different layers have been of different materials of course, it could have been. So, I could have had one type of plastic maybe a white plastic then red then black. Now, could each of this if I take just one of these rings could I have different materials at different sections. Yes, I could have and I could have different patterns different materials even different colours same material of different colours.

So, everything is possible ok. So, virtually any shape what do I mean? Let us say I give you a plate we are talked about cold plate before right, where you have a serpentine channel, you have an inlet, you have an exit and you have a serpentine channel through which the material flows. How am I going to make it? I will take a base plate you make this serpentine channel and then take another lead and bond it that is how I do, that is how we will do. But in 3D printing I do not need to do that, it does not have to be the two layers with a final welding or whatever some addition process; because it will be just layer by layer it is going to be done. And so now, think about it I can virtually make any kinds of shape even a fractal shape inside as long as my 3D printer feature size allows me I can do that ok. So, that is 3D printing alright.

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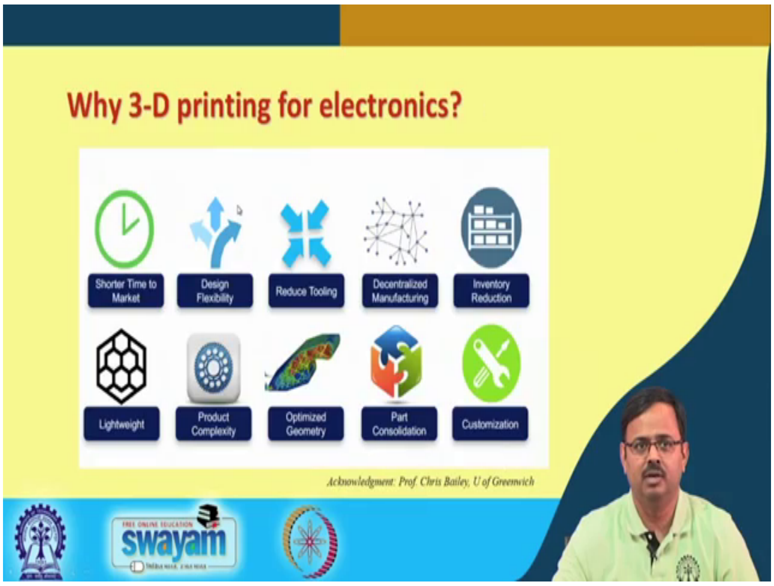

So, why 3D printing for electronics? You can make it very fast, you can make very complex shapes, reduced tooling because it is just one printer now and many other stuff ok; lightweight inventory reduction blah blah all kinds of stuff ok. So, this is again of I want to acknowledge Professor Chris Bailey; I have taken this from his presentation this slide alright.

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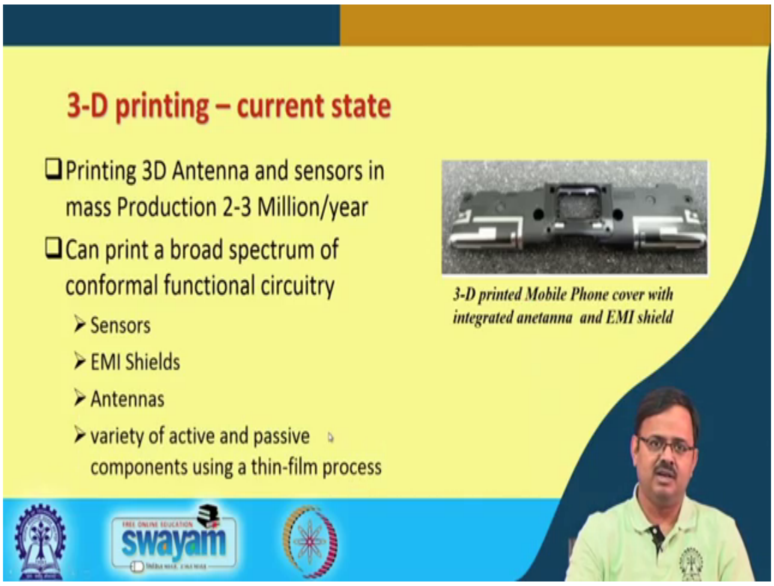

So, current state: so, 3D printed antenna sensors are already there in mass production 2 to 3 million pieces a year ok. It is can print a broad spectrum of conformal functional circuitry: sensors, EMI shields, antennas etcetera, but think about it if it is possible and I am sure it will be why not ok. Before that let us just let us look at this picture; it is a cell phone chassis or a case, mobile phone cover with an integrated antenna and EMI shields 3D printed. Printed layer by layer some plastic some metal whatever you need. Now think about it mother port when we wanted to do it, we had to do that layer by layer right kind of stuff.

We had to etch it, we had to remove you know use photolithography etcetera, but now 3D printing if it allows me to print FR4 print copper wherever I want and I have I can have any kinds of shape. My copper traces does not have to be rectangular anymore right, I can have much more traces. So, all this is possible I can make a whole motherboard out of that; can I slowly can I 3D can I print the solder joints can I print the interconnects layer by layer. Yes why not, it is possible it has not been done yet, but it is possible opportunities are endless with 3D printing. So, it is one of the hottest and very new area hottest techniques.

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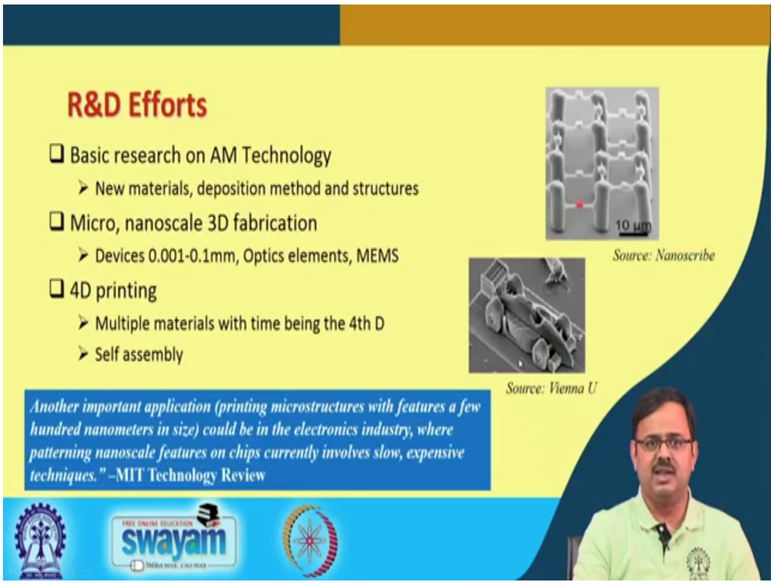

And, lots of R and D efforts are going on new materials, deposition method structures. Micro nano scale of 3D D in micro nano scale 3D fabrication devices of the order of you know 0.1 millimetre to 0.001 millimetre some 1 micron possible. Optical elements, MEMS: Micro Electro Mechanical Systems you see these in Vienna University what they have made these are in microns ok, nano scribe another one.

So, it is an important application, but printing micro structures with features a few hundred nanometers in size could be in the electronics industry. But, currently patterning nano scale features on chips involves very slow expansive techniques. This is from MIT technology review; it is showing the promise of 3D printing.

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So that kind of brings us to the end of this course, we talked about 3 very hot and current areas lead free solder, carbon nano tubes and 3D printing. What I will do is I will end this course with a small video trying to show the relevance of what we just covered as part of this course. This electronics packaging and manufacturing sector, the relevance and importance in the Indian context alright.

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So, I hope you saw that video and the video kind of underlined you will appreciate that the video kind of underlined and highlighted the importance, the growing importance of electronics industry even in the Indian context today. If you look at some of those numbers I mean an annual growth of 26 percent year on year that is really mind blowing. Well honestly I think we have not been able to hit that number the actual growth over the last 4-5 years have been in the range of 12 to 13 percent year on year, but that itself is quite staggering right. And, this is because of the way that electronics products primarily consumer electronics products have percolated into our lives. As you saw there we are the second largest number of internet users in our country.

We are a country which is one of the highest users of smart phones and we see that around almost all of us have smart phones today ok. So, that kind of shows the importance and the growth especially in the consumer electronics markets. And, not just that we are talking about a digitally connected world today internet of things and all these require electronics and electronic products and devices right. So, what we have done as part of the course have been trying to highlight what all goes into the design and manufacturing of these electronic systems. And, also to ensure that it performs reliably as per our expected expectations over its life cycle ok.

So, that as I said before this brings us to the end of the course and today I also have my co-instructor Professor Goutam Chakraborty with me.

Hello.

I hope you have found this experience or found this course to be a good learning experience. And, if nothing else you have been able to appreciate how important and how multidisciplinary this entire area is right. It requires a good electronic product requires expertise not just from a VLSI designer; it requires expertise from semiconductor physics, from electrical engineers, mechanical engineers, material scientists, manufacturing engineers, reliability scientists and so on and so forth. And, we have tried to give you a little flavour of all these aspects that goes into electronic packaging and manufacturing ok.

So, if you recap we started with a little bit on the basics of semiconductors and then we went to what we call the first level packaging which is the silicon on the chip carrier. Following that was the second level by the chip carrier along with the silicon chip was connected to the circuit board. And, the circuit board if you recall was the platform which facilitated communication among different electronic components right. And, then there was a third level where the circuit board went into these sockets and holders and finally, gave the shape to the final product inside a chassis. And, then in the second half of the course we talked primarily about the reliability aspects where, we first talked about thermal management, the importance of it and also some cooling technologies.

We talked about solid mechanics or applied mechanics in ensuring that these products are performed reliably. And finally, we also looked into the reliability considerations the physics of failure and so on and so forth. And of course, in between and at the end also we had some special topics of very high relevance, hot topics of research as of today. So, hopefully I hope or we hope that you found this experience to be useful I will have Professor Goutam Chakraborty, what they say a few words about how he felt as part of this course and then we will wrap up.

Hello. So, I hope that you have enjoyed this course and you have found it useful. Dr. Bhattacharya has taught you different aspects of very complicated subjects; I am sure he did a very commendable job in that and for my part I taught you basics of vibration which is a very important for the packaging industry. But, it is a difficult subject as well, but I hope you have found it useful and in due time you will learn more about this. And, you will feel interested in more detailed research topics on the similar on this subject. And, that will be our remains pleasure if you get yourself involved and if you find whatever way we contributed to your knowledge has become successful. And, with this I think I thank all of you for your kind attention and on our property area.

Yeah, that is a very nice thought I mean as we said I mean whatever we have taught if you can actually use them or pursue them as potential topics of research in your careers ahead, then we would really feel that our effort has been white while have has been worthwhile. So, with that what I would end is with something that I said right at the introductory video or the introduce a small 5 minute introduction that was recorded for this course. As I said, I spent quite a few years at Intel and a question that was often asked to me is you are a mechanical engineer, what are you doing in a company like Intel that is where computer scientists should be or electronics and engineers should be.

So, I hope after this course you will appreciate and you will that the mechanical engineers also have quite a bit of a role. And, I would say quite a bit of a critical role to play in the electronics industry ok.

Thank you very much and we wish you all the best in your careers ahead.