MEMS & Microsystems
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Lecture No. #30
Wafer Bonding & Packaging of MEMS

Wafer bonding and packaging of MEMS is very important topic because in this particular point there is a lot of difference between the conventional VLSI bonding and packing and MEMS devices bonding and packing. In case of VLSI we have seen that bonding means the silicon chip is bonded with the encapsulation. And after that you go for the wire bonding to different leads. But in case of MEMS it is not the same as the VLSI chip bonding and packaging. The major difference here is that in case of MEMS, 2 or 3 even multiple layer of wafers has to be bonded together to get the complete structure. And in that case the total thickness of the wafer will be more than 1 millimeter in some cases. In that case the total height of the device is not very small.

And another point in case of MEMS devices, in many applications you need the outside environment should be reflected into the devices. For example in case of pressure sensor the bonding and packing should be such that the device should be exposed to outside pressure or environment. In case of optical or thermal sensors, the complete device should be exposed to thermal radiation or optical radiation. So in those cases a special kind of bond and packaging is used in MEMS devices. So that is one of the points where lot of R&D is going on. And in case of MEMS devices the package are not unique. Means a special type of package normally TO 5 or DIP which is available in case of VLSI directly may be not used in case of MEMS. So since the requirements are different you have to satisfy a lot of special aspects in case of MEMS.

So each device require custom package and the wafer bonding technology is again very crucial. Because in case of hearts environment or lot of mechanical movement or hesitation like the acceleration sensor, rotation sensor if the bonding between the wafer are now rigid, then during the course of operation, they may come out and total device may be destroyed. So because of all these reasons, this particular topic in MEMS that is bonding and packaging of MEMS is getting lot of importance and lot of R&D is going towards this directions. So now today we will discuss in detail in depth the bonding mechanisms which are followed in case of MEMS and what are the different kind of packages used.

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So assembly and bonding that is the basic objective of today's lecture. Actually since it is a micromachining device, so there will be some mechanical movement among the different components of the devices. So those mechanical movements should not be disturbed by the package itself. So it needs the assembly of the individual components formed using micromachining technique. In this case the wafer bonding in conjunction with micromachining allows the fabrication of 3D structures that are thicker than a single wafer. Basic 3D structure means here apart from the x and y direction the thickness direction which we call as a z direction. That is not very small, that is very large. Because you are going to bond several layers of wafer. And by bonding multiple wafers sometime you can get improved performance and functionality of the devices.

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And so it is obvious that the MEMS wafer bonding is highly critical in some cases. There are various processes normally used to develop the bonding mechanizing in MEMS devices. And in case of the MEMS devices not always you are going to bond silicon. To silicon in many cases we require bonding between silicon to glass silicon to nitrite, nitrite to nitrite, oxide to oxide, glass to glass. So various kinds of the levels of wafers are bonded together. So in this particular area we normally use 3 to 4 kinds of bonding mechanism. First one is bonding of hydrophobic wafers, second is intermediate layer bonding and those intermediate layers bonding several techniques are there namely eutectic bonding polymer layer sometime used for bonding between the two layers. That is photoresist also used were you do not need very hard bonding soft bonding you can make use of photoresist thermo compression layers.

Thermo compression means you have to press in presence of certain temperature high temperature and press there thermo compression bonding and solders. In some cases, you can just use some solder materials to bond the wafer with some another say package or housing. Third one is important fusion bonding sometimes it is also called as direct bonding. And here these substrates are mating together, they contact each other and then you have to for thermal annealing. That is the major steps in case of fusion bonding or direct bonding. And the last one is anodic bonding which is very important and highly promising in case of the wafer bonding technology of MEMS. And there you need an electric field as well as temperature, so that is the anodic bonding. So all this bonding techniques I will discuss little bit in detail in this lecture.

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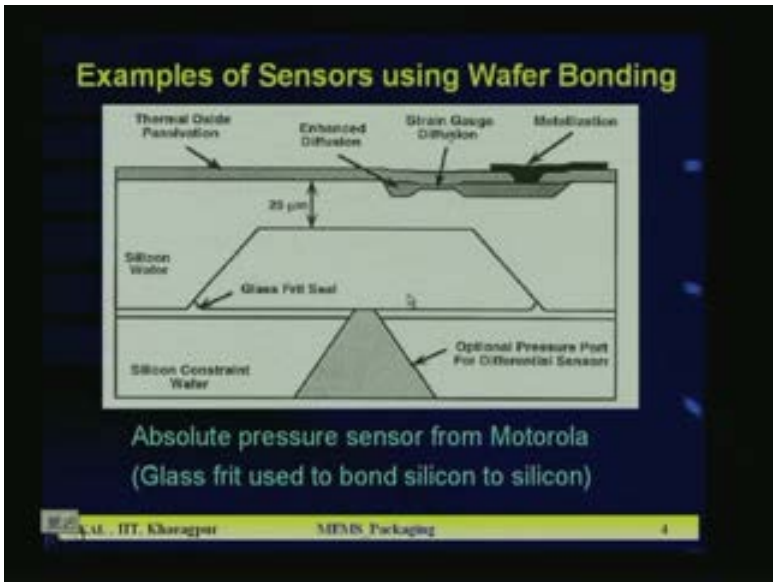

Now first let me give you some examples of sensors which use the wafer bonding. Here the picture is basically a pressure sensor from Motorola is a device which has been available in the market; which is at the present available in the market. So here the bonding is done with the help of some glass frit. What is the glass frit? Basic glass powders which has got very low melting point. So what has been done here? You can see so bottom wafer is the silicon constant wafer and in the top is a silicon wafer were you have made the device. So here is the etching, so 25 micron membrane is there. So basically this wafer is a pressure sensor.

So there is a strain gauge piezoresistive kind of thing. So here is a resistance value is there metallization is here. So now top there is a thermal oxide passivation and now the whole wafer is bonded with the bottom wafer with the help of the glass frit. So some glass powders are distributed and then you put the top wafer and use certain and you apply certain temperature or annealing. So that the glass frit will be melt at very low temperature and it will helps addition of the top silicon wafer and the constant wafer. So this is one of that, one technique which is used in earlier days. That is glass frit silicon to silicon bonding; both the wafers are silicon.

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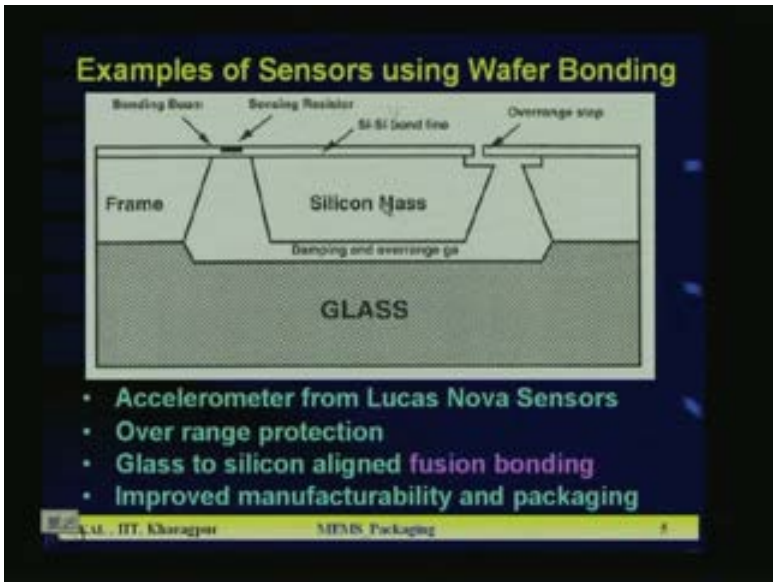

Another example I show you that is an accelerometer sensor from Lucas Nova. Lucas Nova is a company and they are marketing. This kind of sensor here they use glass to silicon bonding. So you can see here the bottom is piece is glass and already I discuss the accelerometer design and technology in earlier lectures. So this small groove is made in the glass. That is for damping and over etch protection and here there is a proof mass, here is the sensing resistors. So here you can see they are going to use here basically 3 pieces. One piece is the middle and in that is a frame only bottom is the glass and in the top is again you can see the sensing material which is the small silicon device where you have seismic resistance is there. And the silicon mass is there and here is the silicon bond line.

So and this particular thing has been used for over etch stop. For example the silicon mass suddenly is goes upward. So this particular portion will heat here and it will be protected before breaking at this flex at the flexure point so that is over etch stop. So now in the top one which is silicon and bottom and middle is also middle with frame is also silicon. That means the top silicon and middle silicon, silicon bonding and another one is a middle silicon and bottom with the glass; silicon glass bonding. So here you are facing the two bonding. One is silicon, other is the silicon glass and in this case normally they use fusion bonding. Fusion bonding, it is especially features and its mechanism will be discussed in future slides. So this is one example.

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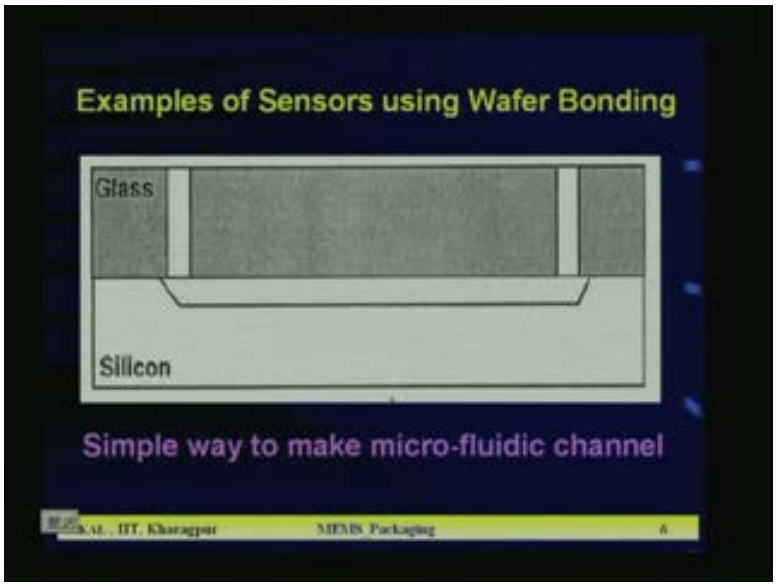

And third example I am showing, that is for micro fluidic channel. So here all this silicon and glass bonding. So micro fluidic has got tremendous application in case of fluidic sensor as well as in biological sensor. So flow channels have been created over a small area with some nozzles that is the micro fluidic. So channel is made in silicon first you make some group and a top is the glass plate were you make some hole. Here is one hole and in the right side there is another hole. So in one hole is used for input flow in flow of the liquid and other is the out flow of the liquid exit. So now and in the bottom with the channel, so in this way just you make you etch or delineate the silicon wafer. And then in glass you make some small holes and now you bond the top glass and bottom silicon together. So that you can have the microfluidic like. This very simple microfluidic structure. Here you need silicon to glass bonding.

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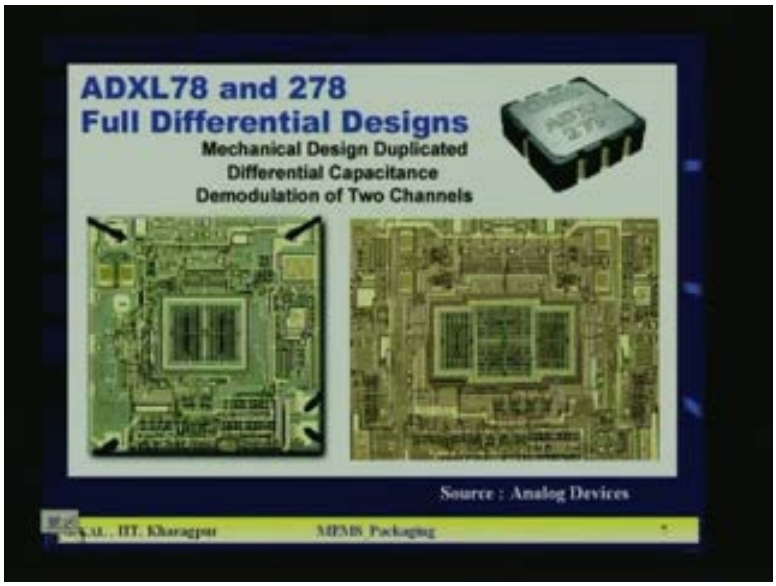

So that is why these are few examples of the bonding. Now I will show you some devices which have been bonded and smart devices are called because there they are going to use the peripheral circuits also side by side. Now this is the ADXL 78 and 278, the chip and particular chip is very popular and one of the major application is there and many places many lot of applications of this particular chip. And here from analog devices here you can see the package is not similar to any VLSI chip package; looks like some custom package. And you can see here the lots of circuits are there in the periphery of the MEMS devices and this is also another design 278. So there also these comb type of accelerometer chips are made at the central region and peripheral regions have lot of circuits are there. So this is a complete device.

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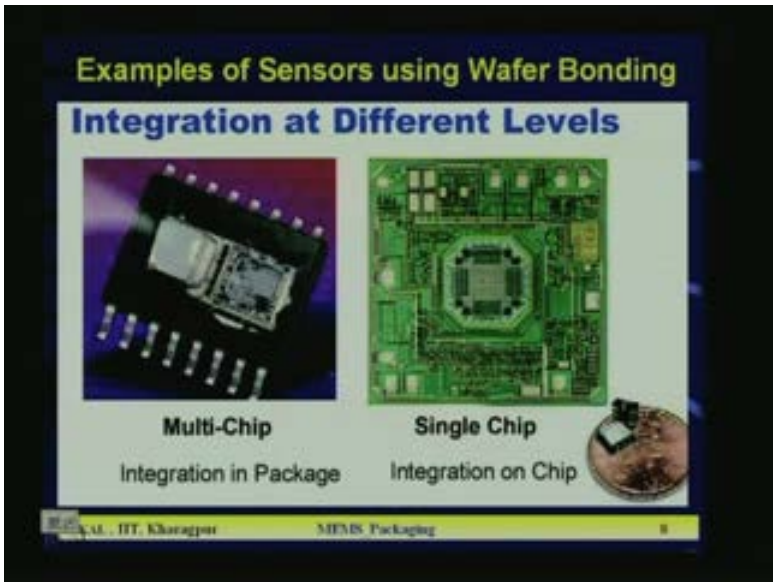

Another is the multi chip and single chip there are kind of approaches in case of the MEMS device bonding. Single chip means there you can have the circuit and in the central region, the MEMS devices is all are made in a single monolithic piece. But in another is a multi chip means in the package you have used two small pieces. But those are interconnected inside the package and then you can go for wire bonding. So that is known as multi chip or sometimes it is known as MCM or Multi Chip module. And sensor part and peripheral reactive circuits parts are all assembled inside the package and they are bonding respective places. So the total function its total chip will be functional if you just use the external pins. So this is these are two examples of commercial the MEMS devices which are bonded and package.

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And now this picture shows the package evolution in case of MEMS devices, in particular accelerometer devices. So here you can see the first one is a header kind of package. So the X in millimeter, Y in millimeter, Z in millimeter, all in millimeter is the dimension 10 millimeter by 10 millimeter and 7 millimeter is a Z direction dimension of this kind of package. Now after that people are switched over from this header type to cerdip type or cerpa type. So cerdip or cerpa type of package looks like that which has been shown in. There the multi chip module package in the earlier diagram also. So this is the 10 by 10 and thickness has reduced from 7 to 5 millimeter. Then this is known as LCC package. So this looks like that because if you go from the header type to the recent.

Once you can see gradually the chip size and dimensions are going to reduce day by day. So this one is LCC package and after that is a LCC is a 5 by 5 millimeter by 5 millimeter and 2 millimeter thickness. Then QFN package is a 4 millimeter by 4 millimeter 1.45 millimeter thickness. And the last one you can see WSP package and that package is 2 millimeter by 2 millimeter and the z direction thickness is close to 1 millimeter. So that means basic objective is to reduce the size of the chip as well as thickness dimension should be reduced. So that it should be much smaller and smaller but not at the cost of performance. Performance has to be maintained and at the same time package size and weight should be reduced. That is the objective of the evolution of newer and newer packages.

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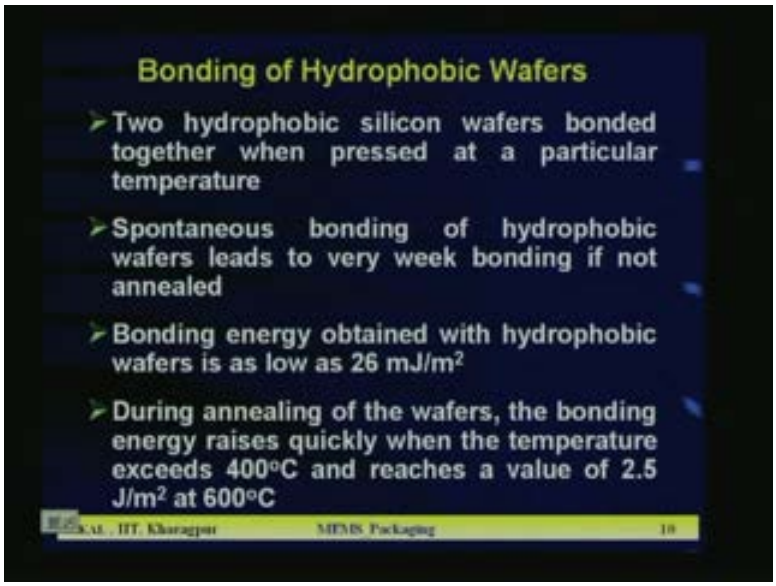

So now, let us now concentrate on the different class of bonding. So first one is a hydrophobic wafer bonding let me discuss. So here basically to hydrophobic silicon wafer if you keep one after another and if you press gently and leave it the wafer of sometime it will be bonded. And that means you are not going to use a special kind of gadgets or machine to have bonding between the 2 silicon wafers. Just hydrophobic silicon wafers you are taking and putting one after another. But in-between a hydrophobic wafer always there will be some native oxides that will be there, very thin layer of oxides will be there native oxide. And now you just put one after another and little bit press and at a particular temperature, that temperature is not very high. So the wafer will be bonded but the problem is this kind of bonding is very weak bonding.

You cannot have the bonding strength, large bond strength in the hydrophobic bonding. So that is why this kind of bonding mechanism is not used in many of the MEMS bonding and packaging technology. Now in case of the hydrophobic wafer bonding the bonding energy is nearly 26 mill joule per meter square. That is the bonding force or bonding energy. Now if it has been observed that the hydrophobic bonding temperature, if you go on increasing so bonding strength also increases. So for example if you increase the temperature from 400 degree C to 600 degree C. That the bonding strength or bonding energy will increase 26 mill joules per meter square to 2.5 joule per meter square if you raise the temperature from 400 to 600 degree C.

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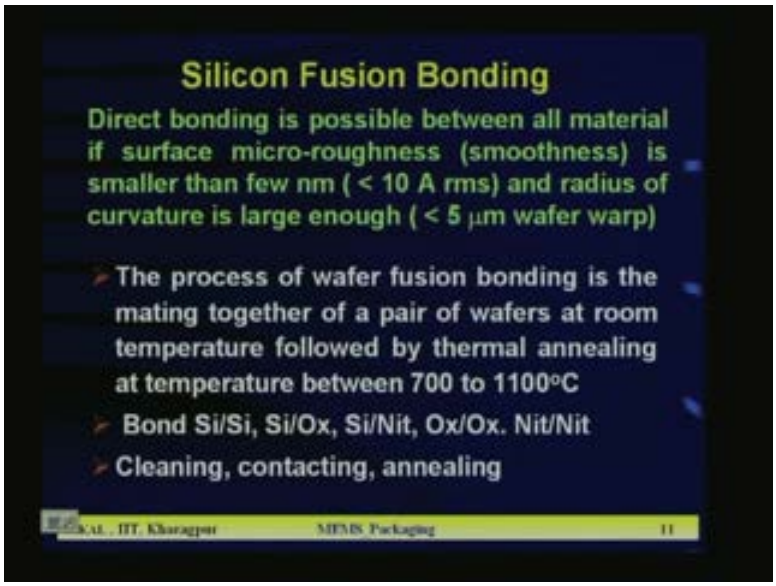

So that is one of the thing but the problems are manifold. But you cannot raise the temperature as you like that can create other problems. I will highlight those problems in next slides. Now the fusion bonding is a direct bonding and it is possible only on certain conditions. What are those conditions? The surface micro roughness or smoothness should be very small in case of fusion bonding. That is a second kind of bonding. Other than a hydrophobic wafer bonding is a basically extension of hydrophobic with certain precautions and certain modifications. That is the fusion bonding. So here the smoothness or micro roughness of the surface should be less than 10 angstrom RMS value. Then the wafer bonding will be very good and at the same time radius of curvature of the wafer should be very large.

That means the wafer warp should be less than 5 micrometer. So these are the two criteria for fusion bonding. The process of wafer fusion bonding is basically mating together of a pair of wafers. Two wafers are in contact and before contact you have to clean it thoroughly. And you make contact of the two wafers at room temperature. And then the combined pieces are treated at high temperature for annealing. Thermal annealing is followed at a temperature between 700 to 1100 degree C. And in this case of fusion bonding you can get silicon bonding, silicon oxide bonding, and silicon nitrate bonding oxide, oxide bonding and nitrate nitrate bonding. So all kinds of bondings are possible in fusion bondings.

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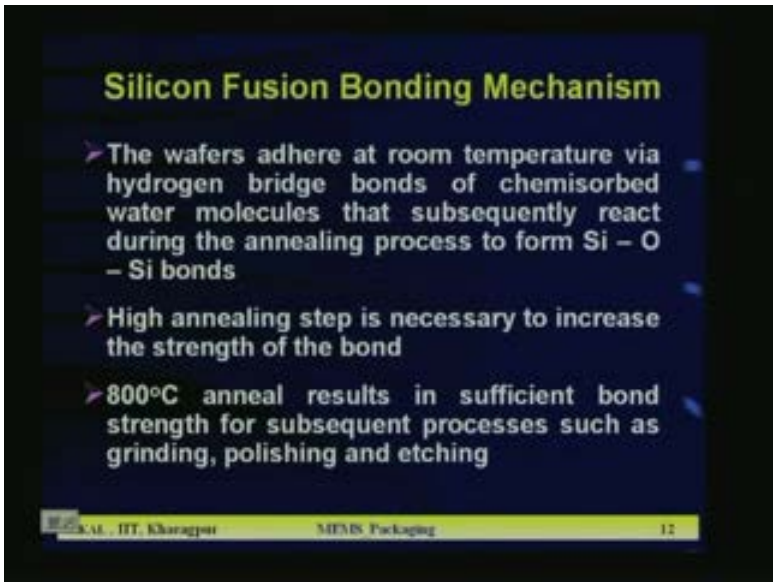

Now what are the mechanisms of the silicon fusion bonding? The wafers at here at room temperature via hydrogen bridge bonds of chemisorbed wafer water molecules that subsequently react during the annealing process to form Si O Si bonds. Details the chemistry or structural I will show you in the next slide. Basically as I told you this kind of bonding they are initiated with the H_2O molecules. So they basically this is known as chemis option you are not putting H_2O. But from environment there, they absorb some of the H_2O molecules. And the H_2O molecule at the interface means the wafer to wafer the interface. There they are separated by hydrogen atom and subsequently it reacts with the silicon. And as a result of which from H_2O, oxygen is coming out and that oxygen with silicon they form Si-O-Si. This kind of bond which are very rigid in nature.

This is the basic mechanism in the fusion bonding. High annealing step is necessary, here to increase the strength of the bond. 800 degree c anneal results in sufficient bond strength for subsequent process such as grinding, polishing and etching. Now in many cases of MEMS devices you need for polishing the wafer as well as you need grinding of the wafer. That means you are going for some mechanical hesitation, your total structures will face certain mechanical hesitation. And because of that you need a very good and strong bonding strength. So for that you need to treat the complete bonded wafer at a very high temperature. That is known as high temperature thermal anneals and is normally more than 800 degree C.

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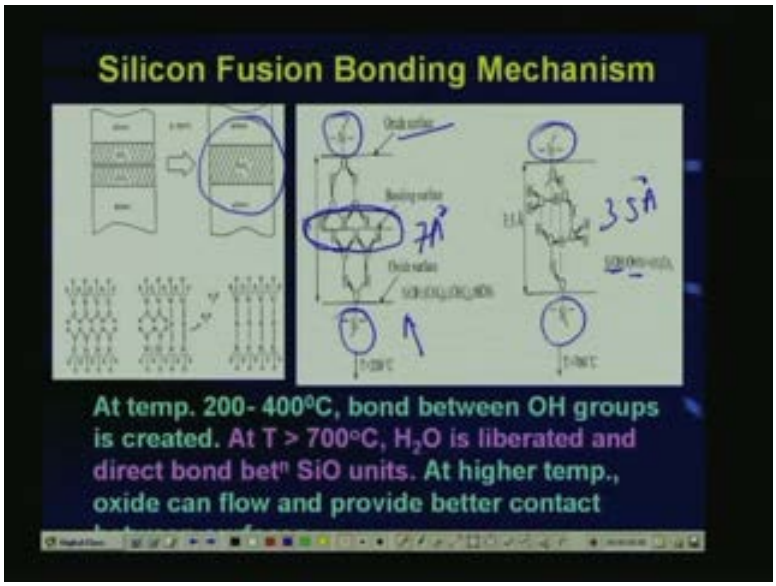

Now the mechanism bonding mechanism you is further shown in this diagram and here you can see there are two or three kinds of steps of reaction are taking place. One is in the range of 200 to 400 degree c. Now when temperature is more than 200 degree c. Here you can show this particular diagram which is shown here its temperature is greater than 200 degree c. This is the oxide surface and here is the silicon and you see this is the bonding surface. Now what happen? This silicon and this is silicon and silicon here is silicon and here is silicon. Now the gap between that is 7 angstrom, all the very few gap and that is the native oxide. And that oxide which is there on silicon surface, they absorb the H_2O molecule and after absorption of H_2O molecule, the H_2O is decomposing the oxygen hydrogen bonds.

So at low temperature when temperature is 200 to 400 you can see the bonding surface is basically predominantly dominated by hydrogen-hydrogen-hydrogen-hydrogen-hydrogen-hydrogen-hydrogen-hydrogen bond. This particular region you can see it is basically the hydrogen-hydrogen bonds. So now if you increase the temperature to 700 degree c, then you see it is not hydrogen bond. They are forming OH ions. So this OH groups are created and the OH together Si OH, then OH Si you can see the silicon and OH and another OH and silicon. So they are forming and this is silicon OH and OH silicon are bonded together and there the gap between the silicon here and silicon here is only 3 point angstrom unit. This is much more closer when T is greater than 700 degree c. So when the bonding between hydrogen and hydrogen, that is not very strong. It is relatively weak. But when bonding is OH versus OH, in between silicon two silicon atoms.

So bonding strength is much more again if you go and increasing the temperature more than 700 degree C the H_2O molecule is liberated. And a direct bond between Si O units as a H_2O molecule. At higher temperature oxide can flow and provide better contact bonding. At again still higher temperature the oxide itself can flow between one surface to other surface along with the H_2O molecule which will help much more strong bond

between the one surface to other surface. In the left hand diagram is also shown you can see here the silicon, dioxide silicon this silicon dioxide is very thin in layer I told you the separation here is 700 angstrom. And here separation is only 3.5 angstrom. So that means here the SiO_2 and SiO_2 is negative oxide. That is a few angstrom 2 or 3 angstrom like that. Now after bonding you can see the interface is much. Both are becoming silicon dioxide. Here silicon in this silicon it is a single piece you are getting here.

So after bonding, now is a chemical structure is shown here. This particular case the hydrogen and hydrogen domination and here you can see in some of our hydrogen hydrogen and then oxygen oxygen. If you go for higher temperature mode, then you can see SiO and Si which is the desired SiO and Si bond. Here is also SiO and Si bond you are getting. So in this particular case you get this kind of the bonding. Ultimately we look for the not H H hydrogen hydrogen bond, not OH OH bond. But SiO and Si bond, that is much more strong stronger bond.

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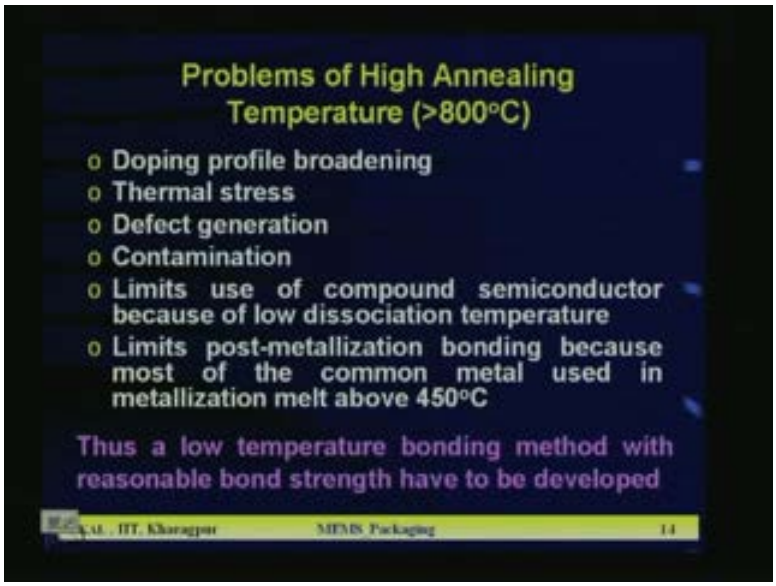

So now next slide shows the problems of high annealing temperature. Now in a fusion bonding we found the temperature should be greater than 800 degree or 700 degree centigrade so that the bonding strength is very good. But there we face certain problems. What are the problems those are highlighted here? The one problem is doping profile broadening. You know when the temperature is more than 800 degree c to in say in some cases you go for 1100 degree c. So doping profile broadens because the dopants which are there in the devices either P plus region or N plus region. So they start lateral diffusion some are out diffusion. So profile may change that is not desirable. Second one is a thermal stress at high temperature. Obviously when you go for high temperature then coming to room temperature the stress development will be higher.

Because of high temperature and then coming to low temperature you required a special kind of the thermal cycle of the high temperature to low temperature. So otherwise lot of

stress will be developed. Defect generation at high temperature there are possibility of generation crystal wave defects. Contamination; because at very high temperature the many of the impurities are mobile in nature. And lot of contamination may disturb or may destroy the quality of the devices and last two points are again very crucial. What are those? It limits the use of compound semiconductor because you know compound semiconductors basically are combination of different elements. For example gallium, arsenide, indium, phosphide, there. But there at high temperature the composition will not maintain.

Because in case of gallium and arsenide, gallium and arsenic has got different evaporation point. So if at high temperature the stichomythic ratio of those compounds, semiconductor elements will not maintain. They will change because of different melting point or different evaporation point of different elements in the compound mixture. So that is one problem in case of the compound semiconductor materials. You cannot go for bonding which requires temperature in the range of more than 700 to 800 degree c and the last problem is there. That is the metallization, because if you go for bonding after metallization. Then you know the in all cases of metals the annealing temperature is nearly 450 degree c. And above that temperature the metal film which is used for contacted inter connects they become soft and they degrade the quality. If the metal which is used for contacted inter connection is soft, then after that, if you go on increasing temperature they will evaporate and they will agglomerate.

So because of that problem after metallization any of the wafers should not be treated at temperature more than 450 or 500 degree c. But fusion bonding we saw that is required temperature is nearly more than 800 degree c. So in that case you will have lot of problem. If you go wafer bonding by fusion technique after finishing the metallization, then after completion of the metal and inter connect lines. So those are serious problems, so people are looking for a low temperature bonding technology which will serve all the purposes, which will not detoriate the quality of the devices. And detoriation means all this aspects which I just now mentioned, so in low temperature bonding method is highly required for future MEMS wafer bonding technique. And that technique is the anodic bonding technique.

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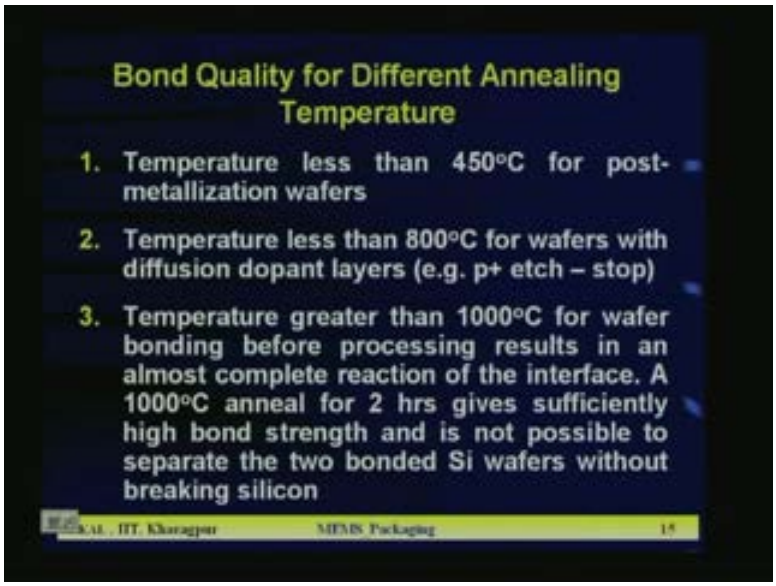

Now bond quality for different annealing temperature. That means what we require for good quality of bond and what are the requirements which will serve all the purpose. Number one is the temperature should be less than 450 degree c. If post metallization wafers are used for bonding pretty sure because you cannot go beyond 450c. But if some wafer you want to bond where there is no metallization line, no metallization contact interconnection there. Then you can go ahead at the fusion bonding technique which gives is a very large bond strength and you can go easily for high temperature. High temperature for example in case of say the micro fluidic channel. So there you were not going to use any metal lines, you are going to need defuse lines. So no diffusion is there, no metal lines are there. You want to have some physical micro channel and some two holes; one is inlet and another is outlet.

So there a fusion bonding technique is no problem you can go for that. Isn't it? So depending on the application you can choose certain bonding techniques. So that means where you require the bonding of the wafers after metallization. Then you have to use certain technique which does not require the temperature more than 450 degree c. Now temperature less than 800 degree c for wafer with diffusion dopants that is p plus etch stop. Some of the cases you require the p plus etch stop. You have seen there that we will give you automatic etch stop mechanism. So there the problem is even if you do not use metal line but p plus etch stop is there. So if you raise the temperature above 700 to 800 degree Celsius, then there is a out diffusion and the p etch stop layer the geometry or dimension will change. So as a result of which you will not get the area of the etch layer same as you design. Because p plus area will broaden externally.

So in that case you cannot go the temperature higher than 800 degree c even the metallization not there. The third one is temperature greater than 1000 degree c. For wafer bonding before processing you can go for where there is no similar p plus layer or diffuse layer where there is no metal line. But it results in an almost complete reaction of

the interface, a 1000 degree c anneal of 2 hours gives sufficiently high bond strength. And is not possible to separate the two bonded silicon wafers without breaking the silicon. That is one of the unique feature in case of the fusion bonding. If you annealing 1000 degree c for 200 to hour 1000 degree centigrade for 2 hour annealing in fusion bonding the bonding is so rigid. You cannot separate it out until and you break the devices. So that you can use in a specific application where those limitations are not there which I mentioned just now.

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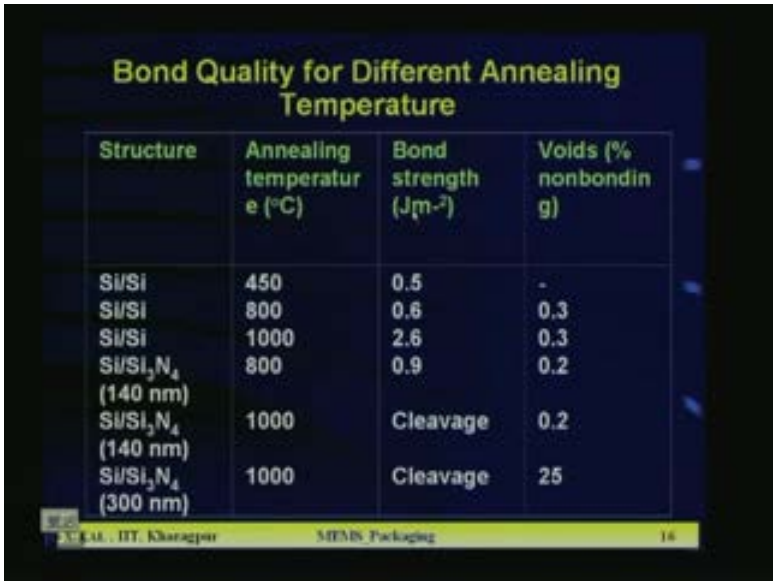

Now bond quality of different annealing temperature we are discussing. Here some of the structure anneal temperature and bond strength are mentioned in this table. You can see here the when you can go for silicon and silicon, silicon, silicon bonding at 450 degree c bond strength is 0.5 joule per meter square. And void formation, void means what non bonding particular point so there is no bonding. They leave with the void and voids are not desirable. And if lots of voids are there, bonding will be highly weak. Isn't it? So that means percentage of void should be as minimum as possible. So silicon silicon 450 degree c, bond strength is 0.5 joule per meter square and voids is 0.3. No voids are there, in that case silicon-silicon if you go for 800 degree c then bond strength increases 0.5 to 0.6 joule per meter square and here voids is 0.3 percent.

Similarly silicon-silicon 1000 degree c, you can see temperature, you have increased from 800 to 1000. So bond strength has increased 2.6 to 2.6 joule per meter square has increased. And voids remains same point 3 percent silicon-silicon nitrite at 800 degree c, bond strength is 0.9 joule per meter square. And void is 0.2 percent silicon nitrite 140 nano meter. Temperature increase from 800 degree to 1000. But here problem is cleavage formation which is not the desirable thing and voids is again 0.2 formation 0.2 percent again silicon silicon nitrite 300 nano meter at 1000 degree c again cleavage formation.

And voids are 2.5 percent not 25 it will be 2.5 percent non-bonding. So now we found that if you go for bonding with the silicon nitrite or silicon dioxide one thing is clear. Here the thickness of the oxide nitrite has to be very thin. If its thickness increases then something some other thing happens which is not desirable. And so in case of the bonding of the 2 or 3 pieces which are covered with the passivation layer of the nitrite or oxide. Those nitrite oxide thickness should be as minimal as possible preferable nearly 1000 nano meter and less 100 nano meter with 1000 angstrom or less.

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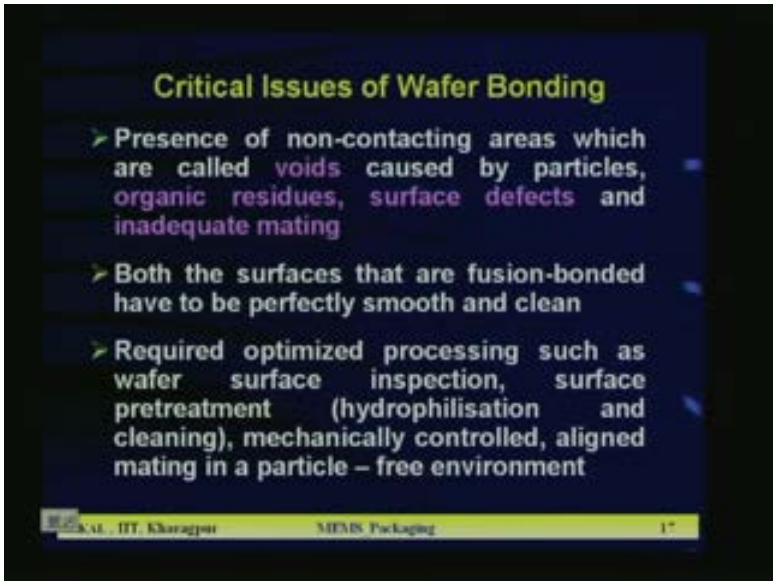

So now the critical issues in wafer bonding and critical issues are namely voids. You should go for certain technique where the formations of voids are as minimum as possible. And from where the voids are formed, these are formed from organic residues, surface defects, inadequate mating between the two layers and by particles contamination. So these before going for the wafer bonding the surface has to be highly cleaned. No particle, no organic residues surface defects as minimum as possible and it should be properly mating. Now both the surfaces that are fusion bonded have to be perfectly smooth and clean. Next is required optimized processing such as wafer surface inspection, surface pretreatment. What is pretreatment? That is hydrophilisation, hydroflic and hydrophobic. So we need hydrophobic kind of surface and cleaning mechanically controlled aligned mating in a particle free environment. These are the some points which you must look into during processing of the fusion bonding technology.

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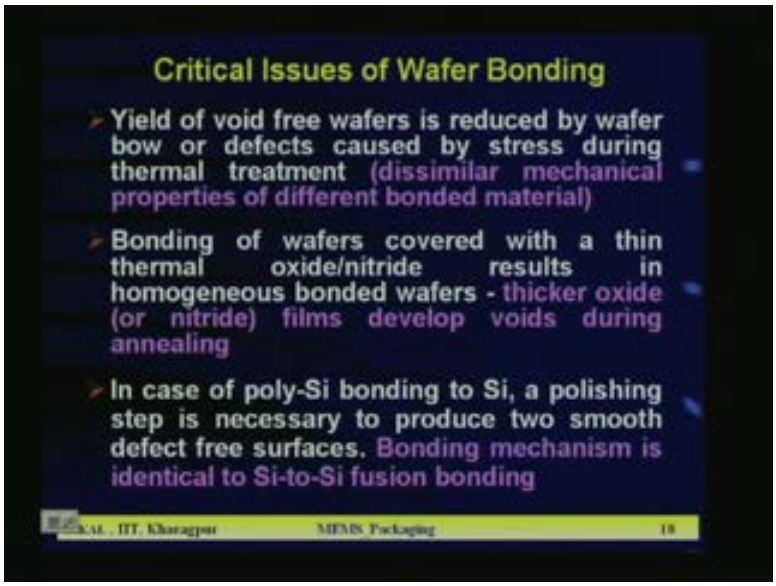

Now there other several issues are there. Those are namely yield of void free wafers is reduced by wafer bow or defects caused by stress during thermal treatment. Stress generation between the surface is obvious during the fusion bonding at higher temperature. If you go for bonding at 1000 degree centigrade more and then if the mechanical properties means thermal expansion and coefficient of the two layer, if it is a dissimilar material silicon or glass or silicon nitrite with glass. So then if expansion coefficient does not match properly, then there is a chance of the wafer bowing and that create to the defects and which will ultimately create voids and yield will be low. Next one is a bonding of wafers covered with a thin thermal or nitrite results in homogeneous bonded wafer. So that mean just I mention so it has to very thin layer if you go for oxide and nitrite. In case of poly silicon bonding in some cases we also use poly silicon material as a bonding layer. So in that case a polishing step is necessary to provide two smooth defect free surface. Bonding mechanism is identical to silicon to silicon fusion bonding if you go for poly silicon the technique is almost same.

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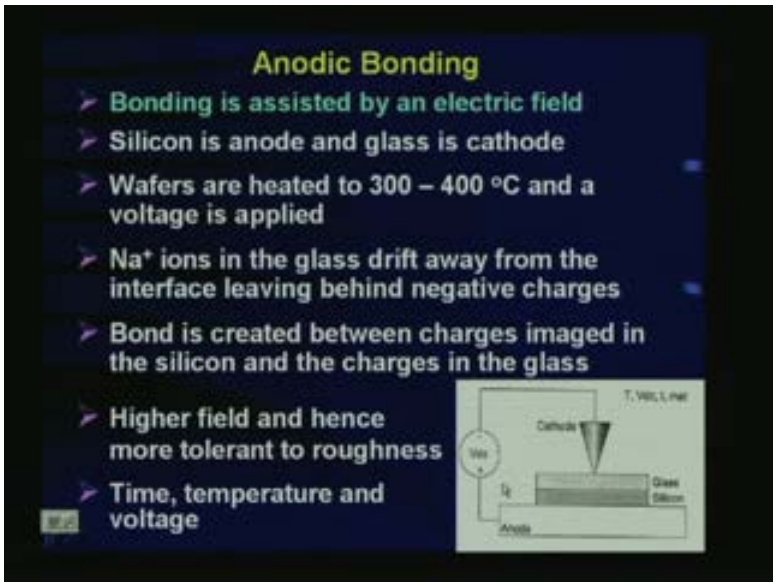

Now we are switching over to the anodic bonding technique which is much more promising in case of the MEMS wafer bonding. So this particular technique is assisted by an electric field till anodic bonding. Earlier other bonding techniques we never used any electric field. Now here you required some electric field. In the bottom you can see pictorial diagram of the anodic bonding technique. So here the silicone and glass bonding is show here silicon is used as a anode. You can see in the picture and glass is used as a cathode and this wafers are kept on a heater whose temperature is raised within 300 to 400 degree c and voltage is applied. So now and that temperature you see here 300 to 400 degrees c is not above 700 to 800 degree c is a low temperature. Now if you apply a voltage than what happens? Glass contains the sodium ions. The sodium ions in the glass they are drifted away from the interface.

What is the interface? Silicon and glass. And silicon is a positive and glass is negative. So positive sodium ions in the glass is drifted away from the interface. As a result of which a negative charge will be left at the interface. They leave some negative charges at interface and this negative charges in the glass. They induce the opposite charge in silicon and a result of which they create a certain depilation layer kind of thing. And this layer is extremely thin and because of that a high field is generated at the interface. And that high field basically prompts the bonding process. So this is the basic technology in anodic bonding technique. The parameters of the or quality of controlling the anodic bonding techniques are time, temperature and voltage. How much voltage you are going to use, how much time you are allowing for bonding and how much temperature you are allowing, these are the 3 parameters which control the bonding mechanism.

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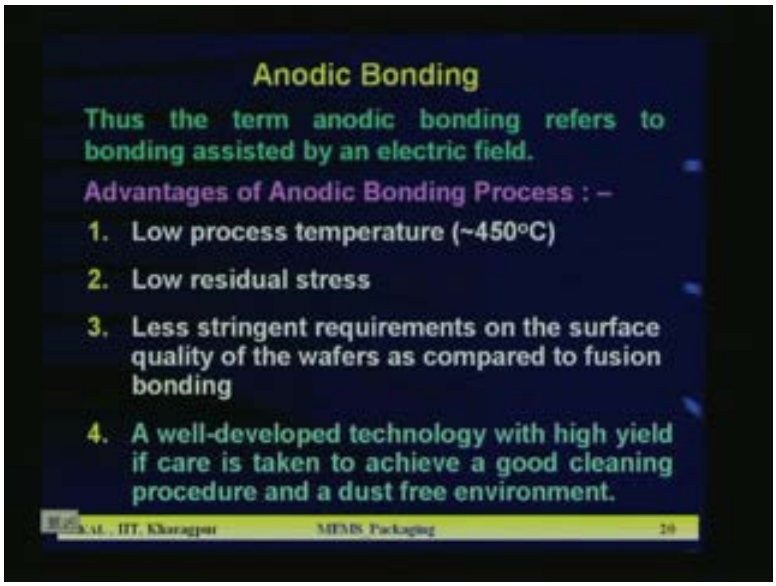

Now so basically the term anodic bonding refers to the bonding assisted by an electric field. And what are the advantages? Advantages are many for what are those? First is the low temperature process which everybody wants it low temperature process means temperature is nearly 450 degree c. Second is low residual stress obvious if the temperature is low, the stress formation will be less. And so defect generation will be less, no bowing etcetera defect generation less means there will be not be voids also. Third one is less stringent requirements on the surface quality of the wafers as compared to fusion bonding. Fusion bonding we told you that it should be highly smooth and smoothness should be less than 10 angstrom rms value. But here that much stringing condition is not required because you are applying here high voltage. Because you are applying a high voltage the surface smoothness or cleanness point is not that much stringent like the fusion bonding. This is the well developed technology with a high yield if care is taken to achieve a good cleaning procedure and a dust free environment. But people look dust free and clean environment there.

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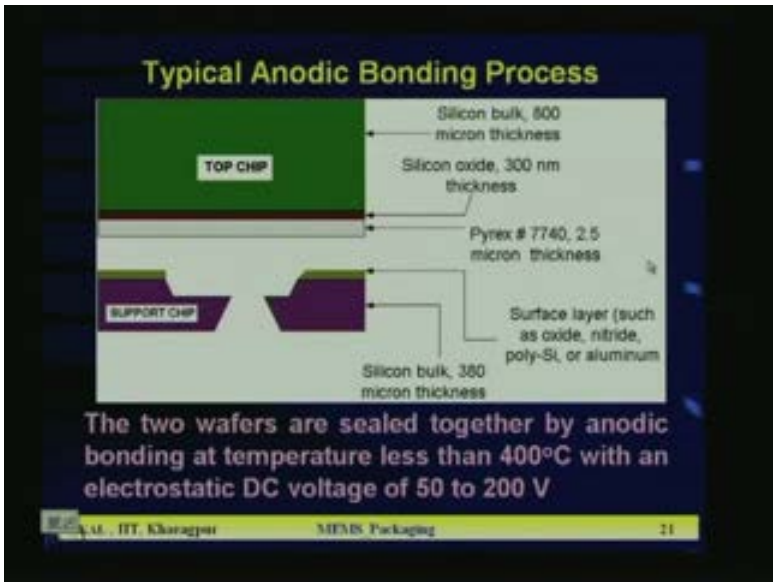

Now here the a typical anodic bonding techniques a process is shown here. For example here is a silicon chip and silicon dioxide 300 nanometer thickness here. And this is a pyrex 77402.5 micron thickness pyrex glass. Top wafer is 800 micron thickness. Now the surface layer in the bottom wafer silicon blocks 180 micron. There you can see the surface layer such as oxide or nitrite or poly silicon and aluminum whatever it is. This is surface layer and a support trim is there. They are going to bond together in using the anodic bonding technique. Now temperature should be less than 400 degree c 4 to 450 degree c as I mentioned. And electrostatic DC voltage applied is 50 to 200 volt from the top and bottom piece.

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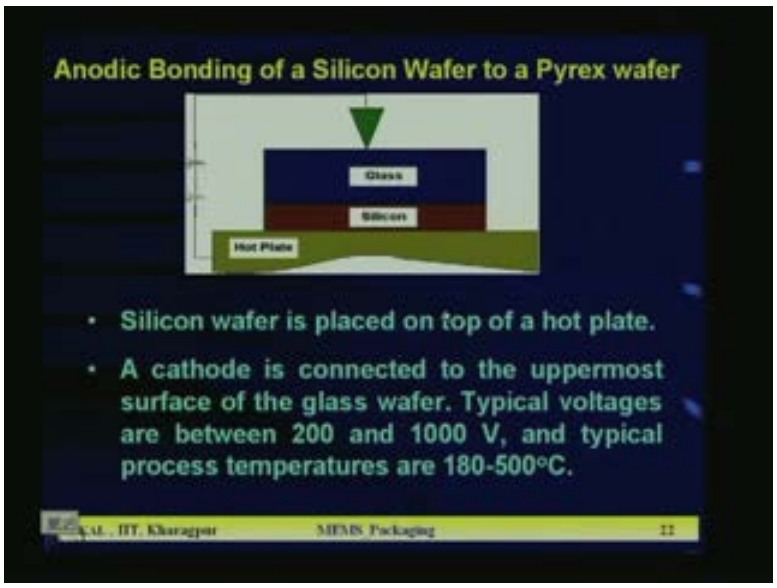

Now this is the complete picture. So the hot plate is a bottom silicon and glass and you have one thing. You have noted down, you are going to use the point contact electrode which is acting as a cathode point contact. And there it will help the bonding pressure uniformly around the silicon because bonding pressure is at the tip and that will generate lot of the pressure wave. And that will proceed toward the silicon. So that the total electrostatic that is field pressure is uniform over the entire wafer. So silicon wafer is placed on the hot plate a cathode is connected to the upper most surface of the glass wafer. Typical voltage is between 200 to 1000 volt. You have to calibrate the whole system depending on your requirement. How much bond strength you need it and typical process temperature 180 to 500 degree c.

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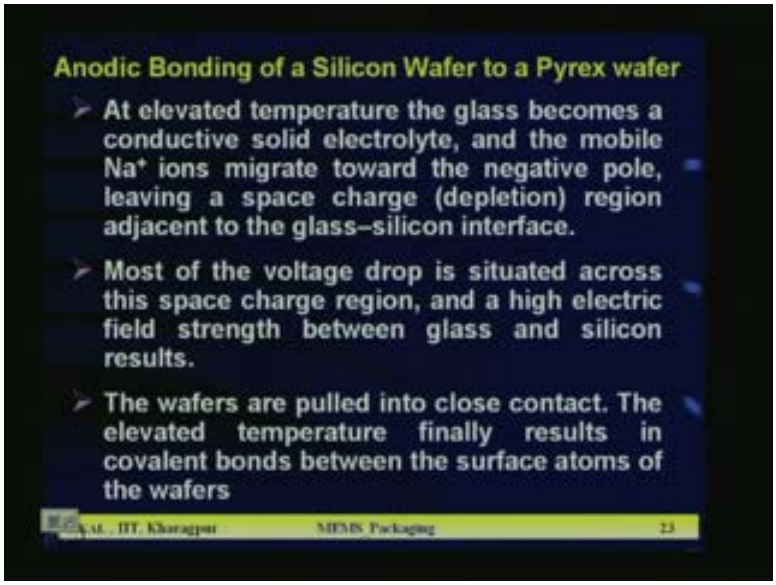

So here again some things is elaborated regarding the bonding mechanism. What happens at elevated temperature? The glass becomes a conducting solid electrolyte. So one point is you are I told you that sodium ions are separated migrated towards the positive towards the negative cathode. So the glass wafer which is used at the top as a cathode must be little be conducting. Otherwise the formation of deflection layer of kind of thing will not be possible. It is to be conducting glass little bit. That is why the pyrex that 7750 or that model is used, that number is used for the bonding of silicon MEMS devices. And as the sodium ions migrate towards the negative poles a space charge which is a depletion layer we say is created adjacent to the silicon glass interface. Most of the voltage drop is situated across the space charge region and a high electric field strength between glass and silicon results because that region is very small. We know the in case of PN junction devices also the to field is maximum in the depletion region. The wafers are pulled into close contact because of that high field the elevated temperature finally results in covalent bonds between the surface atoms of the wafer. Surface atoms of the wafers will form the covalent bond.

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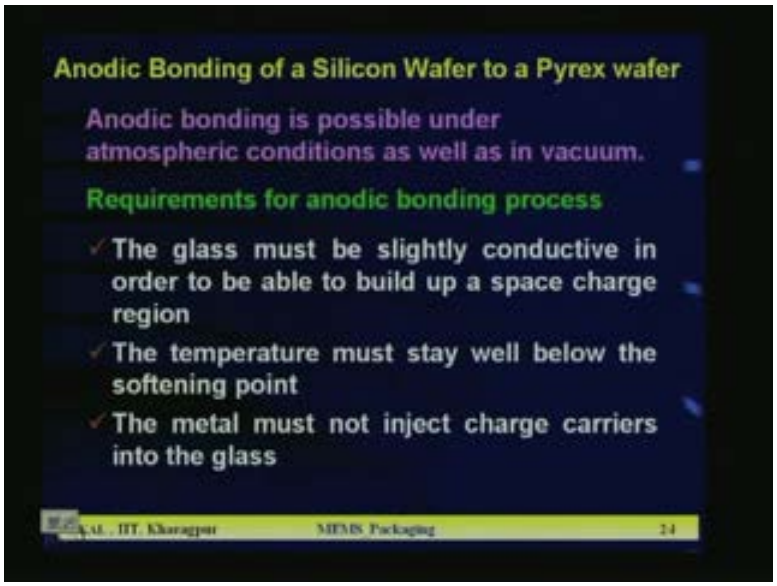

So anodic bonding is possible under atmospheric condition as well as in vacuum. You do not need always in vacuum, in both environment its possible. So what are requirements in case of the anodic bonding? As I mentioned just now that glass must be slightly conducting which you are going to bond it must be slightly conducting in order to able to build up a space charge region. Second requirement temperature must stay well above the softening point. Third is the metal must not inject charge carriers into the glass. If there is metal or a in the surface or in silicon, those metals must not inject any charge carriers into the glass; that is another requirement.

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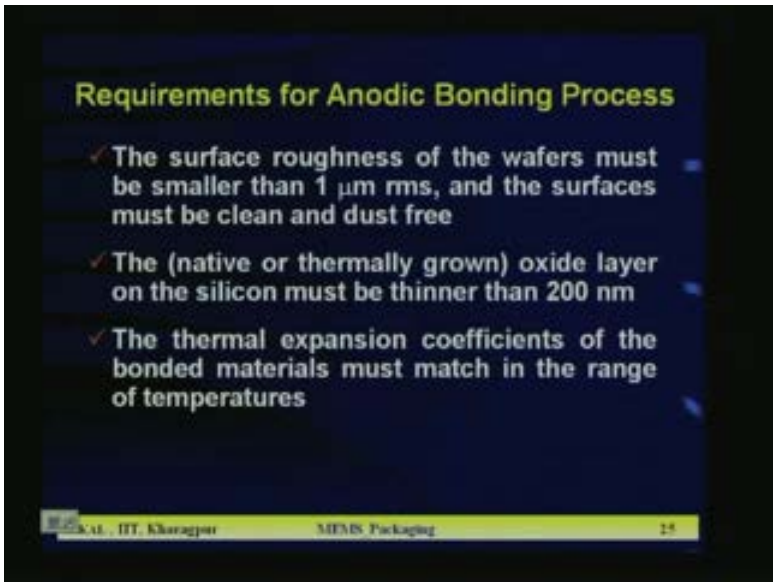

So others are surface roughness of the wafers must be smaller than 1 micron rms. So there in case of fusion bonding it was 10 angstrom. If you remember rms, but here roughly 1 micron rms is also the surface must be clean and dust free. The native oxide layer on the silicon must be thinner than 200 nanometer. Means 2000 angstrom the thermal expansion coefficients of the bonded materials must match in the range of temperatures.

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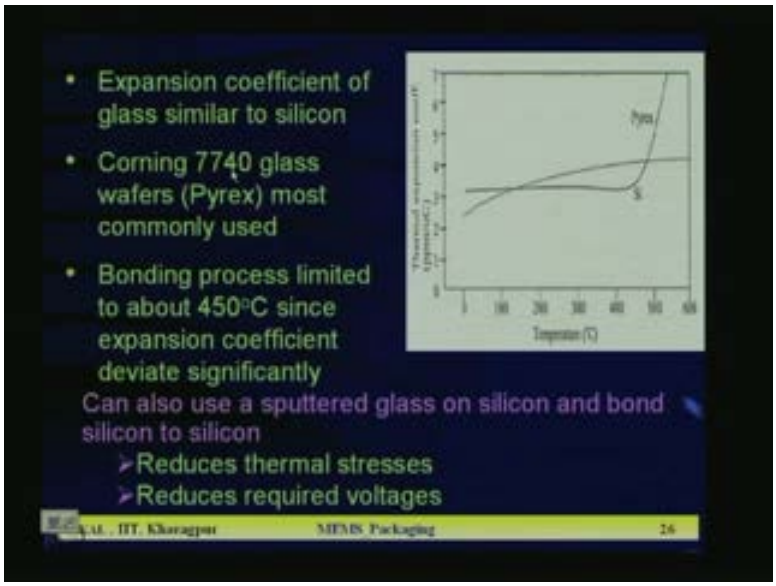

So for that I can show you a plot of the temperature versus thermal expansion coefficient. You can see here up to certain temperature 450 degree c silicon and pyrex the thermal expansion coefficient is almost similar. Corning glass 7740 wafer which is a most commonly use little bit conducting. This particular the number of corning glass pyrexia corning glass is used for most of the glass silicon bonding in case of MEMS. Because there we find that there is a good matching between a thermal expansion coefficient of the two materials. Bonding process is limited to about 450 degree c. Since expansion coefficient deviate significantly after 450 degree c. You can see here the two curve deviate further if you go on increasing the temperature. So it can use a sputtered glass on silicon and bond silicon to silicon. So if you need silicon-silicon bonding it require a glass because a glass sodium ion should be migrated. So then what you should do? A thin layer of glass is to be sputtered on the silicon then you go for silicon to silicon bonding. So it reduces the thermal stresses and it reduces the required voltages also.

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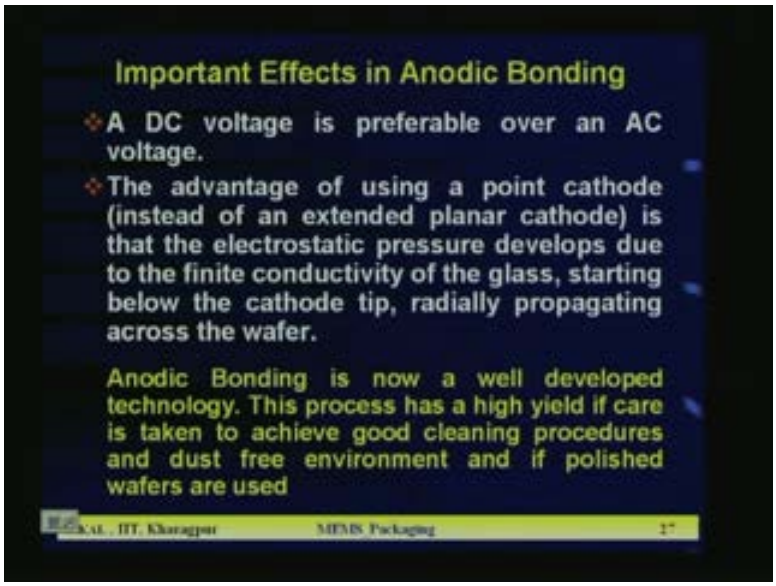

Now what are the important effects in the anodic bonding? There a DC voltage is preferable over an AC voltage. The advantage of using a point cathode just I mentioned few minutes back. You require a point cathode. Why? Because in that case electrostatic pressure develops due to the finite conductivity of the glass starting below the cathode tip and it radially propagates along the wafer. That is the beauty of the point contact cathode. So anodic bonding is now a well-developed technology. This process has a high yield if care is taken to achieve good cleaning procedures and duct free environment and if polished wafers are used.

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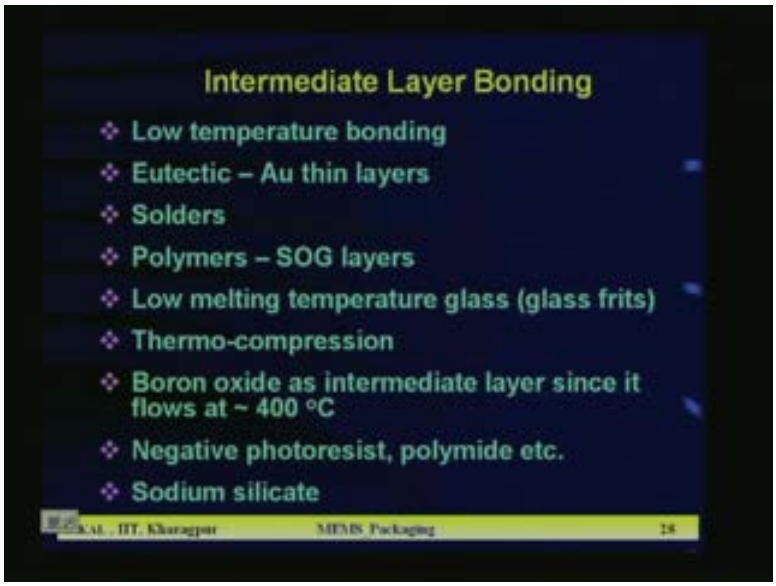

Now there are other bonding techniques which I mentioned, Intermediate layer bonding. These are very weak but in some cases that serves many purposes and we may not go for very good quality. The anodic bonding or fusion bonding techniques, they are low temperature bonding. Basically you take the gold thin layers, you take the bonding means you take the epoxy and use it and then you press it and may be 100 to 150 degree c. You can heat it and you will bonding but that is not very rigid bonding. Solders also use polymers may be used for bonding very soft bonding, low melting temperature glass which is glass frit. For example I showed you using the glass frits. Thermal compression bonding sometimes people use it. Boron oxide as intermediate layer since it flows at 400 degree c. Some people are using boron oxide because at 400 degree c boron oxide soft and it flows and then you it helps bonding due to wafer. Negative photoresist polyamides are also used sodium silicate is another material which is used for bonding.

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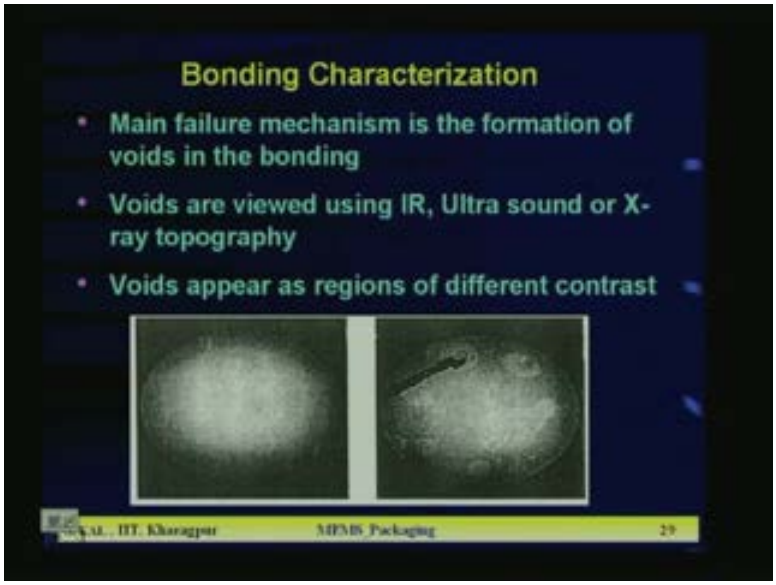

Now if you go for characterization bonding, the main failure mechanism is the formation of voids in the bonding. So that you have to get rid of the voids. Voids are viewed by IR ultrasound or x-ray topography. You can see it to picture; in the left side picture there is no void and right side picture there are some void and it appear regions of different contrast, you can see contrast you can see. So that means here some voids are there. So with this just we will stop today and I gave you a small overview of the bonding technique mechanism. And which is good what are the various aspects and low temperature bonding, high temperature bonding may be chosen for different requirement of the MEMS devices and packaging. So let me stop here today. Thank you very much.

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Preview of Next Lecture.

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Lecture No. #31
Interface Electronics for MEMS

Today's topic of discussion is interface electronics for MEMS. In last few lectures we have discussed on MEMS devices particularly micromachine microsensors. And one of the basic job of micromechanical system is that is a combination of sensors actuators and signal conditioning circuits. So if we do not think of the signal conditioning and signal

processing circuits, then the complete the system is or micromechanical system configuration is not complete. So we have to see what are the various aspects of the output signals coming from the transducers and how do you proceed with those signals before processing. And after processing how those signals are fade to actuators for further function functionalization or for further action. Thus the interface electronics is a important aspect of any of the micro system and at the moment lot of work is going on this important topic which is interface electronics.

Now the signal which is received at the output of the microsensors is of particular characteristics. Because of the different nature of the signal obtained at the output of the microsensors. Its signal conditioning circuits and will be different. And in most of the cases they signal processing part we preferred to have digital component, digital signal. And we are incline or we love to process the signal using microprocessor or micro controller or in a computer. So there you know the only signal which is digital that can be processed. But sensors signals are not digital in nature. So that is the reason we have to go for some conversion also. After getting the signal from the output of the microsensor, it has the condition and then you have to change the analog to digital before further processing with the help of either micro controller or microprocessor. And the outputs are taken and then they will control the actuators and other things.

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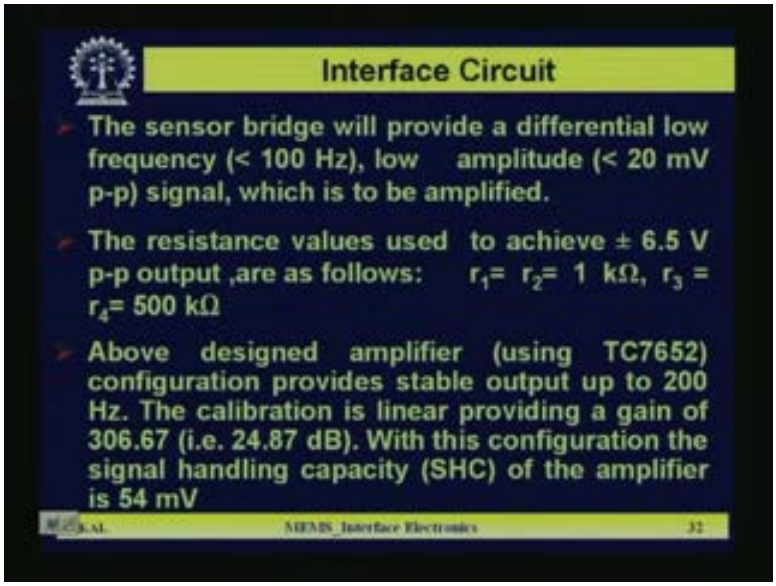

So for as offset is concerned, but temperature compensation is not that much perfect. So this bridge which we used for our circuit provides differential low frequency less than 100 hertz. Low amplitude less than 20 millivolt signal which is to be amplified and in that case this amplification has been done after 6.5 volt in chopper stabilize amplified with r_1, r_2 1 kilo omega r_3 r_4 with 500 kilo ohm. And the TC7652 configuration provides a stable output up to 200 hertz. So these are this is basically some small example which are doing here, but that is not the final. You have to design separate blocks using your required chopper stabilization techniques amplifiers and all other things. If you want to

have monolithic interface electronic chip for any kind of sensors, so there as work going on, nowadays for universal interface electronics.

So the interface electronic chip can be connected to any kind of sensor, either it is a piezoresistive or piezocapacitive or may be other kind of sensor. And it gives an advantage, that the interface circuit. If it is a universal expectable circuit, so that mean you can reduce the cost point of view drastically. If you assemble some microsystem using lot of sensors. So just I tried in this lecture to give you a small background of the requirement of the interface electronic circuit. And some of the solutions what we can adopt for reducing the three things; one is the noise, another is a offset and another is the reduction of the variation due to secondary parameters. So these are the thing three things we have discussed today. So let me stop here. Thank you very much.