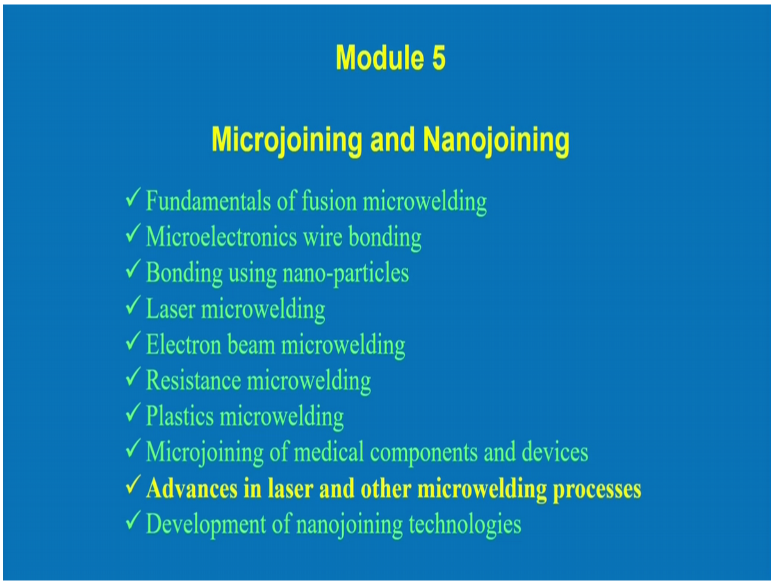
Advances in Welding and Joining Technologies
Dr. Swarup Bag
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Lecture – 14
Micro and Nano Joining Processes Part I

Good afternoon everybody, today I am going to start another module of this, Advances in Welding and Joining Technologies that is Micro Joining and Nano Joining.

(Refer Slide Time: 00:38)



This is the module 5. So, in this module will I will try to demonstrate different micro joining nano joining technologies that have been developed recently and this micro joining and nano joining is significant specifically in today's industry because of the minimization of the product size; specifically the geometric size, the applicability and with the development of the different devices like micro devices and nano devices. So, that type of devices joining technology is very much significant. Micro joining and nano joining is nothing but the that reduced form of the conventional joining processes, but we need to use the conventional technology and different prospective for specifically micro joining processes and nano joining processes.

Although the nano joining processes is still developing but to some extent the different micro joining technologies has been developed specifically the electronics industry and some other medical devices, but nano joining technology is still a very new technology and it is may be applicable in case of nano electronics or may be in different nano devices. So, this module will try to focus on the different aspects of micro joining and nano joining technologies, their basic mechanisms, more or less it is almost same as conventional welding processes but there is a some difference exist from the conventional joining technologies.

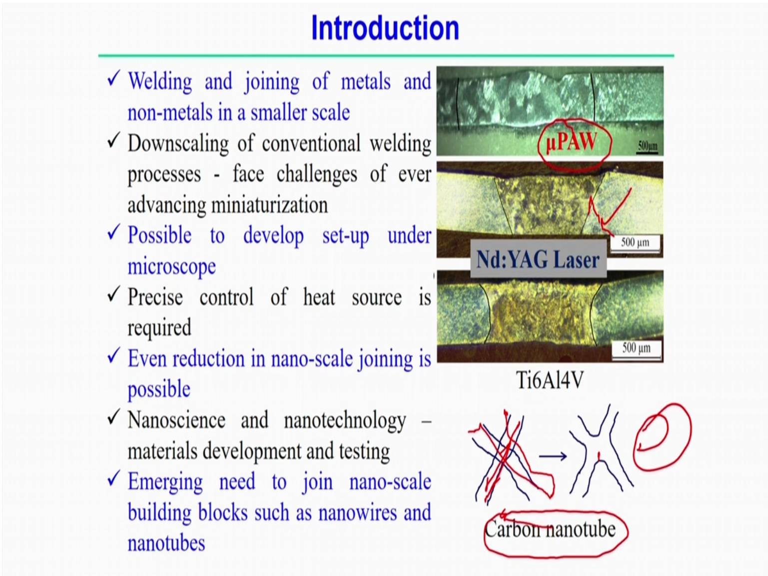
So, let us look into that all the different micro joining and nano joining technologies exist in the current prospective; that means, depending upon the current applications. So, first I will try to cover the fundamentals of the fusion micro welding processes, although the basic features of the fusion welding is we have already known this phenomena, but specifically this fusion micro welding in what aspect we can apply in some micro scale processes.

Second different microelectronics bonding we will try to discuss because, nowadays the electronics industry lot of joining processes are involved in the in this in this industry. Then bonding using nano particles we will try to cover and then we will be covering the laser micro welding processes, which is laser source or may be laser welding it is known to us or we have the idea about the different laser welding technology but how this laser can be used in the micro scale application that we will try to focus on this module.

Next electron beam micro welding; so, although we know that electron beam normally we use when there is a need of high depth of penetration specifically high thickness material, but this electron beam can also be applicable for the micro scale welding processes, but in this case we need to use this source of the electron beam in different way we will try to discuss this aspects.

Next resistant micro welding and plastic micro welding, we will try to discuss the plastic micro welding specifically the micro welding application where we use the nonmetals category. Then micro joining of the medical components and devices which is very significant part of the module because, lot of application we found out in the medical devices and medical components. And then we will try to focus on the advances in the laser micro welding processes and very specific in very specific and at the same time, what are the recent advancement happens in the other micro welding processes. Since this course is related to the advances in welding and joining technologies and finally, we will discuss that development of different nano joining technologies although this field is very new but perhaps there exist or there is some development in that direction. So, we will try to focus on this thing.

(Refer Slide Time: 05:13)



So, looking into all this aspects first we will focus on the micro welding micro welding processes and then nano joining or different nano joining processes. So, if you see that in the picture right hand side here, if you see the first picture that micro plasma arcwelding process and second next two pictures we see that macro graph of laser welding process. Now, if you see that what are the difference in this two cases. In micro plasma arc welding process, if you see the dimension of the fusion zone or size is different from the laser welding processes. Of course, all this cases the materials are same. So, all this cases what we have done? We have tried to join two different seats of titanium alloy. So, (Refer Time: 06:08) alloy, so, that titanium alloy is formed in the form of Bart welding configuration and we use the different sources one cases we use the plasma source and, another cases we use the laser as the heat source.

But we can find out there is a significant difference of the shape and size of the fusion zone. So, this is possible because the concentrated of the heat in this two cases are different and that difference on the different welding technologies. First case it is micro plasma creation of the arc or specifically constricted arc as compared to the GTAW, or gas tungsten arc welding process. And second case we use the laser as a heat source, but this can be considered as a micro scale welding processes because, the sheet thickness in this case is around 0.5 millimeter, or we can say that 500 micro meter, but if you see the welding and joining of the metals and nonmetals in a smaller scale can be considered as a micro joining processes, simply down scaling of the conventional welding processes, but it is faces lot of challenges with respect to the different aspects because, only because of the minimization of the component.

If you see that when try to reduce the thickness of the sheet which we suppose to join, by any fusion welding or may be other welding processes and, then the specifically the distortion becomes a very much problem, when you try to reduce the thickness. So, this is one aspect and at the same time the micro joining can also be possible to develop under the microscope because, manual handling of all these components is really difficult when there is a reduced thick signal.

For example, if we try to handle may be 100 micro meter, or 0.1 millimeter sheet thickness, it is very difficult to put or may be less than that it is nearly impossible to put the manually and conduct manually and, at the same time to conduct some welding processes. So, in this case it is better option to put the development of the any micro welding, or micro joining processes under the microscope.

But even if we further reduce the size of the geometry of a sample, then it is possible to; that means, up to the nano scale, then it is possible to do also nano joining, but definitely now when you try to develop some nano joining technology, the handling of these samples probably not possible using the simple automatic system probably physio electric manipulator, we can use to handle the samples for nano welding processes. So, these are the typical maybe we can say characteristics of the micro welding processes and that we can differentiate this processes as compared to the conventional welding process.

Now, if you see the another figure right hand side the bottom figure it shows that joining of the 2 carbon nanotubes; here, what we can do we can simply placing two different nanotube. And if we very precisely apply the heat source at this joint probably, it is possible to do the joining of these two nanotubes. So, this type of joining we can say that there is a happening of the nano joining.

(Refer Slide Time: 10:08)

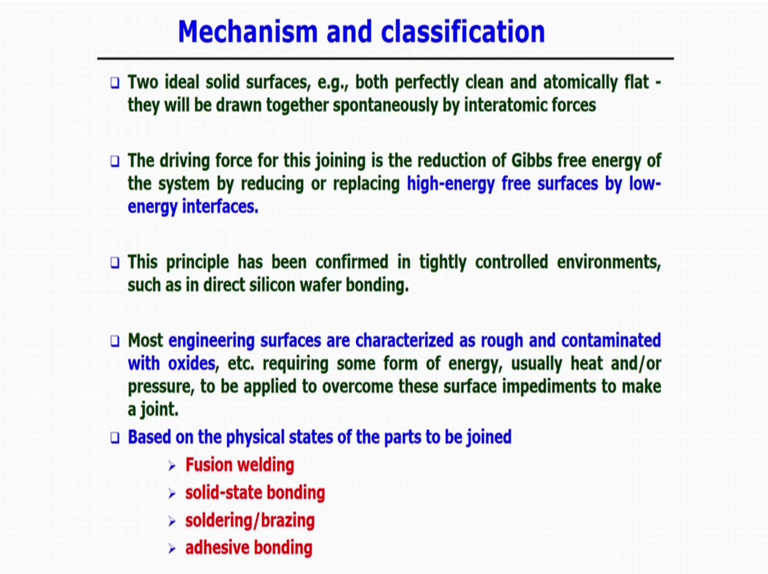
But it is a can imagine that how precisely it is necessary to control, the nano joining process. Now, what is definition of the micro joining, or nano joining processes we see that before that actually the joining means we understand the welding brazing soldering bonding all together can be considered as joining process. And specifically welding maybe when you try to fuse the two material and in general if it is the melting point temperature and, after melting when the solidification offers between the materials and it is come backs to the room temperature, then that type of joining we can say it is called the specific that is called the welding in general we can say like this.

Also there may be possible the mechanical joining for example, fastening riveting crimping also that is also comes under the joining process, but in this case we will try to focus only on the welding, brazing, soldering and specifically solid state bonding processes, at different scale two different scale all these joining processes. One is the macro scale another is the nano scale.

Now, there is no strict definition of the micro joining mostly related to the conventional welding and joining processes, but only difference is that characteristic dimension maybe we can differentiate in the from the conventional welding to the nano joining, or micro joining processes. If the sheet thickness or diameter is smaller than few 100 micrometer, or may be less than 100 micrometer maybe we can consider that as a micro joining process or micro welding process. But the effective micro joining the most critical technical requisition is the manufacturing, at even smaller scale maybe less than 100 micrometer as well, but different variants of the different micro joining technology exists.

Will try to see what are the different micro joining technologies presently were using or what are the up to the current date, what are the development of the different micro joining technologies we will try to see that. But in the other aspect nano joining which is almost new aspect and mostly used in the R and D R and D laboratory, but commercially till now we do not use the any micro joining technologies. But still it is evolving the nano joining technologies and maybe we can use this nano joining technologies for any kind of nano devices, or nano electronics. So, before looking into the different technology and techniques exist in the micro joining or nano joining. we will try to see what are the different mechanisms or principle is responsible for in case of or, what way we can explain the different nano joining from the basic principle or form the mechanics.

(Refer Slide Time: 13:07)



So, to start with that basic mechanism of the micro joining process or nano joining process maybe we can consider the 2 ideal surface both are perfectly clean that means, there is no oxide layer on the surfaces and they are atomically flat, atomically flat means if we see the under the at the scale of the at the atomic scale the surface should appears completely flat.

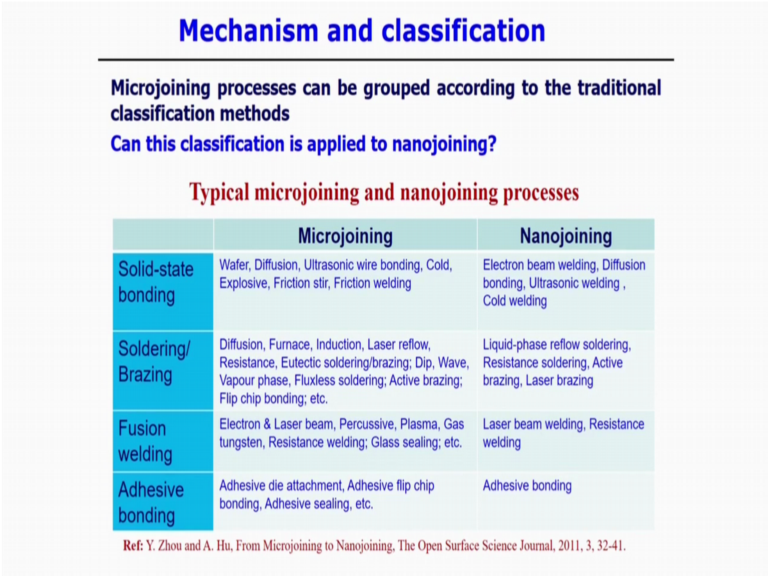
So, this is of course, this is a very ideal case, but in this ideal case if these 2 surfaces come into the together they spontaneously form, or they will spontaneously join between these two samples is possible by the interatomic forces. But in this case what are the driving forces for joining these 2 samples or 2 materials, if we brings them to in the very ideal situation. May be one is that the driving force in this case is the reduction of the Gibbs free energy of the system by simply reducing, or replacing high energy free surfaces by low energy interfaces. So, if it is possible ideally if it is possible to do, then fundamentally it is possible to joining these 2 samples, but in this case the actual case or in practical that always the metal surface may be having some contaminated, or with mostly with oxides or some other materials.

So, that is why if we want to remove that layer of the oxides, or contaminated surface maybe we can use some heat, or some mechanical energy either heat energy, or mechanical energy or mechanical energy in the sense of pressure. Then it is possible to remove that oxides layer and, after removing that oxides layers and these two surface if they come into the towards the ideal condition of the two surfaces may be completely flat, or there is a there is no contaminated layer exist on the surface, then it is possible to join between these two surfaces.

So, that is why all of the welding technologies is involvement some source of energy is required probably that what on the surface maybe to reduce the surface and Gibbs free energy. So, that it is possible to join between the two surfaces by application of the either heat, either pressure or by some other driving forces.

So, based on this principle or physical states between the two parts to be joined and in very specific to the micro joining processes, we can divide the four types of or four classification of this micro joining processes. First is the fusion welding, solid state welding, soldering, or brazing and adhesive bonding. Probably all this type of welding technologies we observed exist in case of the conventional welding processes, but only this four type of classification four type of methodologies exist in case of micro joining process. So, micro joining process in general can be grouped according to the traditional welding processes and that we can classify on this four type of welding processes.

(Refer Slide Time: 17:01)



	Microjoining	Nanojoining
Solid-state bonding	Wafer, Diffusion, Ultrasonic wire bonding, Cold, Explosive, Friction stir, Friction welding	Electron beam welding, Diffusion bonding, Ultrasonic welding , Cold welding
Soldering/ Brazing	Diffusion, Furnace, Induction, Laser reflow, Resistance, Eutectic soldering/brazing; Dip, Wave, Vapour phase, Fluxless soldering; Active brazing; Flip chip bonding; etc.	Liquid-phase reflow soldering, Resistance soldering, Active brazing, Laser brazing
Fusion welding	Electron & Laser beam, Percussive, Plasma, Gas tungsten, Resistance welding; Glass sealing; etc.	Laser beam welding, Resistance welding
Adhesive bonding	Adhesive die attachment, Adhesive flip chip bonding, Adhesive sealing, etc.	Adhesive bonding

But question is that can this classification is applicable for nano joining processes? Let us see if you look into this table that typical micro joining and nano joining processes here if you see that solid state bonding, soldering brazing, fusion welding and adhesive bonding.

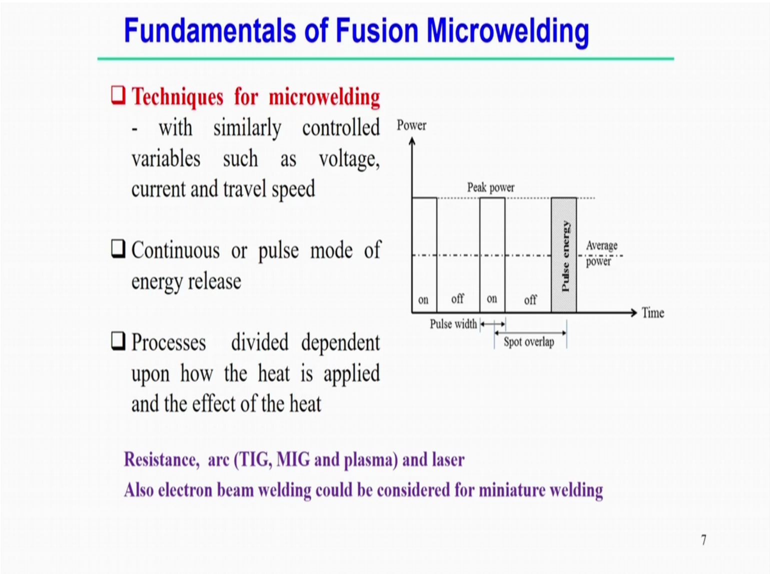
And if we see that it is given that different types of micro joining technologies here, wafer diffusion, ultrasonic wire bonding, cold explosive friction stir and friction welding, these are the typical welding technologies that is under the solid state bonding processes. Next if you see the soldering and brazing here diffusion furnace induction, laser, reflow, resistance, vapour pressure, fluxless soldering all this type of welding processes is belongs to the micro joining processes, but under the category of the soldering, or brazing. Next is the fusion welding; if you see the electron laser, that also use in case of conventional welding processes, then plasma gas tungsten resistance and glass ceiling. These are the typical micro joining processes that we observe or maybe these are practically importance, or practical we use all this type of fusion welding processes.

Next adhesive bonding; the adhesive flip chip bonding mostly used by this joining technology and, it is under the category of the micro joining processes. Of course, there is not much difference the micro in the categories of the micro joining process, when we try to compare with the conventional welding processes, but this similar type of classification can also be applicable in case of nano joining processes as well. If you see the nano joining processes the solid state bonding, there is the electron beam welding, diffusion bonding, ultrasonic welding and cold welding. But if we know that normally electron beam welding comes under the categorization of the fusion welding processes, but in case of nano joining we can put it under the solid state bonding because, in this case probably when we need to use the controlled source of the electron beam to produce the nano joining, but that nano joining happens below the melting point temperature.

That's why it is under the categorization of the solid state bonding. Second thing is that liquid phase reflow soldering resistant soldering active brazing, these are the typical laser brazing, these are the typical processes normally we found under the categorization of the nano joining processes and these are the typical soldering on brazing processes.

Next laser beam welding resistance welding, these are the typical nano joining processes under the categorization of the fusion welding process and finally, adhesive bonding can also be applicable in case of nano joining processes, but probably of course, the different nano joining technologies also developed and still it is developing, but there is a little bit difference as compared to the conventional welding processes, or maybe in terms of the with respect to the micro joining processes. So, that typical aspects will be discussing under respective point of time. Now, focus on the fundamentals of the fusion micro welding.

(Refer Slide Time: 20:34)



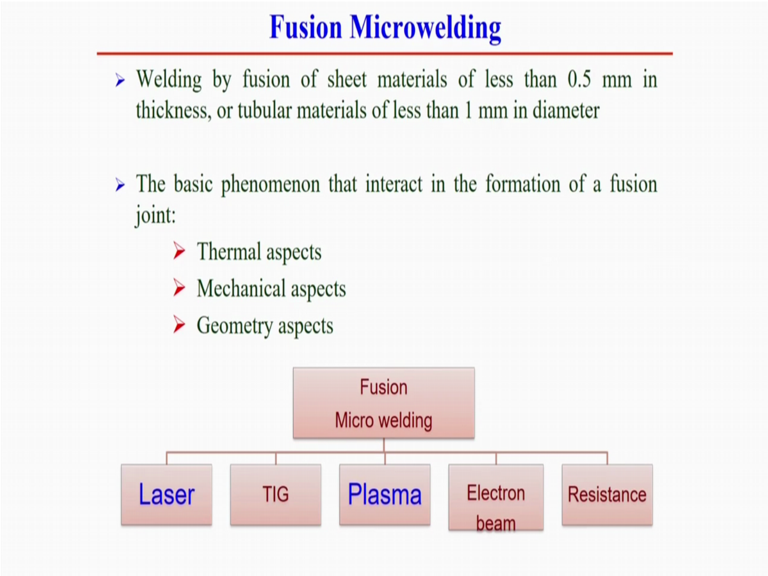
What are the different techniques for the micro welding processes? Already you described the different types of micro welding processes, but what are the basic needs for the development of the technology for the micro welding processes. So, first thing is that we need to control the different variables very precisely. Such as voltage currents and travel speed that also applicable in case of conventional welding processes, but still it is very much important in case of micro welding processes.

For example, we can use the laser as well in case of the micro welding processes, but probably it is more useful if we you if we consider the pulse mode of the energy because, as compared to the pulse mode of energy that energy is applicable to the for the micro joining application in a very controlled way probably in a pulse we are putting, if you look into this picture here, if you see that during the pulse ontime, we generally apply the thermal load to the sample or to the specimen, then remaining time off time that solidification happens again if we put.

Basically it is a if you see the average power also the below as compared to the peak power from this figure. So, here we can say that ramping of the power is possible in case of the pulse mode of laser welding process and that ramping of the power by ramping of the power probably, we can use laser in specific to the micro welding process, as which is very much similar to the conventional welding process as well. So, the different processes exist depending upon the how we can apply the source of the source of the heat applicable to join for the two similar or different material. So, what we understand that basic understanding from this fundamentals of the fusion micro is that, how precisely we can control the source of the heat and based on that, it is possible to generate or it is possible to develop different type of the fusion micro welding processes. So, presently the this development in the in this fusion micro welding processes, that are resistance welding arc welding, arc means T welding tungsten inert gas welding MIG welding metal inert gas welding and plasma.

These are the typical arc welding processes used for micro welding applications and then laser. So, laser can also be used for micro welding processes. Of course, and another is the electron beam welding, can also be considered for the application of the micro welding process, but electron beam welding the prospect is different, or maybe in different way we can use the electron beam, or maybe very controlled way we can use the electron beam for micro welding application.

(Refer Slide Time: 23:51)



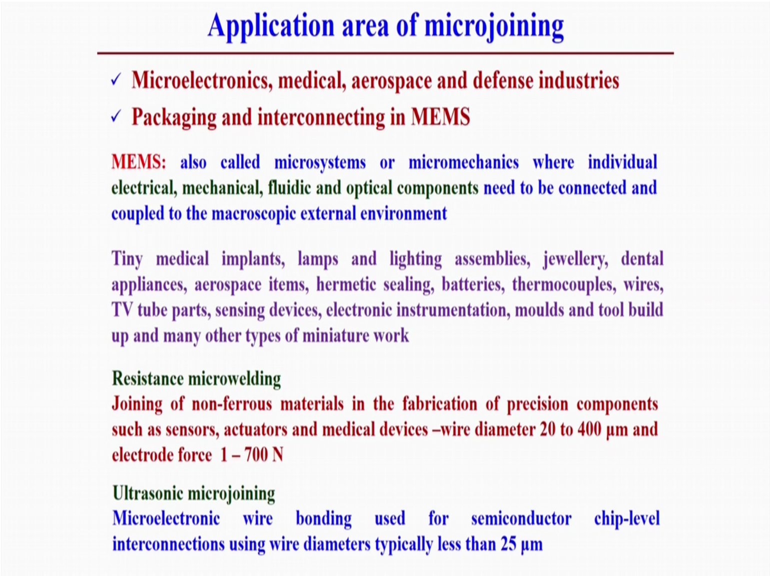
So, fusion micro welding probably we can define further that fusion micro welding process, when the sheet thickness of the materials is less than 0.5 millimeter, or maybe the tubular materials diameter is less than 1 millimeter in diameter, that can be considered as a fusion micro welding process. So, geometric size may be is restricting the definition of the micro welding process as compared to the conventional welding process.

So, but the basic phenomena of the interaction of the formation of the fusion welding process probably (Refer Time: 24:23) to the application of the heat source; that means, thermal aspect, then mechanical aspects means what efficiently it is possible to design the fiction and the holding devices, to hold the sample or to move the sample and that is the mechanical aspects for finally, what type of residual state and distortion level is achieved in case of micro welding processes, that scan comes under the mechanical aspects.

And finally the geometry aspect; that means, size, shape and size of the samples which we are supposed to process in micro welding application; so fusion micro welding these are the typical welding processes, we used one is the laser mostly used, TIG welding process, we use TIG means tungsten inert gas welding or GTAW gas tungsten arc welding process can be used for the micro welding application, then plasma may be plasma micro welding, or you can say the micro plasma arc welding can also be used for the micro welding applications.

Then electron beam and resistance so, this five types of fusion welding process is applicable for the different micro welding micro welding processes.

(Refer Slide Time: 25:39)

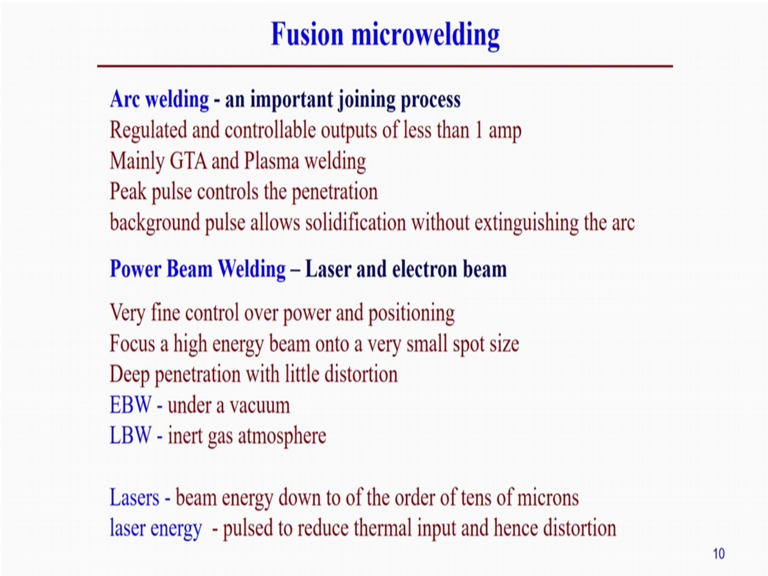


So, let us look into the typical application area of the micro joining processes. So, mostly microelectronics, medical, aerospace and the defense industries tell a lot of applications of the different micro joining technologies exist, definitely packaging and other inter connecting in MEMS, micro electromechanical system generally this application of the micro joining we generally found out. Other application if we see the medical implants, lamps and lighting assembly, jewellery industry, dental applications, aerospace, batteries, thermocouples, wires, TV parts, sensing devices, electronics instrumentation and also moulds tool and a many other small component work We suppose to join, in that cases we will find out this typical application of the micro joining processes and following the different micro welding processes, it may be fusion micro welding processor, or it may comes from the other micro welding techniques.

Resistance micro welding we use most sometimes we use the resistance micro welding processes but in this case mostly the resistance micro welding process is used, for joining of the nonferrous materials. And specific to in micro welding applications and, here if we see the sensor, actuators, medical devices that typical area, or we can use the resistance micro welding process, or the diameter wire diameter may be 20 to 400 micrometer in that range and the electrode force required in this case may be 1 to 700 Newton. So, there is a wide variation of the size of the wire diameter as the same time, the variation of the force of the electrode is a it is also varies very widely for specific in case of resistance micro welding process. Ultrasonic micro joining here also microelectronics wire bonding basically used for the semiconductor, cheap level interconnections using wire diameters typically less than 25 micrometer.

So, less than 25 micrometer where by using the wire bonding mechanism and, we use we can use this type of this specifically ultrasonic micro joining process possibility use. Now, we look into that it is also used in the MEMS also; that means, micro electromechanical system, or micro mechanics or the individual electrical mechanical fluidic and the optical components and need to be joined. So, all in this cases are need to be connected. So, here we can use the different micro joining technologies and specifically, if we see that in the in say in this application MEMS application, there is a combination of the metallic and nonmetallic or different type of components. So, there are different types of micro joining technology exist that specifically used in case of the MEMS.

(Refer Slide Time: 28:53)

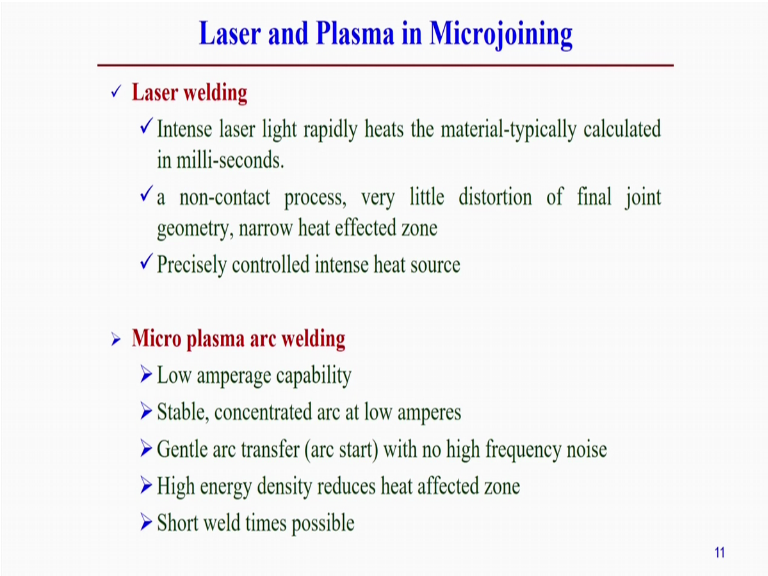


Now, again if we come to the fusion micro welding processes here, see that arc welding that is the important joining process even we know that from the several decades, the arc welding is a one of the most leading welding technologies that generally we use the conventional welding processes, but this arc welding can also be applicable in case of the micro welding process, but in this case it is very much required to very regulated and controlled outputs of less than 1 ampere; that means, less than it is the arc current the current of this in to create the arc welding process, the current can be controlled in that level maybe less than 1 ampere. Then it is applicable in case of micro welding processes. So, mainly gas tungsten arc welding and plasma welding is used for the different micro welding applications, but in this case this can also be used in continuous mode as well as the pulse mode of the arc can also be possible to use in micro welding applications.

Of course power beam welding this is the another categorization of the fusion micro welding process. Here, we can use laser or electron beam. So, very fine, but very fine control of the power and positioning is required in this case. And we know that laser or electron both it is possible to focus in a very small area. So, that is why it is a wide application observed in case of micro welding process specifically for laser. And at the same time that deep penetration with low distortion type of welding can also be possible using both laser as well as the electron beam, but difference between the laser beam welding and electron beam welding, that is we know that electron beam welding the all the melting or phenomena happens under the vacuum. So, there is no interaction of the atmosphere during the welding process. So, in that way it is advantageous to get a very good well joined.

But laser beam welding also occurs under the inert gas atmosphere. So, it will reduce the interaction of the inert gas interaction of the other atmospheric elements in the welded joints. So, here also we can produce a very good well joints but it is also having unique advantage as compared to the electron beam welding processes.

(Refer Slide Time: 31:29)



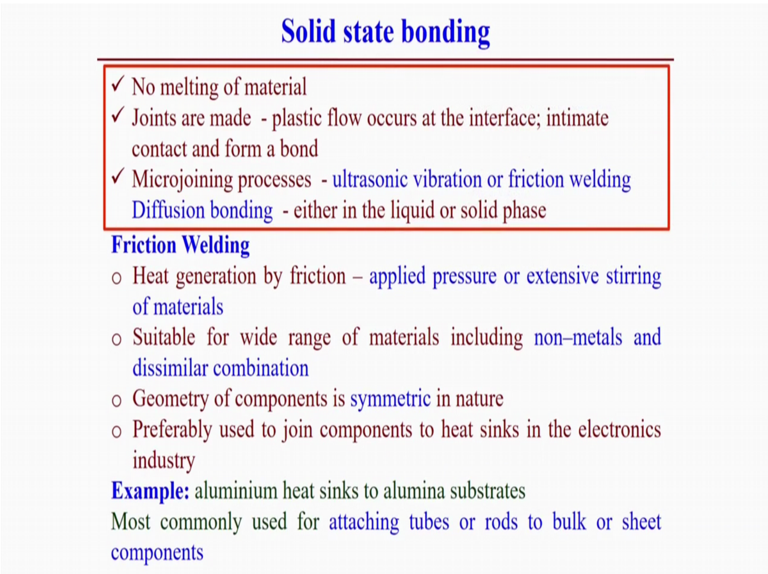
And laser welding, if we see the different typical characteristics of the laser welding processes if we see that laser light typically, we generally use specifically from micro welding applications, the pulse duration is in the level of the millisecond of course, it is possible to generate the pulse even for ultra short for ultra short laser welding at the level of the femtosecond, picosecond in that level. And the nano second level pulse can also be generated micro second and then millisecond generally, but conventional we use the micro welding applications from the millisecond to up to the femtosecond level.

The basic advantage of the laser welding processes is that it is a non-contact mode and the heat is since heat is concentrated is very small zone, the size of the fusion zone and, size of the heat affected zone is very small. So, it may not be so during the welding process, it may not affect the surrounding materials. So, that is why laser welding is very popular, or very useful means specific to in micro welding process. And of course, the typically as compared to the laser welding or electron beam welding process, the micro plasma arc welding is the another variation of the micro joining or micro welding process, where this is relatively low cost as compared to the laser welding process and, but in the it is also applicable because, nowadays it is the micro plasma arc welding machines is available, with low amperage capability; that means, even at the level of 1 ampere current it is possible to control using that machine.

So, it is applicable in case of the micro welding process of course, apart from this other the stable and concentrated arc can also be possible even at low ampere current. So, that is the basic advantage so, that micro plasma arc welding process is developed for micro welding applications. And it is possible to in this case it is the arc plasma, micro plasma arc welding that gentle happens due to the gentle arc transfer with no frequency noise may be, then high energy density reduces that is the heat effected, but not as comparable as compared to the laser of course, short well time possible, but it is not comparable with respect to laser.

Only comparable with respect to laser in terms of the cost, not in terms of the quality, but till micro plasma arc welding is the secondary option for the micro welding application. Now, apart from the fusion welding process, maybe there are several micro welding technologies exist, in case of solid state bonding process.

(Refer Slide Time: 34:16)

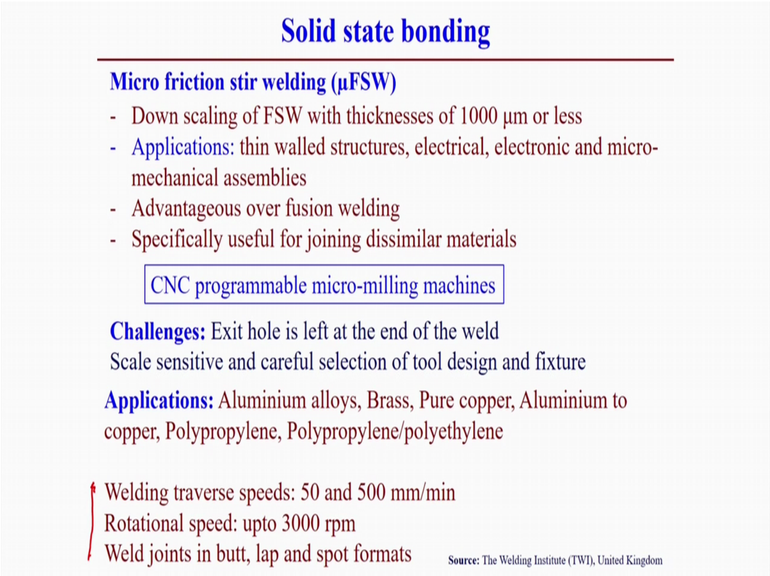


So, what are the typical characteristic for the solid state bonding process, or maybe what were the typical things generally we observe in case of solid state bonding process? First thing is that no melting at all, no melting of the material happens during the solid state bonding process. And joints are made from the plastic flow of the material. So, maybe with or without the aid of the external stirring of the plastic flow of the material. So, in case of solid state if in case of friction welding probably, there is due to the heat is generated due to the friction, but in case of friction stir welding heat is generated as well as friction due to the friction, but joining is happened mostly by the stirring action of the by the tool in case of friction stir welding.

That we have already know the basic mechanism of the friction stir welding, but that same mechanism is applicable here also, in case of micro welding processes. Other type of micro joining processes are ultrasonic vibration, friction welding and diffusion bonding. These are the three types of nonsolid state bonding generally we observe in case of micro welding applications. Now we will start what the friction welding. So, principle is known to us that heat is generated by the friction and that generated heat after the generation of the heats more if we apply the small pressure, then the material can be joined, or if we apply the some stirring action of the plasticized material, then the material can be joined with respect to each other, then that type of joining process is called the friction stirring joining process, or friction stir welding process. But this type of solid state bonding is probably applicable in the wide range of materials even for metals as well as the nonmetals.

But friction welding is mainly applicable when the geometric shape is symmetric in nature, that is the only limitation of this type of welding processes and, one of the typical application for the friction welding is that components to the heat sinks in the electronics industry. For example, the aluminum heat sinks to the aluminum substrates, normally is joined using the friction welding process. Now, with the same principle of the friction stir welding process now, it is the micro fixture stir welding process has also been developed.

(Refer Slide Time: 37:05)



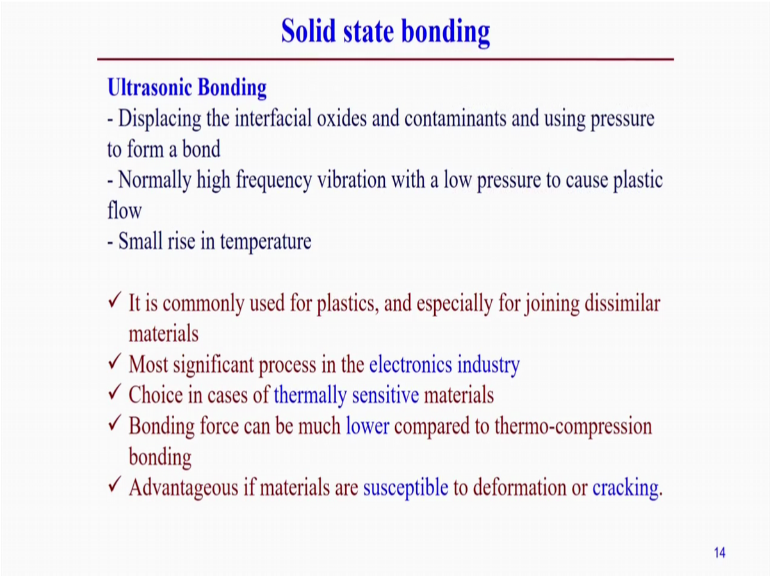
It is a simply down scaling of the friction stir welding process and we define the micro friction stir welding process, in terms of the thickness which is less than 1000 micrometer, or may be at the similar dimension. Typical application thin walled structure, electrical, electronics, micro mechanical assembly.

But it is you know that it is always advantageous as compared to the friction welding process and, specifically the solid state friction stir welding process is applicable for joining of the dissimilar materials. But in this case the CNC programmable micro milling machines, can also be used to develop friction stir welding machines; like, conventional fixture stir welding process normally it is possible to convert 1 milling machine by using the principle of the rotating axis, but similar kind of principle we can follow, but in this case CNC control micro milling machines is possible to convert to the micro scale fixture stir welding process. But challenges is that always there is a exist hole left out at the well maybe to remove that difficulties in case of micro friction stir welding process, maybe some strategies can also be considered.

But another difficulties or challenges maybe we can say, that it is a scale sensitive and careful selection of the tool design and friction is really necessary for a successful fixture stir welded join. What are the typical applications of fixture stir welding process? If you see that mostly we use the aluminum alloy, brass pure copper aluminum to copper and polypropylene and polyethylene. These are the typical materials where you can use the friction stir welding process, till date these are the materials applied for the micro fixture stir welding processes, but if you see the typical parameters used for the friction stir welding process. First is the welding speed around 50 to 500 millimeter per minute, rotational speed at the maximum 3000 RPM and weld joints can also be from the butt, lap and the spot formats.

But till the micro friction stir welding is developing stage, but an specifically for the other types of material. And so, many dissimilar combination of materials still going on. Now, we come to that point solid state bonding process. So, solid state bonding process one of the typical solid state bonding process is the ultrasonic bonding, in this case that to join the different materials the ultrasonic vibration is responsible, first it try to remove the oxide layer from the surface and then application of the pressure probably from the bond between the two materials.

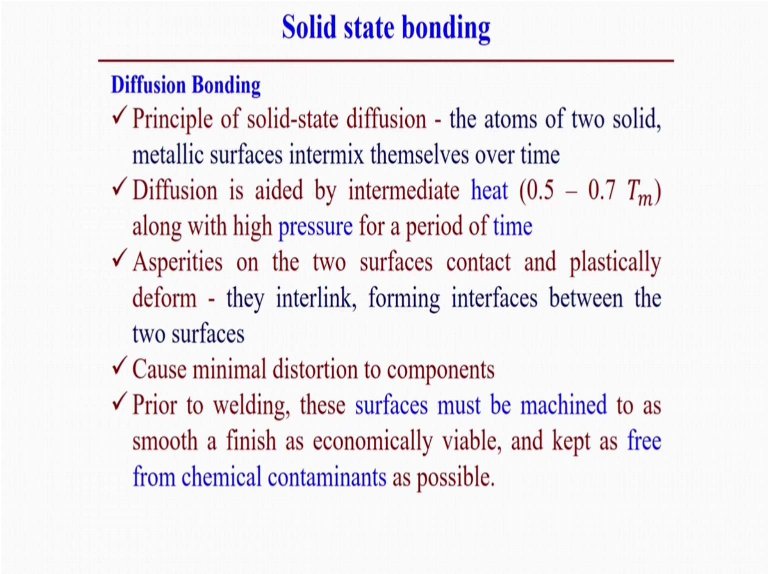
(Refer Slide Time: 40:10)



But the high frequency vibration is the main driving force, as well as the low pressure that cause the plastic flow of the material and the inter linking of the two different types of materials.

But this process is subject to there is a small implement of the temperature small temperature rise may happen during this process. This type of materials so, this type of process is mainly used for the plastics specifically joining of dissimilar materials and more significant application we found out for ultrasonic bonding in the electronics industry. And this may this process is preferable specifically the thermal sensitive materials or metal is having chain to formation of the crack. So, in that case this ultrasonic bonding or maybe applicable.

(Refer Slide Time: 41:10)

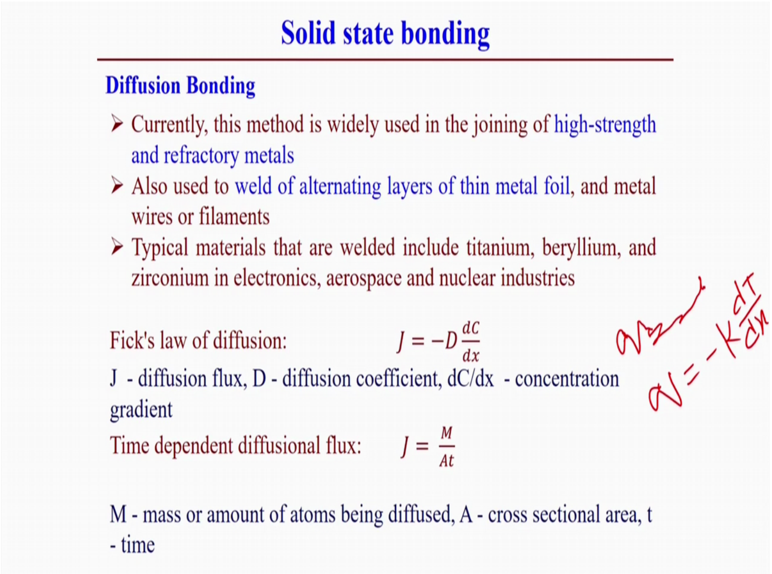


Another solid state bonding process is the diffusion bonding. So, diffusion bonding means that the atoms of the two solids when coming to the two when coming to into the contact there is a diffusion between them, but that is a function of about the time, temperature and pressure.

So, these are the so, these time, temperature and pressure is responsible for the diffusion bonding between the 2 metals. For example, that sometimes maybe heat may or may not be required, but if there is a requirement of the heat probably is a 0.50 percent to 70 percent of the melting point temperature. And high pressure is required, but that should be kept for a long period of time to make the atomic diffusion between the two metals. But the main concern of the diffusion bonding is the cleanliness of the surface because, before joining the two metals it is necessary to clean the surface between the in the surface of the substrate materials and when after cleaning when they come into the contact then the high pressure over the time makes them for diffuse diffusion of the atoms and then finally, it forms the bonding between these two metals.

But advantage or maybe positive part of this joining is that, this is this type of joining cause very minimum distortion to the components, as compared to the other fusion welding processes, but thing is that this in this type of bonding the surface must be machine as smooth as possible so, that the time requirement for the diffusion of the atoms maybe in this case will be less.

(Refer Slide Time: 43:18)

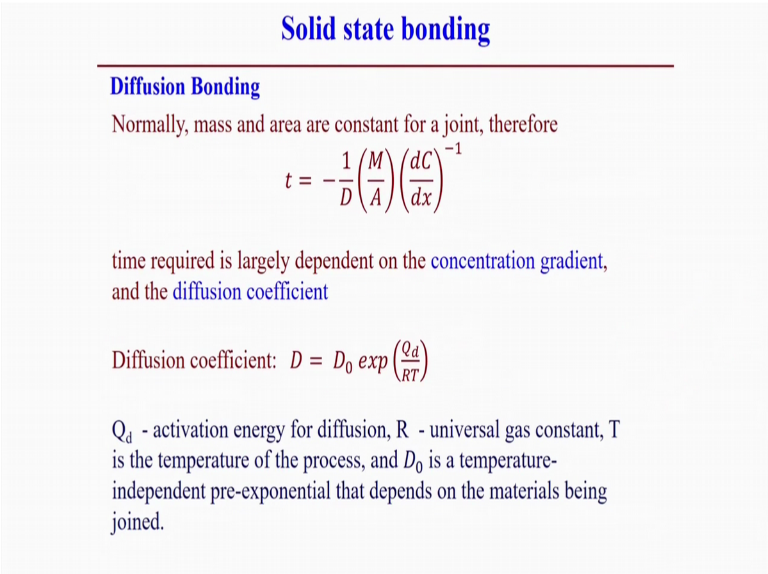


Now this diffusion bonding is specifically widely used in joining of the high strength and specific to a ceramic materials and joining of the alternative layer of the foils of the thin metal foil, with generally it is possible to join by diffusion bonding this mechanism. Typical materials if we see that include titanium, beryllium and zirconium in electronics aerospace and the nuclear industry this process applicable.

Now, little bit about the mathematical aspects of the diffusion bonding. Generally, when to try to analyze this things the (Refer Time: 43:55) Fick's law of diffusion J equal to minus D into d C by d x. So, J is actually diffusion flux, D is the distribution coefficient distribution coefficient and d C by d x is the concentration gradient. So, maybe here the diffusion flux we can estimate J, this equation can also be considered as compared to the Fick law of heat conduction. We generally use Fick law of heat conduction that heat flux q equal to minus k into d T by d x. Now, here q is the q is the heat flux, k is the thermal conductivity and d T by d x is the temperature gradient like this equation decides that the within the application of the flux what maybe the temperature gradient development within the body itself.

And that is controlled by the properties that is called the thermal conductivity in this case, but similar equivalent equation probably we can apply from the Ficks law of the diffusion similar type, but here also if you see the time dependent diffusional, flux can also be estimated by the amount of the atoms being diffused over the time t. So, that is J equal to M by A into T; A is the area of the contact between the two surfaces, t is the time and M is the that amount.

(Refer Slide Time: 45:37)

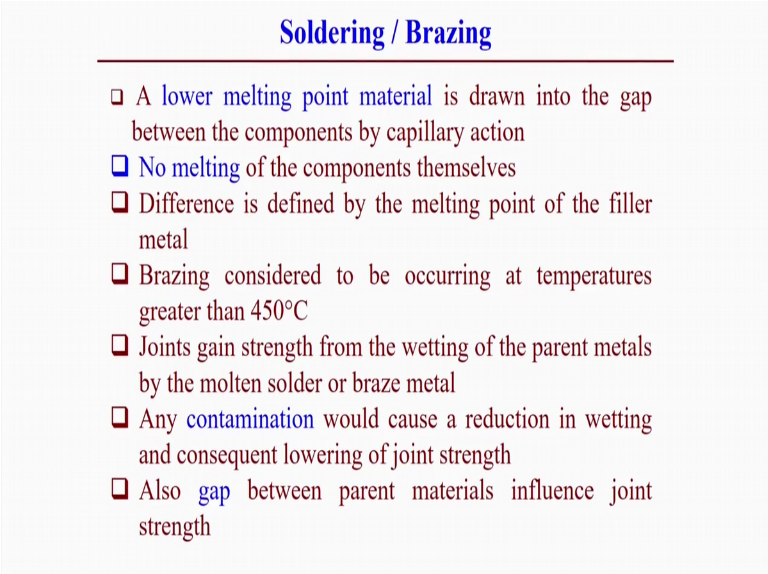


So, from this two equations we can find out that time requirement for the diffusion bonding of the two samples, can also be estimated that minus 1 by D M by A and 1 by d C by d x. So, basically the time requirement is inversely proportional to the diffusion coefficient and the concentration gradient.

So, if diffusion coefficient is very high, probably the time requirement will be the less. And at the same time if concentration gradient is very high, then time requirement for the bonding will also be less. So, that time requirement it depends on this two parameters, but actually the diffusion coefficients may not be the constant it also depends on the or temperature or maybe it is a function of the temperature.

So, D can also be expressed like that these are into e to the power Q d by R T. So, Q d is basically the activation energy for diffusion, R is the universal gas constant, T is the temperature of the process and D 0 is the some constant. That is independent of the temperature and also of course it depends on the material being joined. So, from this expression, we can estimate the diffusion coefficients if the other parameters are known to us, or may be time requirement for the diffusion bonding.

(Refer Slide Time: 47:16)



Now, we come to that point soldering and brazing this is the another typical micro joining processes, maybe conventional joining processes, but that process is applicable for the micro joining cases. So, here soldering brazing we know that, when we use the another material that either second or third material, for second material the similar joining process and third material for dissimilar joining processes. So, that low melting point material is used, that will try to join the 2 metals.

And in that terms in the way that into the heat flows into the gap between the components by the capillary action, but without melting of the parent components. So, that is the basic mechanism for the soldering or the brazing process, but the difference between the soldering and brazing process in terms of the second or third material which material we are using or that which what is the melting point of that material.

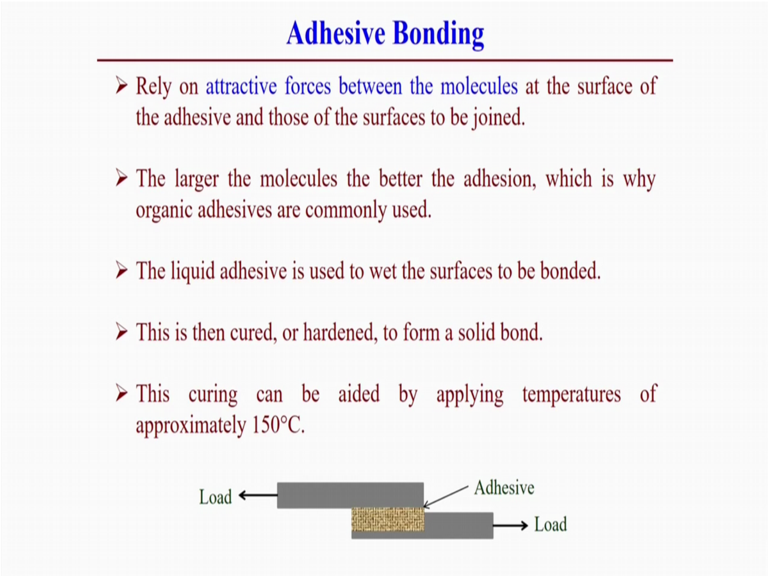
So, brazing is generally considered the this joining occurs below 450 degree centigrade and sorry, soldering is considered that joining process occurs below 450 degree centigrades on and brazing is considered the above 450 degree centigrades. So, based on this temperature we can differentiate the soldering and the brazing processes. So we can see the lot of application of the lot of application of soldering process in electronics industry, but the joint strength actually vary depending upon the contact between this two parent metals.

And that third metal or second metal actually try to weight the parent metals in terms of the molten solder, or molten braze metal. But any contamination may cause the reduction in the wetting action and consequently the joining strength. Also, the gap between the parent metals that also influence the amount of the joint strength when you try to join using the soldering or brazing mechanism.

(Refer Slide Time: 46:32)

So, both similar type of materials or dissimilar type of materials can also be joined using these technique, but soldering primarily we can find out the application joining process for the electronics industry and electrical industry also and that actually use the printed circuit boards or to make the connectivity of the within the printed circuit boards. But one of the major concern of the traditional solders is that, it is most of the case it contains one of the component is lead, that have been used in various applications and we know that is a this lead this component is health hazard component and it so, we try to nowadays we try to find out some alternate arrangement of the solders. We will see what are the alternate arrangements can also be done using the different solder materials.

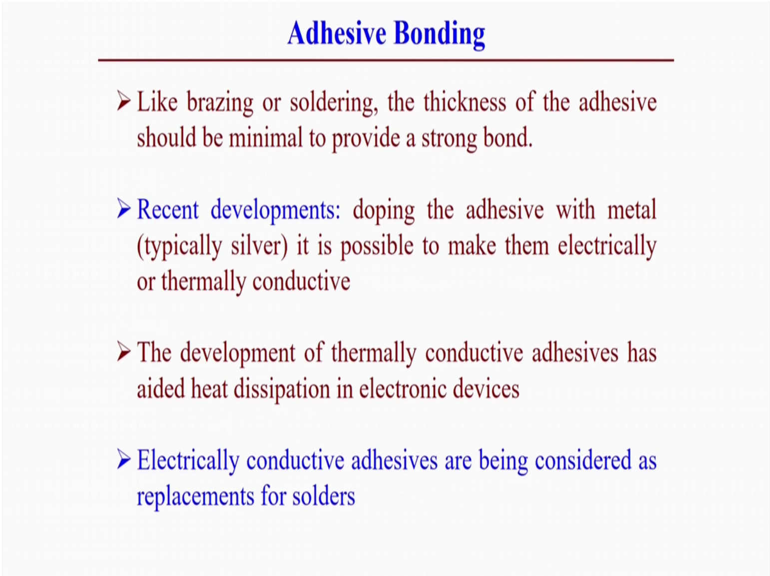
(Refer Slide Time: 50:32)



Now, another joining techniques that is called the adhesive bonding. So, adhesive bonding is basically which depends on the attractive forces between the molecules and, at the surface and adhesive the adhesives and those of the surface to be joined. However, the large the molecules the better will be the adhesion, which is in that that is why the organic adhesives are mostly preferred for the adhesive bonding of the two materials, but we can find out that liquid adhesive also used to wet the surfaces to be bonded.

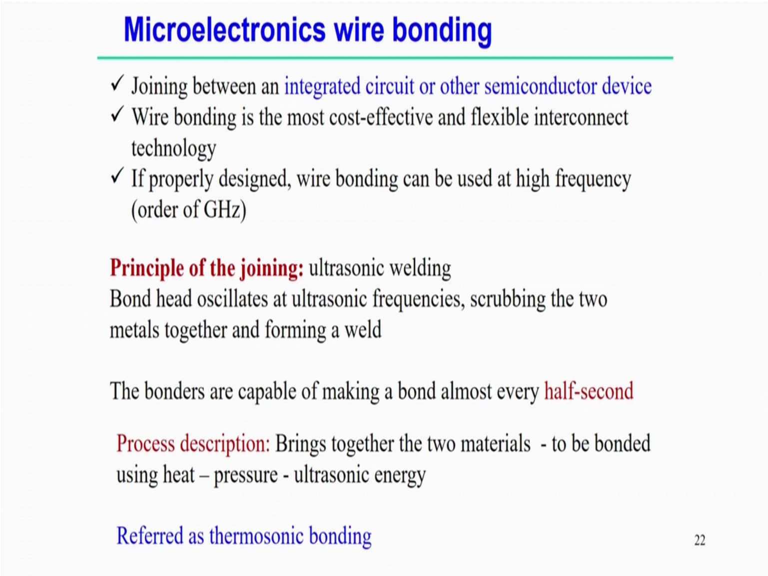
And when after using this liquid adhesives maybe we can see that it needs to cure and, after that it becomes harder and then it forms the solid bond. But sometimes the curing can also be aided, or accelerated by the application of the temperature. Normally certain cases we can use that 150 degree centigrade. If we see that pictures that in between there is a adhesives and the loads two different samples and between these two samples the adhesive can be placed and then it forms the joining of this 2 metals.

(Refer Slide Time: 51:54)



Like brazing and soldering the thickness of the adhesive is also important because, that as minimum as is the thickness of the adhesive the joint will be the joint strength will be more, but if we increase the thickness of the adhesives the joint strength can be decreased. Recent developments happens in this adhesive bonding using the using the adhesives having the metals; typically silver so, which is possible to make the electrically or thermally conductive. So, development of the thermally conductive adhesives has greater heat dissipation rate in electronic devices. So, that is why this conductive adhesives can be a replacement of the solders. And, nowadays this kind of adhesive is typically used for the several other micro joining applications. Now, we come to that point microelectronics wire bonding.

(Refer Slide Time: 53:02)

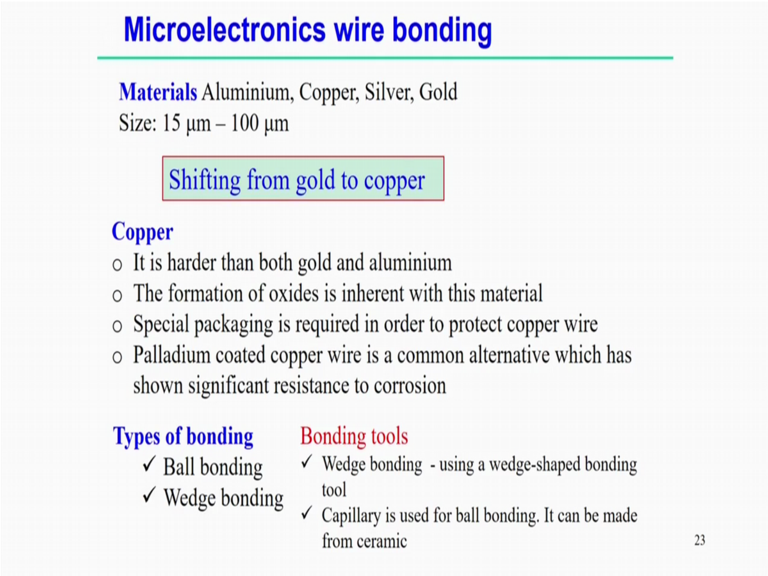


It is a joining between an integrated circuit or maybe other semiconductor devices, but in this case wire bonding is the most cost effective and flexible interconnect technology and, if you see that the wire bonding can also used even high frequency application of the order of the Giga hertz. But what are the principle of the wire bonding technology?

The principle follows the ultrasonic welding process, but bond head; that means it oscillates at the ultrasonic frequency and scrubbing the 2 materials together and then forming a weld. So, the bonders are capable of making the bond almost every half second, so; that means, process is very fast only half seconds it is possible to make a bonding. But what are the process? What are the mechanism of this process?

So, in this case the wire bonding the brings together the 2 materials, we need to connect by through the wire bonding and to be bonded using either heat, pressure and ultrasonic energy, either combination of this things or without any heat only pressure and ultrasonic energy can also be applicable for the bonding. When we use the ultrasonic energy as well as the temperature, then that is called thermo sonic bonding.

(Refer Slide Time: 54:37)

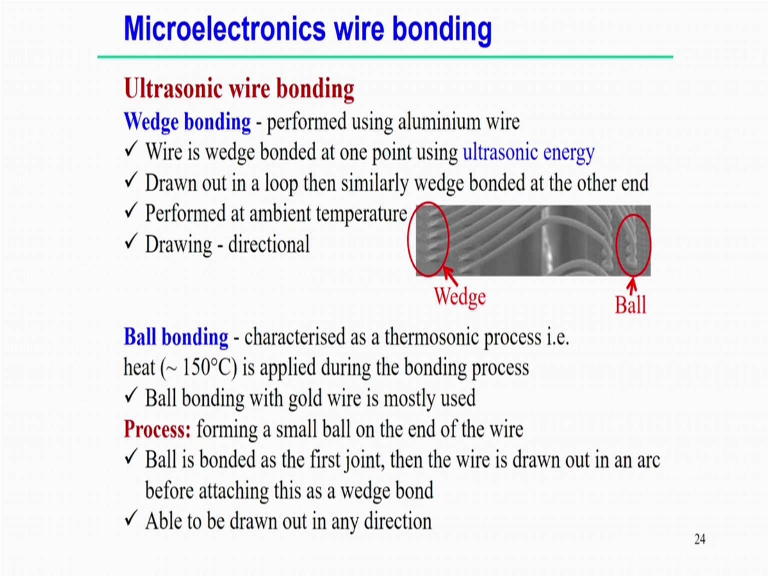


Typical materials we found for the bonding in microelectronics industry that are aluminum, copper, silver and gold, mostly the size of the wire is around 15 micrometer to 100 micrometer, but decent tendencies happens that the choice of the wire is changes from gold to copper, we know that gold is thermal very good having good thermal conductivity, but electrical conductivity, but the cost is very high. So, nowadays the gold is replaced by the copper, but if you see that what are the typical characteristics or may be advantage, or disadvantage using the copper? First is that copper is harder than gold and aluminum this is the positive point.

But there is a formation of the oxides which is inherent with this material. So, to protect this joining bonded join, special packaging is required in order to protect the copper wire, but palladium coated copper wire can also be used and maybe commonly used as an alternate which has been shown which has been observed that significant resistance to the corrosion.

So, that is why now copper can be a replacement of the gold of course, with some negative sides, but till it is comparable with that. Now 2 mainly two types of wire bonding we generally observe, one is the ball bonding another is the wedge bonding. So, in this case two different types of tools can be used. In case of wedge bonding using the wedge shaped bonding tool may be like a sharp wedge and another is the we use for specifically the ball bonding, the capillaries used for the ball bonding, but that is made of mostly from ceramics.

(Refer Slide Time: 56:37)

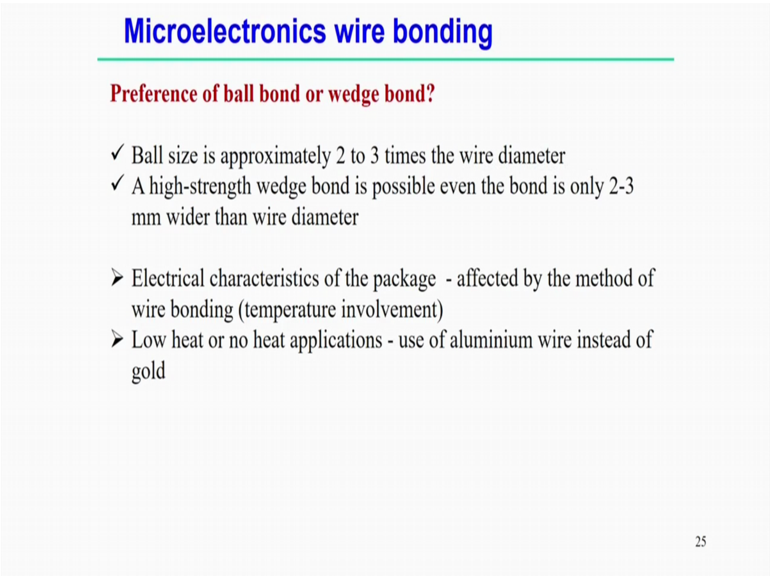


If you see in this figure the typical characteristic of the wedge bonding and the ball bonding, normally the wedge bonding is performed using the aluminium wire. And the wedge bonded at one point using the ultrasonic energy definitely the bonding the wire bonding the source is the ultrasound, the vibration from the ultrasound. So; that means, the ultrasounding energy can be used for the wedge bonding, but in this case wedge bonding it does not involve any temperature as an added thing. So, this happens because this happens at the room temperature. And the drawing of the wire when you do some wedge bonding and it becomes the directional properties; that means, in specific direction that joint strength can be a good or maybe if you want to draw the wire it should be a specific direction not in any direction.

So, and ball bonding on the other way is the characterize the other thermo sonic process maybe because, apart from the ultrasonic energy some heat is required to get the ball bonded ball bonded sample. Now, in this case mostly use ball bonding with a gold wire and here, in this case a small ball is formed at the end of the wire. And once the ball is bonded at the first joint, then the wire is drawn out by forming an arc and before attaching these as wedge bond to the other part of the sample. So, that is why the ball bonding is joined in such way that it can be drawn in any direction, which is having the limitation in case of the wedge bonding because, wedge bonding cannot move the draw the sample draw the wire in any direction. So, that is the difference.

Now, if you look into this figure, if you see the wedge bonding it is a kind of wire is joined on the sample flat and, then other thing if you see the ball bonding also here, if you see that there is a there is a formation of the ball at the end of this joint. So, these two types of process we use for the microelectronics industry. Now, question is that preference of the ball bond, or wedge bond; that means, at which cases we can prefer wedge bonding and which cases we prefer the ball bonding. Now, if you look into that typical characteristic of this processes that ball size is approximately two to three times of the wire diameter.

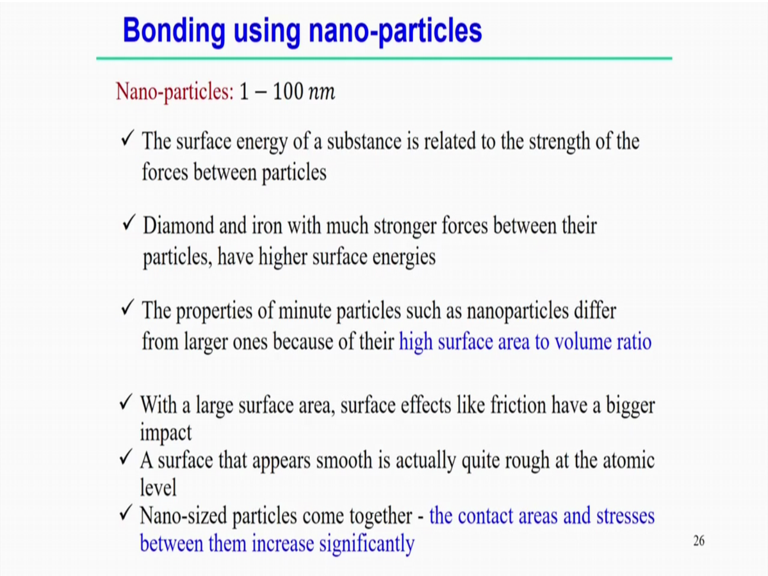
(Refer Slide Time: 59:34)



But in case of high strength wedge bond, it is possible to only 2 to 3 meter 3 micrometer probably wider with respect to the wire diameter. So, in that case an another difference between this ball and wedge bonding is that one case it is a directional another case is the non directional. So, based on that the preference of the ball bonding, or wedge bonding is maybe in other aspects that we can look into the electrical characteristics of the package; that means, if you try to apply this processes whether the surrounding items will be affected or not. In case of ball bonding since apart from the ultrasonic energy, it involves some temperature some temperature; that means, we need to application some temperature in case of ball bonding.

So, that that may affect the surrounding material, so, depending on that whether there is no heat application is required, or the heat application is maybe affected by the surrounding material, we can choose whether we need to go for ball bonding or whether we should go for wedge bonding. So, apart now we will look into the another joining technology that is called bonding using nanoparticles.

(Refer Slide Time: 60:54)

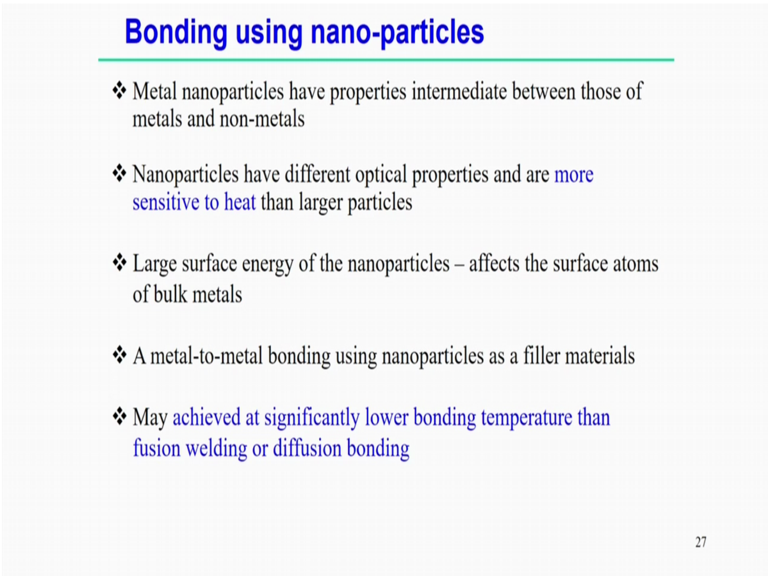


So, this another solid state bonding solid state bonding process. So, because nanoparticle is having the typical characteristics and, if we see here we normally use the 1 to 100 in the nanometer in that size nanoparticles, but if you look into the mechanism of the nanoparticles which is little bit different as compared to the other conventional size of the particles maybe, if you see the surface energy of a substance related to the strength of the force between the particles. So, definitely the surface energy is very significant part, when you try to relate to the strength of the forces between the particles.

For example diamond and iron with much stronger forces between their particles and of course, because they are having higher surface energy, but the properties of the small particles such as nanoparticles differ from the larger particle size because, in the nanoparticles the there exist the high surface area to volume ratio, and that is responsible to bring some different characteristics as compared to the larger or conventional size of the particles. With a larger surface area, but at the same time the friction maybe bigger having bigger impact, but a surface that appears more is actually may not be at rough may not be may be rough, or may not be at smooth in the atomic level. So, size of the particles when size of the particles may be come into the contact in that case, the contact area and stresses between them increases significantly.

So, that mechanism can also be explained in terms of that what is the roughness of the surface at the different scale, maybe at the nano scale what is the surface roughness which may be different from the at normal micro scale, or macroscopic scale. Second point is that the since nano particles having the higher surface area. So, that also it is a surface areas that also impact on the surface energy. So, it is having some other impact for the joining of the 2 metals as compared to the conventional particles.

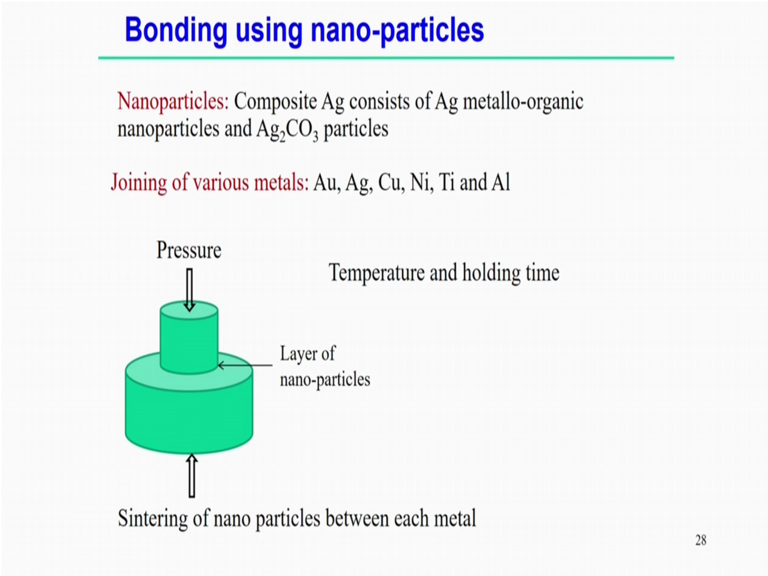
(Refer Slide Time: 63:29)



If we see that most of the nanoparticles maybe having the properties the intermitted between those of the metals and nonmetals, but nanoparticles having different optical properties and the more sensitive to the heat, than large particles large surface energy of the nanoparticles affects the surface atoms of the bulk metals.

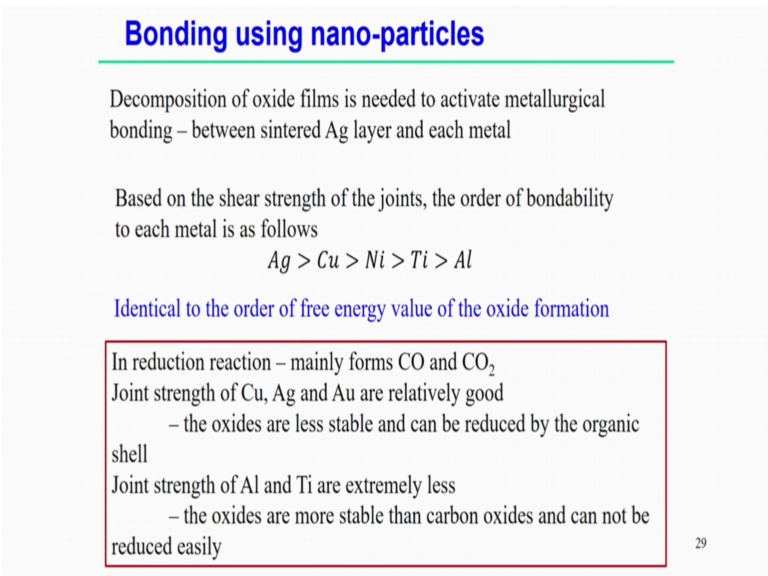
So, a metal to metal bonding using nanoparticles can be considered as a filler material. So, it may be possible to achieve significantly good bonding between using the nanoparticles, even at the low temperature that we observe in the fusion welding, or diffusion bonding processes.

(Refer Slide Time: 64:13)



Here see the nanoparticles we generally use the composite silver consists of the silver metallo organic nanoparticles, and Ag 2 CO 3 particles and using this particles it is possible to joining of the various materials like gold, silver, copper, nickel, titanium and aluminium, but in this case we is that it is possible to layer put the layer of nanoparticles between the two samples and we apply some pressure and, if needed we it is possible to apply some amount of the temperature also and keep it holding for certain time, then this two samples can also be joined using the making the bonding using the nanoparticles.

(Refer Slide Time: 65:00)



Now, what are the basic mechanisms is basically when we try to use the nanoparticles. So, first in general we can say the it is necessary, when you try to join the two surfaces it is necessary to remove the oxide films. And, when it is possible to remove the oxide films and, then active metallurgical bonding is possible between the two samples. And here using the nanoparticles we will try to do that things.

Now, here if you see that based on the shear strength of the joints the order of bond ability of the each materials is given here also. If you see the silver copper nickel titanium and alloy so, basically silver, copper, nickel probably having the good bond ability as compared to the titanium and aluminium. So, this forms that or maybe this sequence actually follows the identical to the order of the free energy value of the oxide formation. So, if it is possible to form or in the some reduction equations, if we remove the oxides layer more easily probably in that case using the nanoparticles we can obtain the very good joint, as compared to the other welding processes.

So, here in the reduction equations mainly it forms the CO or CO 2. So, in this case joint strength for the copper and gold relatively good because, the oxides are less stable and can be reduced by the organic reaction. So, this is the one possible way. And in another case if we see the aluminium and titanium this the joint strength is relatively less because, in this case oxide are more stable. So, it is not easy to form the CO and CO 2 and remove the oxide layers more easily, that is why in this case bond ability is not good using the nano particles.

So, we have discussed that different types of solid state bonding process and fusion micro welding processes in this section.

Thank you very much for your kind attention.