Advances in Welding and Joining Technologies
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Lecture - 16
Micro and Nanojoining Processes Part III

Good afternoon everybody, today we will try to discuss that remaining part of the microjoining and nanojoining technologies. So, to do that first of all we will try to look into what are the works done so far in the field of medical devices using different microjoining technologies.

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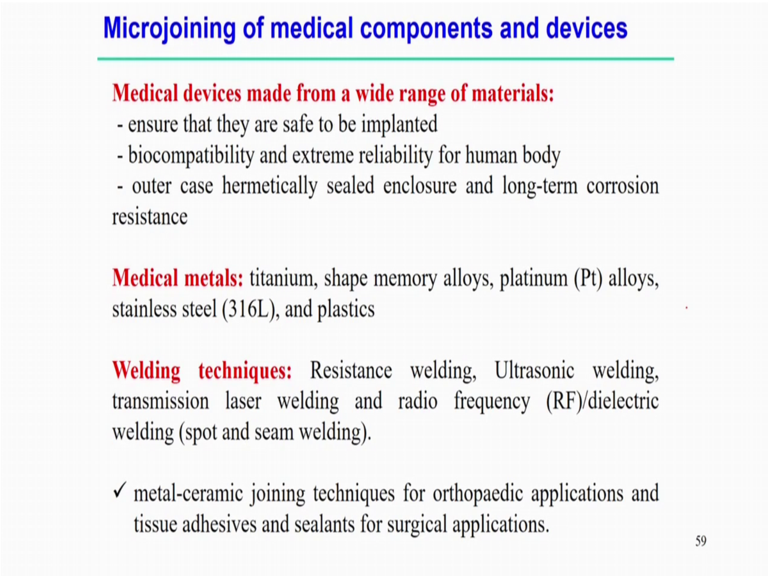

So, if you see that one of the important aspect for the medical devices that actually made from the wide range of materials , but difficulty in the in the sense that when we try to join two different metals similar kinds of materials or non metals that generally used in the medical devices.

So, here first thing is that we need to ensure that to choosing any materials or methods that it should be safe to be implanted in the human body and it should be bicompatibility and should be extremely reliable for the human body. So, we should look into that aspects before processing any materials for medical applications either in terms of the processing working with any medical devices or any implantable things that is implanted in the human body.

So, most of the cases we use that hermetically sealed enclosure and that metal stood have or characteristic of the typical the long term corrosion resistance. So, these are the requirement typically requirement for the application of the any kind of processing technologies specifically for the medical devices. So, what are the typical materials we use for the medical application or maybe in the point of view of the microjoining technologies.

So, that most of the materials we use here the titanium shape memory alloy platinum alloy stainless steel and sometimes the plastics. So, if we look into all these materials and what are the different welding technologies normally applied for the medical devices that are the resistance welding , ultrasonic welding, transmission laser welding and radio frequency or dielectric welding and most in the form of a spot and the seam welding.

These are the individual welding techniques we generally apply for the medical devices, but complexity arises depending upon the geometry of the actual a component. Specifically when we choose any kind of welding processes must have look into the different aspects for example, it should be least affected by the surrounding materials when you choose some certain joining technologies or welding technologies for the medical component that is the most important requirement.

So, in that case may be very precise control of the heat source is required. So, in that aspect probably most commonly or in generally laser welding techniques is more suitable in that respect.

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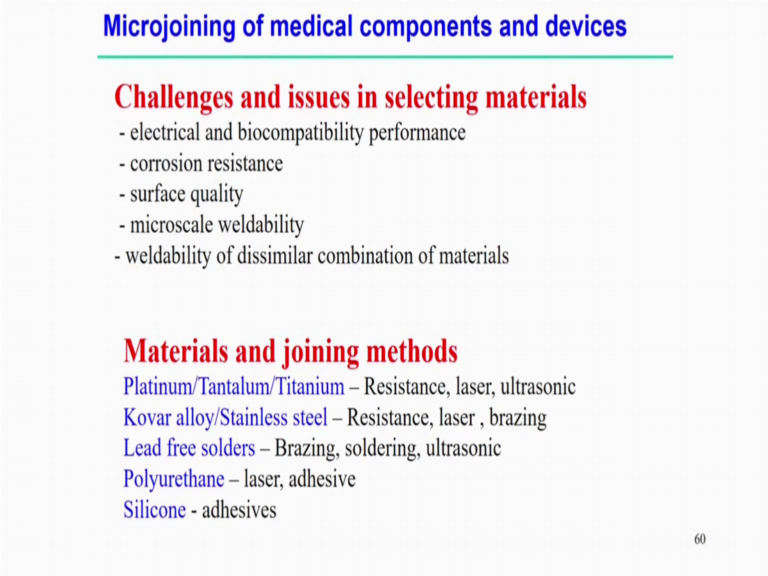

So, in general what are the typical challenges and issues in selecting the materials for the microjoining of the a medical components and as well as devices. First thing is that the compatibility of the biocompatibility performance as well as the electrical in electrical conductivity sometimes stickers for the material corrosion resistance surface quality or surface finish should be very high even after welding.

And the a micro scale weldability of the materials and most of the cases the weldability of the dissimilar combination of the materials or dissimilar configuration the materials is actually necessary. And that we have faced or that actually brings the different challenges in the microjoining application of the microjoining technologies.

So, to even after all these challenges; so, there are several materials and joining methodologies has been so, far used or it still it is evolving for the and specific type of material such as the platinum, tantalum or titanium for this material normally resistance a laser and ultrasonic welding technologies are used. Of course, these welding technologies are used in the micro scale application.

Copper alloy and stainless steel normally resistance laser and sometimes you use the brazing technology and solder or the lead free solder in that case we use the welding methodology or joining methodology like brazing soldering and ultrasonic. And plastic materials probably we use the laser and adhesive and specifically for silicon it is we generally use the different adhesives; So, because adhesives is one kind of joining technology.

So, these are the materials and corresponding joining technologies normally use in case of a microjoining applications.

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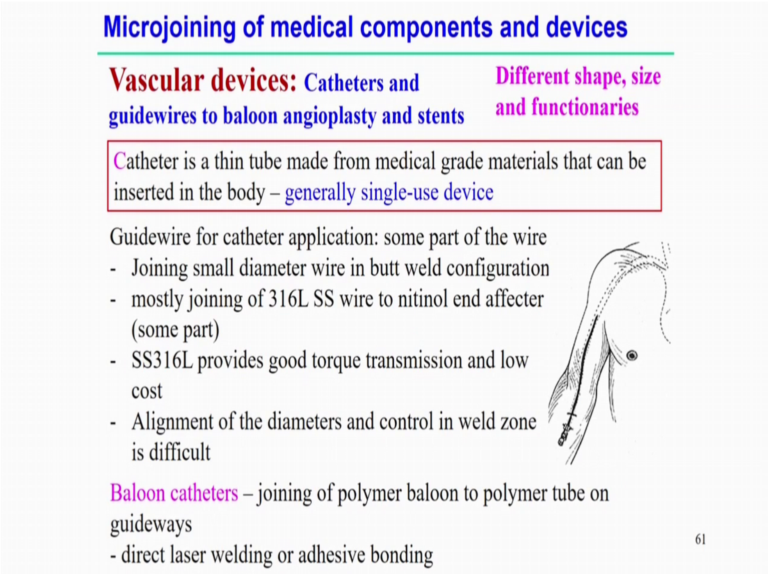

So, first we look focus into that specific microjoining technologies and for a specific vascular devices these are the vascular devices actually catheters and guide wires to balloon angioplasty and stents sense this are the here in this devices we use the welding technology in different way. So, maybe if you look in to the figures probably in this is guide wire or a catheter basically is a kind of wire or a kind of hollow tube.

So, that is typically used and in this case it may be it the size and shape may vary according to the applications and having the different functionalities of the different component of a complete medical devices or medical component.

So, here if we see the catheter is a tin tube made from the medical grade materials that can be inserted in the body generally single use device. So, in this case these sometimes the when the single use device sometimes we use in that way they are high costly nickel titanium alloy can be used for this in this medical devices.

So, sometimes it is necessary to replace some part of the nickel titanium wire or may be tube replaced by the stainless steel tube. So, that can be the cost effective methodology.

So, in that case it is necessary to join the stainless steel tube or wire to the nickel titanium alloy.

So, in that way it is applicable for the joining technology for this specific devices. So, if you see that guide wires for the catheter application some part wire maybe joining small diameter wire in butt weld configuration. So, mostly joining of the SS 316L stainless steel and wire to the nitinol end effector or the some part of the nitinol is necessary to join of course, SS 316L is used because its provides the good transmission and a low cost.

But alignment of the diameter and control in the weld zone is really very difficult. So, in this case probably laser can be a or laser welding can be a good solution arcs like balloon catheters joining of the polymer balloon to the polymer tube on the guide wires is sometimes required. So, in this case either direct laser welding or adhesive bonding generally used in this case.

So, of course, in these the generally single use device this vascular device where the we use the catheters and the guide wires or joining the balloons in this case the it is generally single use device.

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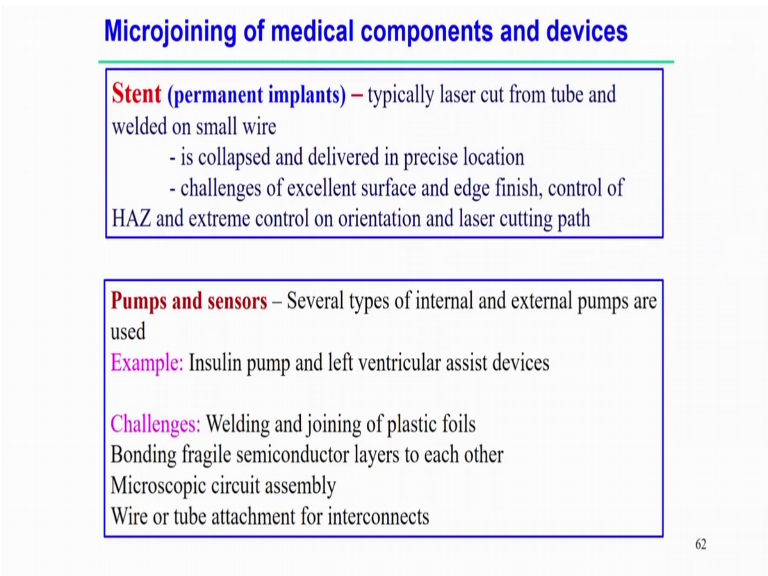

But if we look into the stent is the permanent implant is required in this case typically this stent are produced from the laser cut and from a tube and welded on a small wire.

So, objective is to the this stent is the actually need to put is the collapse and deliver in the very precise location that is objective. So, in this case challenges of the excellent surface finish and the edge finish control of the heat affected zone and extreme control on the orientation and the laser cutting path is the main issues specifically the application of the laser in this in this medical components.

Sometimes you use the pumps and sensor also. So, there are several times of internal and external pumps are used for example, the insulin pump and left ventricular assist device. So, in this case we use it is necessary the joining of the pumps and different type of sensor electrical circuit board is necessary.

So, what are the challenges if we see that welding and joining of the plastic foil is necessary in this case bonding something fragile semiconductor to with respect to each other or sometimes microscopic circuit assembly is required the wire or cube attachment for the interconnection is also required. So, all this joining or different types of materials they are have been a huge variety of the properties is specifically necessary in these cases.

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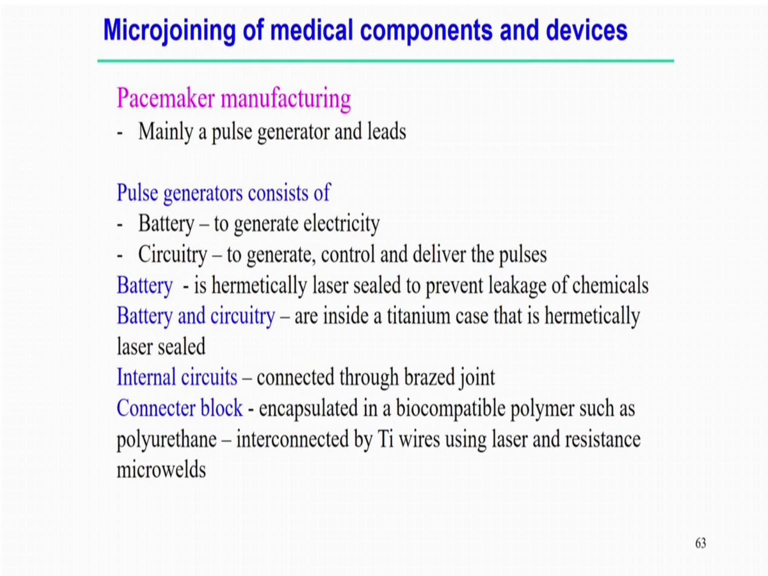

Then we find out the microjoining of the medical components that pacemaker manufacturing it is a pacemaker is basically mainly a pulse generator and leads

So, pulse generator consists of the one is the battery and the second is the circuit board. So, battery basically to generate the electricity and circuit board to generate control and deliver the pulses. So, that is the main purpose of this pacemaker manufacturing processed. So, in this case batteries hermetically sealed laser sealed to prevent any leakage of the chemical.

So, it is sealed in such a way that there must not be any leakage to the chemical steering the body second part is that battery and the circuit board are inside titanium case that is also hermetically a laser sealed. So, when during the sealed probably we need to put the laser put the laser source. And then we seal the materials or these components and then we is a complete making a package of the complete pacemaker.

So, of course, in this pacemaker the internal circuits is generally connected through the brazing process, but connector blocks sometimes encapsulated in a biocompatible polymer such as poly urethane. So, here which is interconnected by the titanium wire and that the typical welding process here using either laser and resistance microwelding processes.

So, we can say even for pacemaker manufacturing although there are several components we can use it , but it is also necessary all this equation for example, should not be leakage the any chemical components exist in the battery. And then that to do that it is always we need the hermetically sealed a sample and that we using laser.

And most of the cases we use the circuit board may be is the soldering and maybe internal circuit either soldering or brazing we can it is connected that is also one kind of joining technologies. And finally, it is necessary the titanium is a titanium is very good biocompatible material. So, sometimes it is the certain part is encapsulated within the titanium within the titanium case.

So, this ; so, several in this all these components will be find we find out that there is a tremendous application of the a different welding and joining technologies in case of pacemaker manufacturing. May be see the other radioactive seed implant that is also one kind of radiation therapy that has been developed as an alternative to the external beam irradiation for cancer treatment basically.

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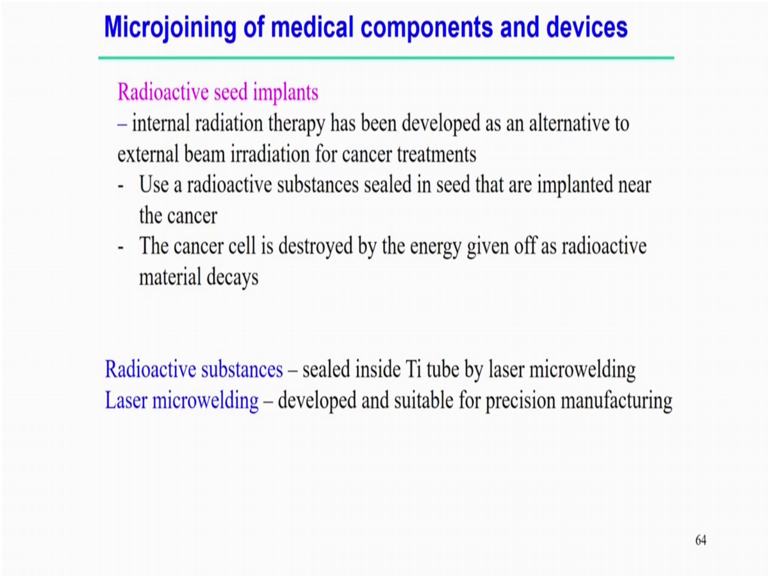

So, in this case the user radioactive substances sealed in a seed that is necessary to implanted near the cancer. So, in this case the cancer cell is destroy it this way the cancer cell is destroyed by the energy given off the radioactive material, but the issues are the sealing of the radioactive substances that is also that is generally done the titanium case and using the laser microwelding process.

And finally, the sorry laser microwelding processes that is the one application of the microwelding in this case, but difficulties is that although we can use the laser microwelding process. So, we need to control the heat affected zone to the radioactive material. So, that is why it is necessary to develop and suitable process methodology using the laser microwelding process for the or this kind of weld precision manufacturing.

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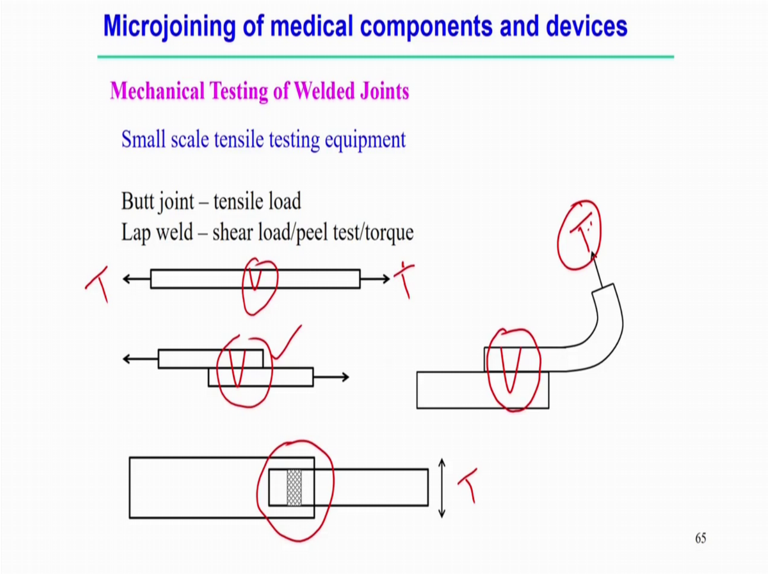

So, apart from the of course, when you use the different microjoining technologies in the for the medical devices is it is necessary to mechanically test the a different welder joint. So, of course, in conventional welding processes we use the different type of testing tensile testing compressive testing or maybe something bent testing all this kind of testing we generally done in the conventional welding processes.

But specifically all this type of micro joint components; So, small scale tensile testing equipment is required to do the any kind of tensile testing for example, we see some examples are also here we see that butt joint. So, joining of the two components if we see two metals are join is butt joint configuration.

And in this case the tensile load is acting in the outward direction and we try to analyze the load versus the we can a failure mode or joint stent using this simple app application of the tensile load. But this since sample size also very small; so, we need to consider all these test in the micro tensile testing with the micro tensile testing equipment.

So, from here from the tensile analysis we can find out the joint strength or maybe the failure mode. Similarly lap joint configuration that we it is pose it is it is necessary to test the weld joint if the joint is lap joint configuration, then some sort of shear load the we can find out the shear strength of this joint.

So, in the second one, but this is the lap joint and sometimes we find out the a peel test. So, application of the load here and the here is the welded joint and there if you do the peel test peel test we can find out the strength of the joint with this geometric configuration of course, with the lap joint way the actual joint is the lap joint or finally, also it is possible to do some torque test also if the lap joint configuration here we can apply the torque to find out the joint strength and we can do the peeler analysis.

So, this like conventional welding processes even for microwelding application; these are the these are the typical type in the butt joint configuration or the lap joint configuration of the weld joint and subjected to different kind of tensile load shear load peel test or maybe application of the torque can reduce some kind of mechanical properties or failure analysis typically used for the medical devices.

Now, after doing the analysis of the medical components here we can look into that what are the advancement is actually happens in the specifically laser microwelding processes. So, to analyze this thing there are several advancement happens till dead in the microwelding or microjoining microwelding technologies specifically using laser in the different way.

So, we will try to look into that; so, here application of the laser control of the laser source.

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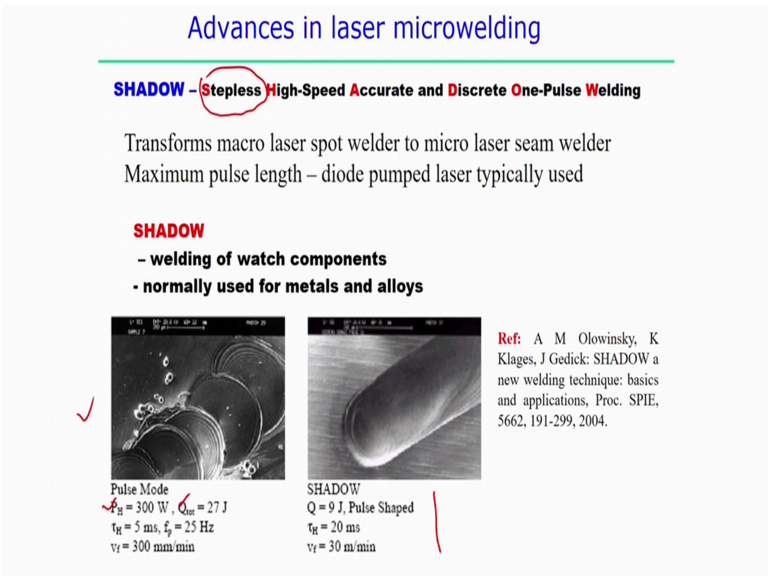

Probably useful to design the different type of or to develop the different type of microwelding technologies; so, first we look into that one of the such technique is the shadow technique. So, shadow technique stands for the stepless high speed accurate and discrete one pulse welding; if we look into that shadow comes from this first a letter of this word and that is highlighted in the red color; So, based on that that is called the shadow technique.

So, what actually we understand from the this shadow technique. If you see that in principle the transforms macro lasers spot weld to the micro laser seam weld that is the basic principle. So, here maximum pulse length is possible in the diode pumped laser that is why diode pumped laser is typically used to develop these shadow techniques.

So, a little bit explanation of this shadow techniques; if we look into these two figures. So, if we look into the first figure if we see that the fusion zone it looks like that after application of the laser may obviously, it is a pulse laser. So, fusion zone kind of overlapping with respect to the speed or we can say that it is say accumulation of the several spot that simply overlaps.

Now, pulse mode and the power is 300 watt in this case and pulse I think pulse energy is 27 joule and the pulse on time 5 millisecond and the pulse frequency of pulse repetition rate is around 35 hertz and velocity is basically 300 millimeter per minute. So; that means, it is a very high velocity 300 millimeter per minute I think 5 millimeter per second are not very high.

And say moderate velocity we can say so, with this pulse with this pulse characteristic; that means, with a typical pulse parameters some pulse on time frequency in the power and the pulse energy it is and with this specific speed means what way we are moving the laser source. So, with this configuration we can find out this is the overlapping of the several spot.

But if it is possible since there is a pulse duration is 5 millisecond; now if it is possible to move that entire duration or entire length throughout the duration of the pulse. So, through it is a maybe I can I can say that it is a kind of equivalent way like a continuous mode of laser welding process. So, in this continuous mode of there is a continuous application of the power or may be cont continuous applicant of the power. So, that it can make a very smooth surface (Refer Time: 21:10) not like pulse in the overlapping.

But this similar kind of things in case of pulse laser welding if it is possible to power the entire length of the weld in single over the duration of the pulse on time; then probably that can be converted is a very single pulse welding process. So, if the second figure if you see here the using the shadow techniques shadow technique is nothing, but the moving of the other pulse energy is nine joule and pulse shape and ; it is a pulse duration is 20 millisecond and velocity Vf equal to 30 meter per minute.

So, it is a very high velocity is when the laser is smooth with the very high velocity probably the weld length can be covered with in the duration of the pulse.

So, that is the implementation; so, instead of using the several pulse overlapping we can we can use only the single pulse and we can use a equivalently in the form of a as a continuous laser. So, that is the technology generally we use in the shadow process. So, that is a one kind of development, but of course, in this case the several trials are require and that may be the metals specific to find out the actual parameters that can be app that can be applicable using the shadow technique.

So, this one type of advances in the laser microwelding process now if you look into the other welding processes that that is called laser droplet welding.

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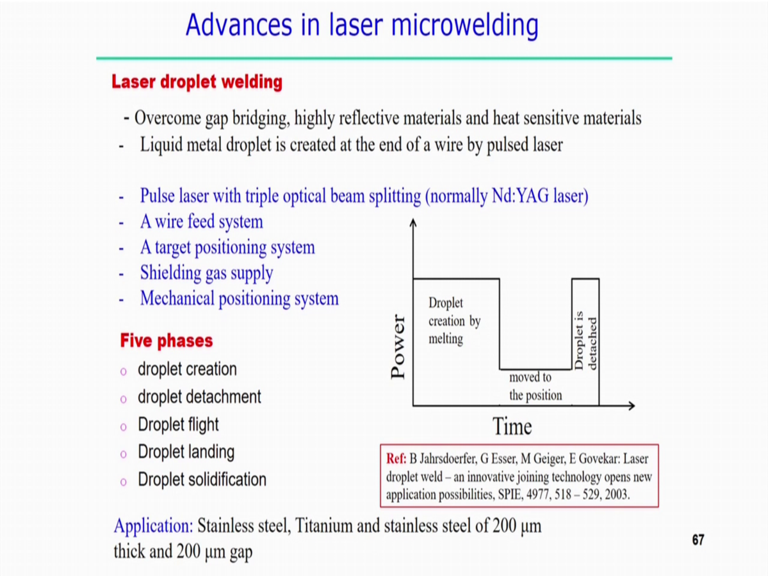

Of course, the purpose of using the or development of this process typical microwelding process is to that overcome the gap bridging. So, gap between the two plates or gap between the two different samples; specifically very high reflective materials and very high heat sensitive materials. So, on this type typical types of materials using the conversional laser welding processes sometimes it becomes very difficult.

So, to do that alternative method for all with the it is possible some using the liquid metal droplet that is created at the end of a wire and of course, using some pulse laser. So, in this laser droplet welding process in there is a that consist of the pulse laser with the triple optical beam splitting. So, the beam splitting the triple optical beam splitting system that is a one requirement and normally Nd YAG laser can be used or probably this processes developed using the Nd YAG laser

And a wire feed system. So, feeding of the wire because is necessary to produce the molten droplet. So, that comes from the wire a target positioning system. So, position a target positioning system when you targeting the droplet of the metal when a specific zone because it is a microwelding process it is a very precisely we have to fix the target position.

Shielding gas supply simply protect the molten pool from the out outside atmosphere and the mechanical positioning system. So, these are the typical components of the laser droplet welding, but how it works. So, if we look into that switch be in general this the more thing is the; if you see the this phases of the process is that first is the in terms of the droplet creation.

Second is the droplet detachment then droplet flight and droplet landing to the accurate position. And then finally, droplet solidified and then after solidification droplet solidification the two materials can be joined even there is a huge gap between these two materials.

So, how it works if you look into that typical pulse shape in the this figure shows the power versus time. So, initially the duration of the pulse is more and the moderate have in the pulse power is good moderate pulse power. So, that actually helps to create the droplet by melting the by melting the wire in this case.

And then next is that the magnitude of the power is very less and over certain del decisions with in that it is actually the droplet is moved along with the wire towards the target point of the welded join and third we it is possible to use the high power, but over a sub duration high pulse power, but over a sub duration. So, that actually helps to droplet detachment from the wire and it actually a exactly put into the exact position of the weld joint. So, that actually helps to create the weld joint in this case.

So, typical application if you see the stainless steel similar kind of material joining titanium and stainless steel which is really very difficult to join in the conventional welding processes. Or most of the cases the joining of titanium and steels is in butt joint can be obtained using the solid state welding process.

But using the laser droplet welding processes are titanium and stainless steel can be possible to join of 200 micro meter thick plate. And even this weld joint is also possible if there is a gap of the 200 micro meter in this case. So, in this prospective of the size of the plate thickness the gap of 200 micro meter is really very big in this case. So, of course, using this technology that kind of problem typical problem can be solved.

So, apart from this laser droplet welding other advanced welding technologies like laser spike welding that is also developed and this is also developed on the keeping in the this thing the normally in the butt joint configuration.

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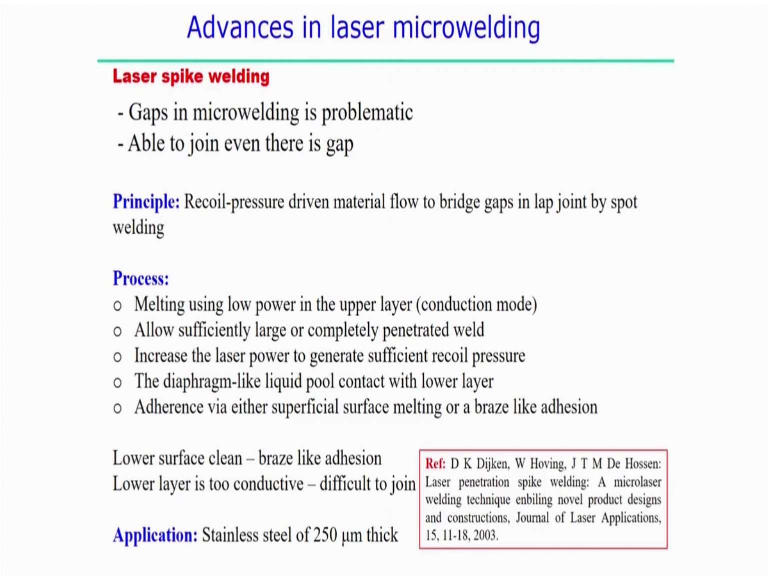

So, sorry lap joint configuration here the gaps if there is a gaps in the microwelding exist that is always problematic. And sometimes it is also exist by if you look into the overload structure of the any kind of devices. So, when we try to two any particle application of the devices sometimes the gap may be very big.

So, in this case the one of the suitable welding technologies is the laser spike welding. So, that this welding technology is useful even there is a huge gap ; what are the principle in this case the recoil pressure driven material flow to bridge the gaps in lap joint by spot welding technology. So, lap joint configuration and normally use and specifically the spot welding technology we use by, but it is a create some recoil pressure driven material flow.

Let us see how it works if you look into the process itself first melting using the low power in the upper layer; So, upper layer is melted using the low power laser and then when using the low power laser probability remains in the conduction mode not the key hole mode. So, we should use the conduction mode laser for the melting of the upper layer.

Then allow it is necessary to allow sufficiently large or completely penetrated welds. So, we need to allow increase the power such that it completely penetrate the weld; then again increase the laser power to generate sufficient recoil pressure. So, that sufficient recoil pressure that actually creates the diaphragm like liquid pool that actually contact with the lower layer. So, even there is a huge gap with upper and lower layer that diaphragm like liquid pool actually with contact with the lower layer.

Now, the joint can be formed it looks like the superficial surface melting or like a bridge like adhesive between the two plates. So, this is the one this is the laser spike welding process, but if the lower surface is very cleaned. So, bridge like addition is possible in this type of typical joint and if lower is two conductive then it is very difficult to zone because with the application of the heater is apart from the creating the or melt increasing the large volume of the weld pool that are the heat will be conducted away.

So, application found out for this typical welding process the stainless steel of 200 micro meter thick material. Another advances in laser microwelding technology if you see that is called twist technology that is transmission welding by an incremental scanning technique.

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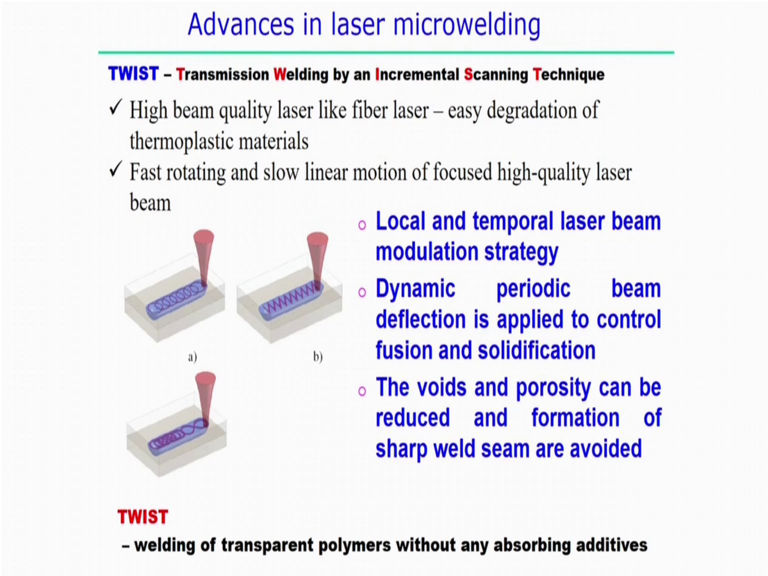

So, in this case that high beam quality laser like fiber laser it is a basically easy degradation of the thermoplastic material is a difficult to app apply in case of thermo mechanical sorry thermoplastic material and when the laser can be move if it is a low velocity. First rotating and the slow linear motion are focused high quality laser beam can be can be used in the different way so, that local and temporal laser beam modulation strategy can be used in this case.

Second thing is that if periodic beam deflection dynamically is also applied to control that can control the fusion on the application so, not ; that means, the not exactly focusing on the laser beam for a long time in a in a particular zone; rather if laser beam will control the if periodically reflect the laser beam and of course, if you control the laser path also that it better opportunity to create to damage of the any kind of thermoplastic materials ; so, any kind of thermoplastic materials.

So, in that case it is possible to avoid the any kind of voids or porosity can be reduced. So, if you see look into this figures. So, different scanning path can be followed it can be circular it can be linear, but linear in the zing zag way or some other combination of the laser path and that comes from the periodic deflection of the beam.

So, basically the look by locally and with the time scale if laser beam modulation strategy can be adopted. So, that high power laser beam can be used easily in this case. So, that not only reduce the damaging of the thermoplastic material for at the same time it try to reduce the other porosity and the voids that is kind of defects in this welding process otherwise defects otherwise it may exist in if you try to use the laser in a conventional way.

So, that is why twist technology is mainly used for transparent poly polymers even transparent polymers; if you want to join using the twist technology there may not be requirement any absorbing additives. Otherwise conventional welding process if you do not add up the twist technology the when you try to join the two transparent material for the laser wavelength. So, in that case some absorbing medium is required interface, but in this case that is not required that is a that is the main advantage of this twist technology.

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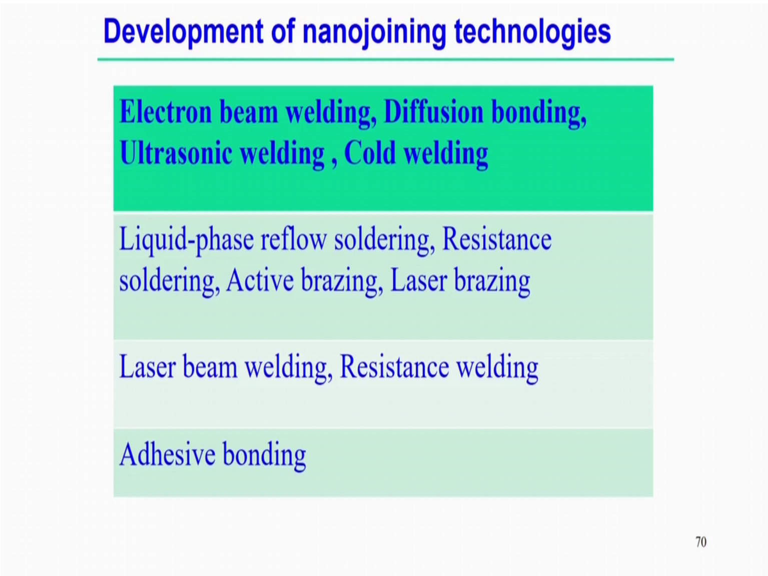

Now, apart from the advances in the different microjoining or microwelding technologies; there is a some advancements also happens or till some research work is going on in the development of the different nanojoining technologies. And most of the cases these are confined in a research and development section, but not to commercially apply, but we will try to look into the few nanojoining technologies.

So, if we look this here if you see the what are the different type of nanojoining technologies. So, here if we see that one the solid state welding nanojoining technologies that we use that is called electron beam welding, diffusion bonding, ultrasonic welding and the cold welding these are the all sold state welding process. And that is used to in nanojoining technologies liquid phase reflow soldering, resistance soldering, active brazing, laser brazing these are the typical processes in the category of brazing and soldering typically in case of nanojoining technologies.

Laser beam welding and resistance welding these are the two fusion welding technologies we observe in the application of the nanojoining technologies and finally, the adhesive bonding are also used for the nanojoining technologies.

So, we will look in to the few nanojoining technologies here.

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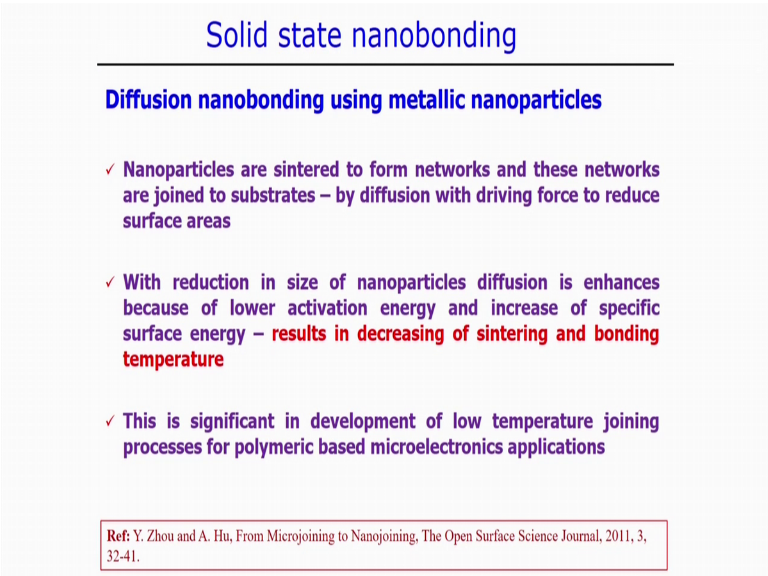

So, first is that looking the solid state nano bonding here the principle is the diffusion nano bonding using metallic nanoparticles. We have already discuss that when we try to use the nanoparticles the nanoparticles the surface area and volume ratio basically it is very high.

So, that is having the different properties that may not exist the other is the very finite size of the particles or may be larger size of the particles. So, nanoparticles is normally sintered to form the networks and these networks are joined to the substrates by diffusion. And the made driving force for the diffusion is the to reduce the surface to reduce the surface area.

Now, with reduction in the size of the nanoparticles the diffusion is actually enhance. So, diffusion mechanism is enhance for the further reducing in the size of the particles.

Because in this case lower activation energy is required and there is a increment of the specific surface energy that actually results in the decreasing of the sintering and bonding temperature.

So, if the size of the nanoparticles is even it is reduced then it actually enhance the diffusion bonding mechanism. And at the same time during the when you when you try to make the joining by the sintering processes. So, in this case the there is a decreasing of the decs sintering temperature and the bonding temperature can be reduced if you try to reduce the nanoparticle size.

So, that is the in that principle the nano bonding of the different particles can be possible , but this is the significant in the development of the low temperature joining process for polymeric based microelectronics application. So, it is best suited for the microelectronics applications and specifically polymeric base. And that is why it is necessary to when you try to application this technology for the microelectronics application or for the polymeric based materials. So, in this case it is necessary to do conduct is process over the low temperature.

So, that is only possible in the because nanoparticle size as very small. So, in that actually it enhance the reduction of the temperature of the process. So, overall process and of course, sintering temperature. So, that is the one of the nano bonding technologies is still it is going on in the R and D phase.

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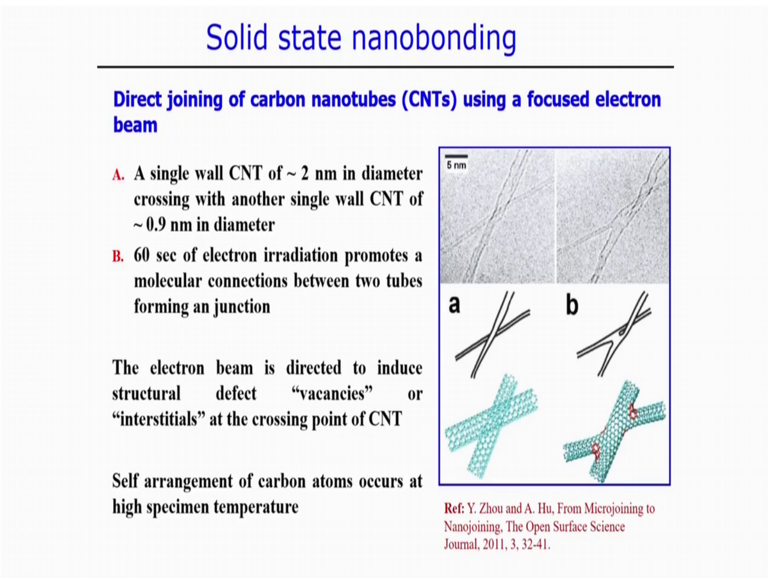

Now, we look into that solid state nano bonding. So, here if you see the direct joining of the carbon nanotubes using a fused electron beam; So, if you see into the figure there are two carbon nanotubes and it is necessary to joined between the two carbon nanotubes.

But of course, we need some external energy. So, here fused electron beam can be used to joining these two carbon nanotubes. So, figure a shows that a single wall carbon nanotube of 2 nano meter in diameter crossing with another single wall carbon nanotube which is having 0.9 nano meter diameters. Now 60 second of electron irradiation promotes a molecular connections between the two tubes that actually forming junctions.

So, of course, in this case it is necessary to re precisely control the electron beam and that should be focused on the exactly on the joining on the joining of the two nanotubes. So, here the electron beam is actually directed to induce the structural defect like vacancies or interstitials of the crossing point of the carbon nanotubes.

So, at that point when you create the vacancies or the interstitial in that point it is necessary to control the electron. And then self arrangement of the carbon after creating that kind of defects basically the vacancies or interstitial that is the one kind of crystal defects; so, if we using the electron beam if you try to create the defects at the joining point. So then after that self arrangement of carbon atoms can occur at the high specimen temperature and they can bond together ah; that means, to different carbon nanotube.

So, this is the one type of technology nanotube, but still it is under in the R and D section; research and development section.

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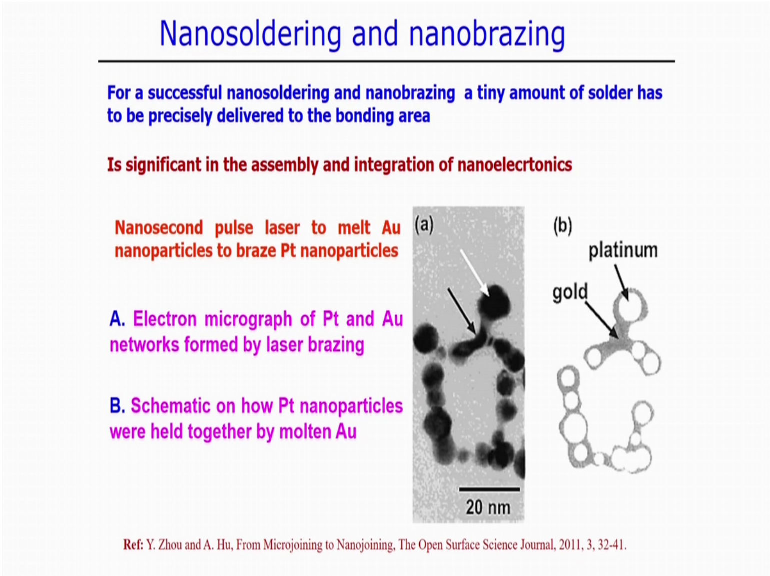

Another point is that nano soldering and nano brazing. So, even like conventional and the micro scale soldering and brazing even for nano soldering and nano brazing probably we understand the soldering and brazing will be the second material; we try to put very precisely that second material join the other two material.

So, for the successful nano soldering and nano brazing tiny amount of the solder has to be very precisely delivered exactly at the bond area. So, is this in this is significant in the assembly and the integration of the nano electronics industry it is very important; So, this type of joining technologies or maybe say nano soldering and nano brazing technologies.

So, how it can be happen that nanosecond pulse laser is used to melt the gold nanoparticles and that gold nanoparticles actually try to join the platinum nanoparticles. So, first figure is this 1 electron micrograph of the platinum and aluminum sorry gold networks from by the laser brazing and the second one is the. So, the plat platinum nanoparticles are held together by the molten gold particle.

So, if here if you see there that very precisely if it is possible to put the gold particle between this platinum particle that that can be joined with the application of the even nanosecond pulse laser. Of course, that this scope of using the femtosecond we can more precisely control the source of the heat. So, in this case that is also possible to precisely use the femtosecond lasers also to create that kind of nanojoining or nano soldering or nano brazing technologies.

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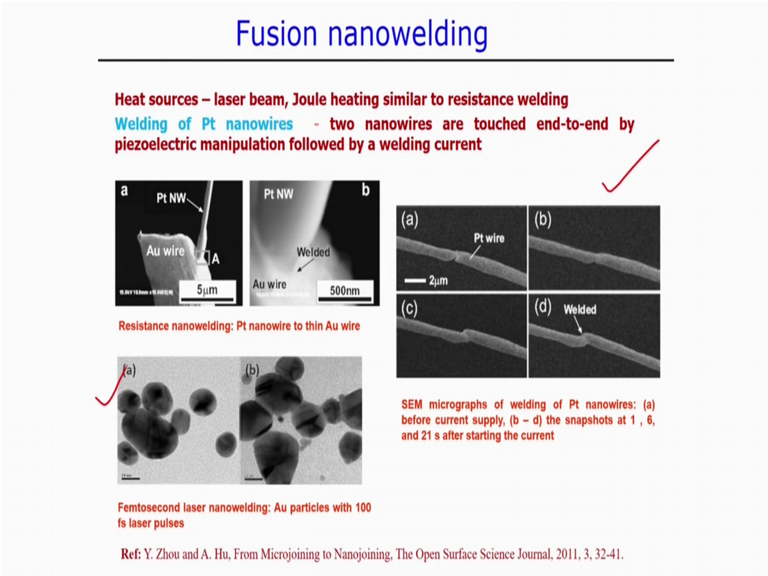

Now, we come to that fusion nanowelding. So, fusion nanowelding what are the typical heat source is used? So, in this case that laser beam joule heating; that means, joule heating means we can use the resistance welding technology. And welding of the platinum nanowires to that is also one type of fusion nanowelding the two nanowires or touch end to end by piezoelectric manipulation and followed by welding current.

See that first figure; so, here if you see that welding of the platinum nanowire it is the first figure if you see the resistance nanowelding. So, platinum nanowire to the very thin gold wire; so, if it is possible at the joint interface there some resistance and if it is if it is possible to pass through the current and if you create some heat at the interface due to the resistance between these two materials.

So, that is his probably sufficient to produce the fusion nanowelding process between this two martials. If you see the right hand side figure here this figure we see there are two platinum wire nanowire before current supply and before current supply, but we put it using, but handling of the proper position of the nanowire.

But handling of this kind of nanowire or may be nanotube is very difficult in this case the piezoelectric manipulation is required to exactly put or two at the proper position of the two different nanowire. So, after putting the it specific position this nanowire then current can be applied and that can be joined by the resistance welding process.

So, third figure if we look into this figure here if you see the femtosecond laser nanowelding; the gold particles with 100 femtosecond laser pulses. So, femtoseconds nano welding means the nanoparticles if we use the ultra short pulse laser here it is a femtosecond pulse laser. So, that gold particles can come each and they can be joined in between the with the in the by the means of the fusion nanowelding process.

So, if I see that all this crases although we use the laser beam and the either resistance welding these are two typical nanowelding processes. So, for developed for the nanojoining technologies, but in this case of course, the control of the heat source is very very much necessary to get the successful. Of course, of course, all this methodology or process of the nanowelding steel in the researcher development stage.

So, if we look back to the different nanowelding microwelding technologies. And if you see over all analysis of this all this processes or technologies developed so, far.

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If we see, that first thing is that very small possible focused beam in the form of a very small spot or in a even all most you like a line of the metals or non metals are possible probably in using the laser process. So, that is why most of the cases we find out the laser microwelding or nanowelding technologies has been develop as compare to the other develop heat sources.

High quality defect free joints are possible for highly conductive materials such as gold, silver, copper, in jewelry industry specifically using different microwelding or microjoining technologies. Microjoining technology of course, it is still continual continually develop continuously developing in some of the new fields like electronics biomedical biomedical instrumentation or the sensor and packing industry; by taking the advantage of the other specific developments like robotics and the automated system.

And of course, with the help of the very precisely control as a laser source. So, or actually helpful using this or they are the several development of different micro joining technologies also going on.

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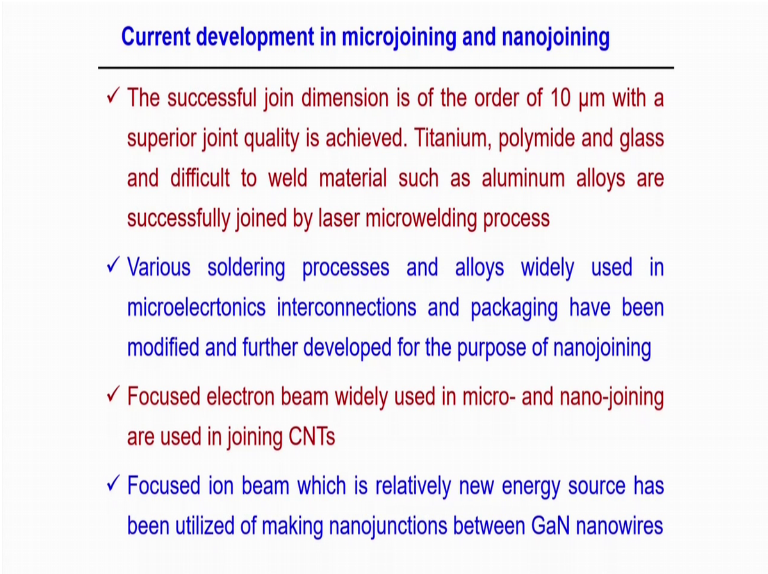

The successful join dimension so, for from this investigation is find out that specifically I am talking about the microjoining technology; the 10 micrometer with a superior joint quality is achieved titanium, polymide and glass and of course, very difficult to weld material such as aluminum alloy are success are successfully joined by the laser microwelding process.

If you see the various soldering processes and alloys widely use in the microelectronics industries interconnections and of course, in packaging industry that have been modified and further development of the further process of nanojoining is also required in this case. We see we have also observe the focused electron beam is can be widely used in micro and the nanojoining technologies as specifically joining of the carbon nano tube.

We find out that focused ion beam which is also another relatively new energy source that can also be utilized for the making nanojunctions using the in different nano wires.

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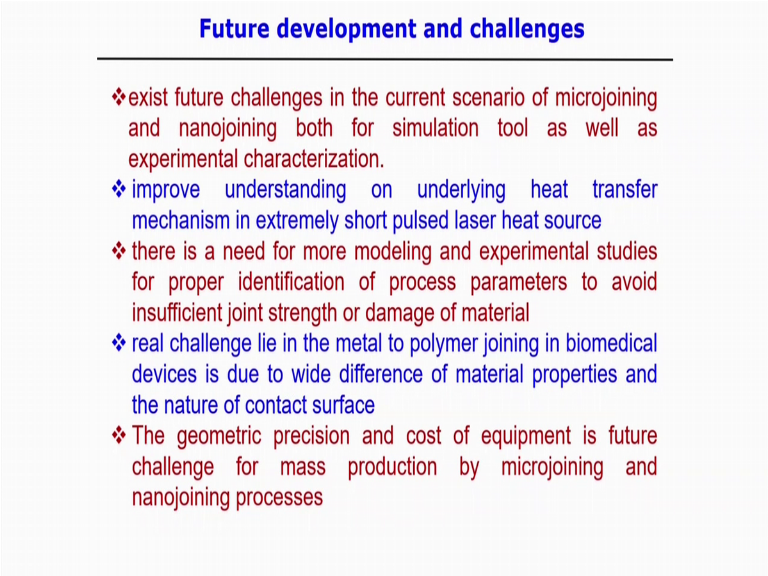

So, but what are the future development and challenges for the in the microjoining and nanojoining technologies that first come to the mind that exist future challenges in the current scenario of microjoining and nanojoining field for the both simulation tool as well as the experimental characterization. So, we can found out that several different types of the these similar combination of the materials may be characterization of the welding technologies like characterization of the welded joints is also necessary.

And of course, the underlying the physical understanding of this process in terms of the different simulation tool are also not develop. So, for specifically in microjoining and the nanojoining that is the one direction that these two have the scope of the development.

And next is the it is the also necessary to understand the underlying heat transfer mechanism in extremely short pulse laser. For example, in the femtosecond laser source on the interaction of the laser with a materials so, that understanding may help to if the physical phenomena that actually happening during the any microjoining or nanojoining technologies.

Of course, there is a need for the more modeling and more and more experimental studies also require for proper identification of the range of the process parameter to avoid the insufficient joint strength or to avoid the any kind of damage of the material basically the successful process parameter domain is necessary to identify through experimental investigation that is also required in case of microjoining and nanojoining technology.

But real challenge in the metal to polymer joining in the biomedical devices is due to the huge difference in their material properties and the nature of the contact surface. So, we need to investigate more on this specific area specific metal to polymeric metal to polymer; then because that is most of the biomedical and medical and biomedical instrument or devices implants also we can find out there is a need to combine combination of the that metals and on metals joining.

So, more and more type these type of joinings may be helpful to strengthen the microjoining and and nanojoining field also it needs to investigate from the various aspects. Finally, the geometric precision and the cost of equipment is another future challenge for the mass production by microjoining and nanojoining technologies. So, in that case more we find out the even for microjoining some microjoining technologies are also develop under the microscope which is cannot be handle in the conventional a processes.

So, in that case probably that precision is required precision when we try to develop in the any kind of microjoining or nanojoining technologies. So, that is the cost is the real challenge now a days.

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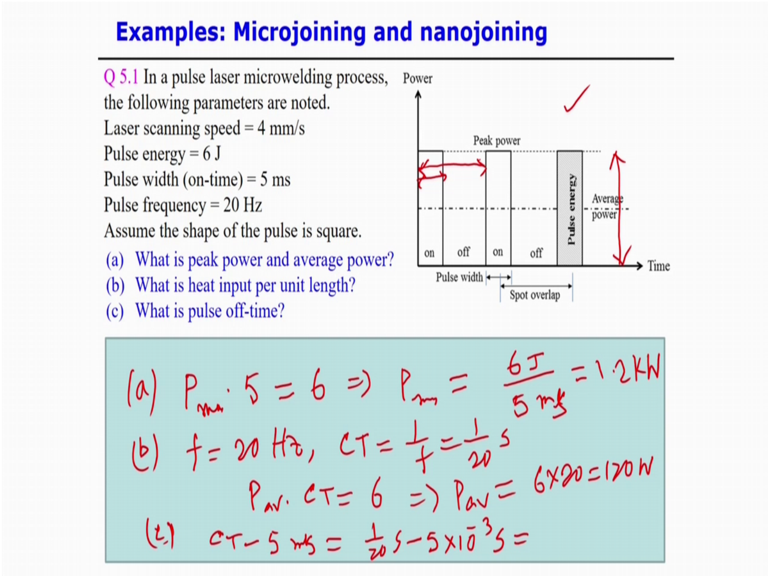

So, now after discussion of this different microjoining and nanojoining technologies; So, at the end I am trying to discuss some numerical problems that related to the different microjoining technology that may help to understand the process and in some mathematical point of view.

So, let us look into the one example for the microjoining and nanojoining technologies; first is that if you to see the in a pulse laser microwelding process the following parameters are noted the laser scanning speed 4 millimeter per second pulse energy 6 joule, pulse width or pulse on time 5 millisecond pulse frequency 20 hertz and assume the shape of the pulse is like a square. Now, if you look into the this right hand side figure if you see that this is the typical temporary pulse sense. So, pulse that may be you can say the x axis represent the time axis y axis represent the power in this case.

So, say pulse on time is the duration of the pulse the on time and may be if you see that this is the complete one cycle time; over the cycle time some initial time or may be some time may be is the that is called the pulse on time and immediate time is the pulse off time; So, that that completes the one cycle time.

So, the area over this shape of the; so, rectangular pulse the area cover by this that actually represents the pulse energy. So, pulse; that means, power into the y axis x axis represents time and y axis represents the power. So, that power and duration the multiplication of this thing that represents the area and that area represents the pulse energy.

So, looking into this here we can see we will try to solve this problem here that first thing is the what is the peak power and average power in this case. So, if you see that peak power suppose we assume this is the peak power. So, if you try to solve question number a; so, peak power and the peak power and may be over the duration the pulse on time. So, here the pulse on time is the 5 millisecond that actually represent the area; that means, pulse energy pulse energy equal to 6 joule.

So, from here we can find out peak power equal to 6 joule by 5 millisecond. So, millisecond; so, from here we can find out that 1.2 kilowatt. So, 1.2 kilowatt is the peak power in this case; now if you see the what is the average power. So, average power we can found out the average power is the that actually estimate over the one cycle. So, if frequency is 20 hertz pulse frequency. So, in this case that cycle time 1 by frequency; that means, 1 by 20 second.

Now, if you see the similar energy balance the average power into cycle time is equal to the pulse energy that is the 6; that pulse energy we assume the over the cycle time the pulse energy is although within one cycle that is the only total amount of the energy that is the pulse energy. So, that is why from here then we can find out the average power equal to 6 into 20; that means, 120 joule per second; so, 120 watt.

So, here if you see that the pulse or the pulse energy 6 joule, but from the here if you know the shape of the pulse and pulse duration pulse frequency all this that are available in this case we can find out what this process what is the total maximum power that is called the peak power.

So, peak power is you can find out 1.2 kilowatt and average power you can find out that 120 watt so; that means, the in pulse energy in pulse measure cases if we consider that is equivalent to the continuous laser; that means, this is a continuous application of the energy; then it is equivalent it is equivalent to the continuous supply of the power. So, in this case laser power is only 120 watt; that means, average power is 120 watt, but peak power is in this case is one 1.2 kilowatt. So, there is a huge difference the peak power and the average power.

And then next part what is the pulse off time? So, definitely pulse off time the total cycle time minus pulse on time 5 millisecond; that means, 1 by 20 second minus 5 millisecond 5 into 10 to the power 3 second. So, if we estimate this thing will be able to find out what is the total pulse off time. So, with this typical characteristic of the pulse parameter, we can find out the different other parameter.

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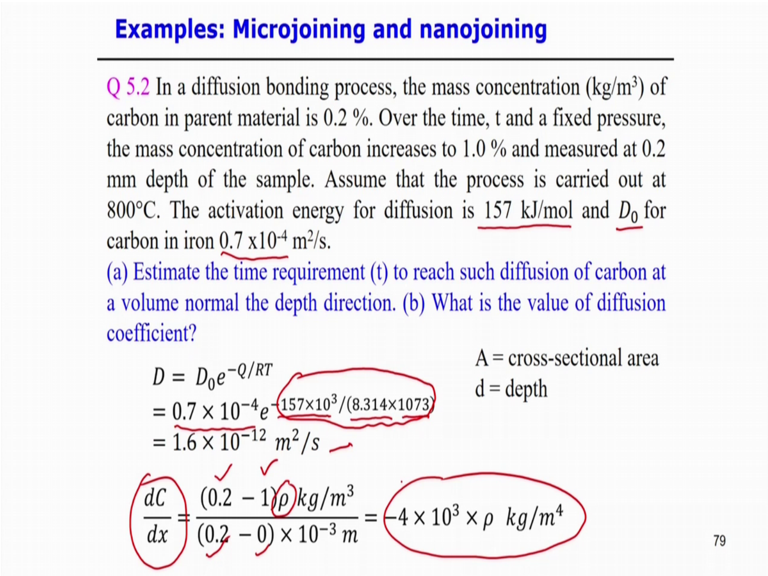

So, this is one type of example if we look into the other example that that is that is corresponds to the diffusion bonding process. So, here in the diffusion bonding process the mass concentration of carbon in present material is 0.2 percent and over the time t and a fixed pressure; the mass concentration of carbon increases to 1 percent and measured at 0.2 millimeter depth of the sample.

Assume that the process is carried out at 800 degree centigrade; the activation energy of diffusion is 157 kilo joule per mole and D 0 that is corresponds to the constant or to find out the diffusion or carbon in iron is 0.7 into 10 to the power minus 4 meter square per second.

So, let us look into first the problem itself. So, diffusion bonding process the with the over the time the carbon atoms becomes diffused and over a certain depth. So, that depth is here 0.2 millimeter and carbon concentrations increases from 0.2 percent to 1 percent and that actually happens over a certain time that time is t and, but under the condition of a fixed pressure. So, at constant pressure and at all the process is carried out at constant temperature; that means, 800 degree centigrade. Now since diffusion coefficients also is the temperature dependent. So, we will try to find out what may be the diffusion coefficients at the at 800 degree centigrade.

So, we use this formula D equals to D 0 into e to the power minus Q by RT we know that Q is a activation energy, R is the characteristic gas constant and T is the temperature. So, basically in this case T the D 0 is given that constant D 0 is 0.7 10 to the power minus 4 it is given here and Q is the activation energy. So, activation energy for diffusion is 157 kilo joule per mol. So, 157 a into 10 to the power 3 joule per mol and we use the characteristic gassed constant R equal to 8.314 and this is the temperature, but remember the temperature in this formulas would be given in the Kelvin.

So, so that Kelvin temperature you put it and we can find out the this thing. So, that this should be should check the dimension of this ah; that means, unit of this equation. So, it should be dimension less when we put the difference units of the different variables in this case. So, then D is coming the 1.6 into 10 to the power minus 12 meter square per second that is the diffusion coefficients in this case for this at this specified pressure and that is specified temperature.

Now, concentration gradient is the another parameter need to define dC by dx. So, concentration gradient it is clearly obvious that carbon concentration in that is given kg per meter cube that mass concentration that changes from 0.2 to 1 percent. So; that means, 0.2 to the initial and the 1 depends and it is given is the kg per meter cube the since it is given in the carbon in the parameter this. So, in terms of kg per meter cube we can find out we can multiply by the density and that actually represents that kg per meter cube 0.2 to 1.

Now, what is dx here dx is given here the depth. So, it is initially on the on the top that carbon present one is the 0.2 percent on the top of the surface, but the carbon is diffuse up to the depth of the 0.2 millimeter. So, 0.2 to 0 that is the change of the dx that is the dx; that means, change of the length along x. So, into 10 to the minus 3 meter; so, from here we can find out this is the concentration gradient.

Suppose this diffusion happens over the cross sectional area A and the depth we measure normal to the cross section area in the normal to the cross section area along the along the direction along the depth amount that is d.

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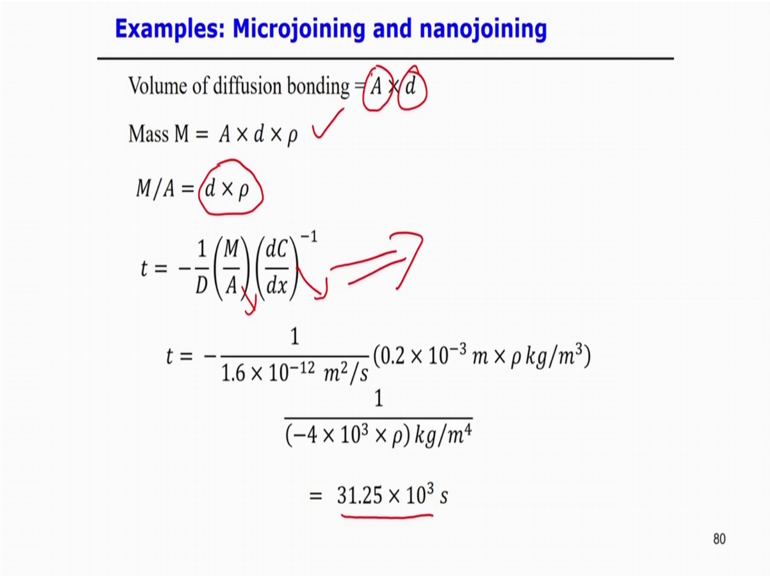

Now, what is volume of the diffusion bonding is basically the cross sectional area and the normal to the cross section area that depth is d. So, that we represent the total volume of the diffusion bonding. So, mass of the diffusion bonding is simply multiply by the density rho and of course, this rho we consider the density of carbon.

Now, M by A is basically d into rho now t using this formula we can find out what is the total time of the diffusion t equal to minus 1 by D M by A dC by dx inverse. So, here concentration get in also given M by A also estimated. So, d and rho given; so, if you put all this values here we can found out that t equal to this 31.25 into 10 to the power 3 second.

So, that time is required; so, 3.25 into 10 to the power 3 second that time is required to each the carbon concentration from 2 percent to 1 percent over the depth 0.2 over the depth of I think 0.2 millimeter. And these actually happens the we use the concentration value as a we assume that this process happens that 800 degree centigrade.

So, we use the value of D at 800 degree centigrade. So, this is one type of problem.

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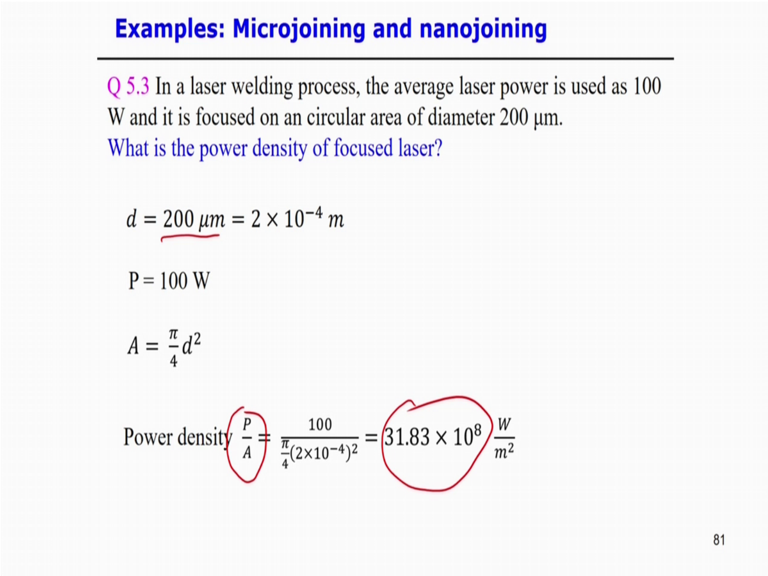

Now, we will look into the another type of problem in a laser welding process the average laser power is used as 100 watt. And it is focused on circular area of diameter 200 micrometer now what is the laser power density in this case? So, how can estimate the power density? So, first the diameter which is focused on the sample that is given 200 micrometer; that means, 2 into 10 to the power minus 4 meter and laser power is 100 watt and what is the cross sectional area over which the power is focusing that cross sectional area equal to a into pi by 4 into d square.

So, we can find out the cross sectional area. So, basically laser power density can be measure by P by A. So, power divided by the cross sectional area and we can find out that 31.83 into 10 to the power 8 watt per meter square. So, that is the power density.

So, we can estimate the power density because sometimes this power density is useful to decide whether the laser focusing on a any sample it will create any kind of conduction mode or whether it will create some key hole formation with the sample it is a based on this power density.

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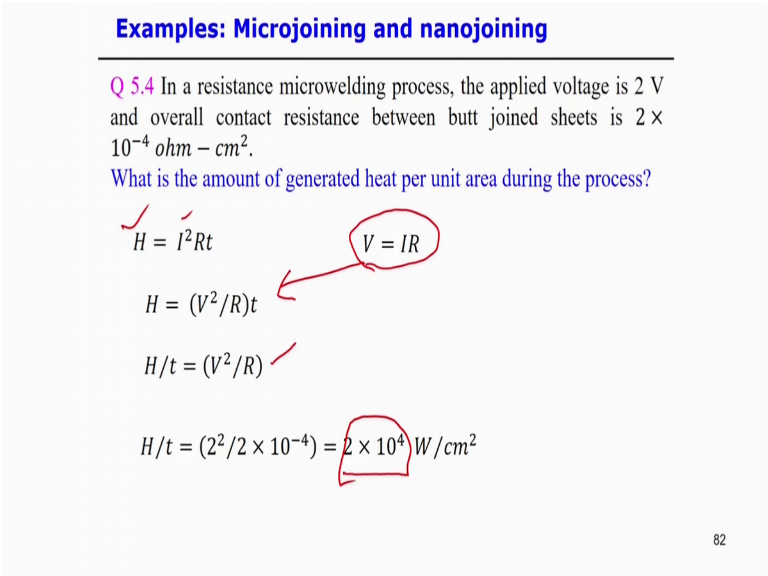

Another type of problem if we see that in a resistant microwelding process the applied voltage is 2 volt and the overall contact resistantance between the butt joined sheet is given 2 into 10 to the minus 4 ohm centimeter square.

Now, what is the amount of the heat generated per unit area during this process we need to estimate. We you see that heat amount of generate H equal to I square RT; I is the current flowing though the sample, R is the contact resistance over a resistance and t is the duration of the time over which you put the current flowing though the through the sample.

Now, volt is equal to I into R. So, from here we can convert H is equal to in terms of volt because current is not given here only the voltage is given. So, H can be in terms of volt and H by t can be represented V square by R. Now H by t, V is given 2 volt and R is also given. So, from here we can find out H by t equal to 2 into 10 to the power 4 watt per centimeter square.

So, that actually amount of the heat generated per unit area; now I think there was some idea about the different welding microjoining and microwelding technologies, their limitation, their development in the current scenario what are the development happens for the microjoining and nanojoining technologies their typical applications and to some extent some kind of numerical problems that will try to help to more understanding mathematically understanding the process. And of course, to estimate the different kind of parameters which actually use in the different laser or other welding processes.

Thank you very much for your kind attention.