Advanced Machining Processes

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Lecture No 12

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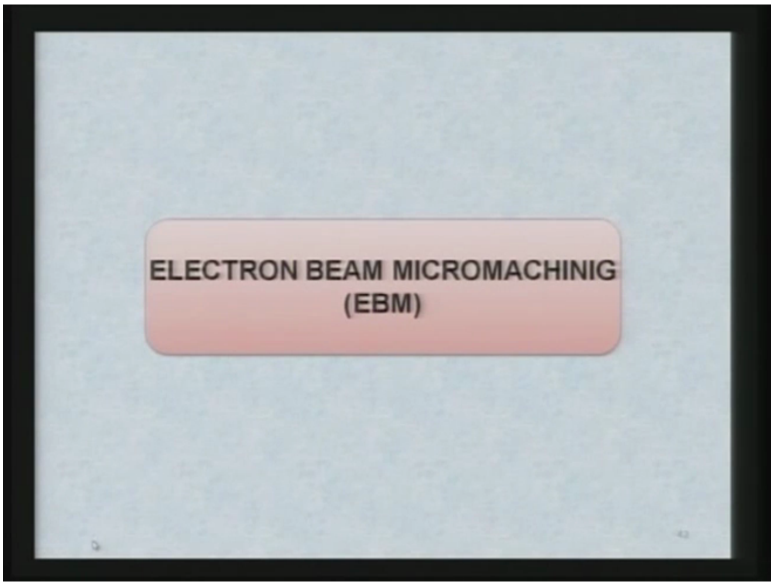

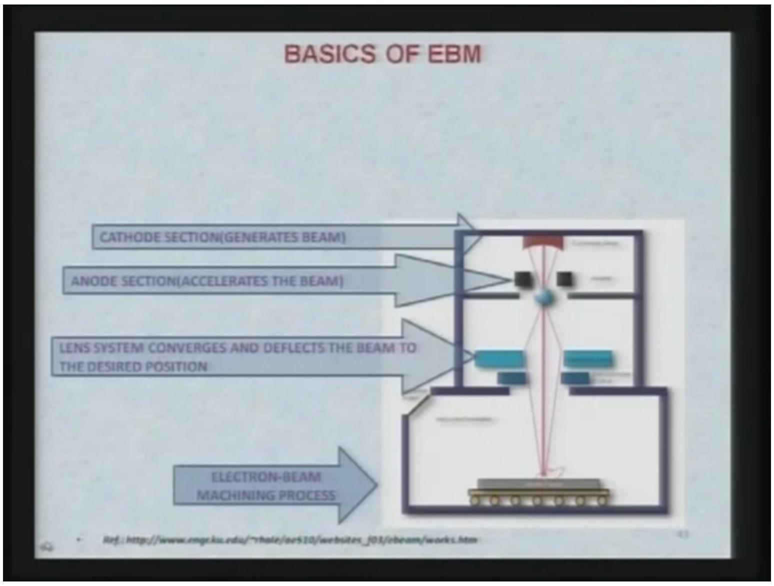

In the last class we were discussing about the micro-machining and we started with the very important micro-machining process that is known as electron beam micro-machining. I had shown you the setup for electron beam micro-machining as you can see here and we have already discussed while you were discussing the electron beam micro-machining section. So various elements are shown here you can clearly see the workpiece where electrons are hitting and raising the temperature of local area to a very high value such that it melts and vaporise the material to be machined in case of metals.

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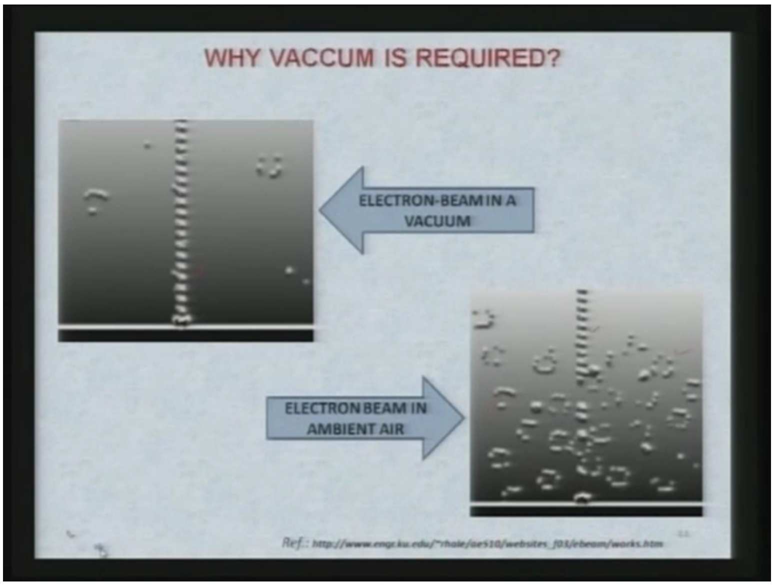

Now electron beam machining is mostly done in the vacuum atmosphere for the very simple reason I will show you, suppose vacuum is there you will get as shown in this particular figure a very fine machining as you can see the beam is coming straight and hitting the workpiece and the scattering of the electrons from that particular direction is very minimal although some is there. Now if you are going to use the atmospheric air in the machining zone then what will happen?

That many of the electrons will strike with the molecules of the air and they will get scattered and you will not get a good cutting as you can see over here that is electrons are scattered all around and you are not going getting a straight beam as before they start hitting the molecules of the air and you will not get as good cut as in the left-hand side where vacuum is there in the machining chamber. So although there are some configurations some system of electrons beam machining where vacuum high vacuum is not created they are able to machined it that time we need very high energy for the electron beam to overcome the scattering to some extent due to the collision with the molecules of the air.

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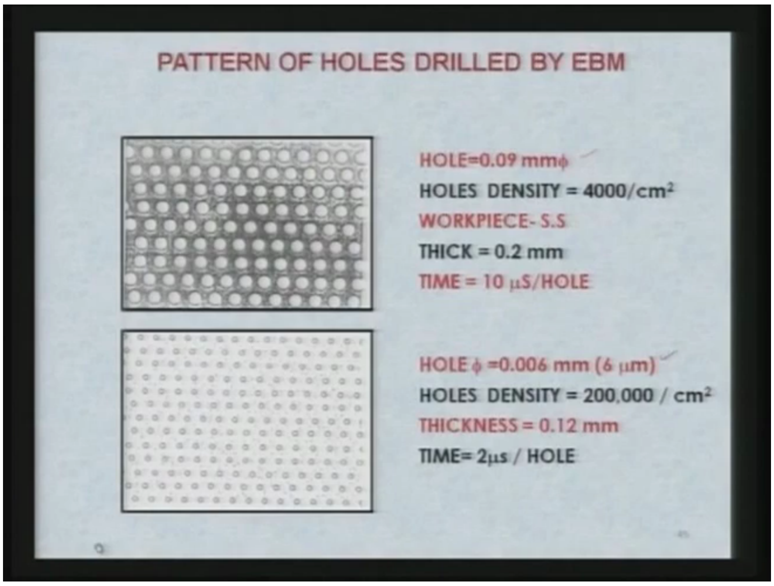

Now I will show you something very important applications in case of micro-machining area of the electron beam micro-machining process, here you can see the pattern of the holes drilled with the help of the electron beam machining process. These patterns of the holes are very important in some of the industries namely food industry where juice et cetera of the various fruits or cereals are prepared and you need very fine holes through with these juice are filtered especially in case of textile industry also you need very fine holes of the filter and that to made on the noncorrosive hard strong materials.

Here again see that hole size is 90 micro-meter and holes density is 4000 holes per square centimetre which is very high density and you workpiece of the material is stainless steel and the thickness of the workpiece is 0.2 millimetre that is 200 microns and total time taken is very small 10 microseconds per hole per…but the industry people some of the industries people are not satisfied with the size of the hole they want still smaller holes, so they have used electron beam machining process again and they are able to create 6 micron size holes at way high-density of the holes per unit area you can see 200,000 holes per square centimetre they have been able to create in the sheet of just 120 micron size and the time taken has substantially reduced compared to 90 micron size holes and here the time taken is to microseconds per hole. So you can see a very specific application of electron beam micro-machining, especially in creating the patterns or circular patterns or the holes in the stainless steel sheets which are used for filter for making the filters.

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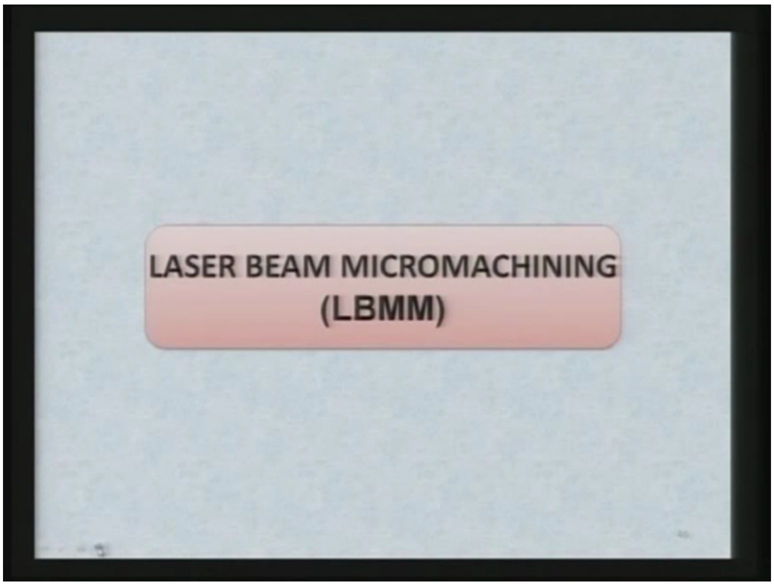

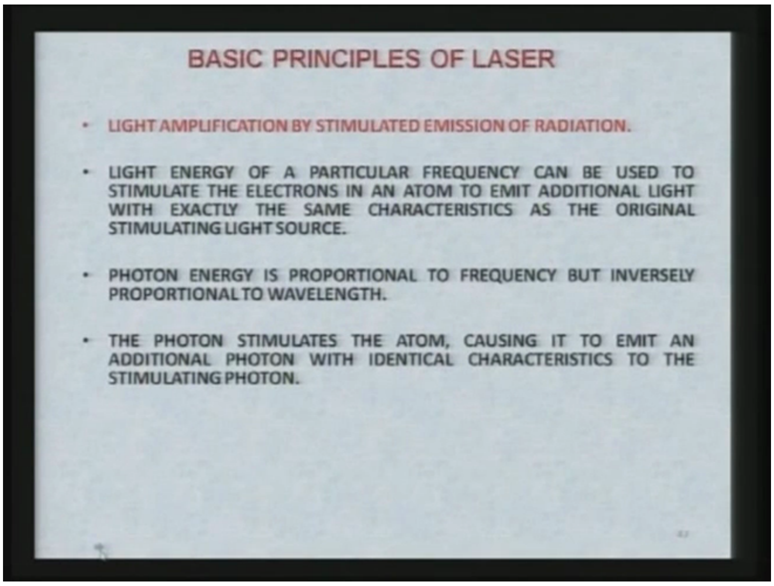

Let us see some specific important applications of laser beam micro-machining. Laser, full form of lasers is light amplification by stimulated emission of radiation we have already studied this. In this case light energy of a particular frequency can be used to stimulate the electrons in an atom to emit additional light with exactly the same characteristics as the original stimulating light source and photon energy is proportional to frequency but inversely proportional to the wavelength and the photon stimulates the atom, causing it to emit and additional photon with identical characteristics to the stimulating photons so this is a chain reaction and you have large number of photons in the area where you are producing the laser beam and there are 3 types of lasers.

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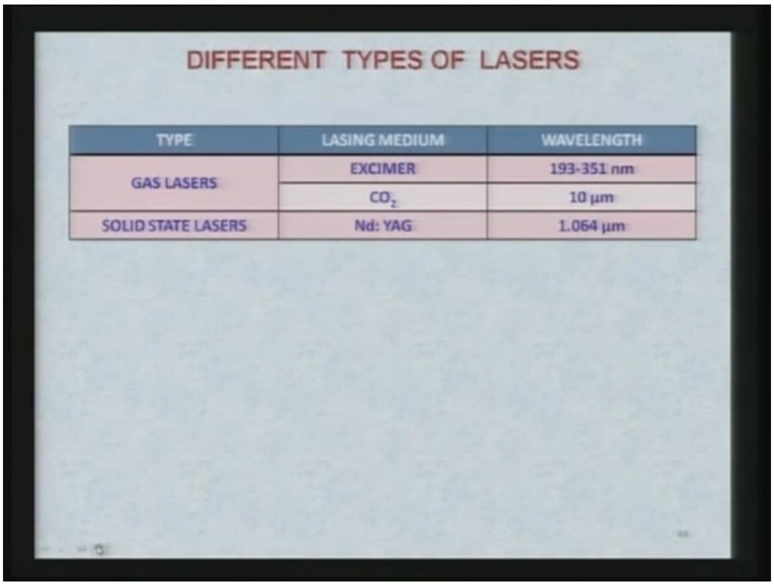

TYPE	LASING MEDIUM	WAVELENGTH
GAS LASERS	EXCIMER	193-351 nm
	CO_2	10 µm
SOLID STATE LASERS	Nd: YAG	1.064 µm

Gas laser, liquid laser, solid laser here two are shown here written here gas laser are CO 2 gas lasers and which are 10 micron at the wavelength and excimer laser which are 193 to 351 nanometre as the wavelength which is smaller than CO 2 laser. In solid state lasers namely very famous laser that is the Nd: YAG laser which has got 1.064 micro-meters as the wavelength.

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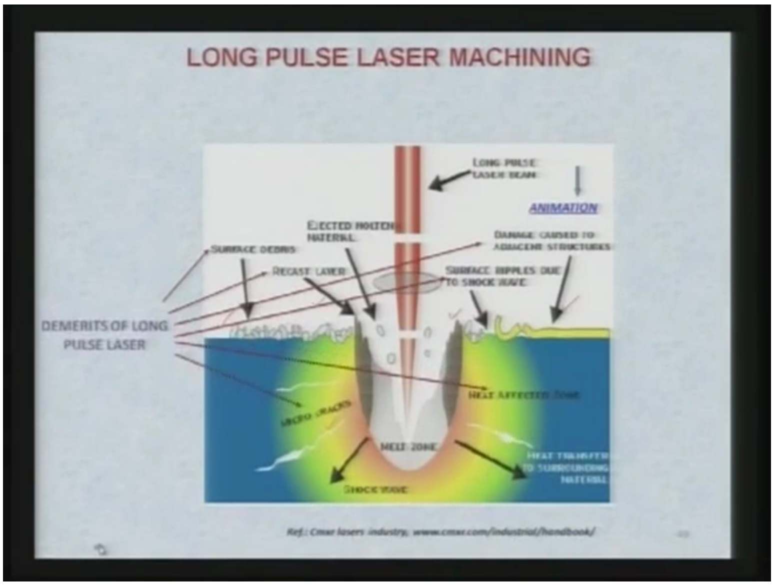

Now when you are using the long pulse laser beam for micro-machining processes, there are certain problems which have been observed as very clearly shown in this particular figure, you can see the surface debris in large number at the top surface being machined and then you can see here damage caused to the adjacent surface, here it is the adjacent surface where

here is the hole being machined, so in the adjacent surface some damages caused, surface ripples due to the shockwave can be seen over here and recast layer which is the property characteristics undesirable characteristics or property of all thermal machining processes.

So here also you get what is known as recast layer which is clearly seen. Apart from that you can clearly see here micro cracks are there and heat conduction is definitely there which raises the temperature gradient inside the workpiece. So these are some of the defects which are really not good as long as machined hole or machined material is concerned they are not desirable.

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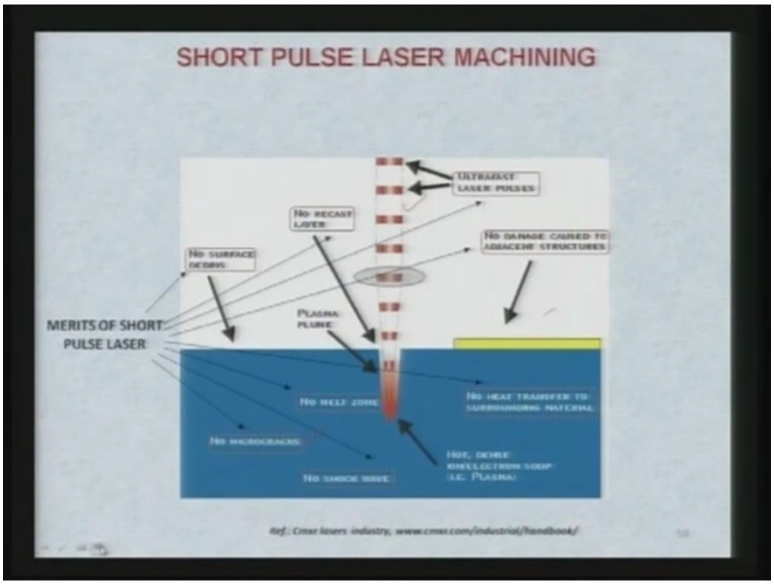

So these are the demerits, now if we go for a short pulse laser micro-machining whatever disadvantages or demerits we saw in case of long pulse laser beam machining they are not seen over here you can see that there is no damage caused to the adjacent structure over here, second thing Ultra-fast laser pulses are shown over here, so you can clearly see the difference in the short pulse and long pulse lasers.

Now there is no recast layers seen over here and no melt zone are is visible, no micro cracks are there and heat affected zone is also not shown over here and there is no damage, no surface debris the top of the surface or machined surface. So these are some of the characteristics of short pulse laser machining, so it we can conclude that short pulse laser beam micro-machining gives better surface characteristics after machining as compared to long pulse laser beam micro-machining. We all know already that 2 types of lasers are there once the continuous wave laser another is the pulse laser, so we talking of the applications of pulse laser. So there are hardly any merits of short pulse laser shown over here.

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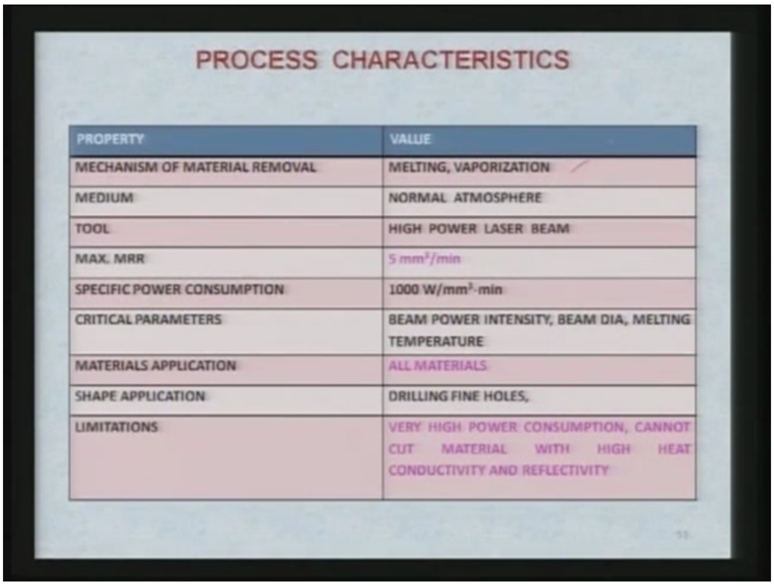

PROCESS CHARACTERISTICS

PROPERTY	VALUE
MECHANISM OF MATERIAL REMOVAL	MELTING, VAPORIZATION
MEDIUM	NORMAL ATMOSPHERE
TOOL	HIGH POWER LASER BEAM
MAX. MRR	5 mm^3/min
SPECIFIC POWER CONSUMPTION	1000 W/mm^3-min
CRITICAL PARAMETERS	BEAM POWER INTENSITY, BEAM DIA, MELTING TEMPERATURE
MATERIALS APPLICATION	ALL MATERIALS
SHAPE APPLICATION	DRILLING FINE HOLES,
LIMITATIONS	VERY HIGH POWER CONSUMPTION, CANNOT CUT MATERIAL WITH HIGH HEAT CONDUCTIVITY AND REFLECTIVITY

Property of the process, process characteristics of laser beam micro-machining. Mechanism of material removal remains the same as in case of macro machining that is the melting and vaporisation. Medium in case of laser beam micro-machining is normal atmosphere, it does not require any vacuum in the machining zone as in case of electron beam micro-machining. Tool is high power laser beam and maximum material removal rate which researchers and industrialist have observed is very small 5 micro-meter millimetre per minute. Specific power consumption is thousand watts per cubic millimetre per minute. Critical parameters are beam power intensity, beam diameter and melting temperature of the workpiece material.

Materials application you can apply it for all materials it may be electrically conducting, electrically non-conducting, magnetic, non-magnetic, metals or non-metals but laser beam micro-machining is not good for those materials which have high reflectivity such as copper it is not good for copper and aluminium the cost copper has high thermal conductivity also. So limitations are as you can see here very high power consumption, cannot cut materials with high heat conductivity and reflectivity that is why I mention aluminium and copper.

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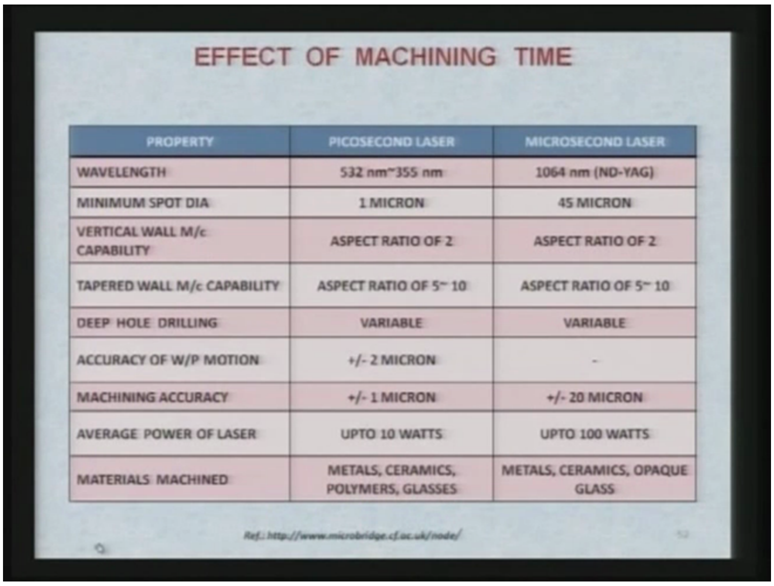

Let us see some other property other type of the lasers, there are 2 other types of lasers known as picosecond laser and microsecond laser. Now wavelength in case of picosecond laser is 532 nanometre to 355 nanometre and for microsecond lasers it is ND-YAG laser which I have already mentioned 1064 nanometre. In case of minimum spot diameter it is one micron in case of picosecond and around 45 micron in case of microsecond laser. Vertical wall machine capability aspect ratio of 2 and aspect ratio of 2 in case of microsecond laser as well, now tapered wall machine capability aspect ratio of approximately 5 to 10 in both the cases, deep hole drilling, accuracy of workpiece motion is plus minus 2 micron in case of picosecond laser. Machining accuracy plus minus 1 micron in case of picosecond and plus minus 20 micron in case of microsecond laser. Average power of laser is about 10 watts in case of picosecond laser and 100 watts in case of microsecond laser and materials machined metals, ceramics, polymer, glasses, et cetera in case of picosecond laser metal, ceramic, opaque glass, et cetera in case of microsecond laser.

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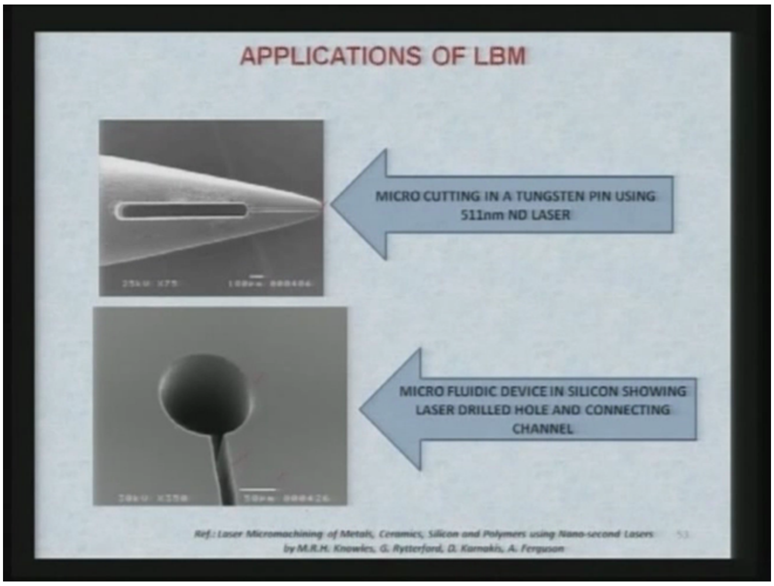

Now let us see very specific applications of laser beam micro-machining, you can see here in this figure micro cutting in a tungsten pin using 511 nanometre ND-YAG laser this is the micro cutting and it is a tungsten pin. Here you can see the micro fluidic device in silicon showing laser drilled hole and connecting channel. Here you can see the laser drilled hole and this is the connecting channel and you can see the scale over here for 500 sorry 50 micro-meter and you can means the size of this whole and the connecting channel connecting channel is smaller than 50 micro-meter as clearly visible from their references are given over here.

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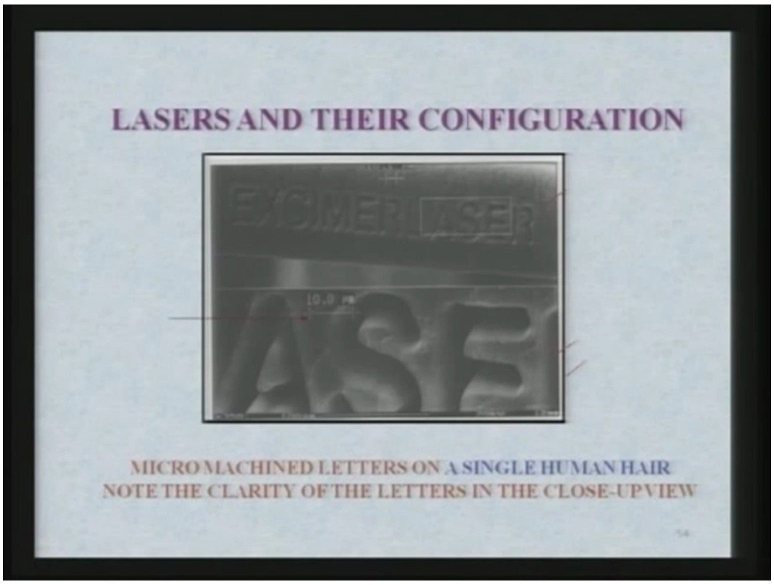

Now here is very interesting application of laser beam micro-machining specifically excimer laser, now you know in the hair it is very difficult to write anything on the hair because if you try to write it with the help of thermal process it will burn immediately, you cannot apply mechanical process for micro-machining and also you cannot apply electrochemical or chemical process. However, researchers have used excimer laser for writing excimer laser word on the hair and you can see clearly shown over here they have written excimer laser and this is the zoomed view of the word excimer and you can see the scale over there and this is very clearly visible, so it is really surprising that researchers are able to write on hair the word excimer and laser and they are very clearly visible over there micro machine letters on a single human hair, note the clarity of the letter the closer view, here is the closer view.

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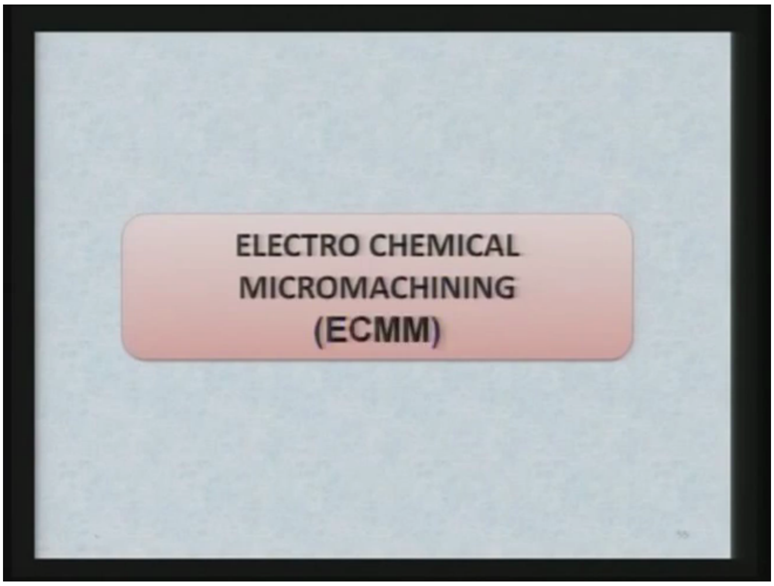

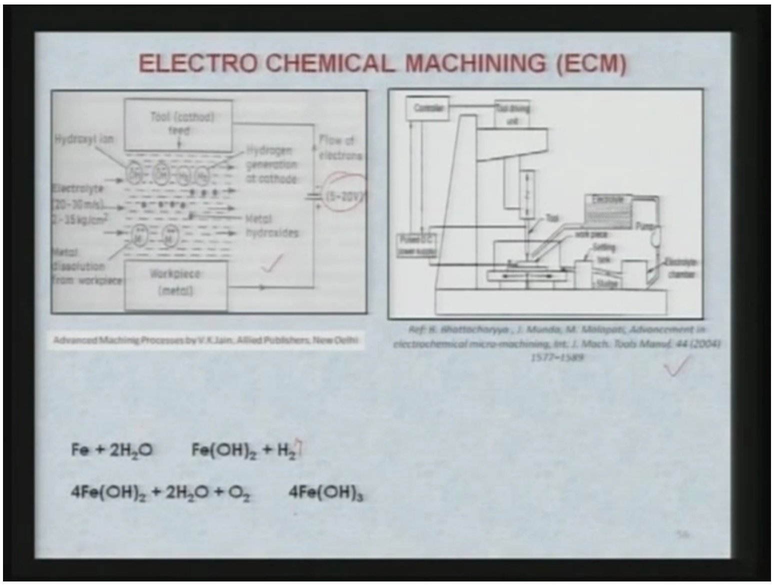

Electrochemical micro-machining, now setup we have already discussed while we were discussing electrochemical machining in our early chapter and this is quite obvious where you have the tool as the cathode and workpiece as the anode and electrolyte this flowing between the gap or in the gap between the 2 electrodes. Now there are this is for macro electrochemical machining but for micro electrochemical machining you have 2 lower down the voltage which you are using over here and this is the setup shown over here developed for electrochemical micro-machining via Bhattacharya (())(16:49) at Jadavpur university.

Now these are the basic reactions that take place when dissolution of the anode that is the workpiece takes place, you get ferrous hydroxide plus hydrogen as the gas and in some cases in place of ferrous hydroxide you also get ferric hydroxide depending upon the machining conditions and here ferrous or ferric decides is decided by the balances at which the anode material is dissolving because ion can dissolve at more than one balance either 2 or 3 that is why you are getting ferrous hydroxide or ferric hydroxide which we have already discussed in case of macro-machining. So you have to scale down the machining parameter, you have to reduces size of the tool depending upon what you want in the workpiece.

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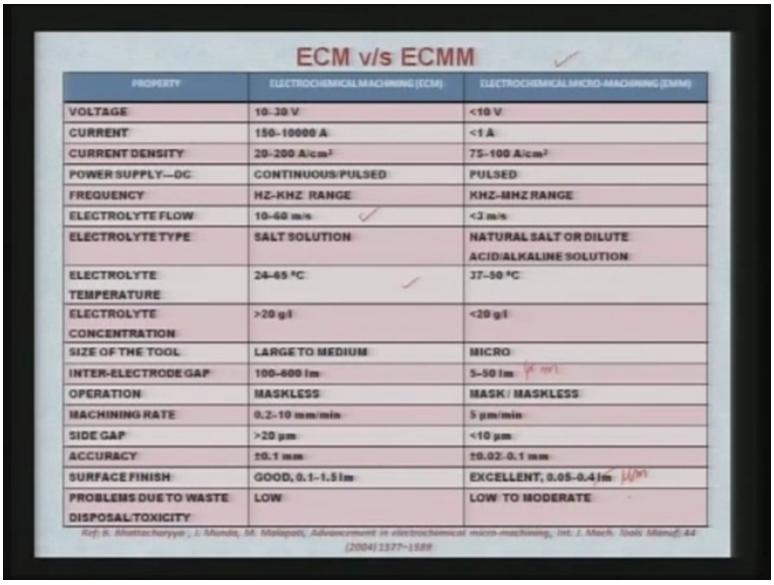

ECM v/s ECMM

PROPERTY	ELECTROCHEMICAL MACHINING (ECM)	ELECTROCHEMICAL MICRO-MACHINING (EMM)
VOLTAGE	10-30 V	<10 V
CURRENT	150-10000 A	<1 A
CURRENT DENSITY	20-200 A/cm²	75-100 A/cm²
POWER SUPPLY—DC	CONTINUOUS/PULSED	PULSED
FREQUENCY	HZ-KHZ RANGE	KHZ-MHZ RANGE
ELECTROLYTE FLOW	10-60 m/s	<3 m/s
ELECTROLYTE TYPE	SALT SOLUTION	NATURAL SALT OR DILUTE ACID/ALKALINE SOLUTION
ELECTROLYTE TEMPERATURE	24-65 °C	37-50 °C
ELECTROLYTE CONCENTRATION	>20 g/l	<20 g/l
SIZE OF THE TOOL	LARGE TO MEDIUM	MICRO
INTER-ELECTRODE GAP	100-600 lm	5-50 lm
OPERATION	MASKLESS	MASK / MASKLESS
MACHINING RATE	0.2-10 mm/min	5 µm/min
SIDE GAP	>20 µm	<10 µm
ACCURACY	±0.1 mm	±0.02-0.1 mm
SURFACE FINISH	GOOD, 0.1-1.5 lm	EXCELLENT, 0.05-0.4 lm
PROBLEMS DUE TO WASTE DISPOSAL/TOXICITY	LOW	LOW TO MODERATE

Ref: B. Bhattacharyya, J. Munda, M. Malapati, Advancement in electrochemical micro-machining, Int. J. Mach. Tools Manuf. 44 (2004) 1577–1589

Here is some comparison between the electrochemical machining and electrochemical micro-machining as long as machining parameters are concerned you voltage that is taken normally is less than 10 volt in case of electrochemical micro-machining while in case of electrochemical machining it used 10 to 30 volt. The current in case of micro-machining is less than 1 ampere while in case of macro machining you can go as high as 40,000 ampere some industry people have used 40,000 ampere as the current. Current density in case of electrochemical micro-machining is very high 75 to 100 ampere per centimetre square and in case of micro-machining it is 20 to 200 ampere per centimetres square.

Now in both the cases you can use continuous DC or pulse DC. Frequency is in terms of kilohertz in electrochemical machining that is macro machining and it may be as high as megahertz in case of micro-machining. Electrolyte flow rate is quite low in case of micro-machining it is normally less than 3 metres per second while it is quite high in case of macro machine 10 to 60 meter per second. Electrolyte you can use various kinds of electrolyte in both the cases whether macro machining or micro-machining. Electrolyte temperature does not go very high in both the cases normally it is between within 60 - 65 degrees centigrade. However, theoretically you can go as high as 90 - 95 degrees centigrade below the boiling temperature of the solvent that is the water in normal cases.

Electrolyte concentration is normally kept less than 20 gram 20 percent in case of micro-machining. Size of the tool is large to medium while in case of micro-machining definitely it is micro size tool and inter electrode gap is very small in micro machining that is 5 to 50 micro-meter and this is micro-meter and you can use the operation as a mass operation or massless operation in case of micro-machining and machining rate in case of micro-machining is 5 micro-meter per minute or so. These are certain figures but they were very depending upon what parameters your choosing. Then accuracy you can get plus minus 0.02 to 0.1 millimetre and surface finish is very good in case of micro-machining as you can see as good as 0.05 to 0.4 micro-meter and feed rate is quite is low, so one has to be very careful in selecting the machining parameter in case of electrochemical micro-machining otherwise your workpiece may get damage if you do not properly select the machining parameter.

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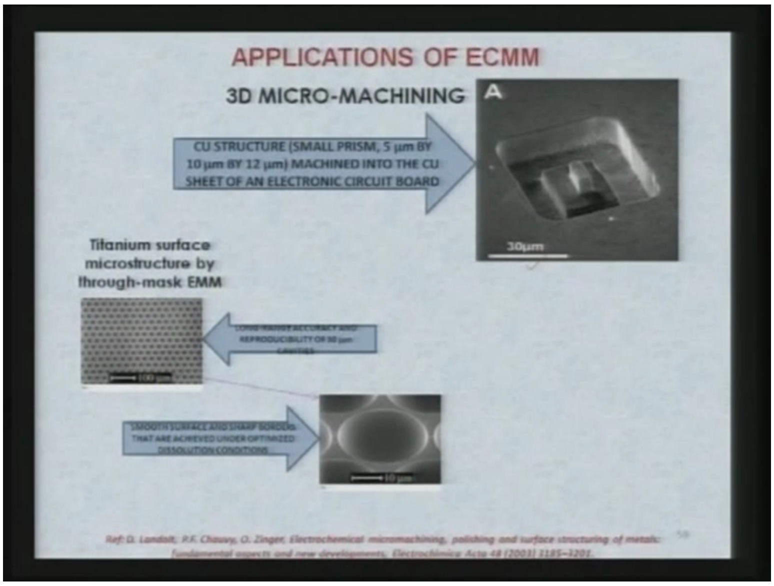

Let us see some of the applications of electrochemical micro-machining, here you can see an example of 3-D electrochemical micro-machining where you can check the portion has been melt and some projections are there, so copper structure small prism 5 micro-meter by 10 micro-meter by 12 micro-meter machined into the copper sheet of an electronic circuit board. Now you can see the scale also given over here for 30 micro-meters, so the sizes of different parts or sections of this cavity and projection can be evaluated. Now here is the titanium surface, microstructure made by through mass electro micro-machining and scale is given over there. If we see the enlarged view of another cavity you can see so nicely made cavity over there hemispherical kind of cavity there are shown here although they are not hemispherical but very smooth cavities are produced with the help of this particular process. So a smooth surface and sharp borders that are achieved under optimised dissolution condition that can be clearly seen over here.

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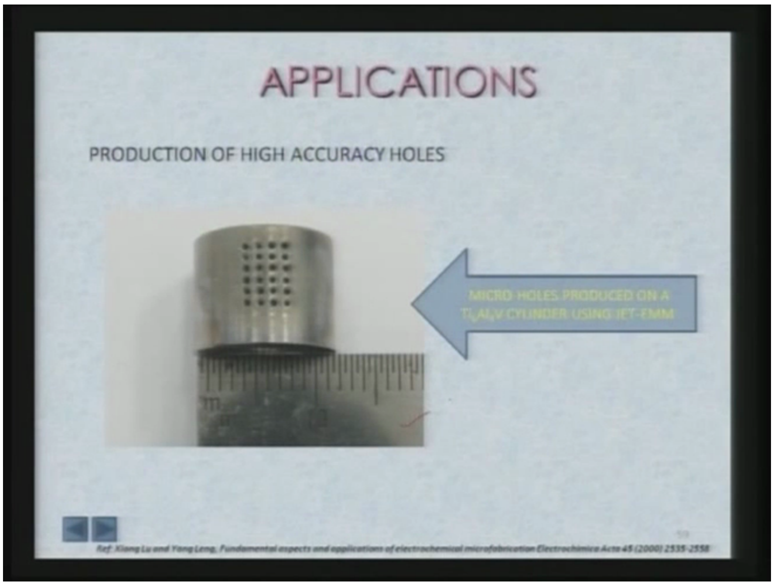

This is another application production of high accuracy holes, you can see the size of the holes scale is given at the bottom and micro-holes produced on an alloy cylinder using jet electro micro-machining.

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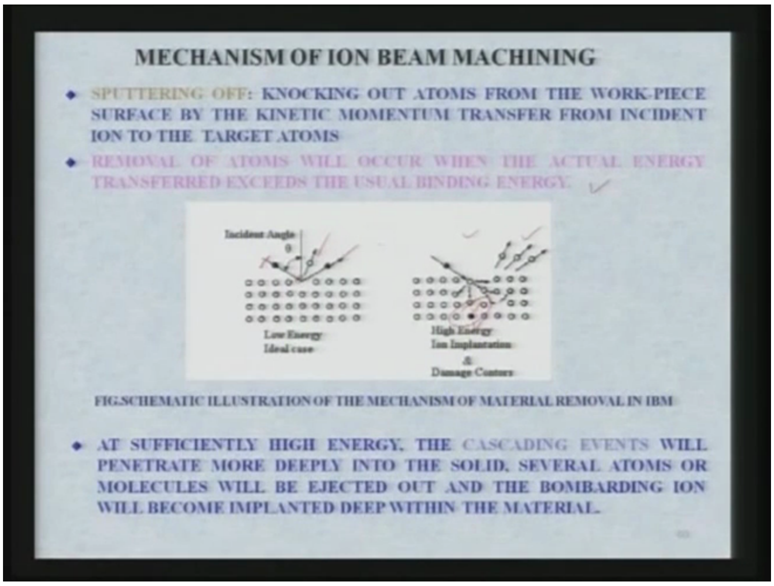

Now there is another very important process in case of micro-machining or nano machining is concerned and that process is known as ion beam machining, here actually the beauty of this processes you are removing the material atom by atom, so sputtering off or knocking out atoms from the workpiece surface by the kinetic momentum transfer from incident ion to target atoms. Now we can see here this is the incident ion which is hitting the top surface of the workpiece.

Ideally it should hit the atom over here and remove one atom as shown over there and the ion itself strikes it and goes away but normally this does not happen because this happens when low energy of the ion is there and this is an ideal case but what really happens in actual practice is like this that the ion has enough large energy and he does not remove one single atom but a cascade of atoms are removed from the top surface of the workpiece and if the energy is very large of that particular ion then it gets implanted in the subsurface of the workpiece and this is what exactly we do not want to because it damages the surface of the workpiece thing machined.

So removal of atoms occurs then the actual energy transferred exceeds the usual binding energy of the atom with reference to the surrounding atoms. At sufficiently high energy, the cascading events will penetrate more deeply into the solid. Several atoms or molecules will be ejected out and the bombarding ion will become implanted deep within the material as you can see over here. So this is not the desirable fissure.

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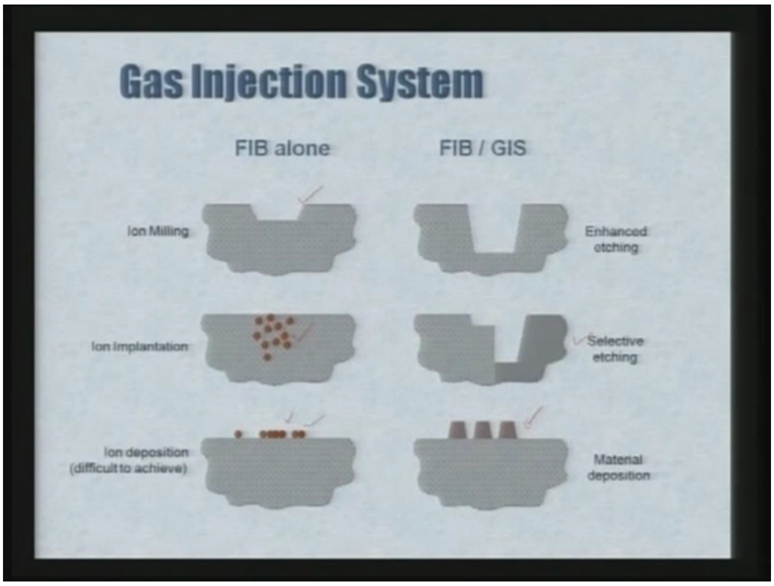

You can see over here that FIB alone ion milling you can get this kind of the surface. FIB with the gases you can get enhanced etching like this ion implantation may take place like this, selective etching can be done like this and ion deposition, now another beauty of this particular process is that it is not only for removal of the material, this particular process can also be used for deposition of the material, so ions of different materials although selected very limited one, they can be deposited on the top surface and you can use it for generation of the micro or nano fissure as you can see here these are the nano fissure which have been developed or produced by deposition of the material, so this is the beauty of this particular process that you can use it for both purposes additive process or attrition process where material is being removed or material is being deposited.

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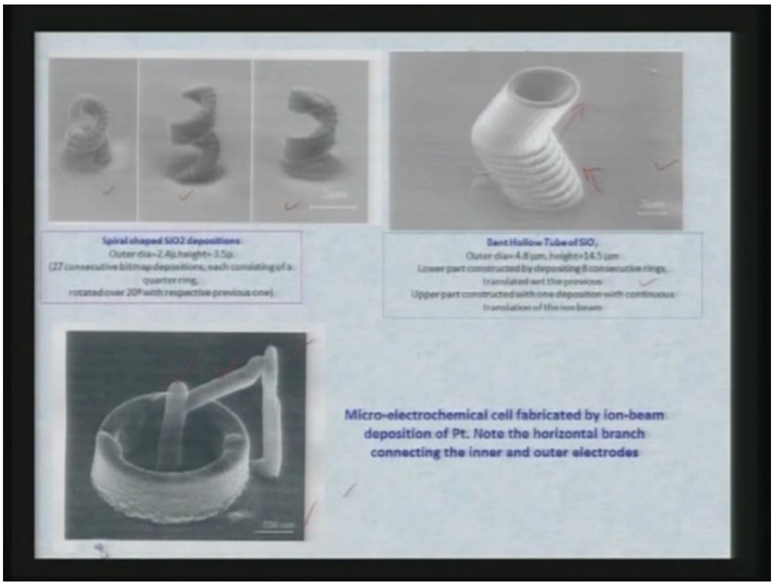

Now these are some of the examples of the products that have been produced at IIT Kanpur, now you can see here some of them have been produced at IIT Kanpur these are the different fissure of the spring that have been built using focused ion beam setup and this is another one bent hollow tube of silicon oxide whose outer diameter is 4.8 micron, height is 14.5 micron and lower part constructed by depositing and consecutive rings translated with respect to the previous one, so you are depositing it and moving upward and you are able to create it.

Upper part constructed with one deposition with continuous translation of the ion beam, this is the upper part and this is very interesting such a micro-product have been developed. Now this is the another example not done at IIT Kanpur, it is elsewhere micro-electrochemical cell fabricated by ion beam deposited deposition of titanium. Note the horizontal branch connecting the inner and outer electrodes you can see this is the inter electrode, this is the outer electrode and this is the horizontal branch which connecting the 2 and this gives you the (())(27:27). So these are some of the very interesting peculiar real microproducts which have been produced using the focused ion beam process.

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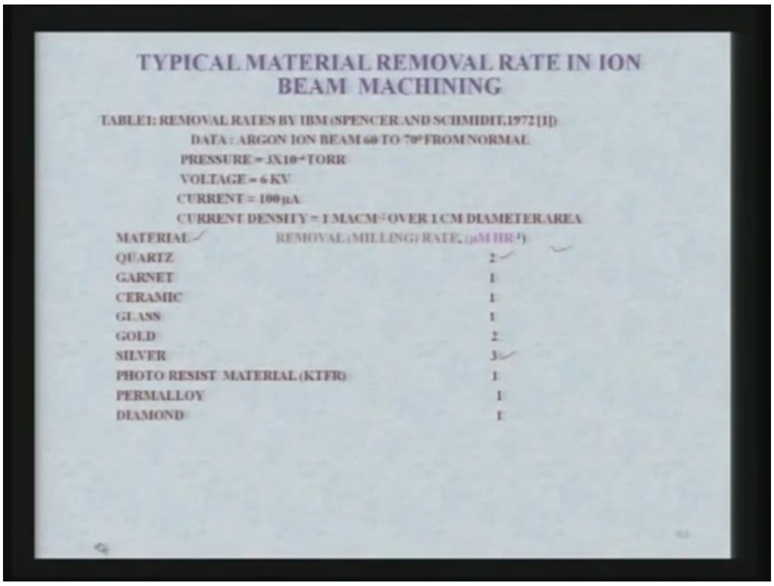

Now this is, this table is very interesting to understand the limitation of focused ion beam machining because this cannot be used, this process cannot be used for mass amount of large amount of material removal as you can see here that are material, various materials are given here and remove rate are given here in terms of micro-meter per hour that means you can remove layer of 2 micron in 1 over from the quartz the large maximum amount of material can be removed from the silver that is the 3 micron per hour and in other case it is just one micron per hour, so this the kind of material you can remove is very small, so you have to be very careful that you do not intend to remove comparatively larger amount of material, the material being removed should be somewhere in nanometre range rather than even many micro-meter range otherwise it is going to a very long time. So thank you very much, Thank you.