Advanced Machining Processes
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A very good afternoon to all of you. I am Shantanu Bhattacharya, and today I am actually going to demonstrate physically how you are able to generate microchannels within PMMA material using the laser engraving process. In our lectures earlier we have made a detailed study of how laser machining works. It is basically based on beam-matter interaction. There is a surface which if interacting with the laser beam would absorb the beam, and because of the absorption coefficient, there would be a local heating. So, there is a photon to phonon or a vibration, bond vibration conversion because of which there is a local increase in the heat, and the heating goes up to an extent that it starts to locally vaporize and melt the material, and there is a change in the solid density in that particular zone of interaction which goes into the particular material, and this is really the process of engraving.

Today we have with us this small laser engraving and cutting system which is from a company called Epilog. This tool is working on the principle of a small 10-micron spot of laser which scans and rasters the surface, thus creating the engravement or the formulation of the microchannel within soft and hard polymeric materials. This is the machine cover, and you can see on the left corner, left upper corner here of the system there is a small lasing head which actually is a CO_2 laser, and the head is assisted mechanically or rather electromechanically to move in a manner so that it moves like an inkjet printer head on the top surface of this machine, and rasters the machine in a line-by-line manner. So, the red actually, the red laser spot, the CO_2 laser spot moves around in a linear manner, line by line manner, and scans the whole surface at a resolution of about 50 microns between the two lines.

So, if I were to divide this surface by scanning it into lines of different types and natures, the minimum spacing between two such lines is about 50 microns, and this really defines the way that the laser is used for cutting on soft and hard polymeric materials. So, therefore, we are really limited on to the process of getting resolution up to the extent of 50 microns, and therefore, anything above 50 microns can really be etched and formulated using this particular machine. There are other systems of laser, and in fact, I am going to talk about that subsequently in one of the presentations, where you can see even higher accuracy lasers which can go up to a spot size of probably a micron, and a super fine resolution achieved by series of demagnification techniques which would eventually be able to write at a 10 micron by 10 micron feature array on to metallic surfaces as well as polymeric surfaces. But in this particular application, as we are intending to show you a way to fabricate a microfluidic channel or a microfluidic device, we really can limit ourselves to this resolution of about 50 microns. Our channel sizes in the current application that we are envisioning are not less than 100 microns.

So, we can easily use this lasing machine for such an application. So, the substrate that I am going to use for doing the whole process of laser machining is a polymethyl methacrylate substrate. You can see it is a clear plexiglass substrate of thickness about 2 millimeters from the edges you can make that, and this is a pretty good material for actually doing replication and molding of soft polymers like PDMS etcetera. If we can change the surface composition a little bit after the etching process is over. So, today throughout this experiment I am going to take you through a series of steps where we are going to first etch the microchannel onto the system, and then with this etched micro channel, I am going to modify the surfaces in a manner so that it can act as a mold, micro mold.

And then in another part of the experiment, we are going to use a polymeric soft polymeric material called polydimethylsiloxane which can be, it is like an epoxy rubber which can be poured on to the top of a micro mold with some suitable release agent which you apply to the surface, and you are able to separate that later, so that whatever channel like features or other structures you have embedded on to this system is replicated. The negative of that is replicated or casted onto that liquid material. This process incidentally is also coined with the terminology micro replication by double inversion or MRDI process. So, coming back to the lasing business, as you know here as I already defined this laser spot needs to be calibrated properly as to the extent of focus that it would have on this sheet. And the step-by-step approach is that you have first of all put this substrate on the lasing, below the lasing head on the laser on the cutting bed of the machine, and you have to first switch on the machine and try to be able to calibrate whether the focus of this laser is matching.

And for that you are using a sort of jig which has been provided by the system manufacturer, which talks about the exact depth from the lasing torch to the surface where it is etching, where the focus would be right about enough for the lasing action to happen. One thing you have to remember is that this PMMA surface is highly shiny in nature, which would create a lot of power loss because of reflection. And our group here has formulated diverse amount of strategies where such optimizations can be performed corresponding to the different cutting parameters so that by minimum usage of power you would be able to generate a very fine finish or fine surface. And I am going to detail those optimization experiments in a later presentation module which eventually would come after this experiment. So, I am going to now put this jig onto the system.

Here you can see it is magnetically assisted. So, it basically goes and clubs onto the laser mount, and this kind of gives you a feeling of how much depth of focus it really needs to achieve for the laser to have a good focal spot. And what we are going to do is to calibrate our system by taking up this bed by suitable distance, so that it starts just about touching this point here by leaving not very high pressure on this particular jig, so that you can actually put it on the focal spot of the lasing surface. So, I would switch on the machine, and it will take some time to initialize. You can see there is a controller here of this machine which has been built in by the manufacturer, and there are several options on this controller which says different or which says about different aspects like go, stop, reset, speed, power, set home, x, y off, job, focus down, up, pointer, so on so forth.

So, what I am going to do is to first calibrate the system by turning on the focus spot here, and the moment I say that you can see that the lasing head has now come on to a certain point which is probably the x, y, 0 of the system, and it is going to now be able to set up the focal spot of the laser. So, I can move the lasing bed up by the z motion control. There is a motor and a slide in this direction, and you can see this bed coming up clearly till the surface of the workpiece touches just about touches the lower portion of the jig. So, this is actually still not touching. So, we can actually go a little further ahead, and this is right about the focal spot of the laser that it has achieved.

You may just try to recall that if the surfaces have various thicknesses, you may use a thicker substrate or a thinner substrate. Accordingly, the z motion would be different, and therefore, this motion and this calibration needs to be somehow incorporated on the system itself. So, what I am going to now do is to sort of take-off this jig, because the purpose of its focusing is over, and there is again if you look at the control panel here on the controller there is an indicator called pointer. So, if I press this pointer system, it is going to generate the spot which is actually now very much visible if you look from the top here, and the lasing is like this. So, it is at a certain angle, and I can actually see that there is a very well-focused spot that is formulating on the top of this acrylic slide.

And one more aspect is that the pointer is used not only for checking the focus but also to see how the rastering action of the laser head happens over the surface of this acrylic sheet. So, supposing if the pattern that we are eventually going to generate through a software is not read at properly by the machine, there has to be a way to find out what is the track or modality that this lasing head is following, or whether it is different than whatever pattern was intended to be engraved on to the surface of the PMMA sheet. So, that is why this pointer. So, I will just now as of now close this pointer and will turn it on later you can see there is a red dot off command which comes on the top of this controller. Let me make it very clear that this controller here is mostly for manual applications.

The machine has an interface with a software and typically is driven by the software. So, whatever drawing formats are generated which actually are drawn in a package, a computer-aided designing package, in this case it is coral draw, that basically converts into numerical data, and there is a format like data exchange format or PDS product data exchange specification format which is followed. So, the data is translated on to the controller here, and beyond that the controller executes a set of commands to the various motors and the various slides which are present within the system. So, electronic data or numerical data comes on to the system, and makes the controller to execute different motions along the different stepper, and analog motors which are available, and the drives there in. So, that all this mechanical action of scanning, rastering etcetera can occur of this head on the top of this whole workpiece surface.

So, I am going to now close off this slide, because we are kind of done with the formality which is here. The only other command that we need to use, because it is an automatic control that I am teaching today is the go command, which will be used once our software is processed, and we are able to draw a feature which we want to engrave on to top of this plexiglass slide. And so, we just need to forget about everything else regarding this controller which is used in case there is a manual job which you are processing. We are now going to illustrate the way that we use a computer-aided design package for printing material, or different shapes and features which are useful for our microfluidic devices using this lasing system or a laser engraving system. So, here we are using this package coral draw x 5, we go into the package and open a new blank document.

And the document shows a reference size which automatically gets, it is a default size which has been sent into the system, which is not same as the size of the acrylic sheet that we have put in the lasing and engraving system. So, I am going to actually change the template to the size of the acrylic block by going up here and making it 609 mm which is what the length of that block that we just put in the engraving bed is. And the width of that particular block is about 300 mm, and we get new set of template size which is similar to the block. The advantage of this ab initio process that we are initializing process that we are doing is that we are trying to make a high throughput production, and the idea is to be able to judiciously utilize the whole acrylic sheet that we are going to get engraved using lasing. And so just as in silicon-based lithography we have a concept of die size, here also each device would be contained in a certain size or certain domain of this wafer which is not the totality, and it is called one die.

So, we are having multiple options of printing these dies onto this whole template so that in one engravement we can have various shapes, features, sizes etc. engraved onto the system. And then we can actually use either CNC milling or some other process even band saw-based cutting to cut these die sizes out of course, it will not have that fine resolution as a silicon processing would have. But in our applications here I think considering the faster speed of the process, and also you know the need of going beyond 100 microns, we can easily manage with such a system to be able to produce accurate enough for our applications. So, here I am going to now first introduce the die size by selecting this tool on the left corner in this particular zone here, it is called the rectangular rectangle tool. And I am going to actually lay out this rectangle in one corner of this template, where I would like to position this not at really the edge of the acrylic block, but at some distance away in order to ensure a proper template size being machine with flat edges.

And what I am also going to do is to sort of change the units here little bit, if you focus here on the right on the center spot of the screen, you find out set of commands called units, where different units which are used, we are using the inches scale here, particularly for the die sizing and the referencing. So, therefore, we will just change this to inches. And then the idea is I can do this selection tool on the left side again, and try to select this block, and this window on the right called the transformation window, it pops up and what you can do is you can change the size into conventionally used die size of 2 point or 2 inches horizontal by 1-inch vertical template size. And once the side has been set, you can apply so that the feature has now been converted into the template size indicated. You can once again do the selection of this particular feature and try to take it to the same spot as before leaving some allowance between the vertical edge and the horizontal edge of the template.

Now, this die size is very small for application of trying to lay out some features here, which would eventually get engraved. So, what I am going to do is to use the center cursor of the mouse here to zoom up, and again go or align myself to the center of the template or center of the die that has been created. And we can draw the features that we want in this particular zone here, which would get engraved onto this die. So, the idea is that there are 2 approaches that the lasing head follows, one is called a vector scanning, where only through cutting action is initiated, and then there is a raster scanning, where whatever features, you are trying to engrave on the inside of this block gets initiated. So, with these 2 features, you can actually cut completely a die size, and engrave in the die size very easily.

And let us make a microfluidic small channel assembly that we were talking about. So, what I am going to do is to print circular reservoirs, go to the left corner here, select an ellipse tool, and bring it back to the die. And I can actually after laying it here, try to change the scale again into millimeters. Through this tab, center tab here, and there again try to do the selection of this particular ellipse, and make this 2 mm by 2 mm. So, because it is an ellipse you have a question of a major and minor axis.

So, here the major and minor axis, because it is we are talking about a circular reservoir are same to each other, we make it 2 mm diameter, apply this. So, it actually gets formulated somewhere in this block. So, we can actually pick this ellipse, move it around through the block wherever necessary. I would like to place it somewhere close to the center of this block, in the interest of the final replication and molding process that we would be doing. And we can create a copy of this file again in the same system and move this copy all the way to the other end of the die.

And would generate an interconnect between the 2 reservoirs, circular reservoirs by using again a rectangle tool. Now, here this channel, rectangular channel is intended to have a size of about let us say close to 1.5 inches. So, I am going to change back the units again back to inches. And so, I am going to convert this rectangle which we had here into a 1.5 inches length, converting the units into inches again, making the selection of this rectangle go back here and make 1.5 inches, apply it so that it goes to that particular length. And then I can actually change back the units once more back to mm and go further selection here and do millimeter size. So, the vertical there can be 0.1 mm or 100 microns. So, this is how the channel really looks like I mean I can now try to again select back these 2 features so that they can be moved to both ends or both edges of this channel. And then we will see how it looks like in a magnified view of the assembly. So, we just go to this finer level and look into how the circle is going to make an interaction with the channel. And you can see here clearly that there is some kind of an edge of the channel sticking out of the circle. So, I am going to now sort of move and align it by making a selection of this circle and moving it back to about this point.

And similarly, trying to match to an accurate extent all these different features and do a similar job towards the other end where the other second reservoir is being placed here. So, here I can again make a selection and try to align it more or less with the centre of this channel. And so, we have now a feature which is like a input-output microfluidic channel of about 1.5 inches length and 100 microns diameter. So, once we are set on all this, we can actually use control and cut control the.

So, what we are now going to do is to make a selection. So, that we can combine both the reservoirs and the channel. So, once this whole feature is selected, I can go to the, I can make a right click here, cut, combine, make a right click here and combine all these images together as a single entity. So, now, these all three different geometric features have been combined together as a single entity. And what we are going to also do is to place or grab this and place it somewhere along the centre of this particular die and again combine the die along with the whole structure by selecting on it and combining the whole thing together.

So, now, if I am able to move this whole combined imagery it, you know, it works as one group and it can move as one group to wherever you place it. So, once we are done with this basic processing, we are kind of left with a lot of other space on this particular template as can be seen from the size of the block that we had actually initially estimated. And you can actually copy one of these blocks and repeat it multiple times. However, while doing that you do not really have a control on the positioning of these different dies across the whole screen. And so, there is a very convenient option which is available here in the edit mode which talks about step and repeat.

So, what can be done here is that you basically take the selection of this whole feature here and go to this step and repeat option which creates a window on the right here, it pops up a window which says horizontal setting and vertical setting. And so, as the step and repeat option means that either the copying would happen in the horizontal manner, or the copying would happen in the vertical manner and both of them cannot be together. So, in one of them you have to program no offset, in other you can actually have spacing defined between the objects, and it will simply copy. In this particular case, let us say we want to copy this one die size vertically to all the way to from one edge here right here to the other edge somewhere here and that way we want to flood the vertical spacing of this one column which has been generated in a row-wise manner. So, what I am going to do is to provide no offset to the horizontal setting tab and then provide spacing between objects to the vertical setting tab.

Let us say the distance between two such blocks is about 1 mm. So, I just formulate this and select this to set it to about 1 mm and the direction of selection can be either upwards or downwards in this case. There is space left in the downward direction and I can apply so many number of copies in this particular case because this is about an inch. So, there can be about this size is about an inch which is about 25 mm and there about 300 mm vertical spacing of the initial die size or the initial PMMA block size the acrylic block size which has been used. So, I can go with about 9 or 10 such features placed one below another.

So, I just do 9 features here and I can actually apply this selecting the group and it will actually copy all these 9 in a vertical manner. Let us just look at the spacing and this seems to be a 1 mm spacing between them. I can actually go to a further higher size to just see you know whether this can be spaced at a little more distance between each other. Let us make it about 4 mm and that way we just limit ourselves to about close to 7 such features let us say and we apply. So, here you can see that this are copied in a very nice manner across this in a columnar manner here.

You can probably flood many features into this whole template and then go for the machining operation. So, now, you have multiple features here on this acrylic surface as you can see and we will all together print this on the acrylic surface using the engraving system. So, for doing this what we have to initially do is to save this file in a certain format in a certain name let us call it advanced manufacturing process for microsystems fabrication. This is name of the file save it in the desktop and I can go and do control P to get into the print menu where you can see different options here. So, we select the printer as the epilog engraver win 32 based and we can also go into the preferences option here to set up the parameters that would be needed for the printing.

So, basically you know you can print at about 1200 dpi and these are some things which have been already optimized by our research team through various design of experiments protocols and one such optimization will be shown subsequently in a presentation, power point presentation later after this whole process is executed. We set up the operating speed to be 60 percent of the maximum speed and the optimum power to be about 40 percent of the maximum power which is available for the system and the power and speed maxima are mentioned in the manual, the service manual related to this or any other system. You have to just see how much percentage of the maximum values you are using for your particular operation. You have to also set the total template size which in our case is about close to 609 millimetres by 300 millimetres which amounts to about 24 inches horizontal by 12 inches vertical. So, it is all preset here and then of course, you can after setting all this you are doing this engraving direction top down.

So, therefore, you know this option has to be selected. There is also a bottom-up approach which can be done in some other laser configurations and this particular machine operates mostly on the top-down approach and we make it ok. So, then we are now ready to set the system. So, what I am going to do is to apply these settings to the controller of the system and use the print option. The moment I do the print command here the particular file name advanced manufacturing processes would be displayed on to the LCD monitor of the controller.

So, I am going to now do the print option here and go over to the machine. So, as you can see here the job one reads advanced manufacturing processes which means the corresponding file which was transported from the CorelDRAW software has now been received by the controller of the laser engraving system. So, probably the DXF or the PDS whatever specification format comes in the numerical data is transported in the same format. So, now, the machine has read the drawing, and it should be able to print just as an inkjet printer. So, all what we need to do now is to switch on the pointer to see how the laser spot rasters over the surface and whether it is doing the job properly and then do the go command.

The moment there is the go command is executed the laser head would start rastering and scanning on the surface. So, it is a pretty fast process you can see features being formulated. One channel has already been made in this particular area in this particular zone as you can see and there are many multiple channels which are being imprinted at a very high rate of machining and this itself shows that how high throughput or how high yield this lasing process is, and it is similar to the yield that conventional lithography process would produce. Because you have to remember that in the lithography there is also time associated with making of the mask in the chromium-coated glass plate where there is substantial amount of this laser etching time which is there for the mask to be made. Although lithography is a one-shot go the light falls onto the resist through the mask, but mask-making is an identical process here.

Here only one shot the whole engravement happens on to the surface and once it happens, we are done with all other steps we do not need any other chemical steps following that. You can now see also you can actually hear the sound of the system. So, you have now seen that the rastering action has happened and all these different features have been imprinted onto the PMMA surface. Now we have to actually do the vector action meaning thereby that these individual templates need to be removed from the acrylic piece by piece and for that the command or the way that we proceed is more or less same we do control P and go to this epilogue engraver option here do preferences and then the only other option that we have to set in is the different cutting parameters. As you know in this particular case it is going to be a more amount of dwell time and higher amount of power.

So, therefore, we have to reduce the speed and also increase the power. So here what we are going to do is to basically go to the vector mode and now do the power and speed settings here take the speed to about close to 8 percent of the actual maximum speed and let the power go all the way to about 100 percent of maximum power. So, you have more dwell time more power. So, that you can actually penetrate through the 2 mm sheet and be able to cut it vectorially and you can increase the frequency of the laser all the way to about 500 hertz 5000 hertz. So, once so these parameters again have been preset based on lot of design of experiment studies done by the research group and we are going to represent all this how these optimization has been done later on eventually.

Right now I am just going to show you the machining process. So, we make this and then apply the settings to it and then do in a similar manner we do the print command and so automatically the file will now be able to go back into the controller and start cutting vectorially. So, you can actually see now job number 2 here which is the same file essentially, but here we are changing from the raster mode into the vector mode. So, that the each individual die can be separated. So, it is actually a die separation step and what we are going to do here is to just press this go button. So, that now you can see that how the lasing spot is able to etch off vectorially the die template of each feature and structure.

And so therefore, you will have a series of these dies coming out at the end of the day which would formulate the basis for all our replication and molding process in the next step of this experiment.

So, we are now going to unload the machine of the work surface, our piece. As you can see here the individual pieces which are formulated as engraving on the centre by the rastering action and a full scale cutting on the sides which makes it of die size 2 inches by 1 inch.

And I am going to now pick off this acrylic sheet and leave back the material which is actually cut and which can be used as a template. So, this for example, is one such template that you can see where the edges here are vectorially cut and the centre member here is raster you know raster or raster cut. I am going to use this further for replication process where there is going to be liquid polymer which will create negative of this. And we will take another step where we will create a negative of that negative which will build the exact same engraved channel on the top of that polymer which we will be using for our further microfluidic applications.