Microrobotics

Prof. Palani Iyamperumal Anand

Department of Mechanical Engineering

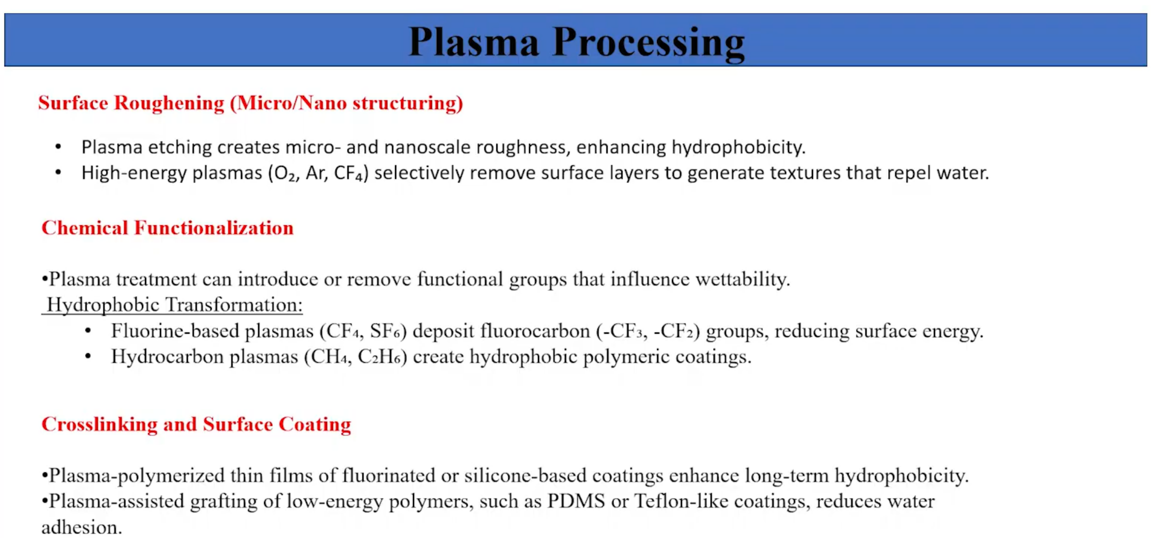
Indian Institute of Technology, Indore

Week- 03

Lecture No- 14

MicroMechanics System Design (Micro-Fabrication of Micro Robots) - Module 04

Earlier, we discussed the different types of microfabrication techniques that are available, such as the bottom-up approach and the top-down approach. Then, we covered the different kinds of microfabrication techniques involved in the bottom-up and top-down approaches. In the last class, we discussed this plasma processing and the different types of plasma processing. As far as plasma processing is concerned, it is mainly meant for realizing the surface with reference to functionality. Plasma treatment is a powerful surface modification technique that is used to tailor the wettability of polymers, enabling the transformation from a hydrophilic to a hydrophobic state. This process is particularly beneficial in applications such as biomedical devices, coatings for microrobotics, and microfluidic systems.

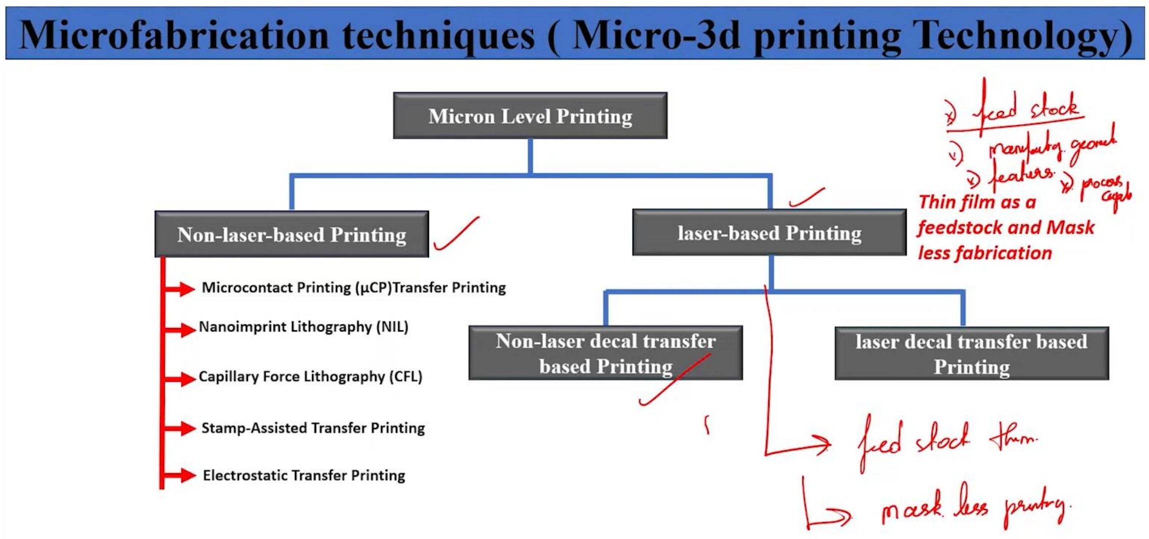


Based on the mechanism of surface modification using plasma processing, which is classified into the surface roughening process, chemical functionalization, cross-linking, and surface coating. Surface roughening is nothing but creating a roughened pattern or a nanostructured structure, so that the plasma etching creates micro and nanoscale roughness, enhancing hydrophobicity. In order to generate such roughness, a high-energy plasma generated by oxygen, argon, or CF4 selectively removes the surface layers to create such textures; it might be a microstructure or it might be a nanostructure. When such kinds of textures are generated, they will be helpful for us to repel water, so they have potential applications in underwater-related micro robotic systems or can even be used for biomedical-related micro robotic systems.

Another technique that is involved is called chemical functionalization, in which the plasma treatment can introduce or remove the functional groups that influence wettability. The hydrophobic transformation occurs when a fluorine-based plasma deposits a fluorocarbon group, reducing the surface energy. The hydrocarbon plasma creates a hydrophobic polymeric coating on it. Therefore, through this particular process, there is a kind of hydrophobic transformation in this system. In cross-linking and surface coating, plasma polymerized thin films of fluorinated or silicon-based coatings enhance the long-term hydrophobicity.

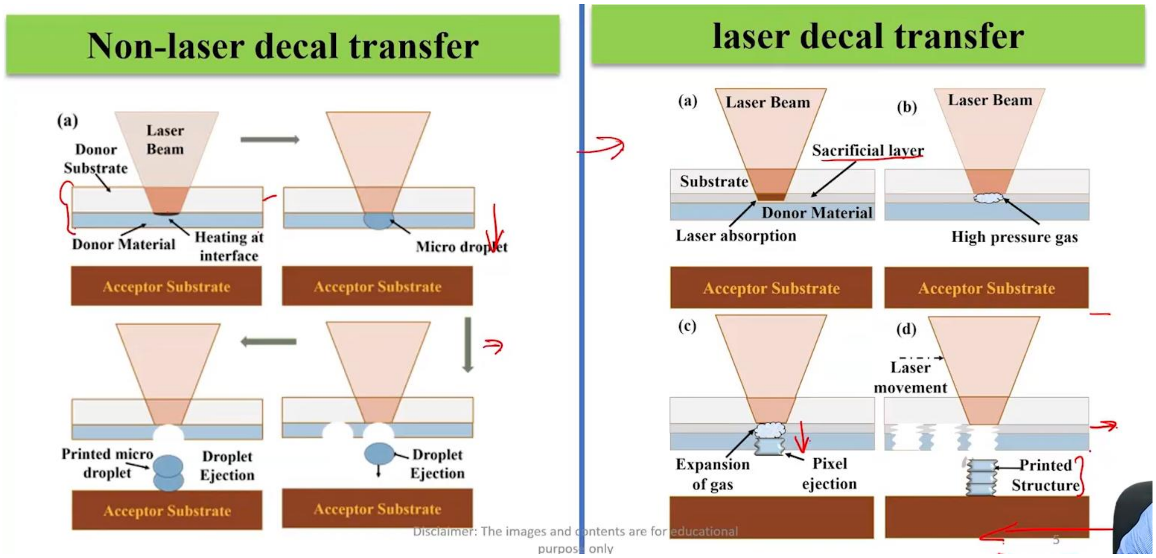
Plasma-assisted grafting of low energy polymers, such as PDMS or Teflon-like coatings, basically reduces water adhesion on the surface. So these are some of the different plasma processes that are being effectively used to protect the device or to improve the functionality of their devices based on the requirements or based on the different functional applications. Let me introduce you to a new technique where 3D printing is used for fabricating micro features or micro devices based on the requirements. For almost the last three to four decades, there has been a huge evolution in the field of additive manufacturing and 3D printing. Whenever discussing 3D printing, feedstock plays a vital role, and it is nothing but the raw material.

Based on the raw material, we normally select the type of 3D printing or additive manufacturing process for different applications. So one is through the feedstock, another is through the manufacturing geometry features and overall process capability. Now, these kinds of parameters are well established with reference to a macro-level perspective. However, there is a need to establish a micro-level-based 3D printing technology so that it has potential applications in printing micro sensors, micro actuators, and micro features, etc. for different applications.



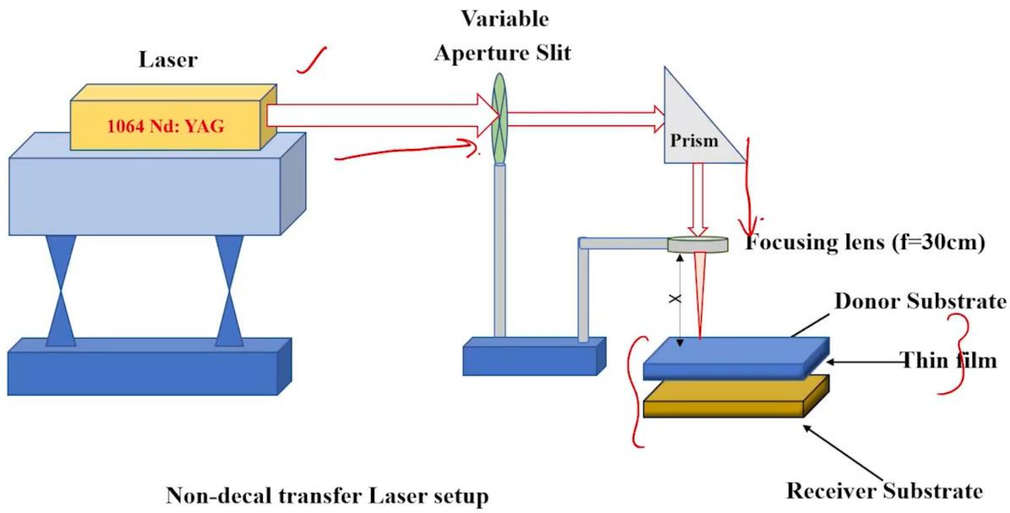
Now the main focus of this particular topic is to discuss the different technologies that are evolving with reference to this micro 3D printing so that it creates small scaled features based on the requirements and practical applications. These micro-level printing methods are classified into two: one is called non-laser-based printing, and the other is called laser-based printing. In non-laser-based printing, it is classified into different categories; one is micro contact transfer printing, which uses two layers. In one layer, there is a kind of printed structure, and through a process of compression, one set of features is transferred to the next layer. Next is nano imprint lithography.

In this particular process, structures are printed on a pixel-by-pixel basis, as discussed in detail in earlier lithography. Next is capillary force lithography. It is mainly meant for transferring liquid or gel-based structures to print different features. Stamp-assisted transfer printing is almost similar to micro-contact printing, where two mask-based structures are brought together, and through a compression, the features are transferred from one substrate to the other substrate. In electrostatic transfer printing, the process functions similarly to that of a photocopying machine.



The same technique has evolved to print on flexible substrates, including flexible PET sheets, or to print micron-level layers on any kind of structure, etc. Laser-based printing is classified into two categories: one is called non-laser decal transfer-based printing and the other is called laser decal transfer-based printing. Both these printing processes have an advantage where both use feedstock in the form of thin film, and one of the key mottos of this particular technology is to avoid mask fabrication and directly print the features based on the requirement. It's a kind of maskless printing that is promoted here. The main motto of this maskless printing is to align the mask.

Normally, in most cases, manufacturing the mask itself costs a lot, and in certain cases, such as when even for 8 to 10 micrometers, it may be necessary to manufacture a mask. So, these can be completely eradicated. This process has a capability that up to 1 to 2 microns doesn't require a mask. So, anything below 1 to 2 microns can go for a lithography process. However, between 1 to 2 microns, this has the capability to directly print the structures.

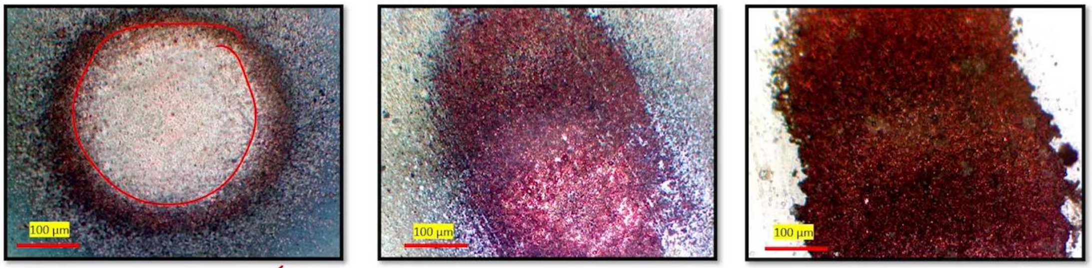


"Figure: Schematic showing Experimental setup of Nanosecond pulsed laser for material ejection"

The overall principle of non-laser decal transfer and laser decal transfer is understood one by one. In non-laser decal transfer, first understand the components used in the process. First is the donor substrate and the donor material. The donor material is nothing but the material that we are planning to print, and the acceptor substrate is the substrate on which we are planning to print the structures. This is a kind of thin film that is going to act as a feedstock.

The laser beam is made to pass through this donor substrate, which is transparent to the laser beam. However, when it interacts with the donor material, this donor material gets transformed into a micro droplet. This micro droplet will be ejected from the substrate as shown here, and it sticks to the acceptor substrate. Continuous transfer or continuous interaction of the laser with such kinds of micro droplets will result in droplet ejection, leading to a kind of pattern. One of the key points that may need to be noted down is droplet ejection, in that there is a transformation of the material from one form to another form and the material will undergo a phase change.

When the material undergoes a phase change, there is a chance that it may lose its properties or may change from the thin film we created. In order to avoid that, there is a second technique available, called laser decal transfer. In this laser decal transfer, we try to introduce a sacrificial layer between the donor substrate and the donor material. In this sacrificial layer, the laser beam is made to interact with the substrate and the sacrificial layer. The sacrificial layer will absorb the laser beam.



SINGLE SPOT — Spot with overlap — Line Pattern using Cylindrical Rod

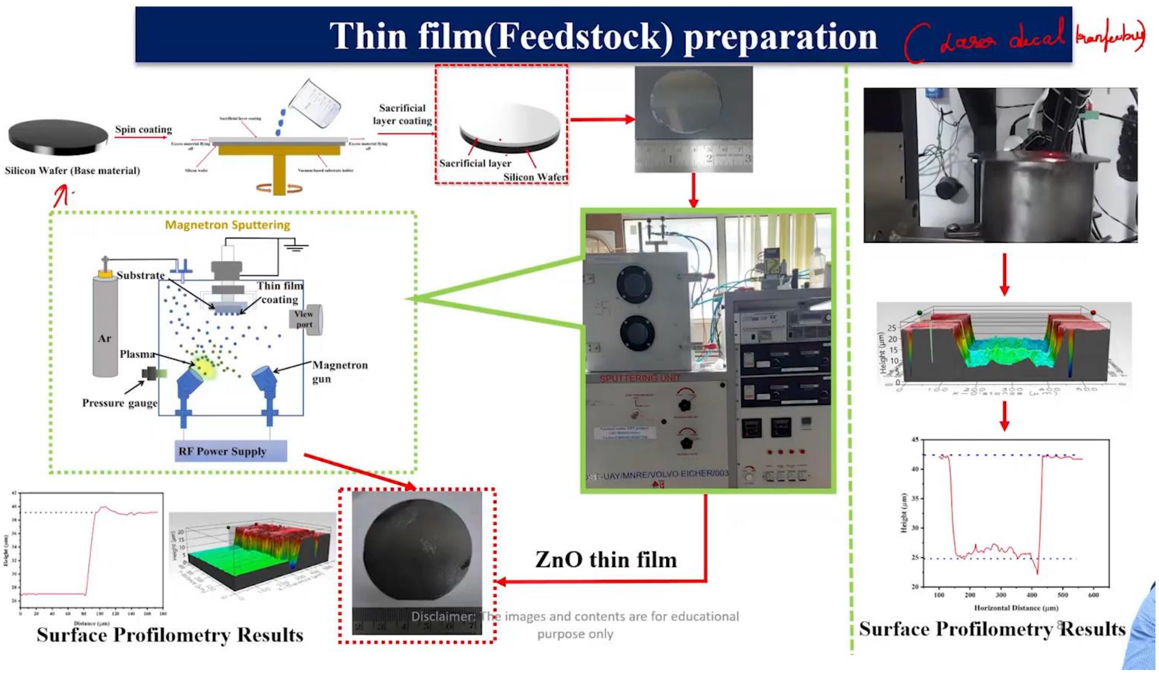
Figure: optimum Material ejection for uniform printing of shapes using various processing techniques

A high-pressure gas is created, resulting in the expansion of the gas, which will eject the pixel. As the pixel ejection moves, the layer will try to get transferred over the printed structures. When we try to manipulate this acceptor substrate and the donor substrate based on that, we generate different features. For example, if I want to create a line feature, I need to move this laser in this particular direction and similarly move the acceptor substrate in the opposite direction. So what happens is there is a kind of pixel-by-pixel transfer that occurs, which will result in the printing of the structure in this particular domain.

By manipulating the donor region and an acceptor region along the three degrees of freedom, we can appropriately print any kind of feature size that we require. Now the size of the feature plays a vital role. How is the size of the features controlled? In order to make a comparison with reference to non-laser decal transfer and laser decal transfer. This is a kind of setup that is used for a non-decal transfer. In this non-decal transfer, there is an Nd: YAG laser, a variable aperture slit, a prism arrangement, and a focusing lens.

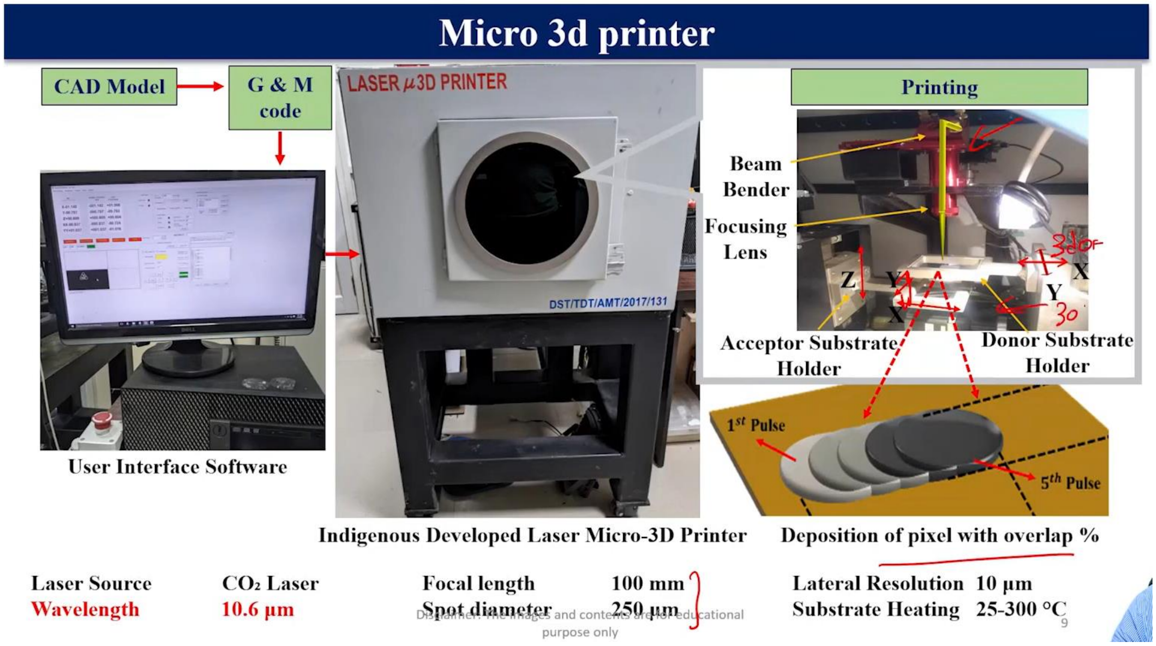
So, what we are trying to do is have the Nd: YAG glazer pass through the aperture slit and the prism through focusing optics. This is the donor region and a receiver substrate. So here, this is a kind of non-DKL transfer. In this non-DKL transfer, there is no sacrificial layer present; thus, it leads to the transfer of the material to the receiver substrate. Now these are some kinds of features that are being generated in the non-transfer region.

This is a kind of single spot, and this is a kind of spot with spot overlap, and a line pattern using a cylindrical rod. In the case of a single spot, this transfer is happening in such a way that material is ejected from the donor region to the acceptor region and a proper spot is generated from it. When these spots overlap, they appropriately create a line pattern. When trying to use a cylindrical rod, appropriately convert the spot into a line to achieve a uniform pattern. Now, the major limitations of this particular process are the phase change of the material, control of feature size, and appropriate adhesion capability.



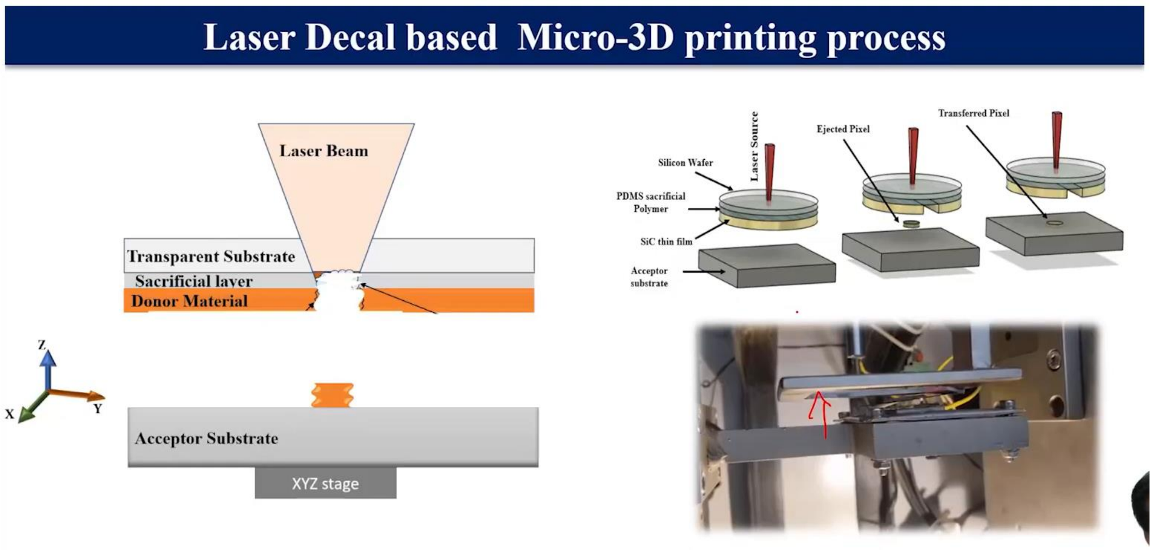
There is a chance that it may lead to a certain amount of defect in the ejected region if a kind of air entrapment occurs within the system. Now, in the laser decal transfer-based process, let's understand from the preparation of the donor material to the printing of the functional material. The donor material is prepared. In this particular case, we have considered a silicon wafer as a base material, and using a spin coating process, the sacrificial layer is coated. In this particular part, we may need to consider one important point: the donor material should be transparent to the laser.

However, the sacrificial material should absorb the laser completely, and it would be helpful for ejecting the particle in the forward stroke. Now, this is a kind of sacrificial layer that is coated over the silicon wafer substrate. So, sputtering is used for coating, and this is the overall configuration of a magnetron sputtering. Using a kind of oxide in this, we are using an RF system to sputter the unit, and these are sputtered onto the silicon wafer, while a surface profilometer is used to measure its overall characteristics. Now, we can see the construction of a micro 3D printer; the features that we may need to print need to be incorporated in the form of a CAD model.

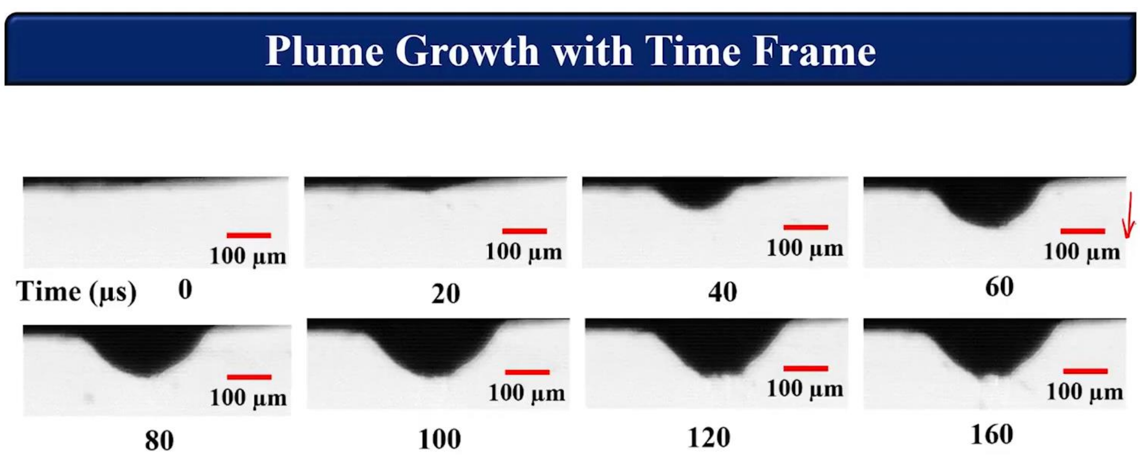


This CAD model is converted into G&M code using a software interface, and this is a kind of micro 3D printer that is kept inside the glove box since we are focusing more on microelectronics or micro sensor-related applications. This is the overall configuration of the printing. Here, there is a beam bender, a focusing lens, an acceptor substrate holder, and a donor substrate holder. The material will transfer from the acceptor substrate holder to the donor substrate holder, resulting in the deposition of the pixel with overlap. So here we have control over the overlap.

We have control over the pixel-to-pixel transformation, and there is control over the kind of lateral resolution and substrate heating. In addition to this, the focal length and the spot diameter also play a vital role as discussed. In this particular process, the donor region has 3 degrees of freedom and the acceptor region has 3 DOF. Based on the donor region and the acceptor region, appropriately printing can be taken up. Now, this is a kind of process that has evolved: a transparent substrate, a sacrificial layer, a donor material, and a laser beam that is made to interact.

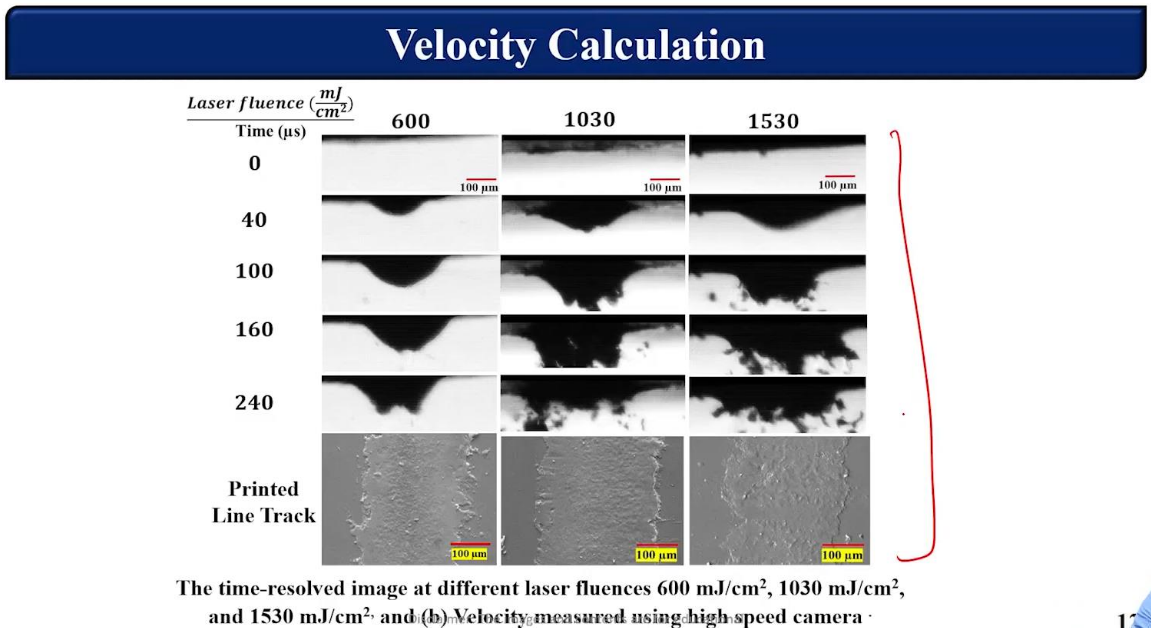


Then, laser absorption occurs on the sacrificial layer, a high-pressure gas is created, and the expanding gas forms, resulting in the transfer of material to the acceptor substrate. These are the kinds of features that are being printed here, and this is the overall mechanism. This technology has the capability to print metal, and it also has the capability to print semiconductor materials and related areas. Now, some of the key aspects, such as the overall ejection mechanism, play a vital role in understanding the overall pattern structure or the transfer of the pattern structure appropriately. In this particular case, the pattern structure occurs because of the plume formation that evolves from it.



Plume formation and expansion with varying time frame at laser fluence 530 mJ/cm^2

With reference to this plume formation, there is a main ejection mechanism that happens, and this will result in a type of deformation that adheres to the surface, resulting in a textured growth. In order to study the parameters, one of the key parameters is velocity; since the particle is moving at a very high velocity, this moving particle will stick to the surface, finally ending up in a kind of pattern structure. These are some of the different parameters and the different spots that are being created, which will give you a kind of clarity on how the parameters impact the different points. So that is with reference to the focal point; the beam can be manipulated, and appropriately, each and every pixel transfer can be controlled. Then, with reference to the influence of laser fluence, there is a kind of impact in such a way that the heat-affected zones can be completely eradicated.



With reference to a pulse lower lap, the heat-affected zones can be efficiently optimized so that we can have a continuous track, allowing it to print a large area structure. This microfabrication technology has potential applications in transferring selective layers layer by layer. For example, if this is a substrate and I need to transfer a zinc oxide material at a particular point, this is possible using this laser decal transfer technology. The only thing is that our manipulation head should have a higher resolution, and the acceptor and donor regions should also have a higher resolution, while keeping the laser fixed to appropriately transfer the system. Now, these are some different samples that are being prepared, and these are some interdigitated structures being printed using the system.

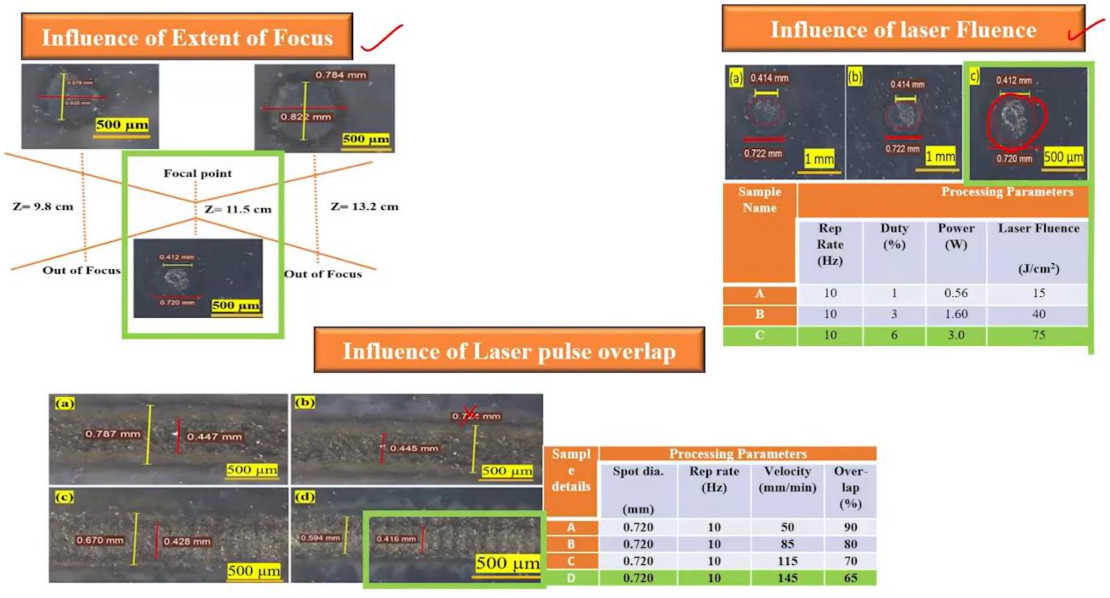
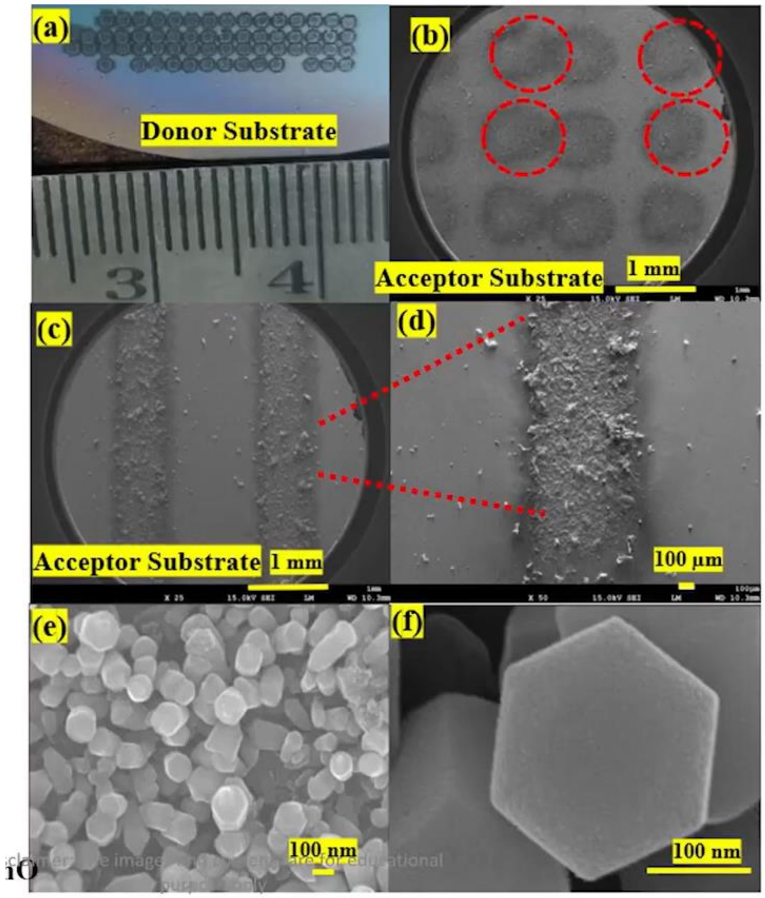
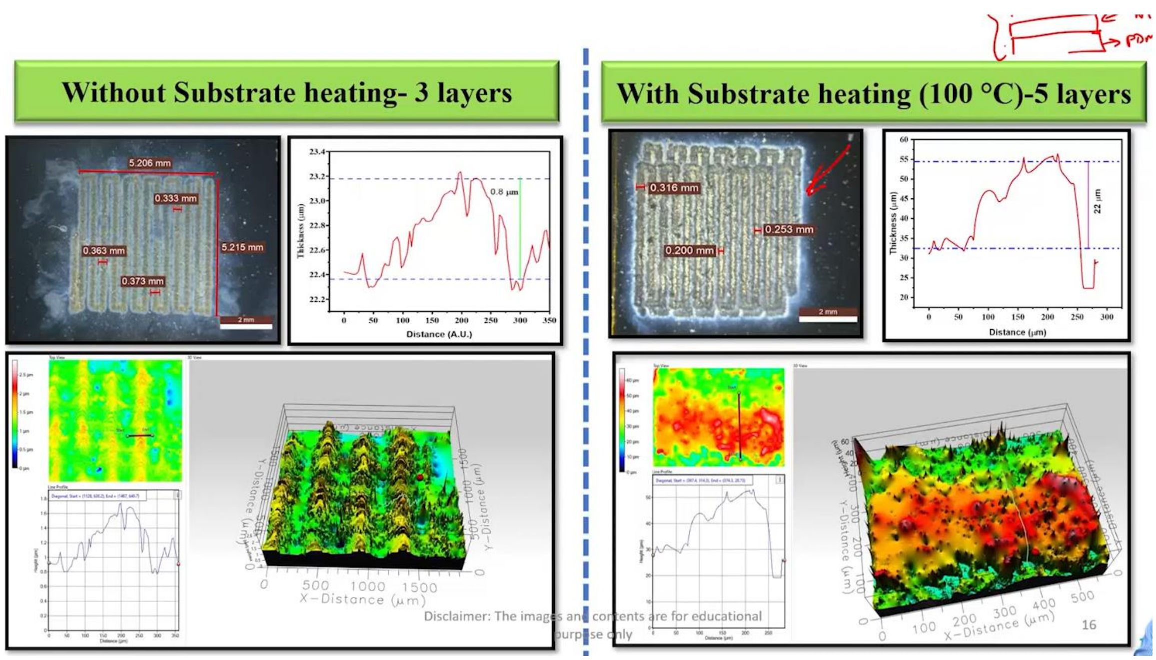


Fig. Microscopic analysis of influence of laser parameters towards effective material transfer and generated heat affected zone

It has the capability to print multi-layer structures. It also has the capability to create sandwich structures; for example, this can be a PDMS, this can be nickel titanium, and over this, it can again print a PDMS. This is one advantage of this particular system, where we can have a kind of multi-material and multi-layer printing using this technology. These are some of the printed structures that are being deployed in different devices. From the perspective of 3D printing microfabrication, it's a kind of novel technology used for printing complex structures based on requirements. This technology can print micro antennas, micro gear structures, grid-like structures, as well as interdigitated structures, and these can be used functionally and efficiently.


(a)
Donor Substrate
(b)
Acceptor Substrate
1 mm
(c)
Acceptor Substrate
1 mm
(d)
100 µm
(e)
100 nm
(f)
100 nm


Without Substrate heating- 3 layers
With Substrate heating (100 °C)-5 layers
5.206 mm
0.333 mm
0.363 mm
5.215 mm
0.373 mm
2 mm
0.8 µm
Thickness (µm)
Distance (A.U.)
0.316 mm
0.253 mm
0.200 mm
2 mm
22 µm
Thickness (µm)
Distance (µm)
X-Distance (µm)
Y-Distance (µm)
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It's a kind of maskless printing that is being demonstrated here. This is a plasma treatment setup. Here it has a vacuum chamber where a plasma gun is located, and where a high-frequency voltage in the order of megahertz to gigahertz is applied, which ionizes the gas present inside it. Here, we place our substrate. After achieving a vacuum, we supply voltage, and plasma is generated. This ionized particle bombards the substrate and causes physical and chemical modification. It can be used for surface cleaning and surface processing.