Design, Technology and Innovation
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Lecture-8
Technology to Solution

Good afternoon, my name is *Ramesh Singh* and I am a professor at the Mechanical Department (IIT Bombay) and I work in a lab called Machine Tools Lab. So, today what we will do is we will talk about what I do as research in a Machine Tools Lab, and there are a lot of products that have come out of my lab, and I will actually take one product in a particular, Laser Vent Cleaning and walk you through the entire development process of that product. So, the first thing is that we are all at IIT Bombay.

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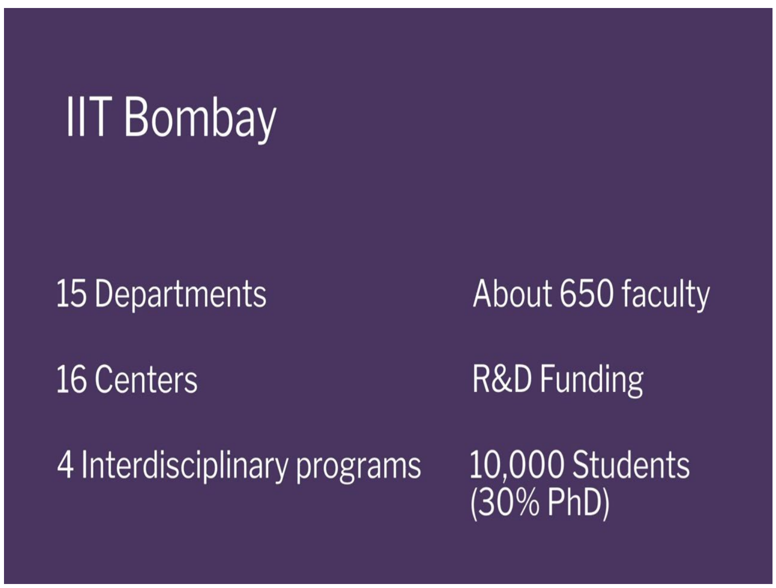

And then, I would just like to give you some details about IIT Bombay. We have 15 departments, 16 centers, 4 interdisciplinary programs and about 650 faculty members, a decent amount of R&D funding, 10,000 students, give or take, out of which 30% of our student body is PhD. So, despite what we think that it is a UG centric institution we have a significantly high number of PhD students. And a few of them work in my lab who are involved with these kinds of product development and basic research which leads to product development. And then we have support staff and infrastructure which actually supports our research.

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And I am part of the Mechanical Department. The Mechanical Department does a lot of things. Some of the key areas of research are something called Micro/Nano Technology, Computational Methods, Fluid Mechanics & Thermal Sciences,

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Manufacturing, then there is Bioengineering, basically that is the need of the hour because a lot of the products of the future, related to healthcare and also to enhance our quality of life. And this is Solar power & Energy, because energy again is a big issue, so we want renewable, sustainable energy and solar power is also one of the focus areas of research.

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So, the basic research area which I do in my lab is. The first one is Micromachining. So either I can subtract material, which will be machining. Machining are of different forms. I can do Tool Based Machining, I can do Electrochemical Machining, I can do Electrical Discharge Machining, I can use different things to remove material or what I can do is I can add material which is, which we do in Additive Manufacturing or I can do joining kind of a process, where I can do weld, multiple things and make a product out of it or I can do something like Casting and Forging which is Mass Conservation process.

We do not really develop the process, we also develop the machines to work with it because these machines are commercially, some of them are available, very few though but they are very expensive. So, I am innovative and I actually go ahead and build those machines. And then once you build the machine there are some challenges with the process itself, because the tools which I use, just to give you some idea what tools I use in machining, can be one-fourth of your human hair. 20 microns.

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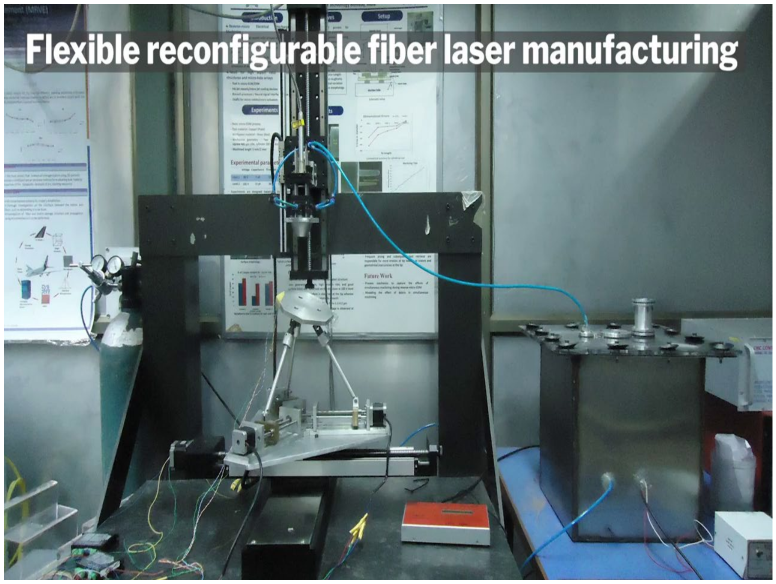

The second thing, what I do is, I call it something called Flexible Reconfigurable Fiber Laser Manufacturing. The reason I use that is that I do not have money to buy 5 different machines. So, what I do is I buy one laser and I and I basically make changes to the spot size, the powers.

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So, basically I can do very high energy intensity to ablate the material, sometimes low to heat the material so I can, I can melt the material, I can heat the material, I can vaporize the material using the same laser by changing the optics.

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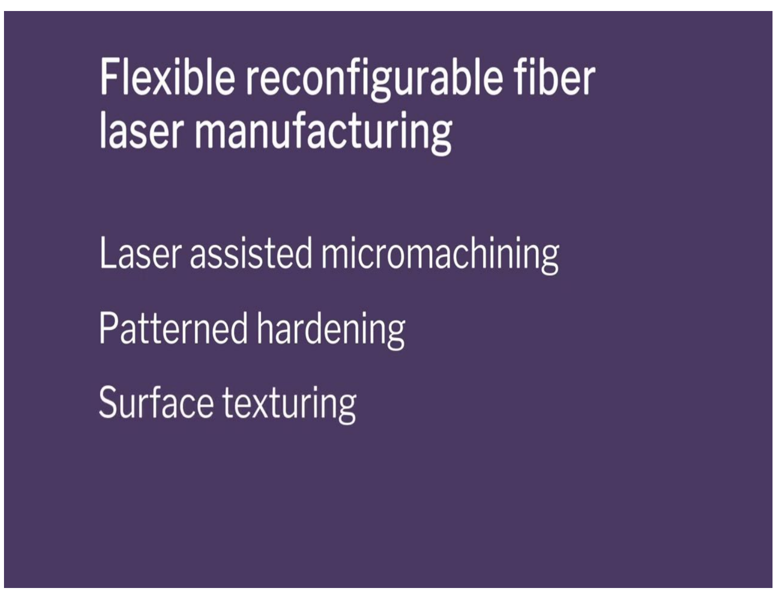

And a combination of other things, to do certain things so do like, texturing, sometimes hardening, sometimes adding material and printing. So basically printing is nothing but you add powder and melt it and create layer by layer a structure.

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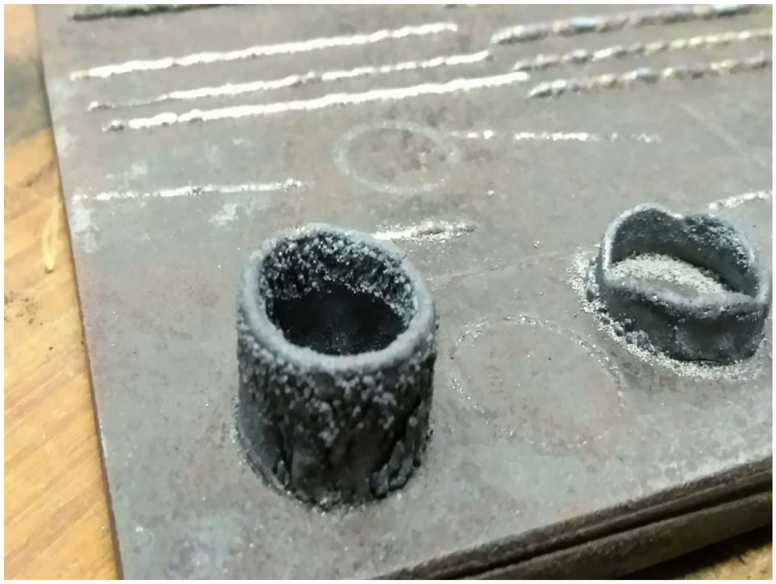

So, that is what you do so I actually do all those things with lasers. Then, since I teach mechanical engineering I have to understand what is happening mechanics wise.

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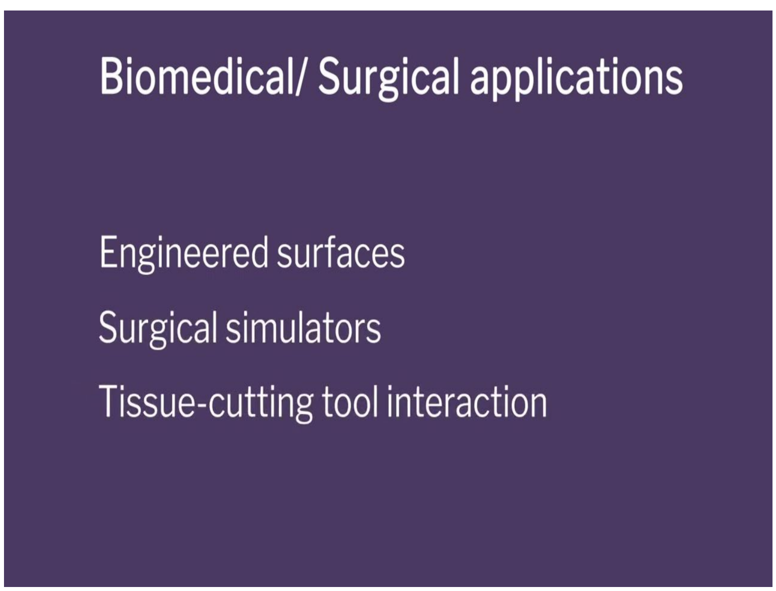

Since I am doing all these things these days, everybody's doing bio right? So I said I cut steel, why don't I take a tissue? So, a couple of students what they do is they try to figure out that if I take a tool and poke a tissue what will happen.

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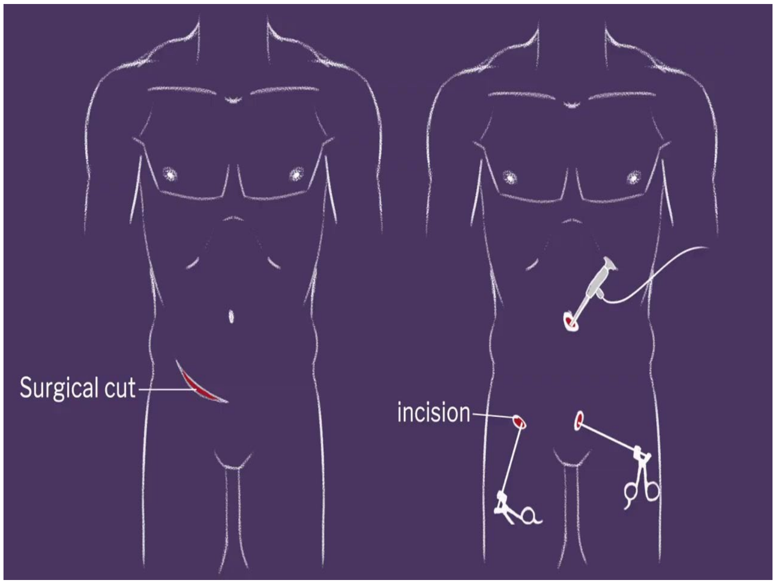

Earlier days people used to just do a big incision and do the surgery. Nowadays you can come out of surgery in a day because they do a very small thing and then they would do something called laparoscopic surgery. They will put a Cannula and then they will put a tool which would go ahead and do local surgery. Now they are not seeing it although they do have some cameras to look at it but they do not have full vision now.

A lot of it depends upon the feedback, so I am cutting liver. I am not cutting something around it. Right? So, they feel it. So a lot of it would be how the force response of a tissue is. So, we want to study that and then get that idea to make some simulators or make some tools where people have a feel, a priori, before he does the first surgery. If he has done 10 surgeries, it is okay. But then how do you make sure that the guy goes and does the right things because bone feels different, liver feels different, stomach tissue will feel different.

I have to go do liver surgery and I go cut my stomach. The only way, the only thing stopping me is: Stomach feels different. If I am poking there it feels different. Create more realistic surgical simulators. We only have managed to just get the forces from different models. So this haptic feedback will be based on this knowledge that what tissue gives what forces. So, this information will build the backbone of it.

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Now these are some snapshots of the lab. We have a whole bunch of machines since the name is machine tools lab, all we do is we have a lot of tools.

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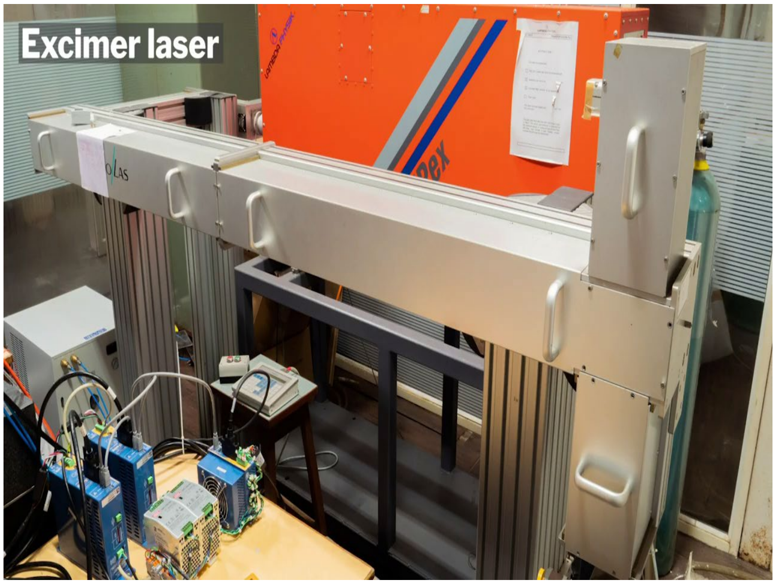

We have Excimer Laser

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Wire Electrical Discharge Machining.

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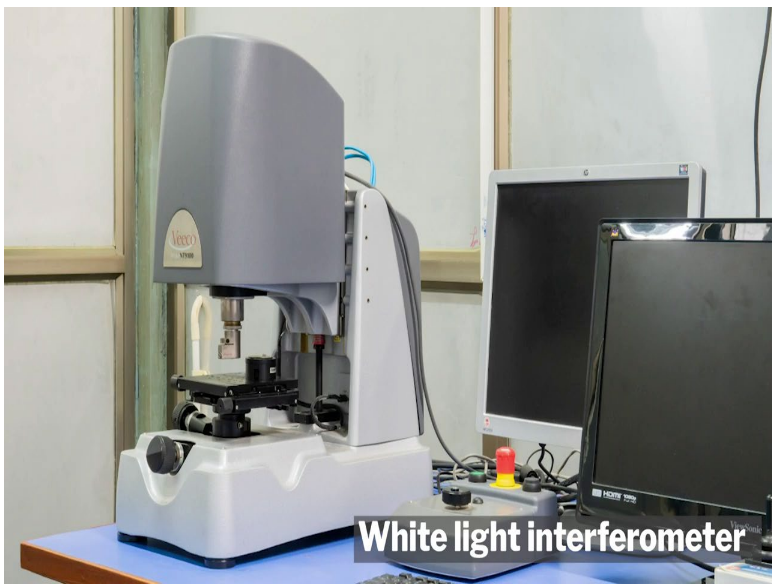

We have something called White Light Interferometer for surface roughness measurement. So, if you machine something we need to measure the roughness, that is the tool for that.

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There is a Micro Machining Center. It is a commercial thing.

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And then Measuring microscope;

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We have lots of Surface Roughness and Metrological microscope, because what we make, right?

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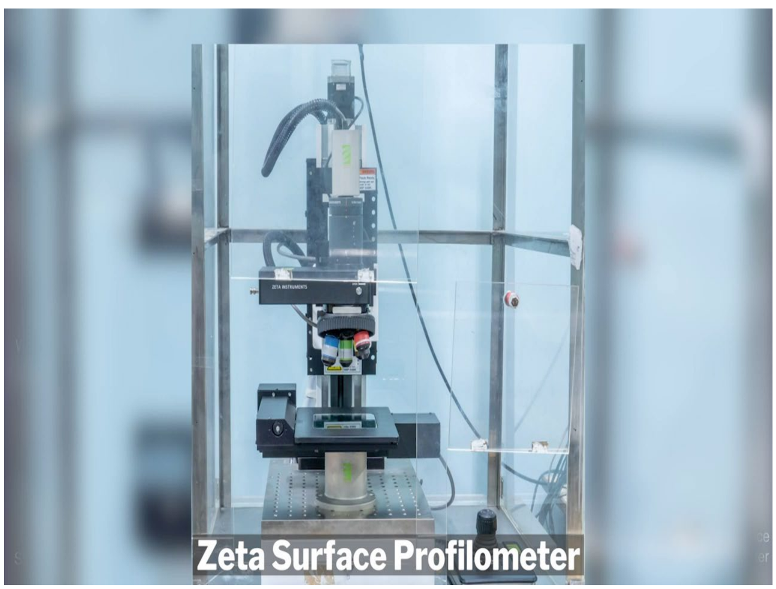

I do micro machining, so I should be able to measure things which I do.

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So, a lot of these equipment actually help me measure what I do. So, I need to be, to be able to measure a few microns, if I am making a channel of 100 microns. I should be able to measure it.

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This is called a coordinate measuring machine, so what it does is any shape you make, it can give you an exact measurement of it. This is a very old machine which we have in our lab but the newer ones can give you 3d models. You just put the product, they will take data all around it, they have, they have a probe that will go and get all the data surface data and build your 3d model out of it. A lot of my money which I do in my research comes from industry.

And the industry typically, if I take money from the industry, I have to give them something. So this is what would be probably of more interest to you being design students.

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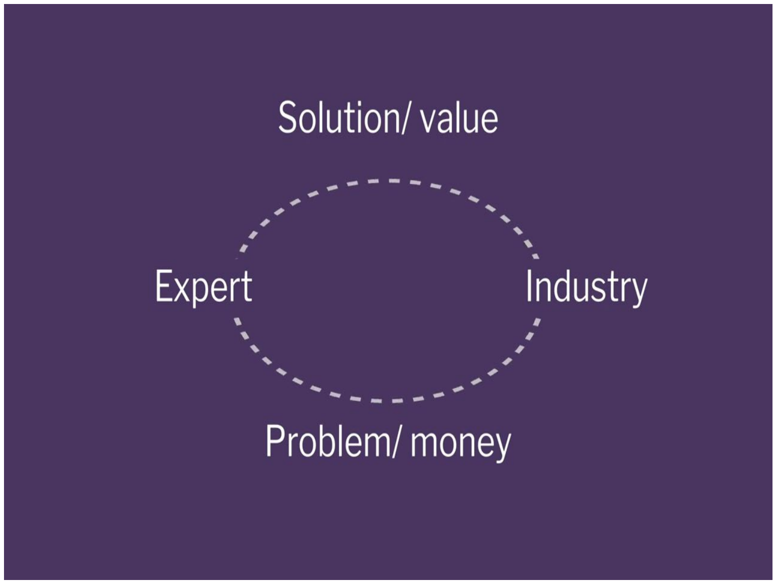

That, how do I go ahead? So they come with the problem, right? So, then I have to interpret the problem in a way which makes sense to me, have a path to design it, have some engineering analysis to back it up, whether it will work or not. And then finally design and build it and it should not be ugly looking.

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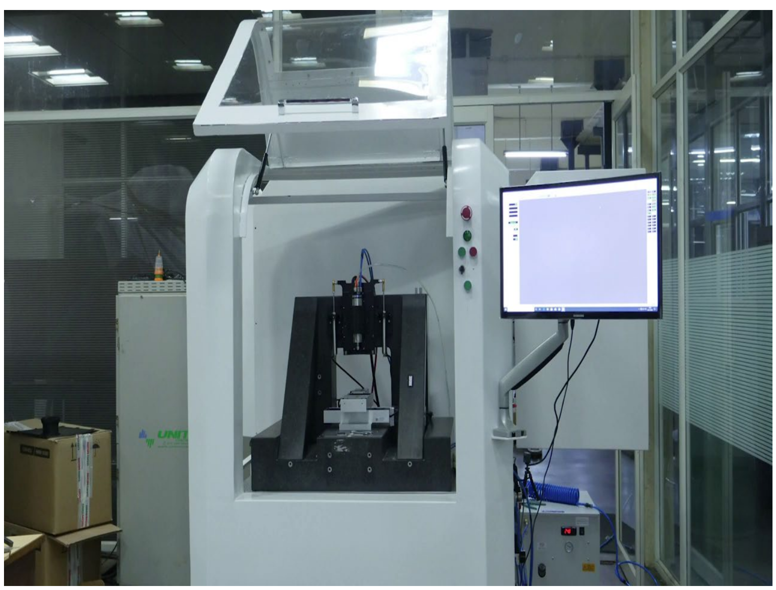

We designed India's first Ultra High-speed Micro Machining Center.

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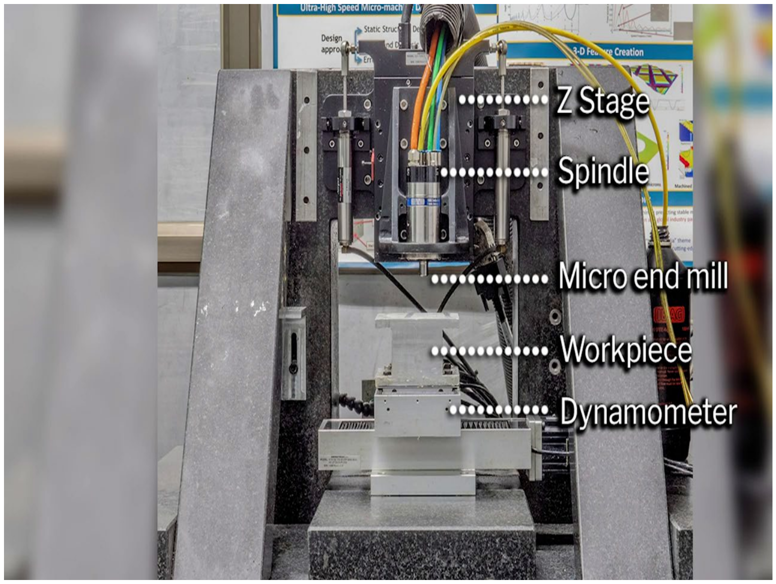

That I told you that there are processes for forging, right? Where, what you do is you heat the material and shape it using a forge using a dye or a mold, right?

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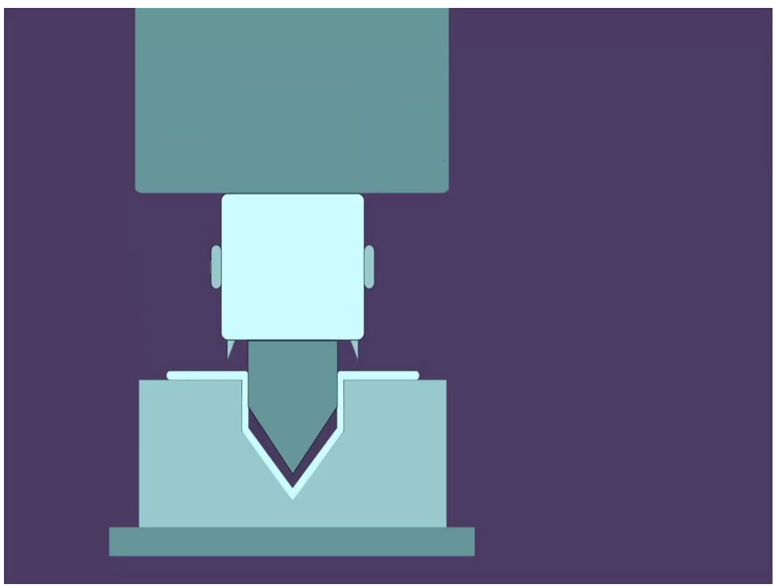

So what happens is after a while since you are taking hot metal and usually compressing it. right? It can wear, so basically what will happen is, it will not have the correct shape after that. right?

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And if it has cracks eventually it can actually crack and break. So, these things are fairly expensive. Each mold can cost you up to 30, 40 lakh rupees. Just one mold right and you can just throw it away.

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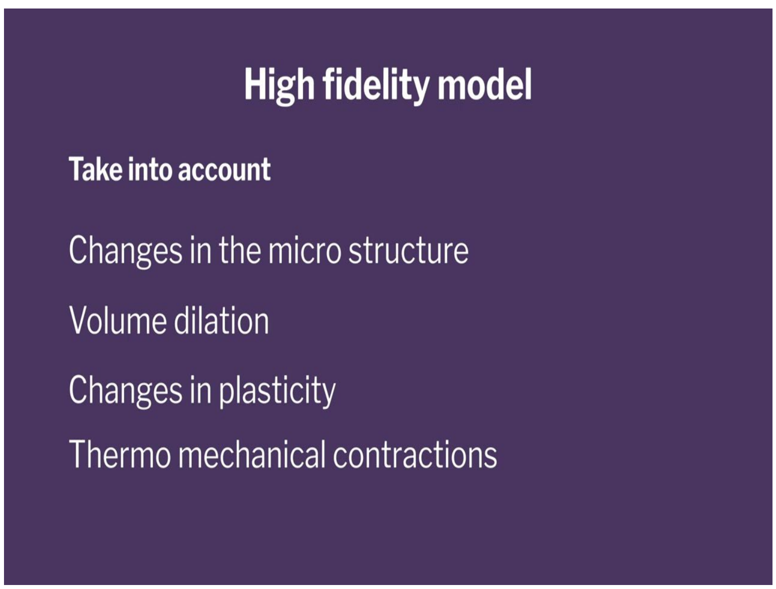

So, we have developed a very high fidelity model, which actually takes into account if the material melts and re-solidifies, there are changes in the microstructure. And this changes what they do is, they create volume dilation and transformations in plasticity. And there is thermo mechanical contraction because as the material cools it will contract, and this contraction will not be even because the higher temperature will contract more the lower one will contract less.

So, there will be a differential contraction post cooling. That will create stress. And then there are transformations in the microstructure because you cool it very fast.

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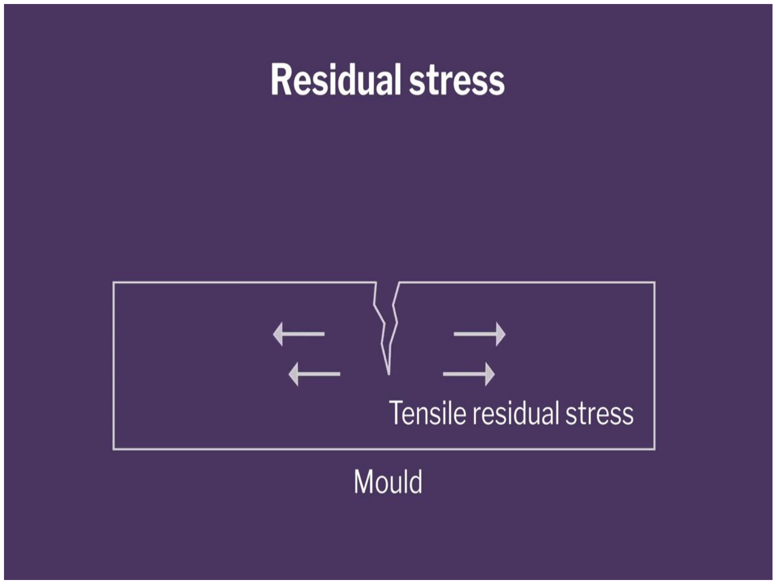

All of them will have a role in the residual stress. For those of you who (don't) know what residual stress is, it basically means that the moment I cool and everything there is no load, still there will be a stress in there, locked stresses. What it will do is if it's tensile, right? And there is a small crack. The tensiles will open the crack. So, your fatigue life gets compromised. So, if I do it just by depositing, not knowing what kind of stresses are evolving, not understanding the process, I barely do a job which will fail again in 3 cycles, do 3 more forging and again it will fail.

So, if I understand the process mechanics, do it the scientific way, with the scientific knowledge I will probably be doing something which has a much longer life. So, that is what I am making a good case of doing it scientifically. You can do it, but if you do it scientifically, it will be more sustainable. Whatever technology you are developing has to be enabled by science.

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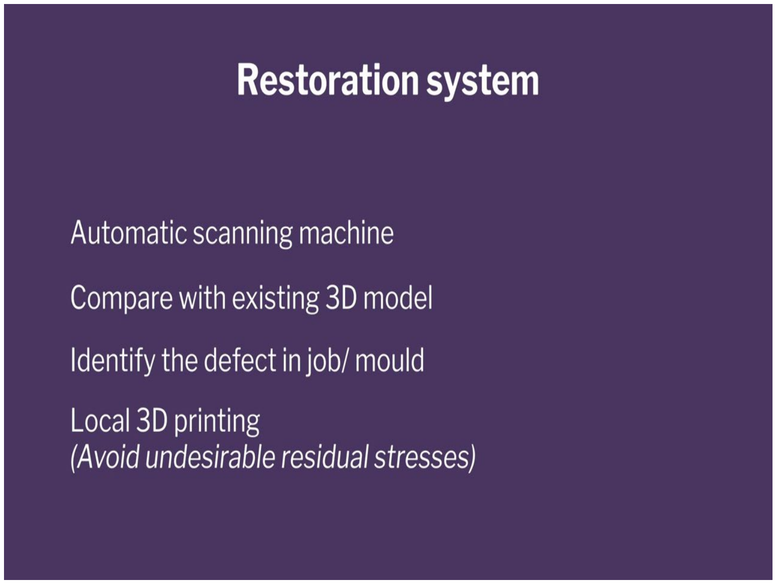

Now, so what we proposed to do in this is, if somebody comes to me and says that we have to develop or prepare for that, you know what I will do? I will actually first create an automatic scanning system. It will go ahead and scan. Compare it to the solid model that what is the actual product look like, and then it will identify, 'this is the defect, these are the defected areas'. Then it will go ahead and take a powdered material and then do a local 3D printing. Local deposition of the material there. And at the process parameters which will not create undesirable residual stresses.

So, the process parameters will come from science and the technology is the actual product and the system preferably that goes along with it. So that is what we propose and we call it the Autonomous Damage Detection system. The Material Deposition system and the entire thing which will come into one package would be called the Restoration system.
Student: Filling of deformities layer by layer, does that create some problems like from the actual material which is?
Sir: Yes it will, so you need to know what it will do. Most of the material which I make by forging it is actually, properties are the same everywhere.

But if I do layer by layer the property variation will be there. And then I build another machine for BARC. They needed very high speed bearings, very, very high speed bearings. And these things have to run 15 years non-stop. So, it has to be very reliable. Now they want to change the material from something what they use right now to sapphire. If I have to machine sapphire, what will be the biggest challenge? Crack is a big problem because it is a brittle material and you need something harder to cut because sapphire as it is very hard.

So, the problem was, whenever you machine you will create some cracks and the only thing you can use to machine is diamond. So, either you buy a super duper expensive machine to do something like this which there are very few in India. So, we said that okay we will do it cheap. I will run it in my lab, I actually machined it in my lab with some crack in it, little bit of cracks minimum possible. I actually cut at 1 micron depth of cut, if you can imagine. Pushed it to the limit, still there were some cracks.

To take care of that we developed the polishing process, and it's a very funny polishing process. I have a cavity to polish, how do you think I should polish this cavity? If I have a cavity to polish. Of course chemical is a good idea because then chemical dissolution would enhance the thing, but even to do that chemical digitations evenly all the way through, I need to make sure that there is relative motion between the, all the points here.

So, the first thing that dawned onto me is, do *idli* and *dosa* thing. Make a ball that conforms to the thing and it just moves. Now what will be the problem if I do something like this? The corners will rotate, the velocity will keep on going smaller and smaller at the center, it will stall so there will be no polishing in the center. So, what we did was we did two things one we did it 45 degrees and then we rotated the ball also.

So, we did a double movement. So initially what we did was we did something like this. We did a motion rotating, a rotating ball with what they do in the *idli/dosa* motion.That was a very kimatically very un-smart of doing it.

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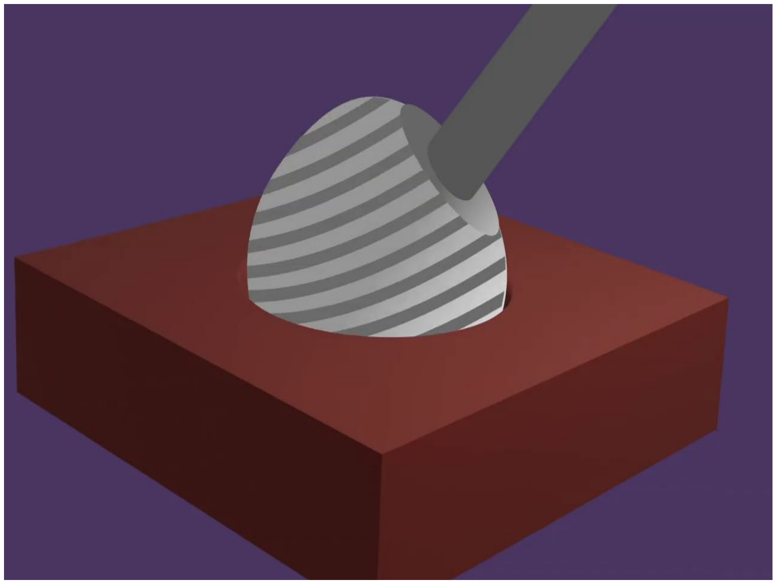

Then what we did was we did this, and at a very precise location we started rotating the ball itself, the cavity itself. So, now there is non zero velocity everywhere and build a machine like that and of course we use something that chemically reacts to the surface, so, the combination of mechanical and chemical polishing, and gave the machine to BARC.
One of the guys from CEAT Quality Control came to my lab and said that when they build these tires, right? So what happens is there is misalignment between those edges.

Once the misalignment is there, regardless of what we do, everything is a waste, and when they do the first pass of the tire building, there is a drum roll and that tire that, basically the rubber piece is rolled over it, is fed automatically and gets rolled over automatically. Now what happens is if the alignment is off, so they have 2 laser markers and the guy eyeballs it. The requirement is 3 millimeters over 1.6 meters and he eyeballs it like this. If it is not right he will take it and do it again by hand.

Each time he does it, he could have built four tires automatically. Each time he unwinds it, he is losing time for 4 tires of manufacturing. So, they came up with a solution. They come and tell me what we will do is, we will take a scale and measure it. I said how on earth you can measure 1.6 meters and get a 3mm accuracy with 1 mm least count of it. How do you even see it? So one guy will see there and the other guy will see there and say here there is 1.5 and here, there it is 1.5 mm. I said this is crazy. It is not going to work.

Then he says then what I will do is I design a special caliper exactly the same which I want and put it there. I said you will use a caliper on a rubber, on a compliant material. 3 mm will compress it. So every time your product will be right. Put a caliper, it will just compress the material, compress the, it is a compliant material, it is rubber, right? So I told them the only way to do it would be that you have a good vision system. Take a camera, measure it real-time, measure it very fast, do it at various locations while the tire is rotating.

Locate it as every location, so I said every 10 degrees get the data and then do it. So we actually build a system for them. Every 10 degrees it measures, it actually takes the laser mark, identifies the edge, measures everything how much of it is, computes real time and tells the operator it is good or bad and logs the data to their quality system. So, the entire system we design and built for them. Now this went out fine. One of my old students who has a company now designed everything.

Now what happened was they came to us and said that we have another problem. This is what I will talk today, primarily the Vent Cleaning system. They came to my lab. 'Oh you use lasers we have a problem'. The problem what they defined was very simple. They said that we have these molds right. So, tires you know they will take so all these threads, it is actually molded. So you take tire and you take a heated mold, get those shapes, cool it and take the tire out.

Now what will happen is all these molds, any mold will always have vents because the material has some porosity, so the gases will come out. So, the gas has to be, to come out and these vents should be there. So, these vents, what happens is, if I do it say about, 1000 odd cycles of molding, these vents get clogged. And if I do more of it with the clogged vents the quality will get compromised. Because my air will not escape, so there will be porosity in the product. You do not want that. Right?

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So, the way the clean it is, somebody actually takes a drill, 600 micron drill, and by hand each tire has 1600 vents, 1600, somebody goes and does it. You have seen a new tire. Right? Each tire will have a hair like structure. That is called a spew, vent spew. So that hair like structure is because you have vents. So, you will actually, new tire, you will see everywhere, even on the radial face, but on the sidewalls you will see even in the old tire, if you look at the sidewall that these tires will, these spiky things will always be there even in the older tires.

Those are vent residues. So this is what actually goes into the vent and that is what needs to be cleaned. So, they will take a thing and (tap tap tap tap tap) they will clean it like that. But that is a process where it is inherently very dangerous. Tool can break, if the tool breaks what will it do? So, it can be in the vent that is also not required and for those of you who have never done drilling, if a drill breaks in a hole while drilling, taking that thing off is a nightmare.

Ek to hole gaya (One is the hole is gone) and then the other thing would be that, to take out is a bigger thing, right? So, now that is one issue which is there. So, what happened to them, the CEAT guy is, they actually gave a tire with metal embedded in it and their entire batch was rejected by Renault. These guys come to my lab (and say) ‘You use lasers, can you do something? Can you design something which actually just removes all this drilling business?’

I said ‘why don't you send me the molds. Let me do some experiments. We will use lasers to see whether we can clean these using lasers or not’. So that is how this product evolved.

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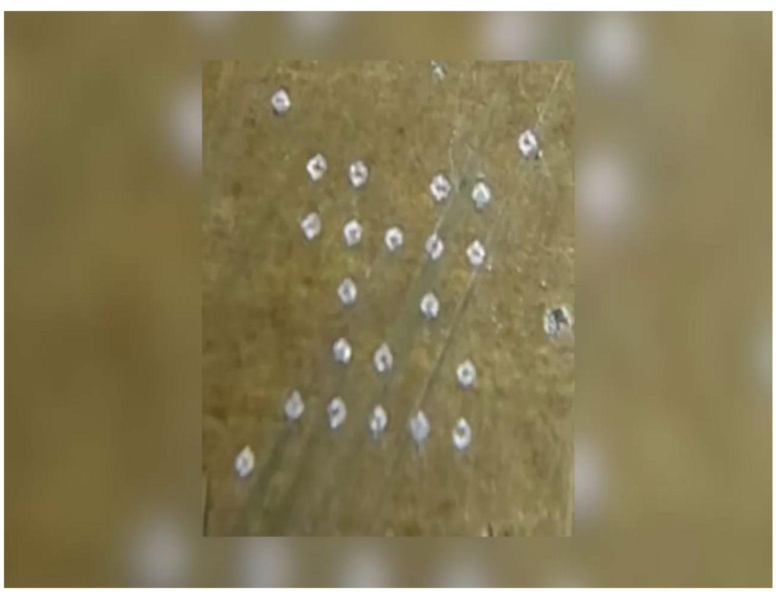

Then a lot of these diamond guys come and worked with me, because they polish diamonds but they never knew what they were producing. So, they came to me and said that, ‘You know, I have an idea. I want to do digital personalization on jewelry and gemstones’. So, I said ‘What do you want me to do?’ So he said that ‘Can you do some digital personalization?’ Every jewelry which somebody buys is unique. You can create an app where you can have a unique code on the jewelry. Somebody scans it, the moment you scan it that unique code is linked with something on the web where you can have your love letters, pictures, messages, blah blah blah, photographs pop up. So, that will be a digital personalization of the jewelry. A jewelry will come along with a lot of things stored. It will have a unique optical code. So, I said ‘I can actually make those codes’. So what I will do is I will machine this small, small array of codes. Actually these are just a bunch of arrays of holes.

Each array of holes once it is scanned, it actually gives me a unique code. It is like a barcode or something, but since you cannot do it on jewelry it will look cheap. I will actually create a slightly fancier design, micro machine it, of course with tools or lasers and then you can do it. So, the only problem with that would be that that has to be amplified. So, I will give them a magnifying glass, a lens attachment with it. So anybody who buys the jewelry will get a lens attachment free with it, with the jewelry, which goes into your cell phone.

So that will be an additional tool which will be given to the guy who buys the jewelry: a magnifying lens. The ideas do not come in vacuum. You need solid science behind it to generate those ideas. So, research is the driver for those things. Unless and until I know about lasers I would not be able to make this machine. So, I have some idea based on my scientific background that I can extend it to a product or extend it to a more marketable idea.

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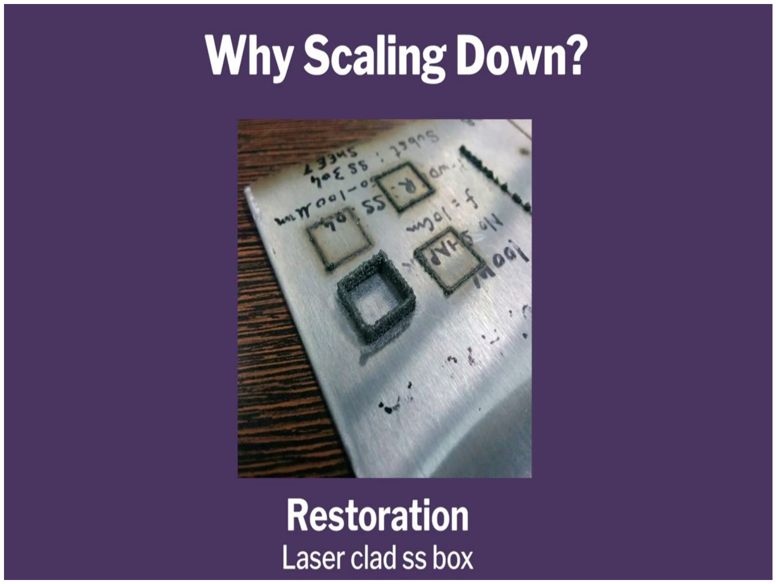

Now everything every small component has been scaled down.

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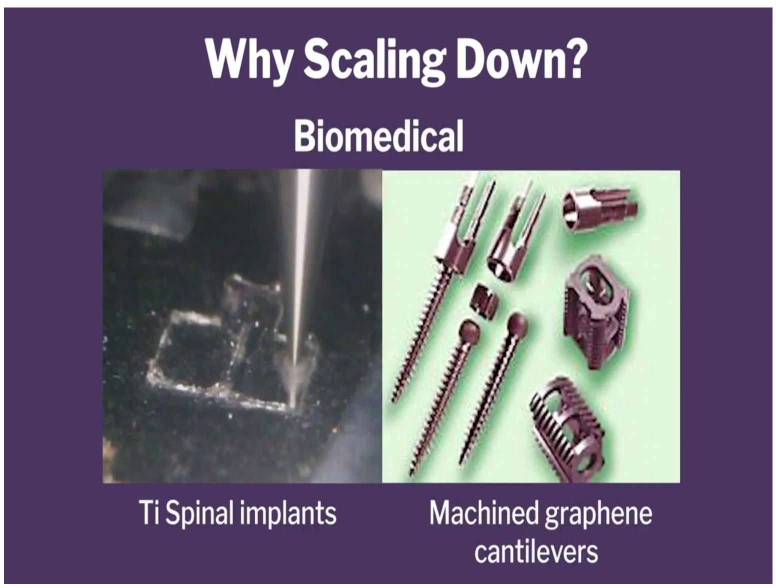

So, the scaling down can be in various fields. It can be in biomedical,

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defense applications,

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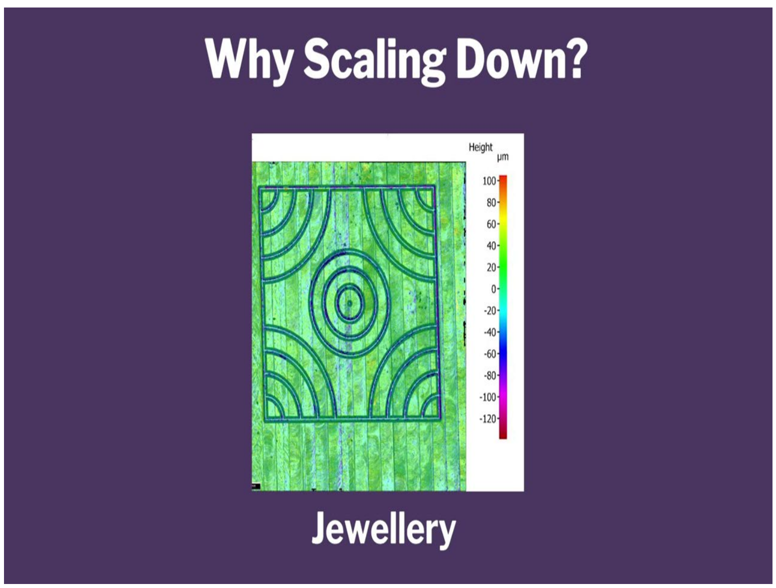

jewelry,

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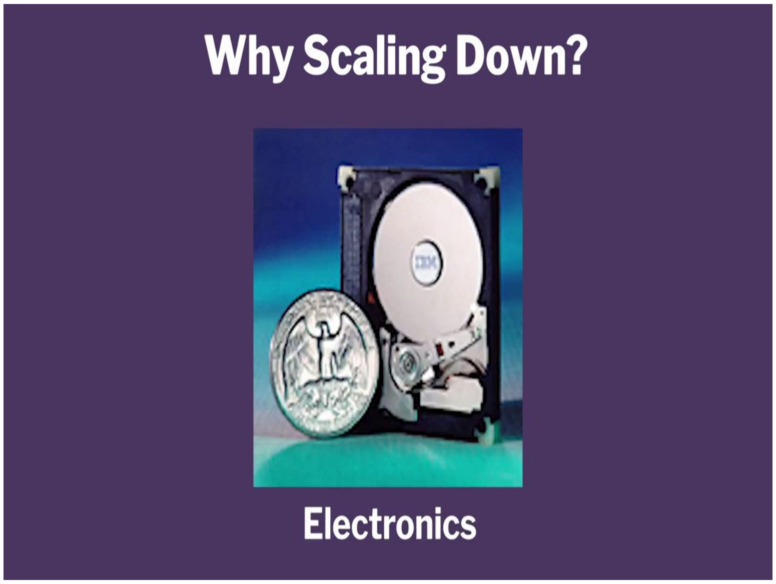

electronics,

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molds for small features. So there is a huge amount of scaling down of things. But traditionally I do not know if you understand, people still used to make a lot of small things.

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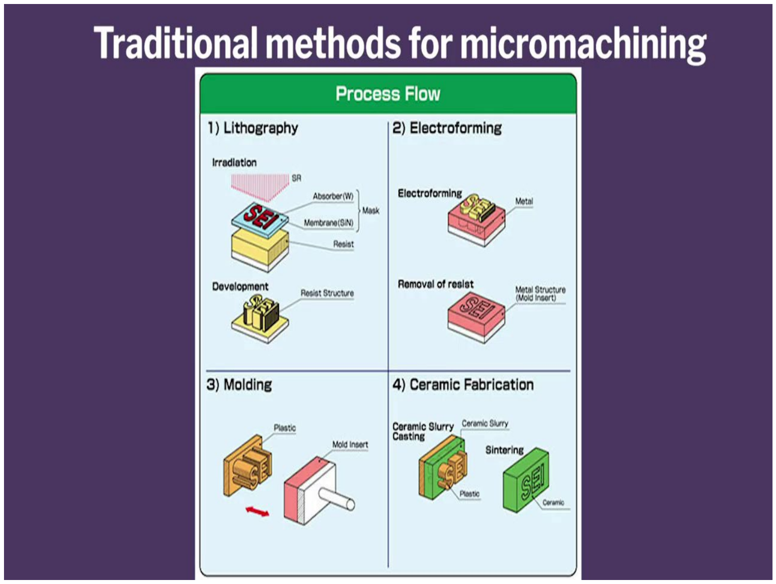

People were making (electronic) chips since the 60's. So they were doing it. The only thing the way you used to do it is they will make a mask somehow,

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and then they would shine a laser on it or UV lamp on it and then they would etch it out. It is called the photolithography process. But then that will do only two and half deep, (and are) still used. All the chips that are manufactured as a seven nanometer technology which is there, the cutting-edge technology, uses lithography, still. But they are primarily for silicon, and that is a process which you do not want to scale up and it will not be used for every material.

So what I say is there is a Nano scale manufacturing which is good. We have the technology for it, great. I have a macro world where all my machines are there.

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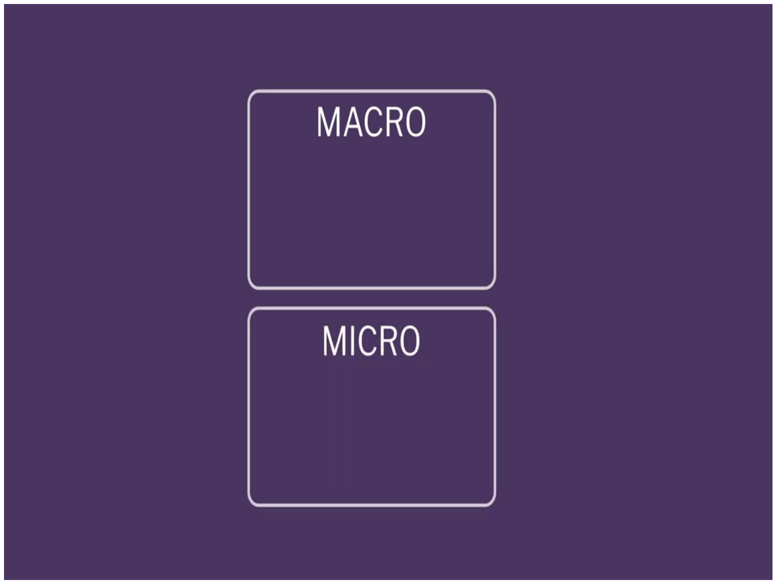

In between there is a micro scale where either I have to come from top, or take these processes up there. That is a gap. All those lithography processes work for silicon. So, if I have to use titanium, steel, all these metals, it is not easy to do. So, why do not I take the macro scale processes (and) scale it down.

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So, processes can be milling, drilling, turning, EDM. Now what is the primary problem?

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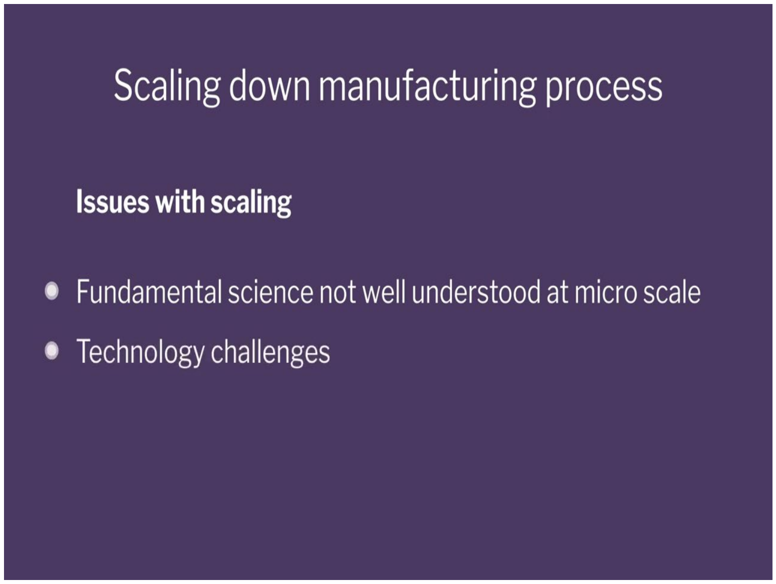

The primary problem is we do not understand the science also at that level. As I told you one example. right? What stiffness does. The stiffness scales nonlinearly, so we have to design a process in such a way that these forces are very very low. Any small force will break that tool. So fundamentally what we said is the way to counter that would be that you go at 100,000 rpm. Normal machines run at 3000 rpm. The problem with going at very high speed is that for those who do not understand dynamics: Certain frequencies can be excited.

Any misalignment, if there is even at-of misalignment, it will be amplified, Omega squared r, if you remember that. So there will be alignment miss-amplifications, misaligned amplifications. There will be some of the natural frequencies, (which) will be excited and any small vibration with a very low flexibility, low stiffness tool is very dangerous. The tool will break. So, you have to understand the science of dynamics very, very well in the machining process to be able to make it properly. That is a big challenge. So, I can make a machine but to operate the machine I need to understand the process very well.