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Fiber Laser Applications Video- January 2007
Transcript

This particular piece….is a multimode laser. Anything above 2 kilowatts, in our case, is a multimode laser. So we've got direct from the laser a 50 micron fiber which is delivering the energy. The issue with it is, and you can see by the robot here, these are deployed by automotive companies, shipbuilders and so forth, and what happens is with robots these are moving at very high speeds. I'll give you an example. I'll show you one of the parts. This is what's called a hydroform part.

(0:33) So in the old days when you build a vehicle you'd have a chassis, you'd put the body on top of and so forth, and what they've gone to is they'll take a piece of sheet metal and form it under great pressure, hydraulic pressure, they'll weld the parts and it'll actually make these complex shapes, which'll give you a much more rigid structure. Think about the new Ford trucks and Nissans; they need to have this towing capacity, so they need this box frame to do it.

But what happens is once they've got this one hydroform part, they need to join the different materials. They need to pass through either lightening holes or brake lines, gas lines, and so forth. They need to stamp these parts out traditionally. What they've done is they've gone to this new material so that it's easier.

(1:15) The first thing you can see is the color difference. The big difference between the two materials is this is high carbon steel. It crinkles under extreme pressure or force, say a vehicle crash, and this is the new high strength steel coming out of Detroit. The issue with it is, one, it's very strong. We've actually taken out blanks of it and struck it with a ten pound sledge and it doesn't deflect at all or it goes right back to its original shape.

The issue is if you go back to the standard process normally done in Detroit to produce these shapes, they're wearing out a set of dies every two days. So they've got to take them off, either use a laser or another process to recondition the die, machine it back to its capabilities, test it, qualify it, and put it back on the production lines. So they're constantly breaking down the lines. To look at it, if you believe what they say, companies like Ford and Chrysler, they rate their time being somewhere between $5 million and $15 million an hour for every hour they're down. So they look at using lasers.

What we've found is using a 3.5 kilowatt laser, using a 6 kilowatt dialed down, we can cut this material at a rate of about 18 meters per minute with good quality of cut. So it's equal to the speed they're doing with the stamping, but it also allows them with a five or six axis system to actually follow the contour of the part. So now instead of having a series of dyes, they can create lightening holes, brake passage holes at a very high rate of speed. By either changing the optic or changing the focal plane they can use the same laser to join two pieces of metal or dissimilar metals together. So now they can use one tool for stamping as well as welding….Well the thing about stamping is besides cutting the hole that it's cutting or the stamp that it's creating, it's actually putting a series of stress lines on the part, whereas with the laser it's a non-contact process. There's no force being required so there's no stress lines.

There's a little bit of stress put in from the heat, but what we do is we use shielding gases like oxygen or nitrogen. If it's a welding process, we might use nitrogen as a shielding gas to remove oxygen because you don't want to impart that in the weld. And if we're trying to do high-speed cutting what you usually do is use high pressure oxygen, similar to an oxy-acetylene weld. It facilitates the burning process. In some cases it'll start to create a fine ash. The ash then creates an iron oxide that burns at a higher rate. So they've gone from stamping to cutting and they've gone from from low strength steel to high strength steel. This is just one example.

(3:50) What I want to get at is besides having a very versatile tool, there are a few financial reasons for having this equipment. If you look at what a United Auto Workers gets with overhead, 401K and everything else, it's about $28 an hour. A robot takes about 30 cents an hour. So they can be more cost competitive with Japan, Asia, Mexico and so forth. But they can also have the flexibility of just programming in something versus needing a die which is something you have to manufacture.

But the biggest issue that I was trying to get at from a laser standpoint is if I go direct fiber to a laser unit, that's all well and good, you get good beam quality and so forth, but now you're stuck with one tool for one laser. The other issue is because this is moving around, programming, hardware and so forth, limit switches... they do fail at some point, operator interventions happen and so forth. So you have the ability to damage the fiber. You can impinge it. I've actually had units come back where they've driven over the fibers with a fork truck at their facility. They don't have good cable management going on. So what we do is we offer a beam switch which you see over here in this box. What that allows us to do.......

If you look at this here, it's an optomechanical switch, electrically operated. We'll bring one fiber in, in this case the direct 50 micron fiber. You can air launch it internally, into…. typically the ratio is 1.5, so if it's a 50 micron you'll want to go with a 75 micron or larger diameter, just because of the divergence of the beam. So we can take a 50 micron, and this happens to be a three position beam switch; I can go to a 100 micron, 200 micron, 400 micron beam switch.

What that allows me to do is – say 100 micron I can do cutting applications, 200 microns I can do welding, and 400 or 600 micron I can do heat treating or cladding. So cladding would be in the case that they wanted to repair that stamping tool, they could actually put metals down, get a near net form and then manufacture it down to where the tolerances need to be. Or on a die stamp they usually want to do selective heating of the part so they can actually increase the wear. So that's another thing that they can do with it. But what this allows them to do is they can switch it in the microsecond regime. Then say the standard is a 20 meter fiber. Now I can have one laser that's shared between four workstations or three workstations depending on the switch. You can always have parts moving in on a staggered sequence, so you're always using the laser so you're getting the most money out of your laser. But also, if I damage a fiber with these passive delivery cables – fork truck, impinging or so forth- it's a quick replacement. So that $5 million, $15 million an hour that the autoworkers are looking at- it's a quick replacement and it's easy to have fiber on hand versus having to send the laser back for repair or rework.

(6:27) So that's really the basic use of this laser from a robotics standpoint. Cutting, drilling, and welding. A robot isn't what I'd use for something like 3D selective laser sintering, producing large parts- I have some parts in the sample case I can show you. There you'd want to use a 12 or 14 inch very fine….. resolution. So choosing the motion control system with the right laser tool is more the integrator's responsibility, and what we do is help them select the right tool for the right job. So if you go to our Apps Labs here we've got a Haas Mini Mill, a standard workhorse you'd find in a lot of job shops, a robot which allows for a large format and a large traversing but it also allows us to really utilize the laser.

If you went back about 10 years ago, you'd find the laser couldn't keep up with the machine- the machine tool was always faster. But with these high speed, high power lasers now, what we're finding is the machine tools can't keep up. We have a video on our website where it shows remote welding applications with one of our robot arms, and the reason why they have that long standoff is to show a few things- the quality of the beam over long distances, it's a good collimated beam. And we're taking advantage of that collimated beam by standing off a slight movement at a distance of about 12 feet equals a very large movement at a distance away. So now I can actually maximize the speed of throughput and really take advantage of the speed of the laser in that case.

(7:53) The issue there is if you're a laser safety officer or facilities manager, it is an infrared beam, so you can't see the beam, there's no guide laser you can see through space and it's very easy to have human interaction, which could cause some damage. When you deal with 5 kilowatts, 50 kilowatts, that's an awful lot of power, an awful lot of energy in, say, a one millimeter spot seven millimeter spot. So you've really got to worry about eye safety and physical contact in that case.

So as you can see in this room, we've got ceramic coated panels and there's actually a honeycomb structure, which helps to diffuse the beam for specular reflection off the surfaces. In addition to that we've got laser curtains around it and that's really just for again operator safety from the specular reflection. Even though it's considered one bounce, two bounces, there's still an awful lot of energy there and even with glasses you want to maximize the safety if you can.

(8:49) A couple of things about the laser you might want to see from an overall standpoint is….You've got a few components here. Of course you've got the fixtures for the parts. You've got the laser, the optical delivery system, the nozzles for gases and so forth. You've got the motion control system, in this case a PLC driven device on the robot, but you've also got a fume extraction system system. A lot of people don't think about it, but as you mill, machine, even with welding and cutting you're producing an awful lot of fine ash or powder and you breathe this in over time that's going to cause you some problems as well. Even though it's an iron oxide, we deal with materials such as silicon, crystal silicons. We deal with a lot of what are considered hazardous materials - maybe not in the solid form. But once we go into a powder form, you're dealing with 1 micron, 2 micron particle size. It gets into the lungs and you have some issues that can build up. Silicon dust is definitely one of those issues.

Silicon has become a big field for us- solar cell manufacturing, semiconductor manufactures. In the past, silicon has always been a UV application. A UV laser is nice, but they're expensive, there's an awful lot of maintenance to them. UV does very nice machining because of the wavelength but the problem is that it destroys all the optics in its own optical path so you need constant revitalizing the laser. That means you need trained staff. You need to watch the process because as these degrade the process will change. You also need to have materials on hand- these lenses cost money and then you need downtime to replace them.

Now we've gone to a one micron wavelength, in our case 1064, very close to YAG and vanadate. What they'll do- I'll give you an example from solar cell manufacturing- is have a draw tower that creates a silicon ribbon. It's not completely flat, and they'll cut out wafers and go through an annealing process to flatten them out. With a UV laser a three inch laser takes about 93 seconds to cut out. With a one micron pulsed fiber laser, because of the beam quality, you only need about 62 seconds. So it's a lot faster, and the prices are different too.

That particular UV laser goes about $144,000, minus motion control, and the fiber laser is about $17,000. So it's considerably less. And there's no need to replace parts, there's no mirrors-it's all done with fiber Bragg gratings. There's no lamps, there's no diode banks for doing the pumping. It's actually single stripe media diodes, telecom grade, that are actually good for 100,000 hours continuous use. So a little more than 10 years. For 10 years, I've got one laser that runs fat, dumb and happy and it doesn't need intervention. That means your process … isn't changing. So now I have a tool and I set my parameters based on the process and I'm not tweaking my laser based on the materials I'm dealing with. Again, it gets rid of the need for a lot of service guys. You'll have one guy servicing fifteen machines rather than fifteen guys servicing three machines.

(12:04) If you zoom in close you'll actually see we have these little copper tips, and there's a couple reasons why they're copper and why they remove like this. One is that they certainly get damaged, impingements and so forth. Two is if you look closely at these we have different diameter sizes based on what we're doing with them. So you'd pick different nozzles with different orifices based on the processes you're doing.

A larger orifice for slow flow gas is very good for welding, it helps to bring in a shielding gas for that, but if you bring it in at too high pressure it will actually draw in oxygen from the surrounding air which you don't want to do. So this is done with a nozzle and what's called a sparging head, where it's basically either metal or ceramic and they just float gas over the process to shield it. In case of a cutting application, you want high pressure – and you typically use oxygen to facilitate cutting – so you'll have a smaller orifice. But again, these do wear out. There's back reflections that go on.

But what you'll see internally here, you've got the lens. So you change the lens depending on the spot size you select, and then internally here there's also a window that is actually between where the gas delivery delivery nozzle is and the optic itself. There's a few reasons for that. One is the high pressure gas is helping to keep any materials from going back in and damaging my lens, which would be expensive. But it's also separating the high pressure gas from the lens so as I change the pressure I'm not putting any pressure on the lens itself. So I'm not changing the beam coming though that lens and changing the beam characteristic.

(13:40) I can change the beam through a couple selections: I know my fiber diameter, I know my collimator length. I can change my collimator; this is actually a plug in.. Let me show you what that is at the end of that fiber.

What we've got is – internal to here is a 50 micron fiber. It's water cooled. It's fusion spliced into a coated quartz block. There's a few reasons for this. (So there's a quartx block here.) What it's doing is, if I have 6 kilowatts in a 50 micron spot, that's a very high fluence, very high energy density. If I was to get dust, debris –certainly there's quite a bit here- or just the oils on my fingers, it's an awful lot of energy and it would burn the end of the fiber and could actually destroy the end of the fiber. A lot of companies are job shops changing these based on the process needs. What you want to do you want to expand the beam up to where the fluence is lower, the power density is lower. But also if I destroy this it's a lot easier to replace this than to have to recleave the fiber.

You'll also notice it's water cooled to take care of any thermal launching going on, and there's two gold plated pins here. And what those do, when they plug into the collimator, they close a circuit that goes all the way through the fiber. If I cut this fiber, if I break into the fiber, it shuts the laser down for safety purposes. Because again, the beam is not launching into an optical path- this (fiber) is my optical path. If I was to cut this in some way I could have laser light on the table and I could actually ruin my process, my machine and my operators or my safety guys. So there's a safety lock circuit as well.

Then you'll notice there's a keyed switch here. So when that goes in there's an optical alignment based on that. So it's very robust for replacement. We have another unit that's not here that screws onto this unit that is a quartz window that's been coated for high transmission. If they touch it and destroy it it's just a consumable they can throw away and replace. It saves quite a bit of failure in the field. Handling is important, but you'll find that a lot of people still damage these on a regular basis.

(15:52)So there are a lot of non-laser safety issues, day-to-day practices you want to get used to. One is you never want to touch an optic with your bare hands. You'll find in all of our labs we have non-powder-coated latex gloves and we dispose of these on a regular basis. You'll see acetone, you'll see in some cases MEK depending on what they need to do cleaning of the optics when they put them in the beam path. Because certainly you are touching the optics in some cases. Usually you hold them from the side. But once you've placed them certainly there is the chance to get a thumb print or finger print which can damage optics.

What you'll also notice here-this just happens to be one, there's five more inside this cabinet- is we've got a bank of different gases, nitrogen, helium, oxygen. Based on the material that we're cutting or welding we change the shielding gas appropriately. if you're dealing with a CO_2 laser, a lot of time you'll be using helium as a shield gas. And the problem with that it's a non-replenishing resource and it's getting very scarce and very expensive. Factories like cheap and abundant. Nitrogen is a very nice way to go- I can use it as a gas or use the liquid for a cooling process.

When you're dealing with a very thin plastic material- a capton film or an ITO film- what happens as you cut it is it will tend to stretch if it's on a membrane. So what you can do is you can actually float cooled, chilled gas through nitrogen that will fix the material and keep it from peeling back so you can keep your geometry constant.

(17:38) What's nice about the fiber laser versus some of the older units is in the old days you'd always have a robot or x-y table or so forth. Let's say you have a set of x-y stages for cutting …….....this can run $60K to $120K. A robot like this can run about $30K. So I can have my x and y stages to move my part around and do all my flying cutting motion with the robot. And while I'm loading a new part I can actually scoot this robot off of that stage and then do complex geometries and so forth. So the workstations themselves are changeable.

But what I was pointing out here is again, cost savings and automation. What they do "lights out", they load the parts and then leave and come back the next day and the parts are processed. What's going on here is a standard solenoid system and then we switch through the bank internal to pick the gas. This is turning on the gas only when needed. So you're saving gas and it's also adjusting the flow rate based on the process. So again, it becomes a programmable tool rather than requiring an operator to make changes on a case by case basis.

(18:43)To give you an idea of scale, a 6 kilowatt cabinet is this size and that's the chiller for it, the coolant. A 6 kilowatt laser in a traditional YAG would probably be about the size of this room and the chiller is usually larger than that. That causes some problems. If they've got a bulk chiller and they bring in house water, which you can see we're doing, that's one way to do it, with a water-water exchanger. The problem is a lot of times they'll drop a new laser product in and they'll have to put a chiller nearby, and in this case it's water to air. Which means I'm now taking heat out of the laser and blowing it into the room, which means now my HVAC and the facilities manager will have to take into account. That'll affect overall cost for the building. You have to keep the temperatures for the operators and the machines at a certain range.

What we - if you look at the back of any of our larger lasers you'll actually see a small air conditioning unit. That air conditioning unit is doing a few things. It's keeping the laser cooler so the chiller has to work less but it's also maintaining a dew point within the laser. I was at a facility last week in Philadelphia, metal Henry building, concrete pad, very thin walls, absolutely no air conditioning. In the summer let's say it's 78 degrees in the building. In the winter it's about 45 degrees. What they do is move air conditioning and heating units around to keep their operators comfortable, but the laser has to be maintained at a certain range and dew point. Dew point is important- you don't want water forming on your circuits and on your optics.

(20:19) We don't build systems here, we just build lasers. So what'll happen is company A will have a part they want to cut. They have a price model they want to stay within. So they'll ask me to do a couple of things. They'll send me samples, and we'll choose the appropriate wavelength 1 micron, 1.5 micron (which is the eye-safe wavelength)

There's a nice graph in pretty much every physics optical textbook that shows the absorption spectrum of a material. Metals play really well at one micron, especially aluminum- there's a very nice peak around one micron. So our YAG, your YLF, your vanadate, your ytterbium - they're all at one micron- 1064, 1053, 1057 or 1070 (nm) in our case.

So if you have the absorption spectrum at that one point, that means I need less power to get the same amount of work done than if I work outside of that peak. And it falls off fairly sharply. So a lot of the traditional use for the YAG or the CO_2 is right around… for the metals. The problem is that if you go back to that now a YAG is 1060, just about 10 times greater than a CO_2, so now I just did the exact opposite of what I just told you; I've gone well outside of that absorption spectrum so I'm pumping in lots of power. (*Note: CO_2 wavelength is 10600 nm, 10 times YAG.)* Traditional YAGs or CO_2s is between 1 and 6% wall plug efficiency, so again getting back to trying to be aggressive and competitive financially if I'm putting in x amount of and only 2-4% of it is actually being used for work and the rest is being dumped out as heat, which is why I need those chillers, that's where I affect my HVAC, my heat load to my building, that's where my electricity bill comes into play. Certainly these are things we don't want to deal with if we don't have to. The fiber laser tends to be 25-35% wall plug efficient. We're getting much more efficient with better conversion rates. There's reasons for that as well; I'll get to them in a second.

Back to the selection. So you send me a part. It's a metal so I'm going to jump right on one micron, typically that's where my peak is. Now the question is how fast can I cut it, if I can interact with it at all. We'll usually do a matrix test. A matrix test is…typically you set up a series of cells, whatever you're doing, cutting, drilling, welding and so forth, and what it does is set the x axis for speed, 100 mm/sec, 200 mm/sec, 600 m/s- you usually want to do that as kind of a ramp. And in the y axis you'll do frequency- how fast am I pulsing it? A pulsed laser, I'm getting peak power by chirping the pulse that'll affect one thing. So a 20 watt average power laser can actually give you a 7 kilowatt peak.

And I want to see exactly where that material will play well for certain speeds. And I can look at that matrix and say ok at 200 mm/sec at 20 watts at 50 kHz I have very good material interaction. So I have a very quick process instead of having to go through huge deal the matrix is a quick way to do this. The other reason we do that is that this is a large part. A lot of the parts we get are medical parts, and they tend to be about 2 mm by 2 mm in area and they don't have a lot of real estate to play with. So we have to find out very quickly. And they tend to be very expensive parts so we don't get a lot, only get about half a dozen total, and at least half of those have to be final parts to return to the customer with a good process. So I have a very little amount of real estate to deal with. We try to come up with the best way to maximize the testing.

So lets say we go through and find out that this material reacts very well at 3 kilowatts at 18 meters per minute. That's perfect, except the customer only wants to spend half that amount of money. So now I have to choose a laser in their price range, and say, ok this is your best process, what is the best process in your dollar band…….. So that would be a one micron test.

(24:25) What we're doing now- and we'll show you a machine we're working with across the hall- there are other materials you use say, ceramics, so you've got green ceramics (before they're fired), white ceramics, low shrinkage blue ceramics some of which are used for implantables like defibrillators, pacemakers. Ceramics typically work really well with the CO_2. The old rule of thumb is that if it's a CO_2, it's organics; blood, bone, wood, paper, these types of applications.

If you went into outer space and looked down at the earth and did a spectral, you're actually going to see a very large peak for CO_2. That's why the interaction takes place there. So what we're doing now is, we've got a CO_2 laser that's been very well qualified and understood in the field, and we're taking that same system and putting a fiber laser on and processing the same materials. We're gonna do it one micron, at 1.5, at 2.1, so, ytterbium, thulium, erbium wavelengths, and we want to see what material behaves best at what wavelength. But we're doing it on the same machine for a reason because if I take one machine and two laser tools, and it's the same physical machine, I can take the machine out of the equation. And now it's laser versus laser. Because if I did some tests on the robot and everything else on the CO_2 on a different test bed, there are different- backlash in the machine, standoffs in the machine and so forth. But if I do them all on one test machine it's a true comparison study.

(25:55)[What about the spot size compared to CO_2? You're doing some very delicate...]

Oh, certainly. Again, when you're dealing with the wavelength you're thinking what is the fundamental limit that I can get with my laser. Something that's really important- it's hard to explain to people up front if they don't understand it, they don't want to deal with the math and they're used to dealing with, say, and end mill- is if I take a spot that's, say 100 microns and I do one set of process parameters. If I halve that spot, I haven't doubled the power, I've done it by a factor of four because you have to think of the area. A lot of people don't think of that- well, I've doubled my spot – well, halved my spot so I've doubled my power. No, it's actually four times the power. That's a good point to bring up.

That can again be affected by changing the fiber diameter that we talked about, changing the collimator length or the focal length. In a lot of cases you'll see that our lasers of lower power will come with a fixed collimator. Typically they give about a 7 mm spot size and there's a reason for that as well. A lot of the processes we do are galvo based. So here we're actually moving the laser across the part, or across the hall you'll see them moving the part below a fixed beam for perpendicularity with smaller parts.

In a lot of cases they'll want a fixed part and they're actually steering the beam with galvos. Galvos are just high speed mirrors that are selected for size based on the spot coming in. The smaller mirror you can use, the smaller clear aperture you need, the faster you can go. The problem is, the smaller the beam, the larger it can actually get on the workpiece. So if I can get the beam to be larger prior to coming into the final focusing lens, I'm filling the aperture of the lens and I can actually get a smaller spot on target. A smaller spot on target means a higher fluence, so I can get a smaller laser to do the same work. So again, for the customer, the price of the laser goes down. And actually the efficiency goes because you're using less energy to run the laser so electrical consumption goes down. That's very important as well.

(27:55) [Can you mention why beam quality is important?]

Oh. Beam quality is really important. Let's talk about the fundamental YAG. Typically a resonator is about a meter long. The longer the resonator, the better beam you can get, but it also becomes more finicky because of the longer rail length. You've usually got a high reflector and a partial reflector that makes your resonator, and you've usually got a Delran or Teflon housing that's gonna hold your gain medium. In that case it's YAG- yttrium aluminum garnet. So you've got something about the size of a chapstick-it's a very large bulk medium, and then I've got end or side pumping going on with either diode bars or lamps.

Now we talked about that 1 or 2% wall plug efficiency? The reason is I'm hitting it with a flashlamp so I've got this large spectrum of light going in trying to get one wavelength out, so the coupling efficiency is poor. If you use a fiber laser you've got these single stripe emitter diodes that are about 960 nanometers, and I'm trying to get one micron out, so it's already very close.

Let's get back to the resonator for a second. So I've got two mirrors, I've got the cavity where I have my lamp and so forth, I've got my bulk media and flowing water will take all that heat out that's not being converted properly. Then I've got usually a Q-switch on there that allows me to release the pulse after it's gone a certain amount of trips. So the problem with that is with that Teflon block and the water, what you've got is a clear flow rod- it's glass- and what it allows me to do is get a nice laminar flow over that bulk media. The problem is, as I pump it harder there is more and more heat and with that flow a thermal gradient takes place. It's cool on the outside from the water, but it's very hot in the center of that, and what happens is the beam starts to spread by internal lensing.

With a fiber laser, you've got about a 7.5 micron core. With that 7.5 micron core there's no thermal gradient that takes place. It's a very long medium that's very fine in diameter. With no thermal lensing taking place, the beam product when it runs through its dynamic range – in this case we go from 105% (power) down to 10%- so a 6 kilowatt laser, I can run it all the way down to 600 watts and I get the same beam product out which is very important. I'm just selecting a power, speed and frequency and so forth based on the process and I'm not actually tweaking my laser based on the need for that particular day or hour even if I'm job shopping. That's important.

Now here's what happens. On that rail what you normally have just after the key switch, prior to the partial reflector where the beam's going to come out, you'll usually see a lot of laser integrators or a lot of laser manufacturers block will have a block there with a set of knurled knobs, and these knurled knobs will have different diameter orifices in them- 1 mm, 1.5 mm, 2 mm. So let's say I've got a 6 mm raw beam coming out; I'll select the appropriate aperture to take out all of these multimodal or interference patterns that are appearing. So what happens is I've got poor efficiency going into the YAG to start with- bad wavelength match-, then I've got a number of trips trying to select out my laser energy, and then I take that 6 mm beam and get rid of the bulk of that energy because it's not useful. So I've got, you know, 1.5 mm of clean beam coming out, let's call it. But I've still got side modes because there's still a little multimodal going on there, and going through an aperture you're going to create a pattern anyway. So now I've got poor efficiency, selecting out energy, so now I've got really poor efficiency.

What I want is the cleanest beam I can have, which takes all the energy of the beam and puts it into the useful part of the beam. So if I've got one nice Gaussian distribution, that's gonna be (my aim). But with a multimode or traditional YAG or YLF, there's all these side lobes, what they'll do is - there's not enough energy there to say "Process the material I want," but there's usually enough energy in there to interact with the material. If I'm doing like a single silicon crystal, what'll happen is that'll cause what's called a heat affected zone and that'll interact with the material. So now it'll cause peelback if there's any chips or any laminations on there. It's gonna cause heat affect and heat affect is going to cause the single crystal to go to some sort of amorphous or some other nondesirable type of silicon for processing. They usually have to grind that off or work it out with shielding gases.

With a fiber laser, because it's coming through a 7.5 micron, 10 micron core, what I've actually done is I've constrained it now so it's truly a single mode laser. There are no side-nodes because they can't exist inside the fiber. Now all of that energy that was wasted and dumped by the aperture in the old method is being turned into usable energy. Again, I can use less energy, I can select a lower power – instead of a kilowatt I can use 750 watts. So I can select a smaller laser, a better price point. But it also allows me to produce a smaller spot on target. When you use the laser with the side lobes they'll actually be imaged on the part. You can see a series of concentric rings- like if you throw a rock into a pond and see the wavelengths coming out. Same idea- and you want to get rid of those.

(33.30) Lastly, the most important part from my processing stand point, again, for cutting applications, with that YAG there's another reason they're putting in that aperture. They have what's called an astigmatism in the beam. Astigmatism is referred to as a cat's eye. Instead of a nice round spot, so if I move in x and y I have even energy density, I'll have something shaped more like a cat's eye. So in this axis I've got more time on target. It's narrower, so I have higher energy in one axis than in this axis.

A good example is if you cut a circle you'd see slitting in one application and you'd see a wide… and it may not do slitting. So I have to increase my power so the lower powered axis can still cut. Then I'm overcutting the other axis. It also changes the geometry and the shape of the part. It's no longer round – it's thinner on this axis because the beam is so wide and it's wider on these two ends so I have an elliptical cut out.

(34:23) This uses a Q-switch. It's basically a piece of quartz, in this case, where we're striking it with a frequency. It changes the lattice structure which basically makes an optical switch. We then take that small seed pulse and put it through a two-stage linear amplifier and then we amplify it up to the power we need. Even though it's 20 Watts average power we're getting gains of something like 7.4 kiloWattts. So it's peak energy that only exists for about 100 nanoseconds in time. What's nice about that is two-fold: one is you get a lot of energy to do work and ablate the material but it's only on target for a short period of time so there's not a lot of heat being applied to the part. This is a problem for a lot of processes, especially thin metals and plastics.

That laser then comes through a delivery fiber, which is armor clad just for the safety of the fiber itself (it's safety interlocked), an optical isolator, which typically consists of a polarizer and a quarter wave plate, and then we've got a collimator which is going to give us a nice collimated parallel beam coming out. That beam is then launched into a galvo head over here, which is a series of galvanometers, two here in this case- two mirrors coated for the appropriate wavelength- in this case one micron, and then a focusing lens.

This is a 163 mm lens, which is going to give a roughly four inch by four inch mark field, and spot size is around 28-40 microns. So based on that energy density…. If you look over here at this software, what they're doing is actually delineating the mark field of this particular galvo and lens arrangement. So as I select a different lens, a different file will launch. What we've done here is selected different parameters; in this case, they call them pens in this software, this is telling me the power of the laser, how hard I'm pumping the diodes, the speed- how fast I'm traversing along the part, and the frequency- how fast I'm turning the laser on and off to get those pulses. Low frequency means I get more trips (through the laser) and more trips through the laser means I get higher peak power. High frequency means I get more pulses in a period of time, but there's less time for them to get that gain going through the medium so I get lower peak power but better average power.

So once I select that pen, I can create some feature, a 2-D barcode, which seem to be the biggest thing for marking, for traceability and so forth. 2-D barcodes seem to be the biggest flavor because they have redundancy. If I lose one line in a standard barcode I lose all the information. This one here is called ECC200. It's used by aerospace and medical and it actually has redundancy of about 35%. If I lose part of that mark through wear and tear in the field I can actually still recover all the information. It may actually include from 50 to about 500 characters.

So we're gonna mark this as "on-target;" what we're using here is a pointer so you can actually see where the process is going to take place. Now you watch the mark take place. It's not actually engraving, but rather heating the material. Based on time on target and energy, fluence, we can get different colors out of the material. It's an oxide formation, so as the light goes through that oxide you get different colors. We're talking about a material maybe a few angstroms in height, so there's nothing that would cause wear and tear on other parts. Oh, ok, there's the part, it's done; that took 62 seconds. If I was to do that same mark as just an engraving… there. It's more impressive to the camera, and a lot faster. That one took four seconds, and that can be optimized by spot size and so forth.