MICRO-MACHINING WITH NANOSECOND PULSED FIBER LASER BEAMS M606

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Abstract

Nanosecond pulsed fiber lasers have made a significant impact on general marking applications. There is now a greater appreciation of the versatility of these laser sources for industrial micromachining applications The low cost compact nature of these sources coupled with the virtually no maintenance requirement gives users a fit and forget option.

Some MOPA fiber laser sources allow users to vary to pulse width and also to operate over wider pulse repetition rate than conventional 1 micron sources. This flexibility in adjustment can enable users to optimise the pulse characteristics for more challenging applications. Fiber lasers can also deliver specific beam qualities through internal fiber design and this has opened up further opportunities with significant benefits to micromachining applications.

Applications beyond the traditional marking are reviewed, including; deep engraving, thin film patterning, micro cutting, drilling, cleaning, scribing and even soldering.

The current generation of pulsed nanosecond fiber lasers are highly flexible, versatile and reconfigurable and are capable of a broad range of micromachining applications.

Introduction

Fiber laser technology has been the dominant new “laser source” in the last decade, proving itself to be a disruptive technology as well as an enabling one. This position is set to continue. Its challenge to traditional 1micron laser sources such as Nd:YAG and Nd:YVO_4 has resulted in wide spread displacement of these sources. Pulsed fiber lasers now represent 1 in 3 laser sources in the marking space. The recession of 2009 hit demand hard for all sources, but sales of fiber lasers held up better than many other laser types.

As we see the predicted upturn in the economy the expectation is that fiber lasers will continue to benefit and sales growth will outpace traditional 1 micron sources.

The key drivers for the adoption of pulsed fiber lasers are that they offer users a compact, low cost and highly efficient source solution that has no maintenance or cavity alignment requirements, yielding a lower total cost of ownership. These lasers are air cooled and so do not require the chillers that most other solid state lasers need to operate at even modest power output levels. The use of single emitter diodes means that the need for diode replacement may never arise, whereas with diode pumped solid state lasers the need to change diode bars is a costly requirement every few years. For non technical users fiber lasers truly represent a fit and forget solution.

The latest generation of nanosecond pulsed fiber lasers are highly flexible offering a range of configurable pulse options and are available with tailored beam quality giving users greater scope for process development and enhancement. Recent increases in peak powers and pulse energies are opening new applications beyond marking and turning these lasers into highly capable micro-machining tools.

Pulsed Fiber Lasers

As the technology has evolved the number of pulsed fiber laser suppliers has increased offering choice to the end users and fostering a healthy competitive environment. Not all lasers offer the same levels of capability due to the varied technical solutions employed by the various suppliers.

The majority of solid-state pulsed laser sources rely on q-switch technology to generate the pulses often limiting the operating pulse frequency range (lower and upper range) and offering no option to change the pulse length. Many fiber lasers use the same pulse generating techniques and suffer the same limitations. However, fiber lasers with more sophisticated MOPA (Master Oscillator Power Amplifier) designs, using directly modulated semiconductor seeds allow greater flexibility in the control of pulse parameters such as pulse duration and frequency. Such designs can give a range of 1Hz – 1MHz and even operate in CW (continuous wave) operation.

SPI's current MOPA design offers fast rise pulses with high peak powers challenging those achievable by other solid state lasers. Recently introduced models give peak powers >20kW and pulse energies >1.25mJ giving 40W average power at 30kHz from a compact air cooled source. Using its proprietary PulseTune technology the pulse length can be varied from 10-240ns helping maintain high peak powers at the higher repetition rates, with some models capable of >10kW at 250kHz. [1]

Materials processing with pulsed lasers is a greater challenge when compared to CW lasers, as there are far more parameters that can influence the quality and productivity of the process. These parameters include peak pulse power (kW), pulse energy (mJ), pulse frequency (kHz), average power(W), pulse duration (ns) and beam quality (M^2). A combination of all of these parameters needs to be considered in the majority of pulsed laser materials processing applications.

Beam Quality

A key feature of the beam is beam quality, which is typically defined by the M^2. Conventional wisdom suggests that the lower the M^2 the higher the beam quality which is true, but does not always reflect the needs of specific applications. The beam quality has to be considered in a context of "fitness for purpose". Low M^2 give smaller focused spots and a greater depth of field and are ideal for applications requiring small features. However, the resulting high central point peak powers can be problematic for applications where large area processing is required (large logo marking) or where substrate damage can be an issue such as in thin film patterning applications or cleaning type operations. For such applications higher M^2 are preferable giving a broader more uniform power distribution. In this case we are not referring to multimode outputs or "flat top" beams with M^2 >8 as these tend to have insufficient peak power and intensity for the majority of the ns pulsed laser applications. All that is required is a very modest change from an M^2 of 1 to 4 and the impact of materials processing can be significant. SPI has a range of tailored beam qualities in its pulsed portfolio to cover a wide range of applications.

The impact on applications is predominantly linked to the focused spot size that can be achieved and this can clearly be demonstrated on marking and drilling applications where the impact of the spot size is dominant. Single shot pulses on anodised aluminium clearly show the influence of beam quality and M^2 (Figure 1).

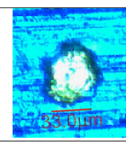
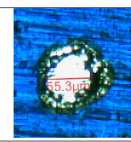
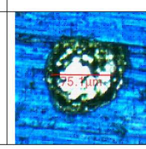
Laser	SM – 20W	HS – 20W	HM – 40W
M^2	1.2	1.9	3.2
Spot size $1/e^2$ (calculated)	30 µm	45 µm	75 µm
Mark diameter (measured)	33 µm	55 µm	75 µm
Image of single spot mark			

Figure 1. The Effect of beam quality on spot and feature size

Pulsed Fiber Laser Applications

Initial applications for these lasers were restricted to basic marking, but as the reliability and capability increased so did the application space. The flexibility of these sources quickly led to the use in novel applications such as silicon cutting, scribing, drilling, thin film patterning and cleaning. The list of applications is still growing!

Laser Marking

Laser marking is a challenging application as the appreciation of quality can be very subjective and is highly dependant on the end use of the mark in question. [2] Many marks are purely related to coding where basic legibility is often considered sufficient and marking speed is the prime requirement, whereas marketing marks such as commonly used in giftware the visual quality take higher precedence over speed.

In the majority of marking applications the pulse repetition rate is the prime driver for marking speed. Marking relies on overlapping spots to create the marked lines that we see. Insufficient overlap produces a rough scalloped edge, often a sign of going to fast or using to low a rep rate (Figure 2). Marking applications that require high pulse energies and peak powers tend to be carried out at low repetition rates typically in the 20-30kHz range and at slow marking speeds <2m/s. This is typical of many metallic marking applications where significant pulse energy and interaction time is required in order to get an adequate mark.

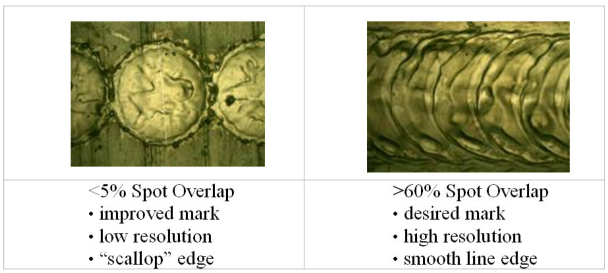


Figure 2. Mark quality based on spot overlap

However, processing materials or specific marks that are more thermally sensitive is best done using shorter pulses at high repetition rates, this significantly improves the control over the heat input to the process. Processing of polymeric materials particularly benefits from the ability to maintain high peak powers while limiting overall heat input. In these cases the pulse energy is not the key process driver. For many plastic marking applications the peak power of the pulse is the controlling feature of the pulse responsible for creating the colour change. The pulse energy and overall average power can lead to localised melting. This can result in a reduction in contrast and so in many cases high average powers can not be used. Some pulsed fiber lasers with lower frequency limits (20kHz) are sometimes limited when processing these materials. The ability to use shorter pulses with sufficient peak power to promote colour change at higher rep rates contrast can be maximised and localised melting minimised yielding improved marking (Figure 3).

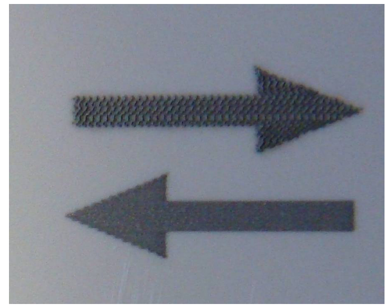


Figure 3. (Top) 25kHz 0.8mJ mark excessive material damage and mottled mark, (Bottom) 375kHz 0.05mJ even fill with good smooth high contrast mark 5m/s

Applications benefiting from high repetition rates

The flexibility in the frequency operating range of some pulsed fiber lasers can offer specific process benefits. [3] In addition to the plastic marking example in Figure 3 other applications where >100kHz pulse rates benefit marking include: Black anneal marking on stainless steel, colour marking[4], IC marking, Night and Day marking (selective paint removal) and thin film patterning (Solar & FPD) [5] .

Black anneal marking is a commonly used technique for marking stainless steels. This application differs from general metallic marking in that surface melting must be avoided at all cost. In order to get an intense dark mark control of heat input is critical and can be best achieved by using a combination of high repetition rate, pulse width control and a tailored mode (Figure 4).

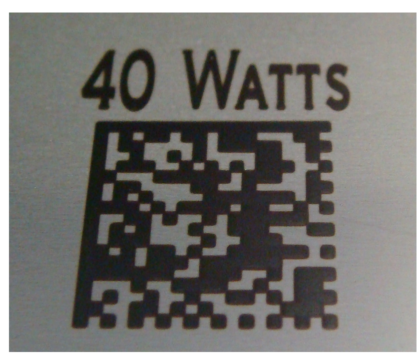


Figure 4. Black anneal mark on stainless steel made in focus with 40W laser

Micro-machining applications

The use of pulsed nanosecond fiber lasers has extended beyond the conventional marking into the micro-machining regime.

Deep engraving of metals is perhaps the closest application to marking where multi-pass operations remove significant material to produce high quality contoured surfaces. High quality precision engraving is a good example where control of pulse characteristics can be critical. The best results are often not at the highest peak power or pulse energy. Companies specialising in intricate 3D engraving utilise the flexibility offered by the various waveforms to optimise the material removal regime for any given application. A commercial example is ALE who specialise in roll engraving using a range of materials including brass (Figure 5), which is considered a difficult material from a processing perspective. These companies have proprietary methods combining optical arrangements, fill techniques and pulse parameters generating processes where just a few microns of material are removed per pulse but with exceptional quality.

Figure 5. Rolls created by ns pulsed fiber micro-machining.

Deep engraving has conventionally been a lamp pumped YAG application as the smaller ns pulsed fiber lasers have lacked both pulse energy and peak power, However, SPI's 40W HM laser with >20kW peak power and >1.25mJ has shown itself to perform well in this application achieving high bulk material removal rates >3mm^3/min. Ideally suited to the engineering industries growing need for alphanumeric and 2D data matrix codes. While the higher beam quality afforded by the 20W SM enables feature sizes in the order of 10microns to be achieved.

Other materials including more exotic materials such as glassy carbon can be readily micro-machined. As a material the high melting point and unique hardness properties of glassy carbon make it difficult to conventionally machine, so the laser provides a welcome solution. Work performed by Cambridge University shows the precision that can be achieved with repetitive patterns such as this array of close packed grooves (Figure 6) done with a 20WHS 0.8mJ pulsed laser [6].

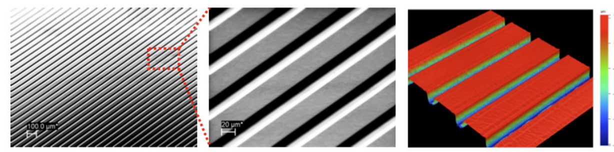


Figure 6. Micro-machining of grooves in glassy carbon image courtesy of Cambridge University

Laser drilling

There are numerous industrial applications for fine holes that can not be manufactured by conventional mechanical means in a wide range of materials. Holes with diameters <100microns are more typically machined by pulsed lasers. Examples include filters in materials such as stainless steel where close packed arrays of high toleranced holes are required with minimal thermal distortion to the part. Up to 400 50micron holes per second can be machined with a 40W pulsed fiber laser in a 200micron stainless steel sheet (Figure 7).

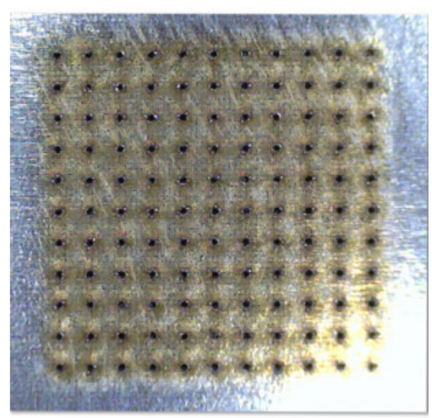


Figure 7. Array of drilled holes as processed with 40W fiber laser

Applications where lines of blind holes for scribe and break applications are also widespread primarily in the manufacture of semiconductor ceramic substrates. In the 90s this was an application dominated by the CO_2 lasers but the larger spot size means that their use for the manufacture of small parts is uncompetitive. For this application the high beam quality and the resultant energy intensity means that pulsed fiber lasers are becoming the tool of choice. Deep high aspect ratio holes which give clean break characteristics are needed and these are best produced by single mode pulses. In this application the beam quality is critical as the difference in M^2 from 1.3 to 3.2 can result in a difference in hole aspect ratio of 5:1 vs 2:1 (Figure 8)

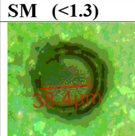
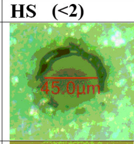
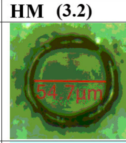
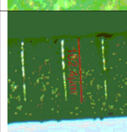
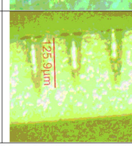
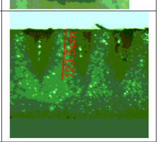
Laser	SM (<1.3)	HS (<2)	HM (3.2)
Ceramic drilling surface hole size			
Ceramic Drilling hole profile			

Figure 8. Effect of mode quality on drilling

Laser cutting with pulsed fiber lasers

A growing application is the use of nanosecond pulsed fiber lasers is for thin foil cutting. Laser cutting using conventional CW and ms pulsed lasers is well known and extensively used. However, the cost of these systems with lasers and XY manipulation is high compared to a pulsed fiber laser and a simple scanner. Using multi-pass technique no processing nozzle or assist gas are required. Cutting speeds on thicker materials are extremely slow, however, at thicknesses below 200 microns respectable speeds and good cut quality can be achieved [7]. Even cutting highly reflective materials such as silver, copper, brass and even gold can be achieved (Figure 9).

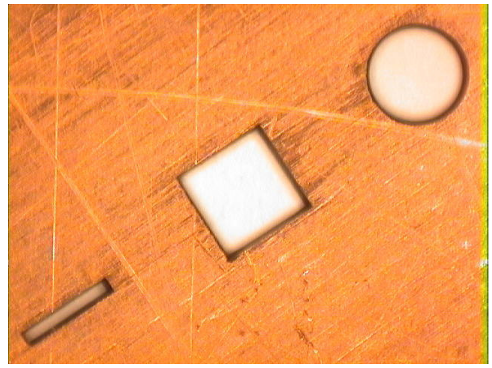


Figure 9. Copper cutting with 20W pulsed fiber laser courtesy of Miyachi Unitek

Laser Cleaning

The use of short pulses can also be effectively used for a range of cleaning applications. An example of this is a rubber mould tool that can suffer from a build up of material which results in poor part release and even reduced part quality. Periodic mould cleaning using a high repetition rate laser ensures high machine up time and enhanced product quality (Figure 10).

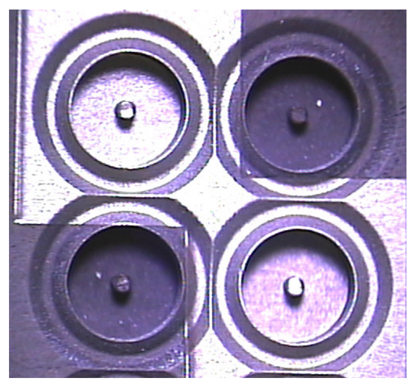


Figure 10. Rubber mould tool showing square areas that have had residue removed by laser cleaning

Laser Soldering

Soldering is typically an application that is carried out with a CW fiber laser or with a direct diode. However, in applications where the total heat input is critical to part quality the use of a pulsed fiber laser should be considered. By using long pulsed at high repetition rates improved energy utilisation efficiency can be achieved giving the required solder joints with lower associated thermal damage. Using scanner based beam delivery the laser energy can be deposited over a larger area using a carefully selected raster patterns (Figure 11).

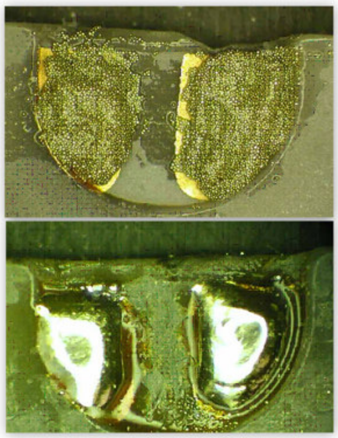


Figure 11. Solder joint made with 40W laser 240ns pulse at 500kHz

Conclusion

Nanosecond fiber lasers have now matured and are no longer considered to be just marking lasers but have become versatile micro-machining tools capable of performing multiple operations. Whatever the micro-machining or marking application the use of nanosecond pulsed fiber lasers is seriously worth considering.

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