MICRO-CUTTING WITH NANOSECOND PULSED FIBER LASERS

Paper M901

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Abstract

Nanosecond pulsed fiber lasers have made a significant impact in the material marking arena, but as laser sources they are proving to be extremely versatile finding many applications in a variety of micro-machining processes. One such process is micro-cutting.

Until recently high precision micro-cutting has been the domain of DPSS pulsed lasers and CW-M fiber lasers, as epitomised by applications such as electronic stencil and medical stent cutting. However the short high peak power pulses are proving to be ideally suited to cutting a wide range of thin <0.5mm section materials both metals and non metals!

Rather than a melt and blow process requiring a fixed optical arrangement and an assist gas nozzle assembly, the process is primarily vaporisation driven, using a scanner based beam delivery arrangement with no cutting gas nozzle, resulting in burr free cutting with minimal heat affected zones.

This study looks at the effects of beam quality, laser power and a range of pulse parameters on cutting a variety of materials including both ferrous and non ferrous metals including reflective metals, and a range on non metallic materials. The effects of various optical arrangements such as focusing optics and beam expansions are also reviewed.

The pulsed fiber laser offers a flexible low cost cutting alternative to traditional laser cutting systems.

Introduction

The laser cutting is one of the most widely used laser based processes and is considered to be the benchmark cutting process for metallic materials. The conventional laser cutting process is based on a melt and blow principle, where the focused laser beam provides the energy to melt the material while a coaxial assist gas is used to blow the material away generating a cut with a characteristic narrow kerf width and parallel sided cuts. For sheet metal cutting the CO_2 laser has been the dominant technology for the past 40 years [1], however, recent developments in laser sources and process refinements has increased adoption of 1micron solid state sources of rod, disk and fiber based technologies.

Although the process is widely used the process has to be carefully set up and optimised as the laser and gas parameters have to be well aligned to give good consistent performance. Conventionally CW lasers dominate the bulk of cutting applications, however, for finer features and improved cut quality pulsing of the beam is commonly used. Pulsing the beam provides greater control of the heat input to the process which impacts the cut quality. Good examples of fine cutting are stencil cutting for the electronics industry and medical stent manufacture [2]. Both of these applications are typified by fine feature sizes, high process repeatability and superior cut edge finish, but require sophisticated machine tools with high price tags >$200k!

Laser cutting can also be achieved by the use of a vaporisation technique where the material is predominantly removed by vaporisation rather than melting. In this process, short pulses with high peak powers are generally used and the high power densities achieved enable processing of highly reflective materials which are problematic to process using the conventional laser cutting process [1]. The process can either be single pass where the relative motion between the beam and the material is relatively slow and high levels of pulse overlap are used to achieve high quality cuts. This process is generally used with fixed optic delivery where the workpiece is moved under the laser beam and this is more often the solution adopted when using high pulsed energy Nd:YAG lasers. Using this process relatively thick materials can be cut but once again the capital cost of these laser can be high.

An alternative is to use a multi pass cutting process utilising high speed scanners to repeatedly pass over the cut line removing a small amount of material per pass. This technique offers a flexible, accurate and very affordable solution. The equipment is basically a simple laser marking system!

Nanosecond pulsed fiber lasers are ideally suited to this vapour cutting process as they are low cost, compact, reliable and require no maintenance. The short pulses and relatively high peak powers that can be achieved with directly modulated seed MOPA designs enable these lasers to be effective cutting tools.

Optical Considerations

The vaporisation cutting process relies on an incident power density that will achieve a predominantly vaporisation response from the material. Although a small spot size is a key attribute of the process it is not the only beam characteristic that needs to be considered.

Spot size

The spot size is influenced by three things:

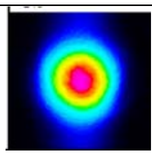
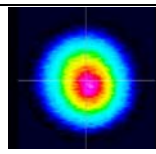
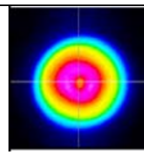
- The Focal length of the processing lens
- The incident diameter of the laser beam
- The beam quality (M^2)

M2	1.3	1.9	3.2
100mm FL	22	32	53
160mm FL	35	51	85
254mm FL	55	80	135

Figure 1 Effect of F-Ø focal length and beam quality on calculated spot size (µm) based on 8mm beam diameter.

Beam Characteristics

Although beam quality is often defined by the M^2 value the impact of the beam related characteristics are far broader. As shown in Figure 2 the M^2 has a direct correlation to the spot size, however, pulse characteristics such as the pulse energy, peak power and duration also have a significant bearing on the process.

Laser model	SM	HS	HM
Beam Quality	<1.3	<2	<3.6
Mode			
Pulse energy	*	**	***
Peak power	*	**	***
Spot size	***	**	*
Depth of field	***	**	*

*** Low **Medium ***High**

Figure 2 Laser model, beam quality and pulse characteristics

Experimental results show that all three of the above lasers can be used effectively for laser cutting, but exhibit slightly different cutting characteristics that are dependant of the material and the desired output. For example for very narrow kerf widths the SM is best suited while for thicker materials the HM generally produces better results [3].

An example of the difference in mode quality can be shown when cutting through painted sheets. A comparison of similar cuts made using identical optical arrangements using a 20W SM and a 40W HM laser showed that both lasers could cut the 1mm hole to high tolerance required but the high beam quality SM laser did far less damage but at a far lower speed, while the higher moded HM laser put more heat into the cut resulting in damage to the paint but achieved the cut through 4x faster. For the user the question is therefore one of quality vs productivity.

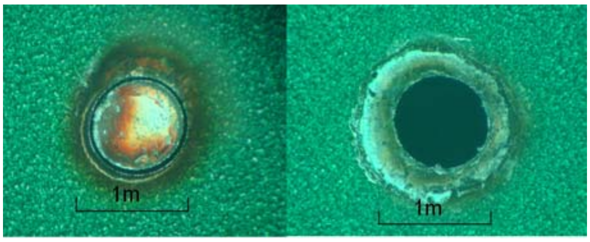


Image 1 1mm diameter holes cut in painted steel. Left: 20W SM - M^2 <1.3 2s cycle time low paint damage, Right: 40W HM - M^2 3.2 cycle time <0.5s some paint burn back

Cutting strategies

Pulsed laser cutting can be broken down into a string of individual events governed by the interaction of individual pulses. The process of cutting is the amalgamation of many such events or many overlapping pulses. Using the vaporisation process the typical pulse event is the formation of a crater whose size and shape are dependent on the incident energy characteristics. Typical removal rates can be from 1-50microns for a single pass.

The motion speed and the pulse frequency govern the amount of overlap achieved. For cutting a high level of overlap is generally required, but studies have shown that too high an overlap can reduce the material removal efficiency. This does vary considerably based on optical characteristics and the material being processed and so requires some initial optimisation.

For fine foil cutting a single pass may be all that is required, however, in the case of thicker materials multiple passes are required to achieve full penetration through the material. In this case there are a number of issues that need to be considered. For thin materials <200µm a relatively simplistic process can be adopted where the passes are coincident and each pass follow the exact same trajectory and uses the same conditions. For thicker materials the beam attenuation resulting from the aspect ratio of the kerf being >10:1, results in a reduction of processing efficiency. Adjustment of the focal position during cutting can improve the situation, but yields only marginal benefits.

To be able to cut thicker materials using this technique some novel cutting strategies need to be adopted. The key issue is that the width of the kerf restricts the ability of the beam to remove more material and so the kerf needs to be effectively widened. To some extent this can be addressed by using an appropriate spot size through selection of FL and beam diameter, but this also reduces the incident power density which effects the vaporisation efficiency to a point where a threshold is reached at which there is no significant material removal.

Beam Wobble

One technique that can be effectively used to widen the kerf is to apply a “wobble” to the beam such that the beam is effectively spiralling and a predefined amplitude along the cutting line (Image 2). This feature is typical in all scanner based marking software solutions and is extensively used to broaden line width when part marking.

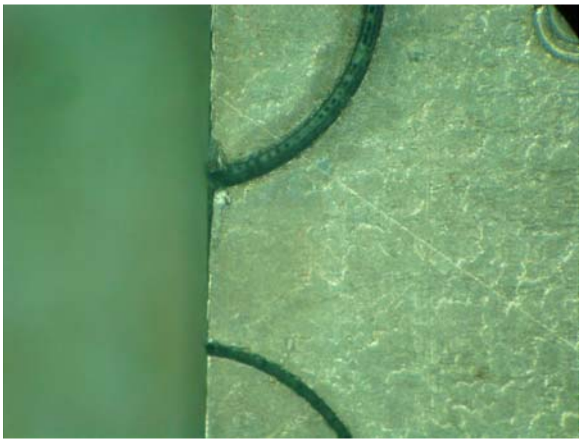


Image 2 Arcs cut showing effect of increased kerf width resulting from beam wobble (top) vs no wobble (bottom)

Cut line off-setting

Another technique is that of off-setting the cut line between passes. In this technique the cut line is displaced by a fixed distance (< diameter of the beam) between subsequent passes (Figure 3)

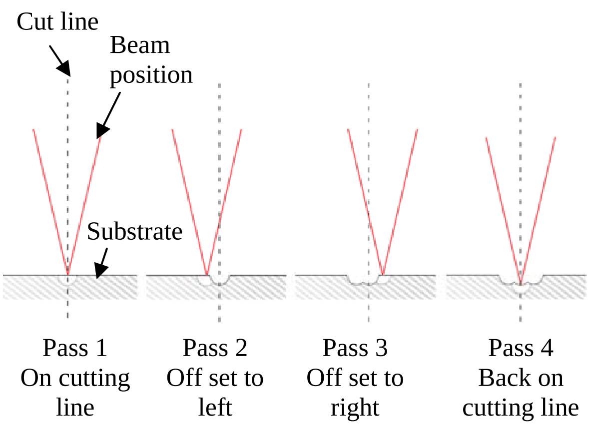


Figure 3 schematic of off-set cutting path strategy

Care need to be taken in the programming to ensure that the finished part has acceptable finished dimensions. One point to note is that on the thicker materials there can be a noticeable taper on the cut edge ~2-3°.

Using such techniques a wide range of materials and thicknesses can be cut (Image 3)

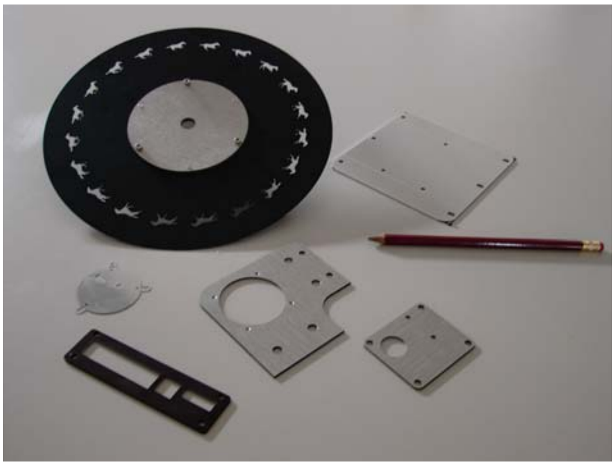


Image 3 Cut samples include: 1.2 mm aluminium sheet, 0.2 mm tinned steel sheet 0.5 mm & 2.0 mm anodised aluminium courtesy of Newson Engineering NV.

Materials Cut

This cutting process can be applied to a wide variety of materials ranging from ferritic and non ferrous metals to ceramics, polymers and carbon composites. The cutting speeds that can be achieved vary quite considerably from >10 m/min for thin foils to <10mm/min for thick >1mm materials. Compared to conventional laser cutting these speeds may be slow but for many applications the low capital cost and the flexibility offered by ns pulsed fiber laser cutting/marking systems are highly attractive.

Stainless steel

Stainless steel is a widely used material particularly in the medical industry where there are significant fine cutting requirements. Cutting speeds of >20mm/min can be achieved with good quality in 0.5mm thick 304 grade material [4].

Using a 40W HM laser with a fixed cutting head and coaxial assist gas >1.5m/min cut speeds in 200µm stainless steel can be achieved (Image 4).

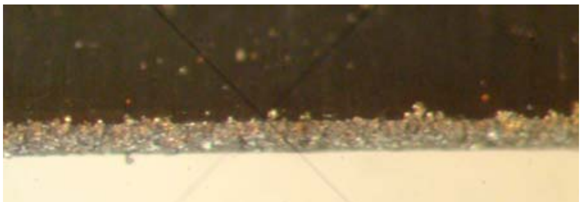


Image 4 200µm thick stainless steel sheet cut with 40W HM at 1.5m/min

Highly Reflective materials

Copper, brass silver and gold have an extremely high reflectivity and conductivity and are therefore considered difficult materials to cut. High power densities are required to initiate the cutting process and this is readily cut with ns fiber lasers.

Brass is a material that is typically considered to be difficult to cut with lasers and is often used as a test material to develop parameters for cutting gold. With sufficient peak power in the pulses excellent cut quality can be achieved in relatively thick material up to 1mm with 20W HS and 2mm with 40W HM (Image 5)

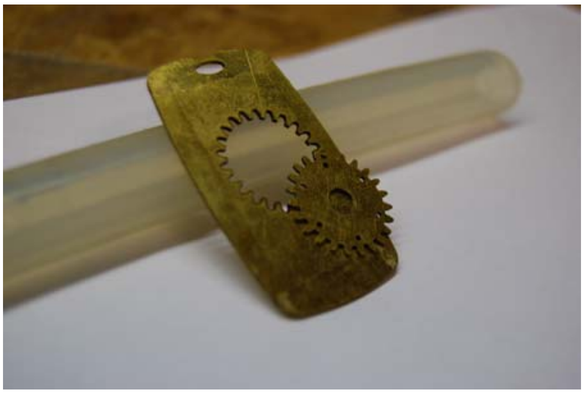


Image 5 Brass sheet cut with 20W HS 0.8mm thick in 7min image courtesy of Orotig srl

The cutting of copper has many applications particularly in the electrical and electronics areas particularly of foil type materials. An emerging application is the cutting of copper deposited tracks on PCB boards where there are requirements to cut conductive tracks on the boards.

The cutting of precious metals such as silver and gold are increasingly being done using pulsed lasers. The ability to do intricate patterns with very low material wastage is highly attractive to the jewellery sector. As an example a high quality ornately patterned silver disk of 20mm diameter has been cut using a 20W HS laser (Image 6).

Image 6 Silver disc 0.55mm thick cut with 20W in 13minutes image courtesy of Orotig srl

Silicon cutting

Silicon is a material that is widely used in the electronics and solar industries and here are numerous cutting applications. This material is conventionally diced or cut using mechanical diamond cutting wheels, however these have limitations on thinner materials and do suffer from chipping at the cut edges. The pulsed laser offers a flexible alternative that can to used to cut complex profiles and shapes with ease. The 5mm squares were cut out in 6sec using 20W SM (Image 7)

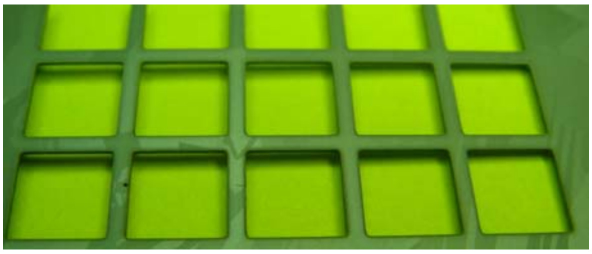


Image 7 Squares cut from 200μm thick polycrystalline silicon sample courtesy of University of Lisbon, Faculty of Sciences

Ceramic cutting

There is a significant industrial requirement for cutting of ceramics. Within the electronics industry there is a lot of thin substrate material that is cut either through scribe and break or through cutting. Again the limitation is the absorption of the material. The key materials are alumina and aluminium nitride and their ability to be cut with 1μm lasers depends on the specific material and surface finish. An example that processes well is green AlN where small discs can be rapidly cut from substrates (Image 8).

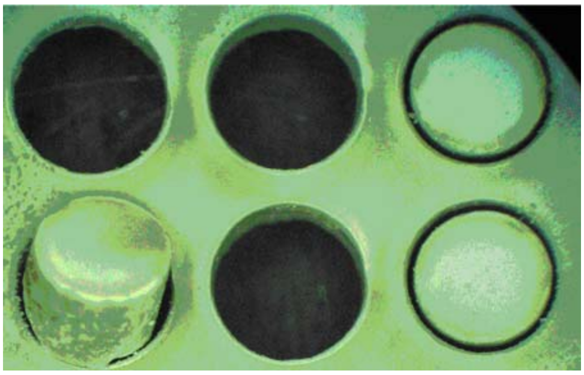


Image 8 ALN green ceramic 3mm thick cut with 40W HM laser using 6 passes at 50mm/s

Non metallic cutting

The pulsed laser can also be used to cut a wide range of non metallic materials such as plastics and even rubbers. A key factor in determining if a material can be cut is the level of the absorption of the material to 1μm laser light. Many plastics have high transmission at this wavelength and are therefore not suitable, however, some materials can be cut. An example is plastic labels which can be marked as well as cut out from the sheet with a simple change in processing parameters (Image 9)

Image 9 Marking and cutting outline of labels in heat shrink material samples courtesy of Thinklaser

Composite materials

Composites such as carbon fiber materials can be cut in thicknesses in excess of 1mm however, processing conditions need to be tailored to the material as some are more sensitive to charring. Perhaps another alternative is the cutting of multilayer materials. An interesting application is in the electronics industry where 20W HS lasers are used for component cross-sectioning. The flexibility of the laser allows all of the different material layers to be cut successfully (Image 10)

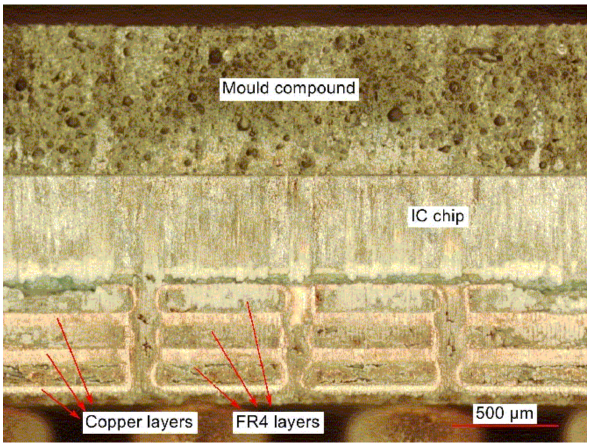


Image 10 An IC chip sectioned with 20W HS laser to show the various layers

Summary

Nanosecond pulsed fiber lasers are ideally suited to vaporisation cutting applications. This paper highlights some specific techniques that can be adopted in improve cut quality and the material thickness range and the impact that beam quality can have. A diverse range of materials can be successfully cut showing the extreme versatility of these sources.

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Meet the Author(s)

Dr Jack Gabzdyl is the Product Line Manager at SPI Lasers for pulsed lasers and has over 20 years of laser materials processing experience. He obtained his PhD in laser processing from Imperial College London in 1989. He has since had a number of technical and marketing positions at BOC Gases, Advanced Laser Solutions and TWI before joining SPI in 2007.

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