NS PULSED FIBRE LASER: A VERSATILE TOOL FOR DRILLING APPLICATIONS

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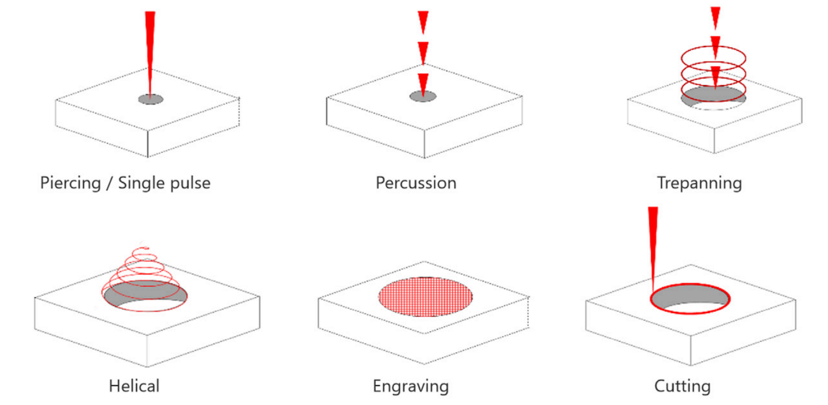

Figure 1: Alternative techniques for laser drilling

Laser drilling has found applications in almost every industry sector, from medical and aerospace to automotive, electronics and semiconductors. Traditionally, holes have been produced by mechanical drilling or processes such as chemical etching. However, with the increasing pace of technological development, end-user requirements are being driven by higher quality, faster production rates, and lower costs. Lasers are proving to be one of the most appropriate tools for many of today's drilling challenges.

The boom in photonics has created a diverse range of laser sources with different wavelengths, pulse durations, and pulse energies, making it challenging for end users to select the most suitable source for a given application. As with many industrial processes, this decision must be driven by cost, quality, and productivity.

CAPABILITIES OF NS PULSED FIBRE LASERS

Pulsed nanosecond (ns) fibre lasers such as TRUMPF's TruPulse nano range have been commercially available for around 25 years and have made a significant impact on global manufacturing. These short-pulse, high peak intensity laser sources are well known for marking, engraving, cutting, and even welding, but their use for drilling is often overlooked.

The pulse control offered by the Master Oscillator Power Amplifier (MOPA) design provides exceptional parametric flexibility. Operating in the infrared at 1.06 µm, these lasers deliver pulse energies from a few microjoules to over 1 mJ, with pulse durations from 3 to 2,000 ns, peak powers exceeding 10 kW, and repetition rates up to 4 MHz. The ability to tailor temporal pulse characteristics is key to their industrial success and effectiveness as drilling tools capable of processing most metals, as well as some ceramics, semiconductors, and composites.

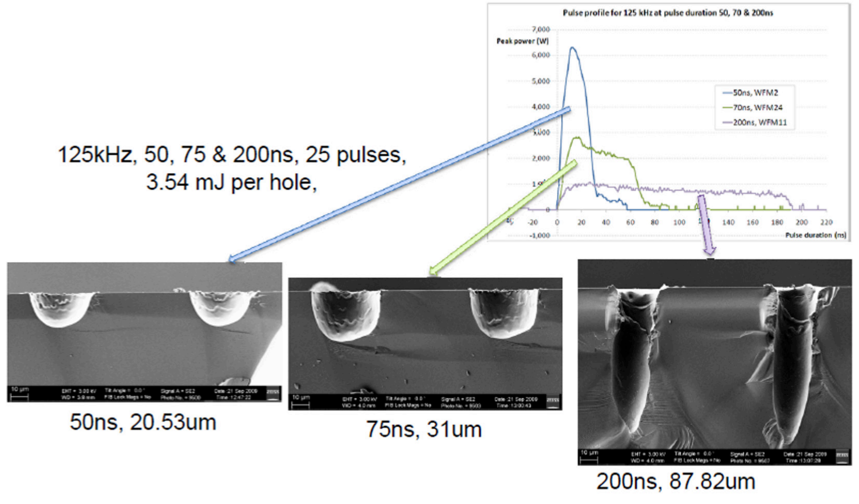

Figure 2: Drilling blind holes in silicon - pulse duration and the corresponding impact on peak power shows significant impact, with 200 ns/low peak power pulses achieving 4x the depth of the 50 ns/high peak power pulses

SCANNER-BASED DRILLING TECHNIQUES

A range of scanner-based drilling techniques can be implemented using ns pulsed fiber lasers (Figure 1). In the simplest case, a single pulse can be used to pierce very thin materials such as metallic foils. Although limited by pulse energy, the high repetition rates allow thousands of holes per second to be drilled in scanner-based "on-the-fly" processes.

For thicker materials, percussion drilling is commonly employed, where multiple pulses are delivered to a static location to increase hole depth. Hole diameter is largely governed by the focal spot size, which must provide sufficient energy density for material ablation. Aspect ratios of up to 10:1 are possible, although 6:1 is more typical for consistent, high-quality holes. Laser-drilled holes usually exhibit some taper, typically in the 3–5 degree range, which can be minimised through focal position adjustment and pulse optimisation.

Pulse characteristics such as peak power, pulse energy, and pulse duration have a significant impact on drilling performance. In blind-hole drilling of silicon at constant pulse energy, longer pulse durations with lower peak power can achieve substantially greater depths than shorter, higher peak power pulses (Figure 2).

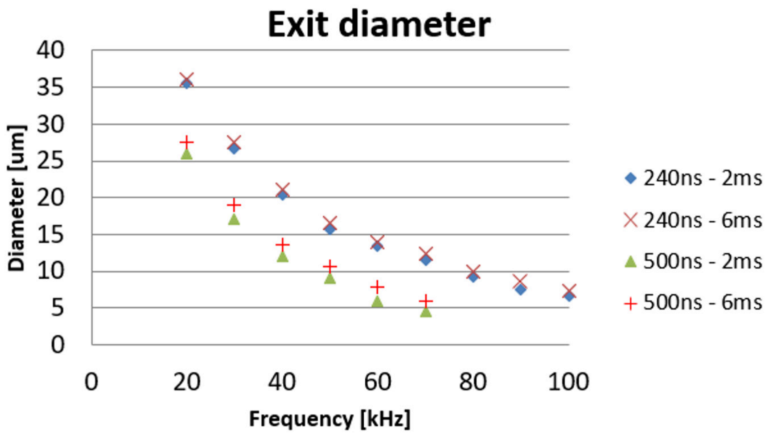

Figure 3: Drilling of 300 µm thick 5052 aluminum

It is often assumed that focal spot size determines hole diameter, but pulse characteristics also play an important role. With the focus at the material surface, the entrance diameter is usually larger than the exit, resulting in taper. However, exit hole dimensions can be significantly smaller than the focal spot diameter through appropriate selection of pulse duration and repetition rate.

In tests on 300 µm thick 5052 aluminum, consistent exit hole diameters of less than 10 µm were achieved using a focal spot of approximately 30 µm. Full penetration was achieved in under 2 ms with a 20 W laser source, and extending the drilling time to 6 ms resulted in less than 5% variation in exit diameter (Figure 3). This indicates that the process is, to some extent, self-regulating.

THERMAL MANAGEMENT

Although additional pulses may not significantly change hole geometry, they do add heat to the bulk material. This can be problematic for materials with poor thermal conductivity, such as stainless steel, making thermal management critical. Over-processing should be avoided, and appropriate hole sequencing strategies should be used when drilling large arrays.

Local temperature increases can affect subsequent holes, as pre-heating may result in larger, irregular holes with increased burr formation. One mitigation approach is "on-the-fly" drilling, where the scanner continuously traverses the material and pulse spacing is controlled by scan speed and repetition rate. Multiple aligned passes allow deep hole arrays to be drilled with more uniform heat distribution than conventional static percussion drilling.

ADVANCED DRILLING STRATEGIES

Modern scanners can achieve speeds greater than 10 m/s with positional accuracy of around 5 µm, ensuring good hole alignment. These techniques are widely used in applications such as fuel cell manufacturing. In conventional percussion drilling, jump delays can represent more than 50% of the total process time.

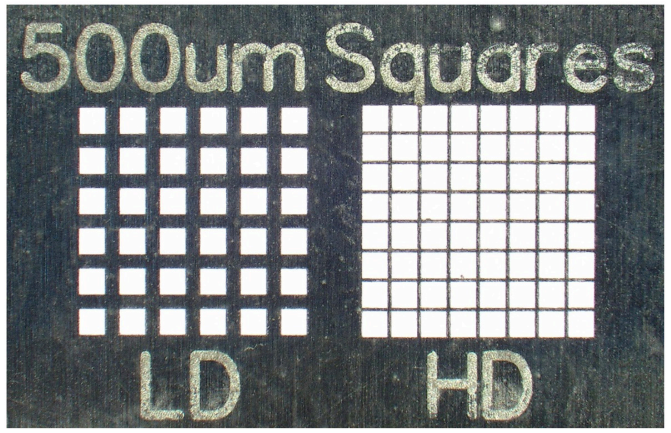

Figure 4: Arrays of 500 µm squares with corner radius of circa 10µm and web widths of <100µm can be made in 300 µm aluminum

For hole diameters larger than the focal spot size, alternative methods such as trepanning are required. In trepanning, a pilot hole is drilled and enlarged using circular beam motion. This approach is generally effective for hole diameters up to around 2.5 times the spot size, but can suffer from heat accumulation and often produces better exit quality than entrance quality.

Helical drilling is another technique in which the beam follows a spiral path to remove material. This method offers improved heat management and is particularly well suited to circular holes larger than about 80 µm, especially in high hole-density applications.

Non-circular holes can also be produced by filling the drill area with a hatch pattern, effectively engraving the required shape. These features typically need to be larger than 100 µm to achieve good definition. Although relatively slow, this method provides excellent thermal control (Figure 4).

For very large holes, multi-pass perimeter cutting offers a flexible, low heat input solution. Only the hole boundary is processed, minimising material impact and enabling dense hole patterns.

CONCLUSION

Ns pulsed fibre lasers provide a flexible and universal drilling solution. When combined with modern scanner systems, they support a wide range of drilling techniques capable of meeting many industrial requirements.

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