

# SPI Lasers' Pulse Fiber Laser

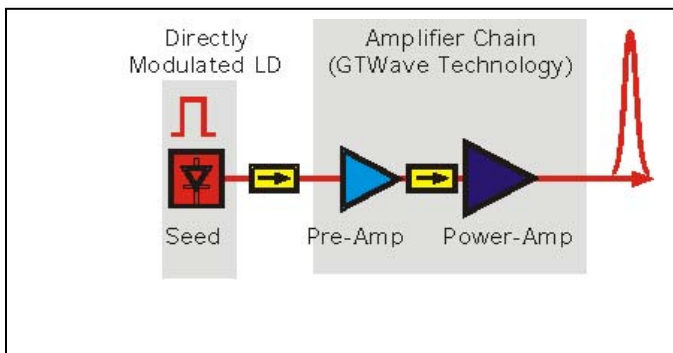
## Optimising processing performance with SPI's pulsed lasers:

For materials processing there are two main laser types; CW (continuous wave) and pulsed. Although CW Lasers can be modulated to effectively give a 'gated' pulsed output, these are limited in the maximum peak power of the base laser. True pulsed lasers can generate very short pulses with very high peak pulse powers, even though the average energy of these lasers can be low compared with CW lasers. However, these high peak powers create new materials processing regimes that can not be mirrored with CW lasers.

Laser processing with pulsed lasers is well established and although there are regular incremental improvements in laser source capabilities, step changes are few and far between. The majority of pulsed lasers rely on q-switching to generate the high peak power densities by using an external crystal to store and release energy in pulses. These devices are limited by q-switching technology that limits the flexibility of pulse frequency, pulse length and pulse energy. SPI has recently introduced a range of pulsed fiber lasers that do not rely on q-switching to generate these nanosecond pulses. This gives significantly more flexibility in terms of pulse frequency, pulse length and peak pulse power, giving users a broader range of processing parameters that enable users to optimise the pulses to specific applications.

## SPI's DM-MOPA pulsed fiber laser:

This pulsed fiber laser uses a MOPA (Master Oscillator Power Amplifier) architecture, (Figure 1), with a directly modulated seed laser that is amplified using a proprietary fiber laser based amplifier chain. This in turn allows the pulse parameters to be more effectively controlled.



This design enables high peak powers that are not achieved with standard modulation. Peak

pulse powers in excess of 14kW can be achieved at 25 kHz with an average output power of 20W. The unit also has a high pulsing frequency range from 1-500 kHz and with pulse widths in the 10-200ns range. The laser is also capable of working in continuous wave (CW) mode.

The MOPA arrangement allows control of the pulse shape, duration using a range of preset pulse waveforms are available as shown (Fig. 2) below. This flexible control over pulse width and peak power with the *PulseTune* function enables very high repetition rates whilst maintaining relatively high peak powers (Fig. 3).

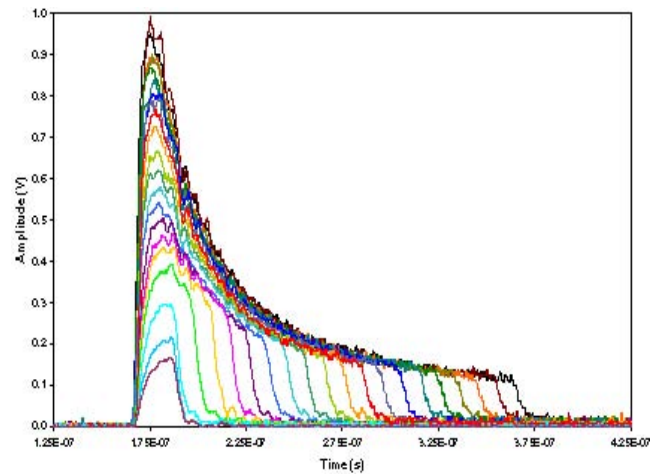


Figure 2: Pulse wave forms showing range of pulse energies 0.04mJ – 0.8mJ

Each of the wave forms is optimised based on peak power for a specific frequency. For example Wave Form 0 (WF-0) in the 20W laser is optimised to give a peak power of 14kW with a 0.8mJ pulse at 25kHz which give an average power of 20W and is categorised by a FWHM pulse length of 30nsec or a full pulse length of 200nsec. However, WF-0 can be operated at any frequency in the range of 1-500 kHz, with a corresponding impact on average power, pulse energy and peak pulse power (Table 1). This is presented as a specific example based just on WF-0 and does not show the effect of all possible combinations and permutations which are nearly limitless – and represents a key feature of SPI's pulsed lasers with *PulseTune* technology.

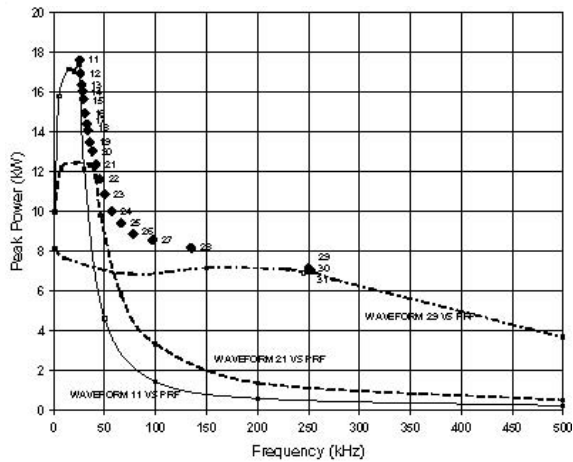


Figure 3: Peak pulse powers available over the operational frequency range.

Condition	Optimised	Lower (kHz)	Higher (kHz)
Frequency (kHz)	25	12.5	50
Average power (W)	20	10	20
Pulse Energy (mJ)	0.8	0.8	0.4
Peak Power (kW)	14	14	8
FWHM Pulse Length (ns)	30	30	60
Full Pulse Length (ns)	200	200	200

Table 1: Showing the effects of using WF-0 at above and below optimised condition.

In a given application where the primary requirement is peak power, then the wave forms should be used at optimised frequencies. However, there are a large number of applications where other factors are relevant and in these cases operating at other frequencies can give significant materials processing benefits. An example where the use of lower frequencies might be appropriate might be in the marking of certain plastics, where the peak power is required to give the required colour change, but excessive average power causes localised melting resulting in a poor final mark, whereas using higher frequencies could benefit processes such as thin film ablation, where high peak powers can lead to substrate damage.

In general, operating at frequencies below the optimised level will result in the same specific pulse conditions of peak pulse power, pulse energy and pulse length but with lower average power as a result for fewer pulses which follows a linear relationship with pulse rate. Operating at higher than the optimal frequency maintains the average power, but the peak power and FWHM can decrease quite dramatically while pulse energy decreases linearly as a function of pulse frequency.

If WF-0 does not provide the optimised pulse conditions then there are 24 more to choose from. Through careful selection of wave form, pulse frequency and set power, an extremely broad range of pulse forms can be created covering the range of 0.04-0.8mJ with peak powers in the range of 2-14kW from 1-500kHz and pulse widths in the 10-200ns range (Figure 4). With 25 preset wave forms this gives users an extremely wide scope for pulse parameter selection in process development and refinement.

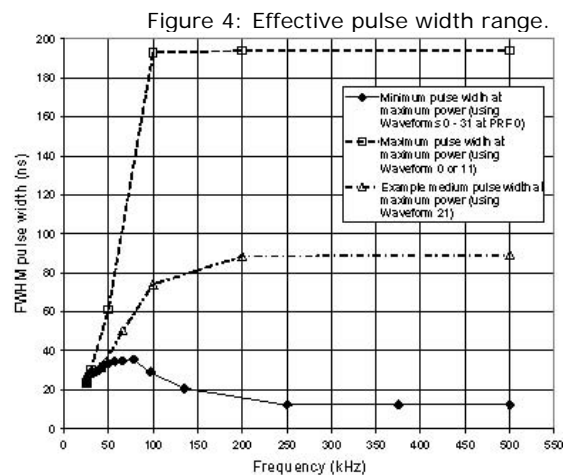


Figure 4: Effective pulse width range.



## Processing Applications:

The majority of laser materials processing applications are governed by:

- **Peak pulse power** - typically required to overcome processing thresholds.
- **Pulse energy** – it governs the amount of thermal energy available to effect any material processing.
- **Pulse duration** – it impacts the beam material interaction time.
- **Power Density** – reflects the intensity of the laser energy on the substrate.

It is a combination of all four of these parameters that needs to be considered in pulsed laser materials processing applications.

Adjusting the first three of these parameters individually is relatively easy to understand. What is not widely accepted or understood is that all of these three parameters are related and it is very difficult to differentiate the effect of any one of these individually unless changes are very large, >20%. In reality, this is impossible to achieve without affecting one of the other variables. It should be noted that power density, measured in  $W/cm^2$ , (or more correctly peak power density) has a dominant effect on materials processing and this is a non-linear function, related to the area of the focussed spot. It is widely accepted that power density on the target determines the response of the material to the laser beam. It is then the material properties that decide whether heating, melting or ablation results. So any change in power density, such as that caused by a change in focussed spot size either through switching optics or de-focussing can have a dominant effect on the laser process.

In this case where high peak powers and hence high peak power densities are employed, this is usually vaporisation and ablation. The real attraction of the high repetition rate available from this laser is that even at 500 kHz, and 40uJ average power of 20 W is still available with peak power of circa 4 kW.

The nature of pulsed processing relies heavily on overlapping laser spots to achieve the desired result. Spot overlap controls the number of pulses that each element of the target surface sees and hence controls the temperature rise of the surface in a precise manner. It is widely accepted that 30% spot to spot overlap is the

sweet spot for many laser processes although no apparent theoretical explanation appears to be available for this. At 500 kHz, this 30% spot overlap can be achieved even at high scanning speeds of 7.5 m/s, at the limit of most industrial scanners. Thus, if a longer beam material interaction time is required, as in some micro-machining and marking processes, these processes can be readily accomplished at the highest possible scanning speeds.

The processes that respond most favourably to this high repetition rate process are; the removal of absorbing thin films (most notably silicon nitride) and many plastics that mark through the process known as foaming. For some types of metal marking, in particular those that employ a polishing mechanism, excellent contrast can be achieved using repetition rates >250kHz.

Experimental results from a wide range of processes and materials have shown that having a broader range of pulse parameters can help to refine processing applications providing end user benefits in terms of quality and productivity. With the ability to operate at higher frequencies, a range of specific benefits have been identified for a wide range of materials processing applications. These include; marking, thin film patterning and micromachining applications. SPI's pulse fiber laser offers the greatest flexibility of any laser currently on the market. For further information refer to SPI's range of process Application Notes available for download from the SPI website or contact our sales team who will be able to provide you with more details.



For further information & to register for your **FREE 30-day SPI Fiber laser evaluation unit**, please contact the following **BFI OPTILAS** offices:

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20W Pulsed SPI Fiber Laser



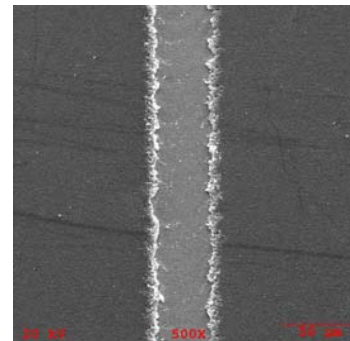
**IC Marking**

Marking parameters can be seen on the IC sample; material used is filled epoxy potting compound.

For further information:



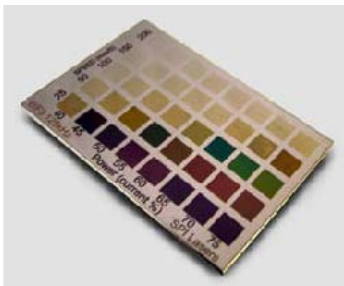
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**Thin Film Ablation**

The Scribing of Molybdenum on glass at 250 kHz, 4m/s; focal length 163 mm.

**Examples of applications benefiting from the versatility of SPI's PulseTune Waveforms:**



**Colour Marking**

Polished 304 Stainless Steel colour marked at 25 to 200 mm/s, laser power 8 to 25W at 125 kHz.



**Night & Day Marking**

Painted ABS marked at 3 m/s, laser power 10W at 500 kHz.