Micro-machining with nanosecond pulsed fiber lasers

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SPI Lasers at a Glance

- Specialists in fiber laser technology
- Focused on fiber lasers for industrial micro-machining & marking applications
- Internal R&D and production of optical fiber and key components
- Global presence
  - HQ in UK
  - Offices in Asia, Europe and USA
  - Global distribution network
The majority of laser materials processing applications are impacted by:

- **Peak pulse power** - which is typically required to overcome processing thresholds. **kW**
- **Pulse energy** - which governs the amount of thermal energy available to effect any material processing. **mJ**
- **Pulse duration** - impacts beam-material interaction time. **ns**
- **Power Density** – which reflects the intensity of the laser energy on the substrate. **W/mm²**
- **Average Power** – typically governs productivity and processing speed **W**

It is often a combination of these parameters that needs to be considered in pulsed laser materials processing applications.
Pulsed Fiber Laser Benefits

- Low cost
  - <$1k/W
- High reliability
  - 50,000MTTF
  - 2 year warranty std
- No maintenance
  - No optical components to adjust or replace
- Low Operating costs
  - High wall-plug efficiency
- Compact
- Air cooled
- Flexible pulse parameters
  - ability to use different frequencies and waveforms
Advantages of MOPA architecture:

- Pulse parameters can be controlled independently at different stages
- Extensive pulse energy and peak power parameter space
SPI’s PulseTune Optical Pulses

Directly Modulated @ 20W

Q-Switched Fiber Laser @ 20W

Increasing rep rate by using different Wave Forms with shorter pulse lengths limits peak power reduction

Increased rep rate significantly reduces peak power
Spot Overlap: Marking quality up-close

Spot overlap is a key
- Greater overlap produces a more continuous mark appearance
- >60% overlap desired for many marking applications

To increase spot overlap
- Slow down the mark until the pulses overlap
  * Or (better put)
- Increase the pulse repetition rate at your desired marking speed!
Marking Speed, Repetition Rate and Spot Overlap

Doing the numbers...
- Marking speed, pulse repetition rate and spot overlap are all related

![Graph showing calculated spot overlap for 50 micron spot size.](image)

- **Scan Speed (m/s)**
  - 0.5
  - 1
  - 2
  - 3
  - 4

- **Pulse Repetition Frequency (kHz)**
  - 20 (50%)
  - 30 (67%)
  - 40 (75%)
  - 50 (80%)
  - 70 (86%)
  - 80 (88%)
  - 125 (92%)
  - 250 (96%)
  - 375 (97%)
  - 500 (98%)

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- **Calculated spot overlap for 50 micron spot size**
  - Applications range from 40-100 microns

- **The SPI Advantage:**
  Extending process quality and flexibility at higher marking speed

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### Tailored Beam Quality & Pulse Energy

**The right tool for every job!**

<table>
<thead>
<tr>
<th>Series</th>
<th>SM</th>
<th>RM/HS</th>
<th>HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>M²</td>
<td>&lt;1.3</td>
<td>&lt;2</td>
<td>~3.2</td>
</tr>
<tr>
<td>Key attribute</td>
<td>Fine feature &lt;25micron</td>
<td>Multi purpose 35-80micron</td>
<td>Wider lines &gt;60micron</td>
</tr>
<tr>
<td>Application</td>
<td>Scribing fine marking</td>
<td>General marking and micro-machining</td>
<td>Wide marks deep engrave area/logo</td>
</tr>
</tbody>
</table>
Ceramic Comparison

Drilling Ceramic

SM  | HS  | HM
---|---|---
M2 <1.3 | M2 <2 | M2 <3.4

SM hole is 15% smaller than HS
Ceramic scribing comparison

Snap and break holes in ceramic

<table>
<thead>
<tr>
<th>SM</th>
<th>HS</th>
<th>HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>![SM image]</td>
<td>![HS image]</td>
<td>![HM image]</td>
</tr>
</tbody>
</table>

- SM hole is 30% deeper than HS

M2 < 1.3  M2 < 2  M2 < 3.4
Flexible Tool Diverse Applications

Images and samples courtesy of: Miyachi Unitek, Electrox, LMCo & Orotig

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General marking

- Metallic Layer removal
  - Anodised aluminium
  - Oxidation marking – Aluminium/stainless steel
  - Anneal marking – stainless
  - Colour marking

- Polymeric materials
  - Carburisation
  - Foaming
  - Engrave
  - Paint on plastic
Metal Engraving

Using short 80-100mmFL F-theta >7mm beams
- achieve good metal engraving!

Multi pass engrave with 30W HM utilising 2 high pulse energy passes and a 3rd smoothing pass at high rep-rate (top line of image only)

Detailed stamp engraved with 20W HS Image courtesy of ACSYS GmbH
Metal Engraving (Silver/Brass/Steel)

- Operation from CW-500kHz gives total control of peak power and pulse energy giving fine processing control
- Engrave:
  - 25kHz Waveform 0
  - 2 cross-hatch passes at 2m/s can remove 0.13mm depth
- Smoothing:
  - 250kHz Waveform 3
  - Single pass at 3m/s
  - “Whitens” mark & smoothes engraved surface

Images courtesy of: LMCo & Applied Laser Engineering

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Deep Metallic Engraving

- 40W
- Capable of deep marking
- Required short focal length lens and high beam expansion
- High repetition cleaning pass to improve

10mm
Cutting with Pulsed Laser

The high peak power and power density can achieve excellent results in scanner based multi pass fine cutting.

Copper  Aluminium  Stainless

Images courtesy of Miyachi Unitek
Highly conductive and reflective materials
- Gold – >0.4mm
- Silver – >0.4mm
- Brass – >0.3mm

Silicon

Even ceramics can be cut!

Sample courtesy of Orotig
Metallic Drilling

- 40W HM - 30kHz 1.25mJ
- Material
  - Stainless steel 304 0.2mm
  - Bronze 0.5mm
- 163mm F-theta
- 121 holes in 0.33s
  - >350 holes per second

Hole circa 50micron as processed

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Silicon Processing

- **Scribing**
  - Low rep rate 25kHz
    - Deep scribe
    - High level of debris
  - High rep rate >100kHz
    - Shallow scribe
    - Low level of debris

- **Drilling**
  - Similar effect to above
  - >400 holes/s in 200µm Si wafers with 20W laser
  - Diameter circa 50 µm
Thin Film Processing

Solar

- P1 scribing
  - Molybdenum
  - ITO
- Edge isolation
- Edge deletion
- Thin film annealing
Molybdenum thin film ablation

- P1 scribe
- Electrically conducting back contact film for CIGS or CIS modules
- 0.25-1 µm thick
- 125kHz, 4 m/s
- 30-40µm wide lines on 0.2 mm pitch
Solar Energy/Display Technology

Scribing Transmissive Conducting Oxide (TCO)

- Typically Indium Tin Oxide (ITO)
- Careful control of the pulse energy is crucial in order to:
  - completely remove the film,
  - produce minimal burr to the patterned edge,
  - lack of cracking/delamination of the TCO
  - no damage to the glass substrate.

20W; 25kHz WF0
1m/s scan speed
80µm scribe width

20W; 125kHz WF2
1m/s scan speed
40µm scribe width
Enhanced Ohmic conduction

- Annealing of thin metallic film
  - Array or overlapping spot fill techniques
  - Enhanced contact with underlying layer
  - Control of pulse to minimise damage
Thin film isolation

- Narrow controlled isolation of multi-layer films
- High repetition rates >350kHz
- High speed 1.5m/s
- Through glass
Glassy Carbon Machining

NPL Micro probe

Difficult to process
TG ~3000°C
ns Pulsed fiber laser 20W HS
Good solution for micromachining

..GC micro fluidics

Blood plasma separator

IfM UNIVERSITY OF CAMBRIDGE
Processing Rubber

- Cutting
- Drilling
- Mould cleaning
- Micro-machining
Conclusions

ns pulsed fiber lasers offer:
- Low cost of ownership
- Flexible & versatile micro-machining laser sources
- Expanding application space

Thank you for your attention!

redENERGY™

CW Performance, Versatility, Stability, Repeatability 500kHz