Welding with ns Pulsed Fiber Lasers

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VP Pulsed Lasers Business Line

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Company Overview

- Leader in Fiber Laser manufacturing & technology
- Development of highly effective Laser solutions
- Industrial macro, marking, & micro-machining
- R&D and production of optical fiber & key components – across 2 UK sites
- Vertical integration across the business
- Global ‘Sales & Service’ presence
- Focused on providing market leading products & service support.
Company History

- **1999**: SPI Lasers Founded
- **2000**: Spin out from the ORC
- **2002**: Re-launched as a Fiber Laser Supplier
- **2003**: Business Re-focus
- **2004**: CW Fiber Laser Launched
- **2005**: Stock Market Flotation
- **2006**: Pulsed Fiber Laser Launched
- **2008**: Acquired by TRUMPF
- **2012**: New Korean Office
- **2013**: New China Office
- **2014**: High Power Pulsed Fiber Laser Launch
- **2015**: Acquisition of JK Lasers
# Fiber Laser Products

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>redENERGY G4</strong></td>
<td>Flexibility &amp; speed for marking &amp; micro machining.</td>
</tr>
<tr>
<td><strong>redPOWER R4</strong></td>
<td>Power &amp; control for cutting, welding &amp; micro-machining.</td>
</tr>
<tr>
<td><strong>redPOWER OEM</strong></td>
<td>Efficiency &amp; flexibility for macro materials processing.</td>
</tr>
<tr>
<td><strong>redPOWER System (Multi kW)</strong></td>
<td>Providing exceptional levels of power &amp; control.</td>
</tr>
<tr>
<td><strong>redPOWER Multi kW OEM &amp; HPC</strong></td>
<td>Building blocks for high power Fiber Lasers.</td>
</tr>
</tbody>
</table>

## Specifications

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Power Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>redENERGY G4</td>
<td>10W - 100W</td>
</tr>
<tr>
<td>redPOWER R4</td>
<td>200W – 1kW</td>
</tr>
<tr>
<td>redPOWER OEM</td>
<td>500W - 1kW</td>
</tr>
<tr>
<td>redPOWER System (Multi kW)</td>
<td>2kW – 4kW</td>
</tr>
<tr>
<td>redPOWER Multi kW OEM &amp; HPC</td>
<td>2kW – 4kW</td>
</tr>
</tbody>
</table>

### redENERGY G4
- Easily integrated, compact and robust
- Common interfaces for all Lasers
- Enhanced connectivity
- 3 years standard warranty

### redPOWER R4
- Pulse Shape Equalisation (PSE)
- Dynamic pulse shape control
- 2 years standard warranty
- High stability

### redPOWER OEM
- Integrated power & temperature monitoring
- High power connector options
- High back reflection protection
- Multimode delivery fiber options
- Compact design for OEM integration

### redPOWER System (Multi kW)
- Low order mode fiber beam delivery
- Patented back reflection protection
- Multiple fiber delivery options
- High frequency modulation
- Integral pulse shaping capability

### redPOWER Multi kW OEM & HPC
- Optional module for system safety control
- Partnership approach with patented technology
- Integral pulse shaping capability
- Rack mount (19") format

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19/10/2015
Types of Laser Used in Welding

- **CW Lasers**
  - Laser measured by power – able to provide continuous stable laser output at rated power

- **CW/Modulated Lasers**
  - Lasers that produce a gated output with the maximum power being the CW limit

- **QCW Lasers**
  - Able to produce ms pulses at higher peak powers at reduced average power than their continuous duty operation

- **Pulsed Lasers (ref Nd:YAG)**
  - Producing short high peak power pulses with low average power.
Portfolio

Average Power Rating for Continuous Operation

Low Power
Medium Power
High Power

10 W
100 W
1000 W
Challenges for Joining

- Control of heat input
- Price vs performance
- Quality and repeatability
- Flexibility
- Joining of dissimilar materials.

How can a ns pulsed laser source address the above???
• Limited to thin sections <1mm
• Focus on Lap and spot welding
• Stainless Steel and copper
• Explore ability to weld bright metals and various combinations
ns Fiber Laser Technology

• Highly efficient
• Air cooled
• Compact
• Monolithic design
• No associated cooling issues
• No need for alignment
• No maintenance requirement.

Fit and Forget Technology
Introduction to MOPA

- Use of semiconductor seed provides greater control capabilities of the generated pulses
- Characteristic fast pulse rise - Quick to overcome processing thresholds
- Greater dynamic operating frequency range - 1kHz - 1Mhz
- User settable pulse duration - 3-500ns though up to 40 waveforms + CW operation
- Broadest pulse characteristics - Tuning pulses to specific application requirements.
Parameter Flexibility - PulseTune

• Each PulseTune waveform can be used at any frequency
• They are optimised for peak power and pulse energy-PRF0
• Operating <PRF0 gives same kW and mJ but less W
• Operating >PRF0 gives same W but <kW and <mJ.

Key differentiation to Q-switch.
System for ns Lasers

• Scanner based beam delivery
  • High flexibility & control
  • Challenging for gas shielding if required

• Fixed optic delivery
  • Through processing head
  • Lower flexibility and control options
  • Easy to apply shielding gas.

SPI G4 Laser, 70W EP-Z
163 F-Theta Lens
75mm BEC
$Z_R$ 1.2mm
$F_S$ 40um
## PulseTune Waveforms

### Waveform Description

<table>
<thead>
<tr>
<th>WFM</th>
<th>PRF (kHz)</th>
<th>$E_{\text{max}}$ (mJ)</th>
<th>FWHM (ns)</th>
<th>10-90% (ns)</th>
<th>$P_{\text{max}}$ (kW)</th>
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<tbody>
<tr>
<td>0</td>
<td>70</td>
<td>1.00</td>
<td>46</td>
<td>240</td>
<td>13</td>
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<tr>
<td>3</td>
<td>102</td>
<td>0.71</td>
<td>40</td>
<td>175</td>
<td>10</td>
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<tr>
<td>11</td>
<td>151</td>
<td>0.48</td>
<td>36</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>16</td>
<td>200</td>
<td>0.36</td>
<td>34</td>
<td>55</td>
<td>10</td>
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<td>21</td>
<td>291</td>
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<td>26</td>
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<td>10</td>
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<tr>
<td>25</td>
<td>490</td>
<td>0.15</td>
<td>16</td>
<td>20</td>
<td>9</td>
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<tr>
<td>27</td>
<td>850</td>
<td>0.08</td>
<td>9</td>
<td>10</td>
<td>8</td>
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<tr>
<td>28</td>
<td>1000</td>
<td>0.07</td>
<td>9</td>
<td>10</td>
<td>7</td>
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<tr>
<td>29</td>
<td>70</td>
<td>1.00</td>
<td>72</td>
<td>270</td>
<td>8</td>
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<tr>
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<td>34</td>
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<td>100</td>
<td>420</td>
<td>6</td>
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<tr>
<td>36</td>
<td>70</td>
<td>1.00</td>
<td>115</td>
<td>520</td>
<td>5</td>
</tr>
</tbody>
</table>
• Complex interaction of multiple process variables to control heat input
  • Spatial and temporal interaction of pulses.
## Beam Quality is Important

### Micro Laser Welding G4 Solutions

<table>
<thead>
<tr>
<th>Key Attributes</th>
<th>S-Type M² &lt;1.3</th>
<th>Z-Type M²&lt;1.6</th>
<th>L-Type M² 1.6-2.0</th>
<th>H-Type M² 2.5-3.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM</td>
<td>10W</td>
<td>20W</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HS</td>
<td>20W, 30W, 50W</td>
<td>12W, 20W</td>
<td>-</td>
<td>40W, 70W</td>
</tr>
<tr>
<td>EP</td>
<td>20W, 70W</td>
<td>20W</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Apps</td>
<td>Fine features &lt;25µm</td>
<td>25-35µm</td>
<td>Multi-purpose 35-80µm</td>
<td>Wider lines &gt;60µm</td>
</tr>
</tbody>
</table>

- **High beam quality and small spots.**
- **Broader energy profile.**

**Broad range of products offering choice of:**
- **Power, Functionality & Beam Quality**
Plastic Welding

- Traditionally a diode or CW application
- Materials need some absorption at 1µm
- Applications where spot size and depth of field are important considerations can benefit from a G4
- Either used in CW or with high frequency >200ns pulses.

“It gave me the control of the beam in terms of spot size, energy distribution and depth of field that I required”

- Joe Lovotti, Director of Laser Technologies Okay Ind.
Soldering with ns Pulses

- Usually a diode or CW application
- Miniaturisation and heat sensitivity may need a finer solution
- Using a 40W laser and a spiralling scanner based delivery
- Heat input can be minimised to just the pads. Highly localised heating!
Metallic Welding Using ns Pulses

- Need to use pulse waveforms and frequency to tune parameters to go away from vaporisation and melt ejection to a more controlled melt generation.

Weld Ø – 5mm
Beam Ø - 5mm
SpotØ – 70µm
FΘ - 163mm
V=25mm/s
Material - SS

Using high PRF with waveforms can produce a QCW weld.

Note:
Single pass no shield.

70W, 1mJ
>10kW peak,
<2% duty.

70W, 0.5mJ
>2kW peak,
<4% duty.

70W, 0.15mJ
>500W peak,
<15% duty.
Moving to Lap Joints...........

• 304 SST 150µm sheets welded in lap configuration
  • Parameters - 70W  100mm/s - 6mm Ø welds.

Similar results were achieved in 250µm sheets at 50% welding speed.
Improving Welding Through Wobble....

- Using standard scanner wobble function 100kHz wobble and 50µm radius.

| WF0 PRF179kHz | WF0 PRF490kHz | WF0 PRF900kHz |

Note: Higher rep rate was needed to give a bright smooth weld.

Note: Single pass no shield.
Micro Coil to Coil Joining

- Medical components benefit from the controlled heat input.

50µm wire to wire weld with 20W EP-Z at 250kHz.
Fine Wire Welding

• Greater precision can be achieved for wire to wire bonding
• The choice of laser can be dependent on the application.

Bonding outer metallic braid to twisted wires. 40W HS-H M²>3 SS.

Spot welding of micro thermocouple 12.5µm x 2
20W HS-S M² <1.3 Dissimilar materials.
Functional Welds?

- These welds really strong enough for serious applications.

Tests completed on stainless steel to stainless steel welds show shear strength for two 1mm welds in a full 0.5mm lap weld to be > 224 lbs. In one case with a 180 degree peel test on a linear weld 5mm long and 1mm wide, the part yielded at 241 lbs.
G4 welding 316L – Tensile Test


Full penetration on 0.5mm 304L SST lap weld with >250 lbs yield in tensile.
Trepanning Spot Welding in SS

- 70W EP- Z G4 Welding – Up to 7 lap welds per sec on 0.5mm SST.
HDD Part Welding

- Stake weld to hold parts + continuous seam with wobble
- Using 70W EP-Z.
Total Welding Flexibility

• When asked what else we could weld.......I received this!
• A cornucopia of dissimilar welding..............
  • Copper to Stainless
  • Copper to Aluminium
  • Copper to Brass
  • Aluminium to Stainless
  • Stainless to Aluminium.

...but are these welds any good?
• Joining copper to aluminium is a common joint requirement in battery and consumer electronics
• Joining 150µm Cu foil to 0.5mm Al by 3x 1.2mm spot welds done in <1sec.

11.7 LBS Static Shear Load on 3x 1mm Spots!
Welding Dissimilar Metals

• The Challenges:
  • High reflectivity, in the near infrared
  • Dissimilar melting temperatures
  • Brittle intermetallic structures
  • Different cooling rates.

**Objective:** create mechanical joints independent of these challenges with an NIR Laser using ns pulses.
Challenging Materials

- Focus on ability to weld bright metals
  - Range of material Types and combinations
  - Using spot welds.
• Method for making spot welds.

Spatially overlapping spots >98% linear fill separated by 50% the $F_s$ on the rise radius.

$R_1$, Inner Radius, 0.02mm
$R_2$, Outer Radius, 0.5mm
a, Ramp, 3mm
b, Rise, 0.02mm
The Results

- Surface quality.

Cu - Cu
Brass – Brass
Cu - Al

It’s not always a beauty contest!
Weld Properties

- Tensile strength
- Spot welds.

<table>
<thead>
<tr>
<th>Joint</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Cu-Cu</td>
<td>20 lbs</td>
</tr>
<tr>
<td>2 Brass-Brass</td>
<td>61 lbs</td>
</tr>
<tr>
<td>3 Bronze-Bronze</td>
<td>42 lbs</td>
</tr>
<tr>
<td>4 Cu-Al</td>
<td>26 lbs</td>
</tr>
<tr>
<td>5 Cu-Brass</td>
<td>20 lbs</td>
</tr>
</tbody>
</table>
Spot welds do not show characteristic form of conventional pulsed spot welds

More closely resembles multi-staking.

WF 36, 520ns, 70 KHz

Al flow to surface

Possible intermetallics

150µm

Cu in pool of solidification.
Weld Strength

- Tensile specimens all show failure in HAZ & the base metal.
Improved Results

- Post process cosmetic pass.

**Key Developments:**
- Reduced surface porosity with bright finish
- Increased joint strength to 48lbs on 150 um copper.
Lap Seam Welds

- Wobble welding can be used to great effect.
More Challenging Dissimilar Combinations

• Joining Stainless Steel 100µm foil to Titanium 250µm sheet.

“Using just a 20W single moded ns pulsed laser gives us a lot of control over heat input and weld geometry in a competitive and compact package for particularly challenging micro welding applications, such as this stainless steel 0.1mm foil to 0.25mm titanium foil.”

- Dr Geoff Shannon, Amada Miyachi America

Image courtesy of Amada Miyachi America
Applications

- The applications for fine welding is growing with the general push for product miniaturisation.

  - 50 um thick Al Battery Foils
  - Battery Cell Al on Ni-Steel
  - Copper Constantan TC <50um Combined
Cleaning with ns Pulses

• The high peak power pulses can be used for selective material removal, surface processing and cleaning
  • Selective removal of zinc pre-welding
  • Hydrocarbons and rust.
Conclusion

• Efficiency
  • low power, low cost solution
• Quality
  • repeatable and reliable
• Utility
  • bright and dissimilar combinations.

ns fiber lasers are well suited for fine welding.
ns Pulsed Lasers for Micro Welding

• S-Type & Z Type
  • Precision heat input
  • Bright metal
  • High melt temperature
  • Blind welds – penetration weld

• H-Type
  • Low mode - high quality
  • Surface flatness
  • Wires, ribbons, and coils
  • Micro welding in conduction mode.

New 100W EP-Z source.
• For further information contact: jack.gabzdyl@spilasers.com

Or

sales@spilasers.com

Thank You for your attention

Special Thanks to Daniel Capostagno for the practical work
redENERGY® G4 ns Pulsed Fiber Laser

Versatility comes as standard...
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