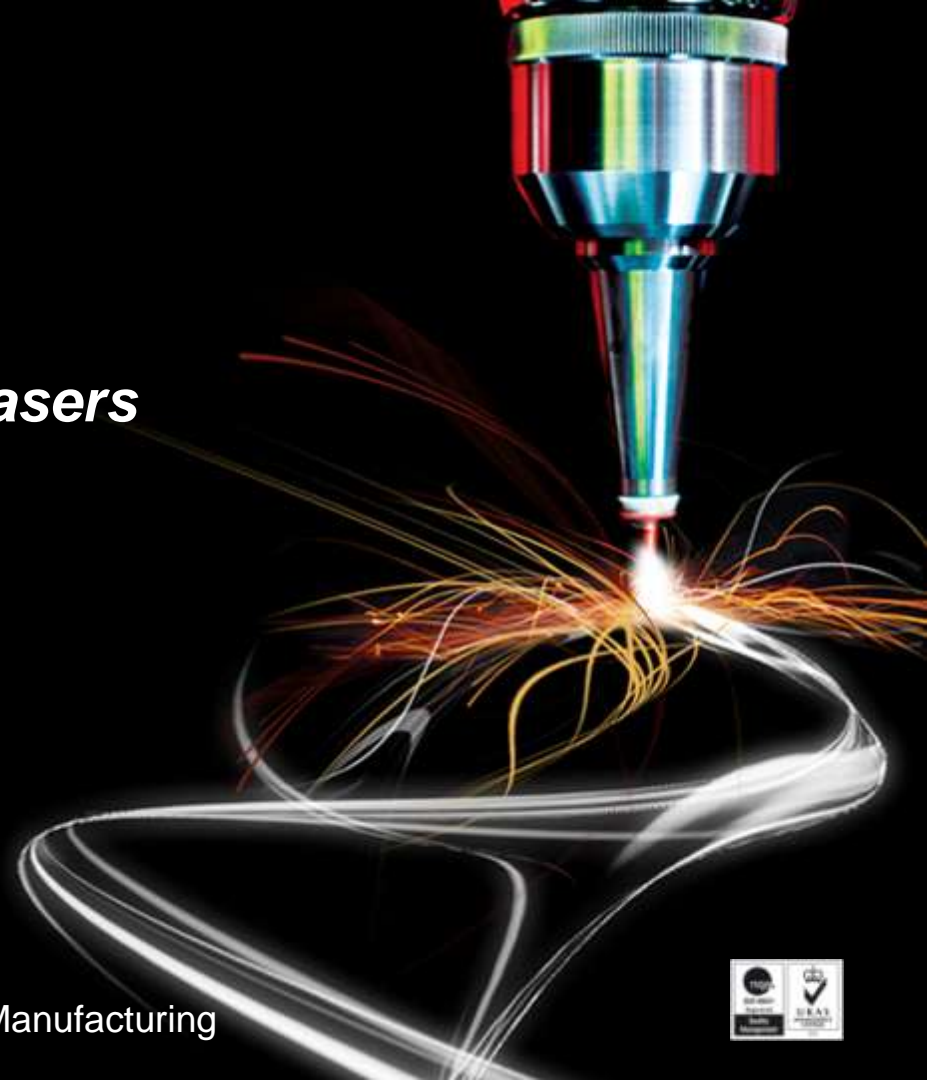




Welding with ns Pulsed Fiber Lasers

Dr Jack Gabzdyl
VP Pulsed Lasers Business Line

19th November 2015



Marking | Cutting | Welding | Micro Machining | Additive Manufacturing

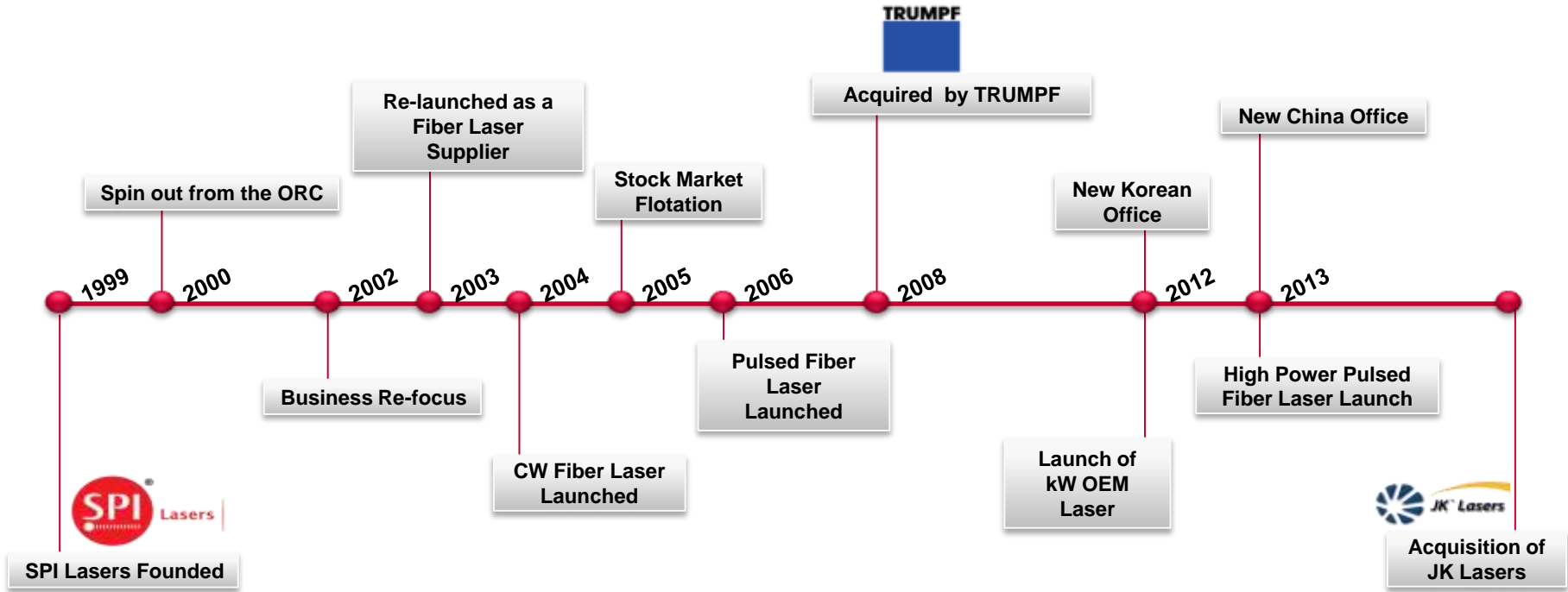


Company Overview

- 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



JK Lasers has joined SPI Lasers.
One company, stronger together!



Fiber Laser Products

redENERGY G4
Flexibility & speed
for marking & micro
machining.

redPOWER R4
Power & control for
cutting, welding &
micro-machining.

redPOWER OEM
Efficiency & flexibility for
macro materials
processing.

**redPOWER System
(Multi kW)**
Providing exceptional
levels of power & control.

**redPOWER Multi kW
OEM & HPC**
Building blocks for
high power Fiber
Lasers.

10W - 100W



200W – 1kW



500W - 1kW



2kW – 4kW



2kW – 4kW



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

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

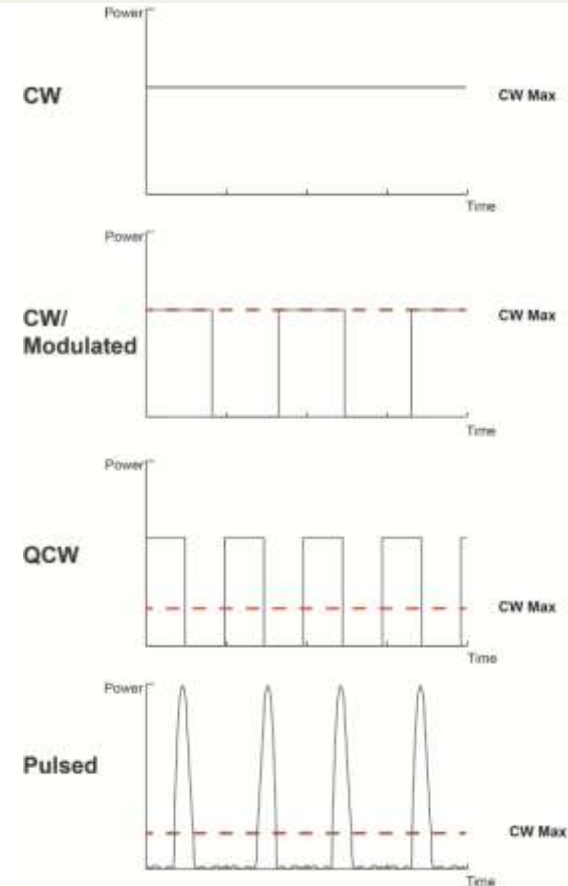
- Integrated power & temperature monitoring
- High power connector options
- High back reflection protection
- Multimode delivery fiber options
- Compact design for OEM integration.

- Low order mode fiber beam delivery
- Patented back reflection protection
- Multiple fiber delivery options
- High frequency modulation
- Integral pulse shaping capability.

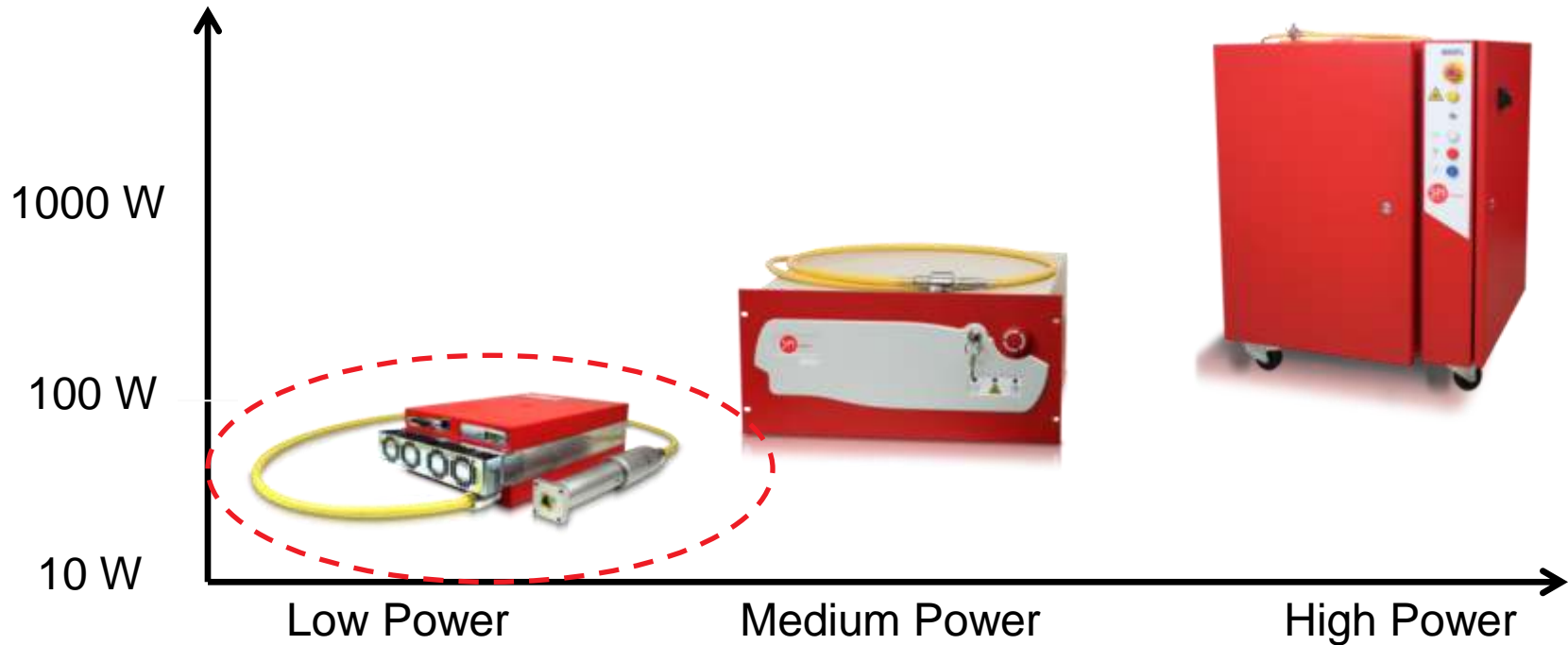
- Optional module for system safety control
- Partnership approach with patented technology
- Integral pulse shaping capability
- Rack mount (19") format.

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

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.

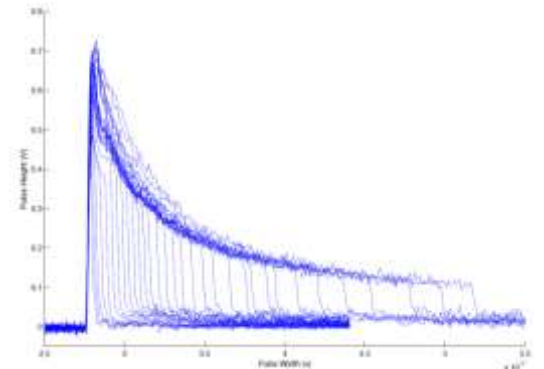
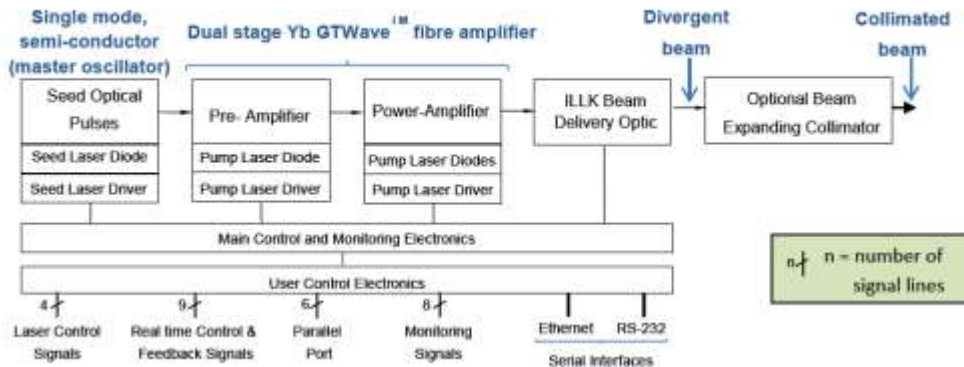


**Fit and Forget
Technology**

Introduction to MOPA

- Use of semi conductor 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.

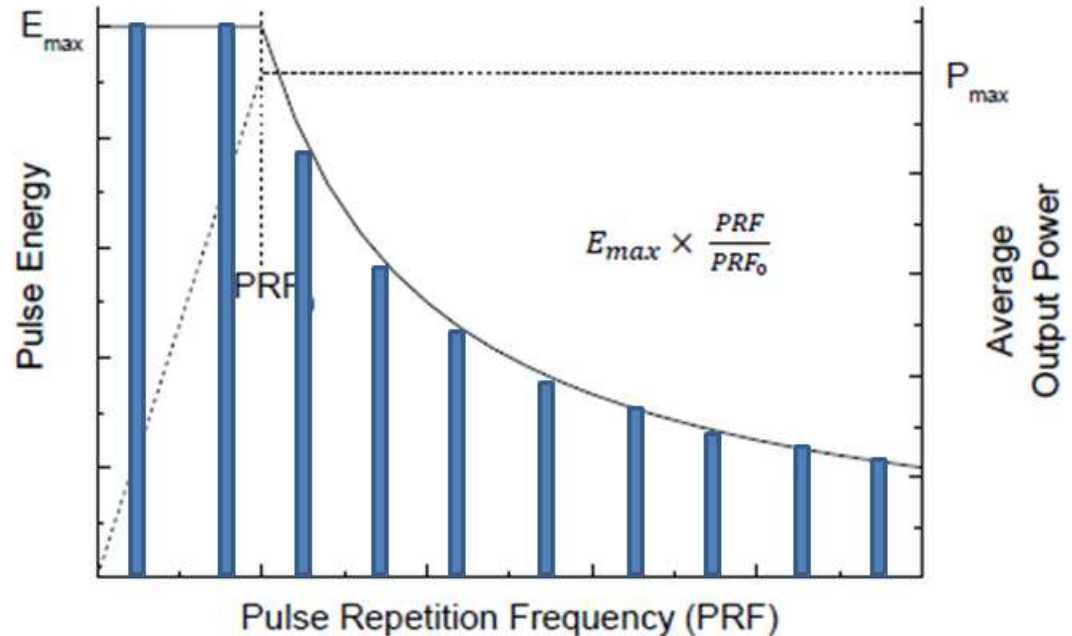
G4 System Architecture



Parameter Flexibility - PulseTune

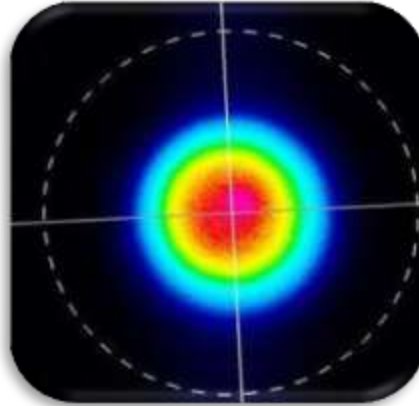
- Each PulseTune waveform can be used at any frequency
- They are optimised for peak power and pulse energy-PRF0
- Operating <PRF0 gives same kW and mJ but less W
- Operating >PRF0 gives same W but <kW and <mJ.

Key differentiation to Q-switch.

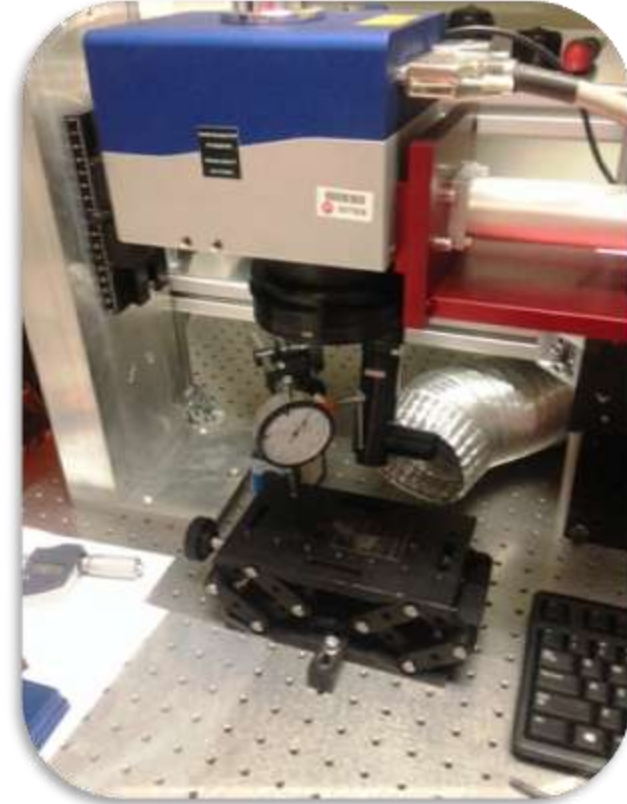


System for ns Lasers

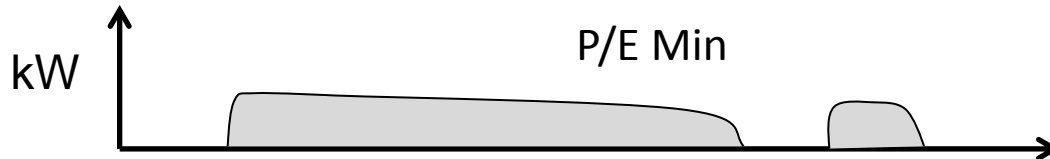
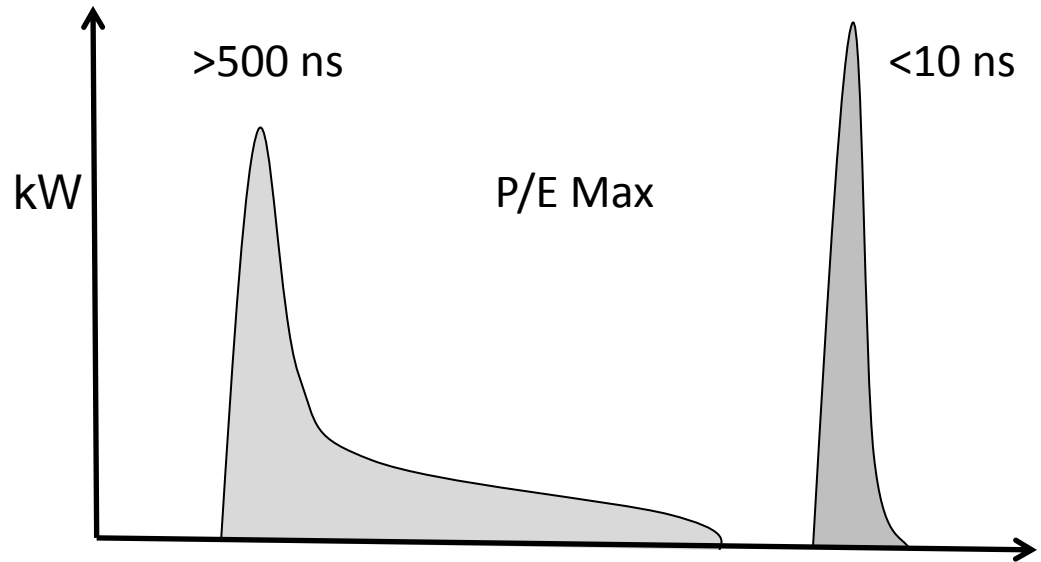
- Scanner based beam delivery
 - High flexibility & control
 - Challenging for gas shielding if required
- Fixed optic delivery
 - Through processing head
 - Lower flexibility and control options
 - Easy to apply shielding gas.



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



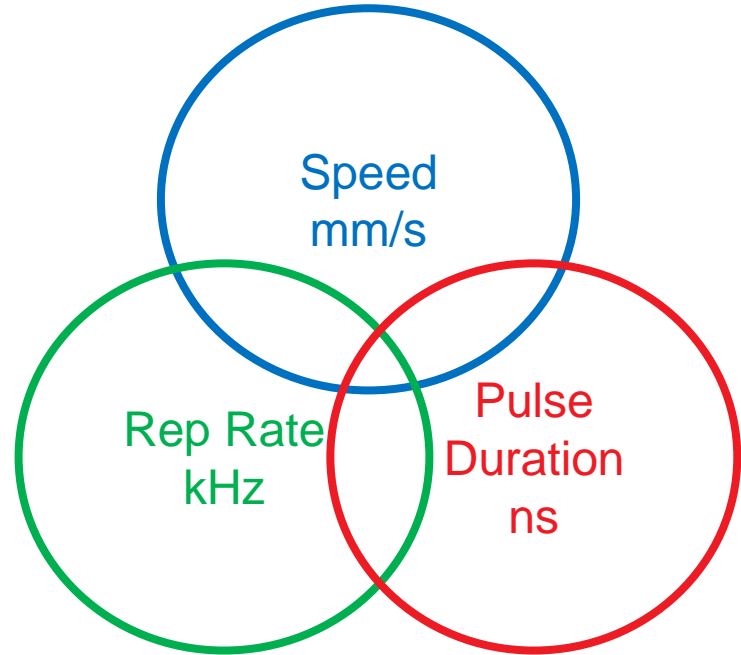
PulseTune Waveforms



WFM	PRF 0 KHz	E_{\max} mJ	FWHM (ns)	10-90% (ns)	P_{\max} KW
0	70	1.00	46	240	13
3	102	0.71	40	175	10
11	151	0.48	36	90	10
16	200	0.36	34	55	10
21	291	0.25	26	33	10
25	490	0.15	16	20	9
27	850	0.08	9	10	8
28	1000	0.07	9	10	7
29	70	1.00	72	270	8
31	70	1.00	85	320	7
34	70	1.00	100	420	6
36	70	1.00	115	520	5

Process Variables

- 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

	S-Type $M^2 < 1.3$				Z-Type $M^2 < 1.6$		L-Type $M^2 1.6-2.0$		H-Type $M^2 2.5-3.5$			
RM	10W	-	-	-	20W	50&70W	-	-	-	-	-	-
HS	-	20W	30W	50W	-	-	12W	20W	-	-	40W	70W
EP	-				20W	70W	20W		-			
Key attributes	Fine features <25µm				25-35µm		Multi-purpose 35-80µm		Wider lines >60µm			
Apps	Scribing (P1) Fine marking				↔		↔		General marking & micro-machining			
Wide marks deep engrave/ logo												
Broad range of products offering choice of: Power, Functionality & Beam Quality												

High beam quality and small spots.

Broader energy profile.

Plastic Welding

- Traditionally a diode or CW application
- Materials need some absorption at $1\mu\text{m}$
- Applications where spot size and depth of field are important considerations can benefit from a G4
- Either used in CW or with high frequency $>200\text{ns}$ 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!



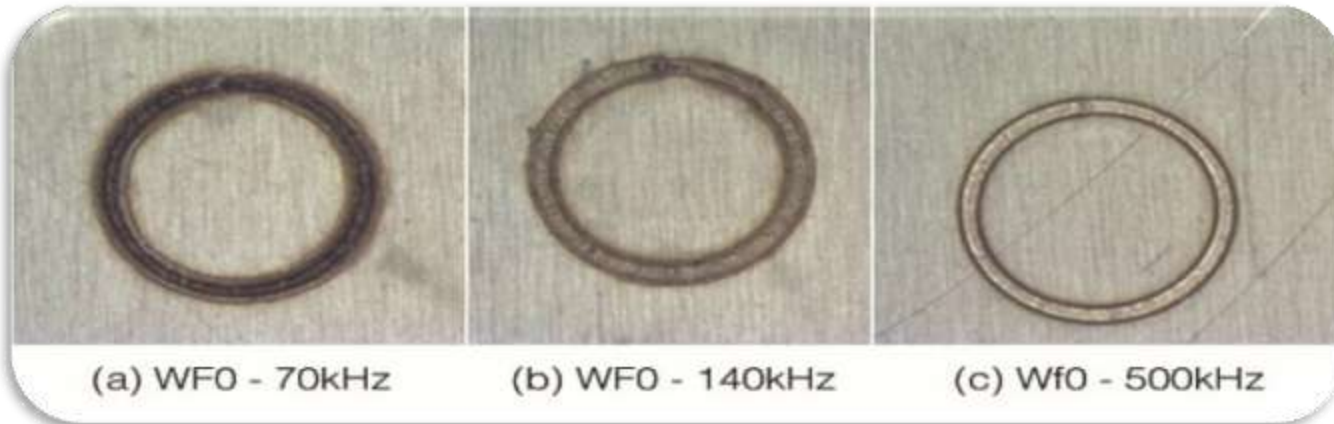
Solder mesh on Au plated pads.

Soldering with 40WHS-H at 500kHz.

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
 FØ - 163mm
 V=25mm/s
 Material - SS



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



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



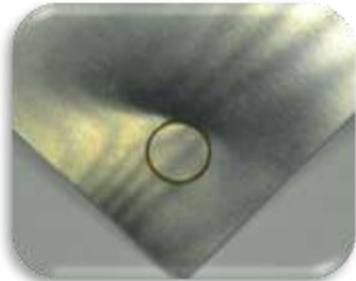
70W, 0.15mJ
 >500W peak,
 <15% duty.

Using high PRF with waveforms can produce a QCW weld.

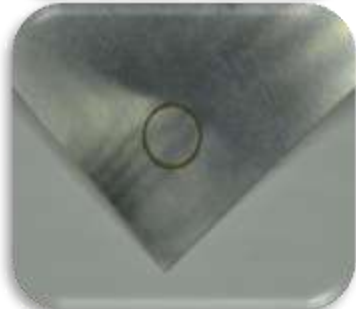
Note:
 Single pass
 no shield.

Moving to Lap Joints.....

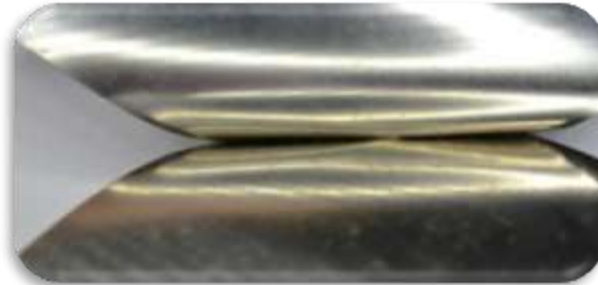
- 304 SST 150 μ m sheets welded in lap configuration
 - Parameters - 70W 100mm/s - 6mm \varnothing welds.



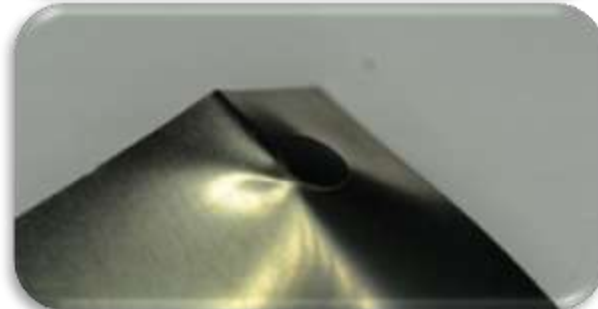
Top weld view
no cover gas



Bottom weld view
full penetration



Weld under
manual peel
stress



Failure mode
at weld
interface

Similar results were achieved in 250 μ m sheets at 50% welding speed.

Improving Welding Through Wobble....

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



WF0 PRF179kHz



WF0 PRF490kHz



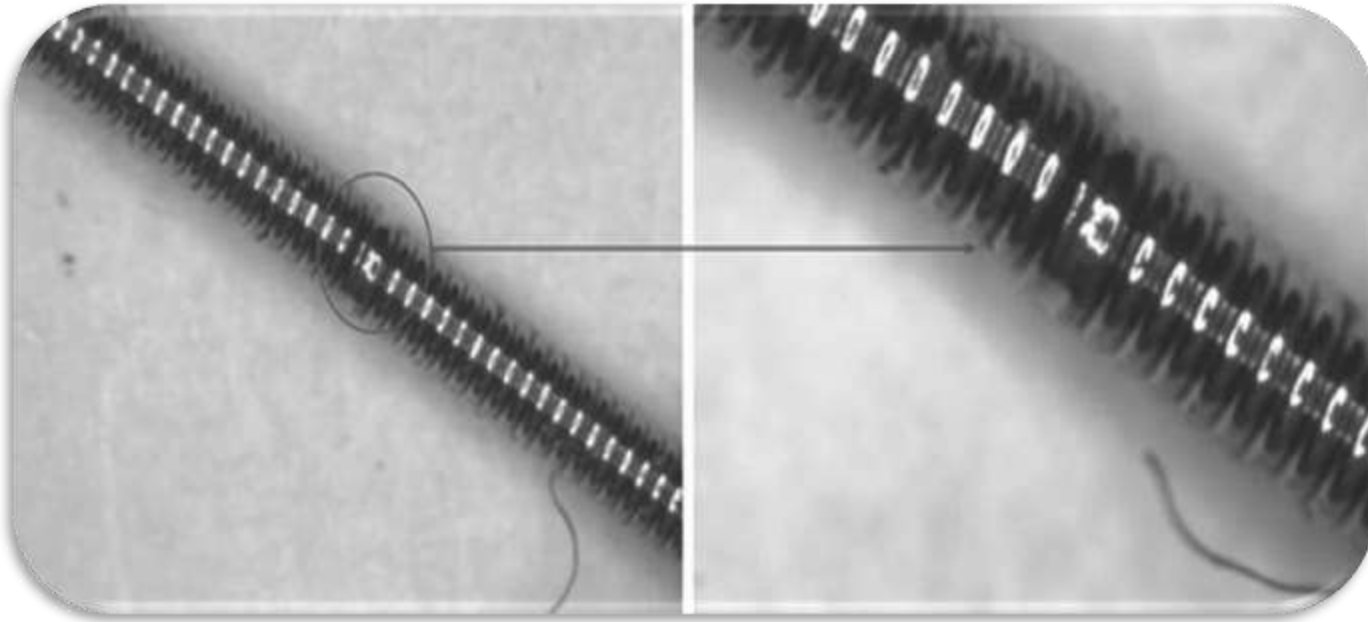
WF0 PRF900kHz

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.

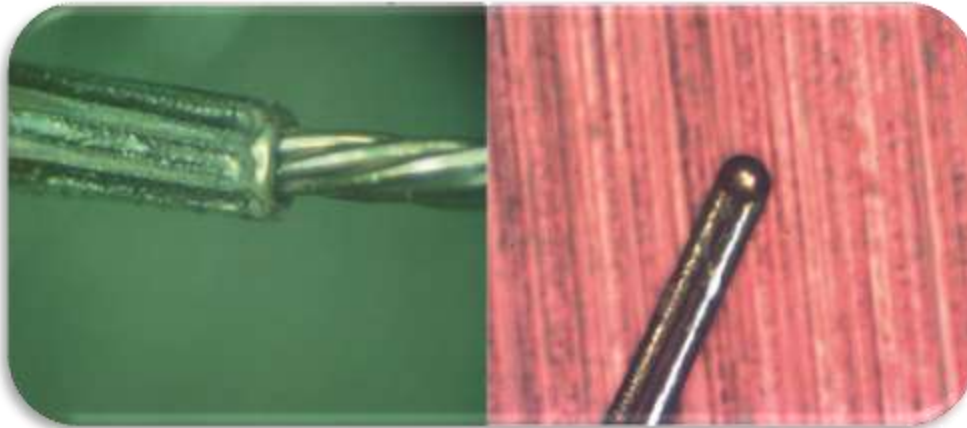


50 μ m wire to wire weld with 20W EP-Z at 250kHz.

Fine Wire Welding

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

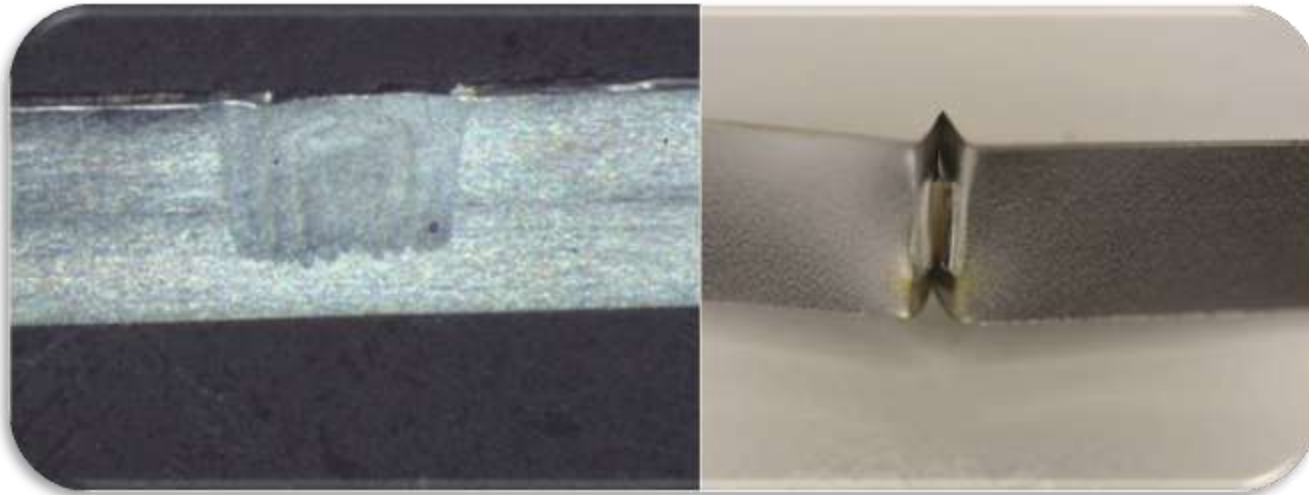
Bonding outer
metallic braid to
twisted wires.
40W HS-H
 $M^2 > 3$
SS.



Spot welding of
micro thermocouple
12.5 μm x 2
20W HS-S
 $M^2 < 1.3$
Dissimilar materials.

Functional Welds?

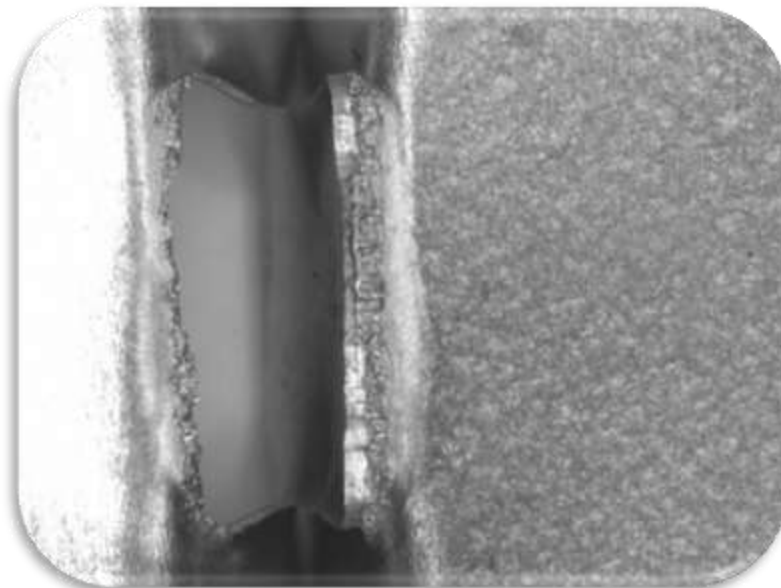
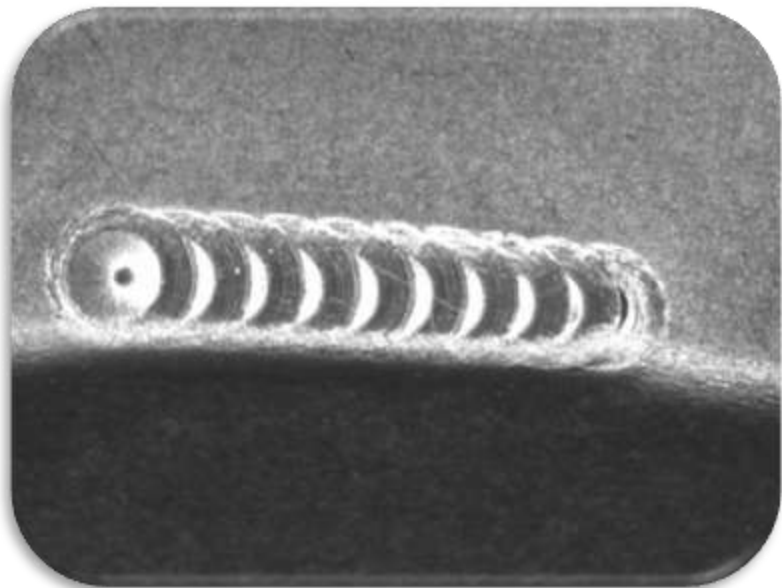
- These welds really strong enough for serious applications.



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

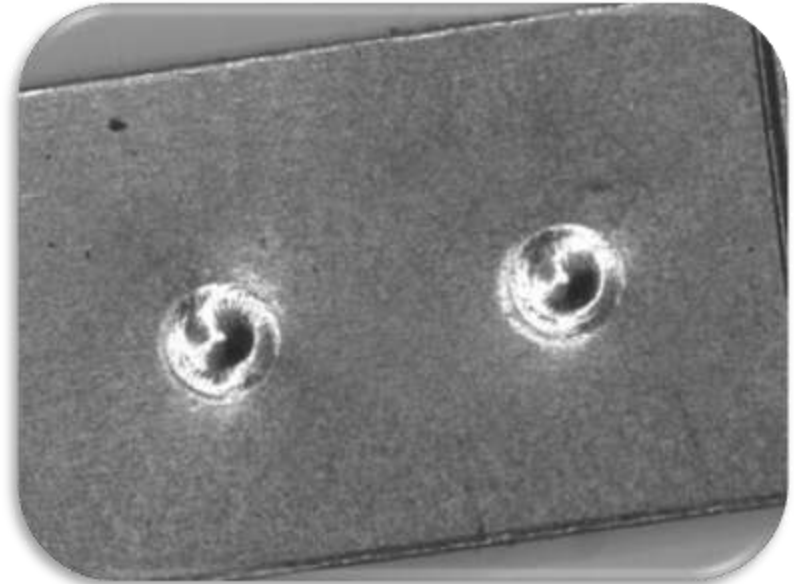
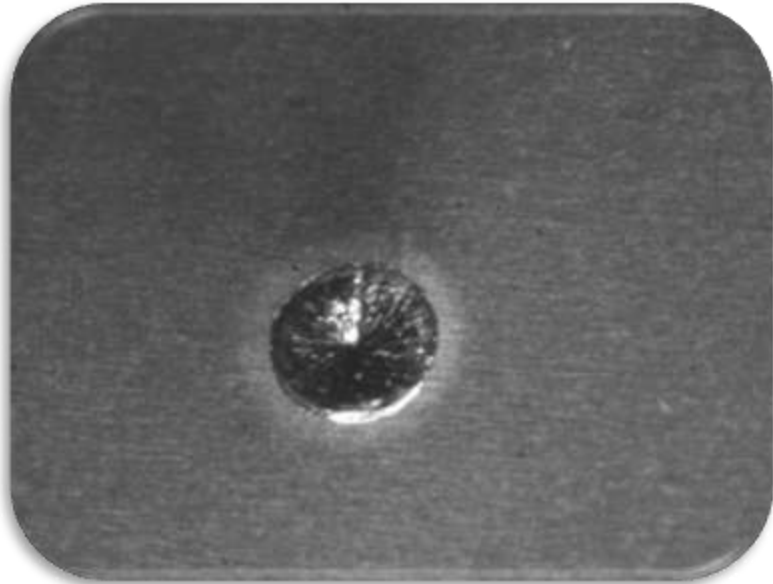
- 70W EP- Z G4 Welding – Wobble Weld with Overlapping Spots.



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.

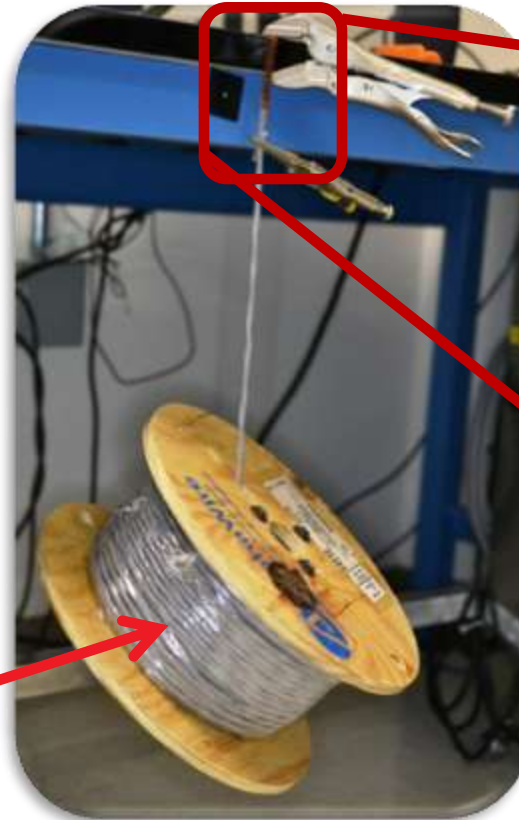
...but are these welds any good?



Welds Under Tensile Load...

- Joining copper to aluminium is a common joint requirement in battery and consumer electronics
- Joining 150 μ m 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.

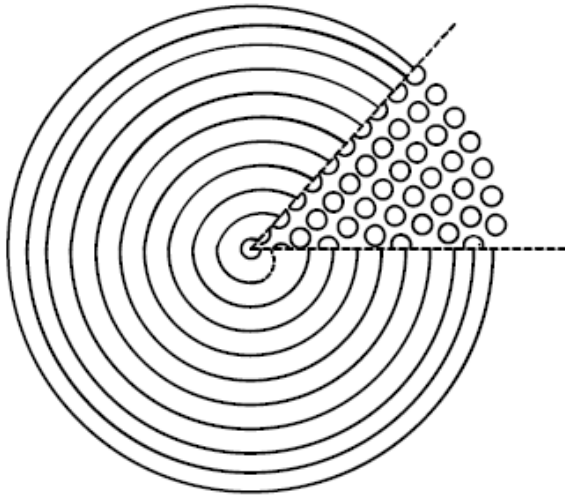
Challenging Materials

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

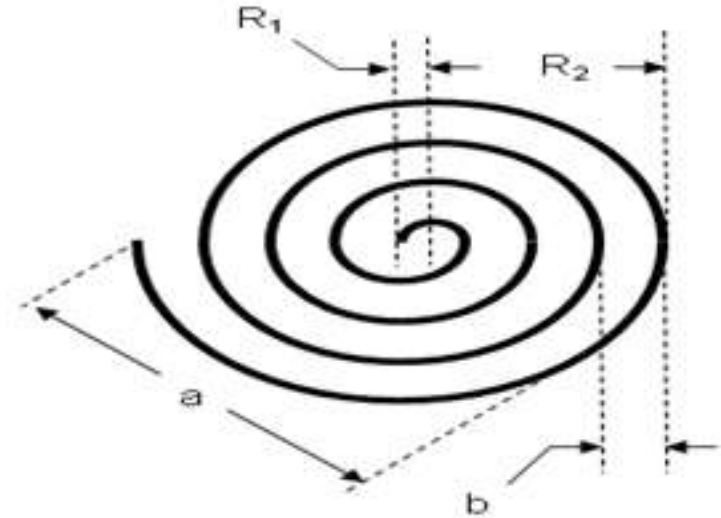


Ns Pulsed Spot Welds

- Method for making spot welds.



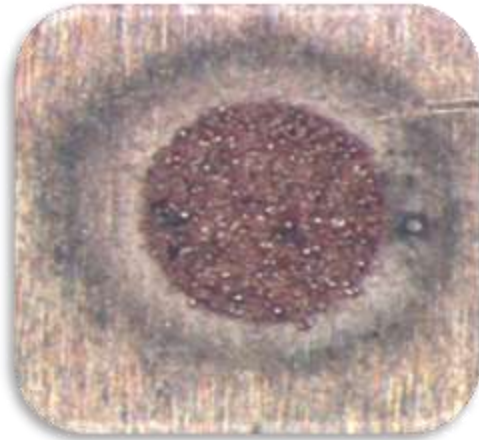
Spatially overlapping spots >98% linear fill separated by 50% the F_s on the rise radius.



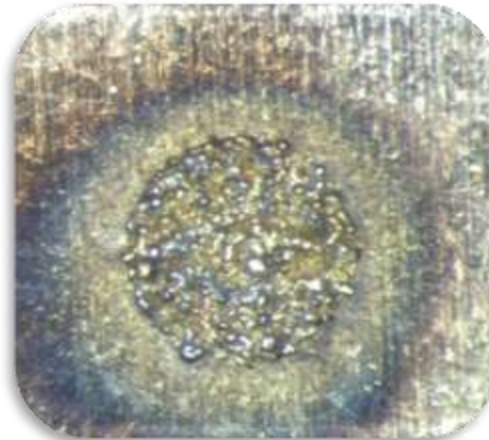
R_1 , Inner Radius, 0.02mm
 R_2 , Outer Radius, 0.5mm
 a, Ramp, 3mm
 b, Rise, 0.02mm

The Results.....

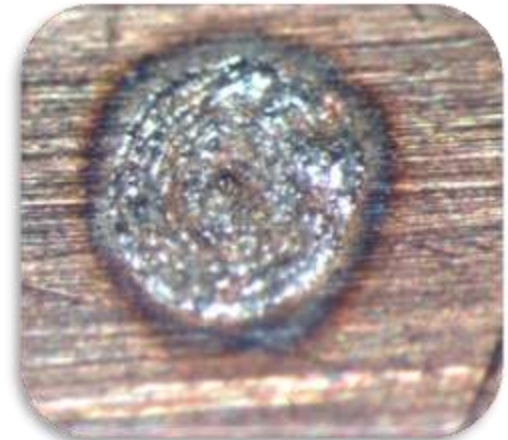
- Surface quality.



Cu - Cu



Brass – Brass

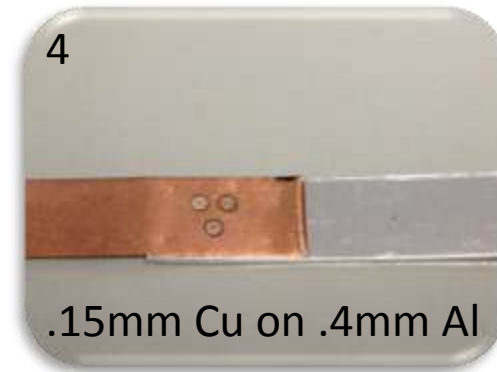


Cu - Al

It's not always a beauty contest!

Weld Properties

- Tensile strength
 - Spot welds.



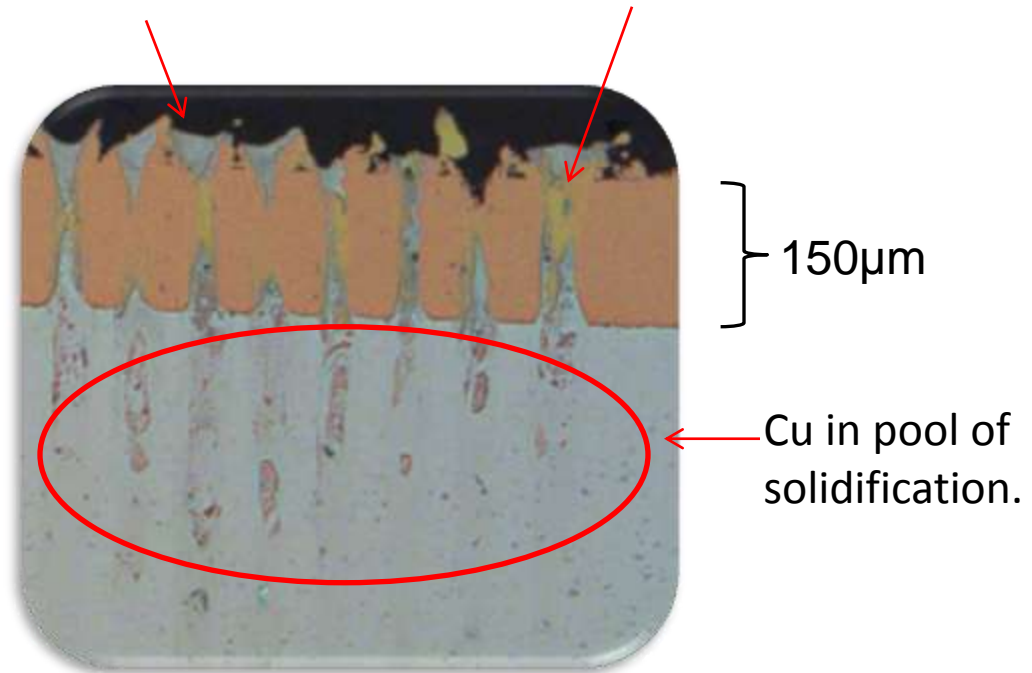
	Joint	Yield
1	Cu-Cu	20 lbs
2	Brass-Brass	61 lbs
3	Bronze-Bronze	42 lbs
4	Cu-Al	26 lbs
5	Cu-Brass	20 lbs

Metallurgically Interesting.....

- Spot welds do not show characteristic form of conventional pulsed spot welds
- More closely resembles multi-staking.

Al flow to surface

Possible intermetallics



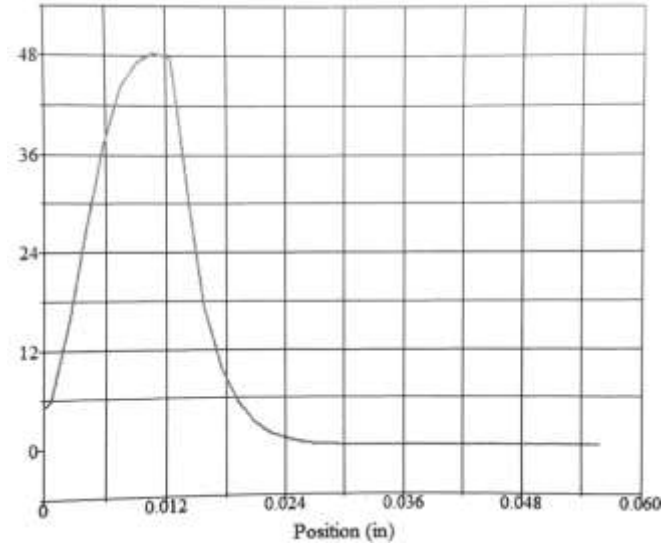
WF 36, 520ns, 70 KHz

Weld Strength

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



Improved Results



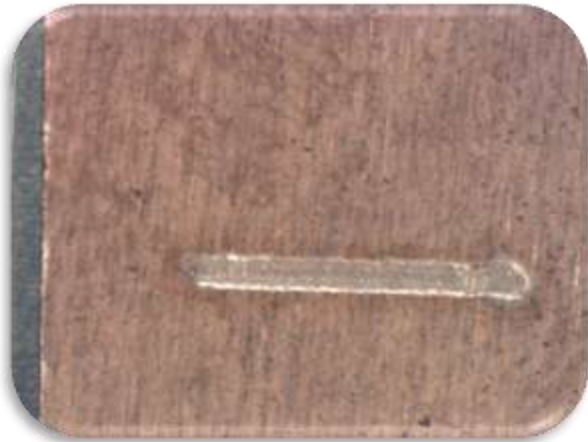
- Post process cosmetic pass.

Key Developments:

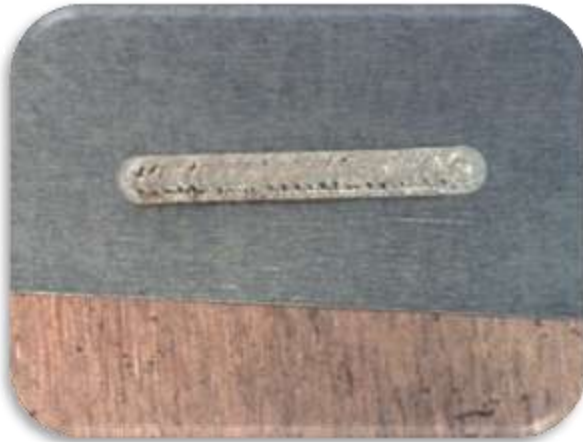
- Reduced surface porosity with bright finish
- Increased joint strength to 48lbs on 150 um copper.

Lap Seam Welds

- Wobble welding can be used to great effect.



Cu - Al



Al - Cu



SS - Al

More Challenging Dissimilar Combinations

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

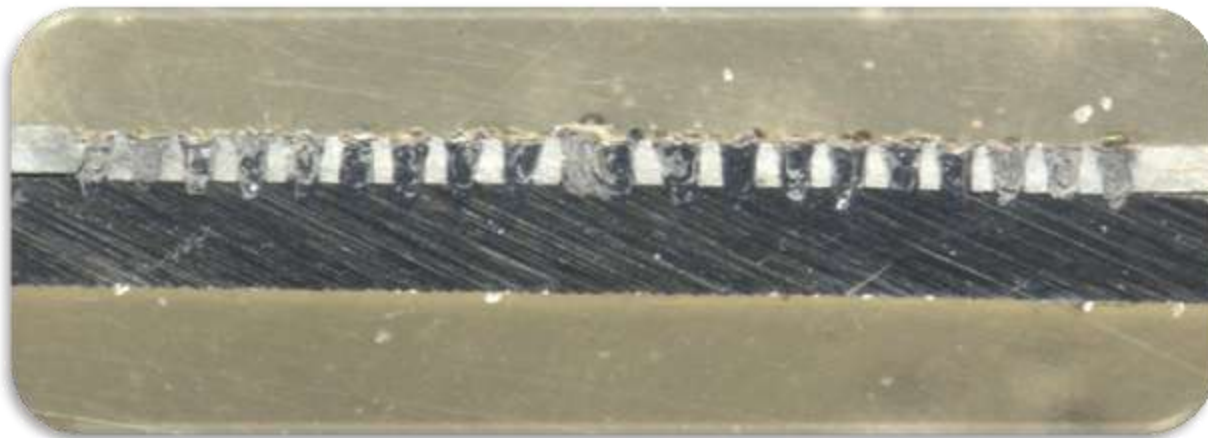


Image courtesy of Amada Miyachi America

“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

Applications

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

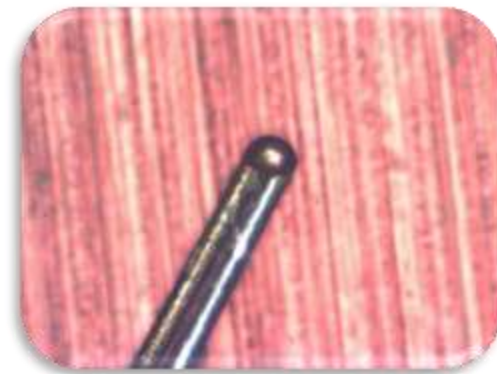
50 um thick Al
Battery Foils



Battery Cell
Al on Ni-Steel

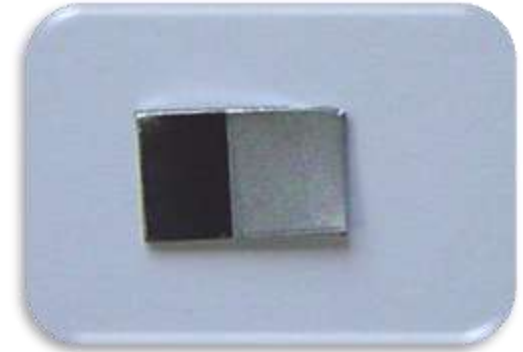


Copper Constantan TC
<50um Combined



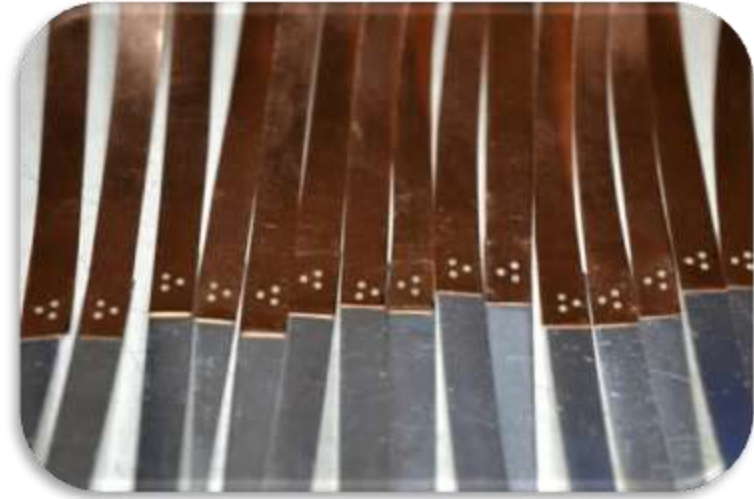
Cleaning with ns Pulses

- 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



Lasers

redENERGY® G4 ns Pulsed Fiber Laser



Versatility comes as standard...
www.spilasers.com