Fundamentals of pulsed Nd:YAG and fiber laser welding

Laser fundamentals

Elements of a laser welding system

The route to a successful weld

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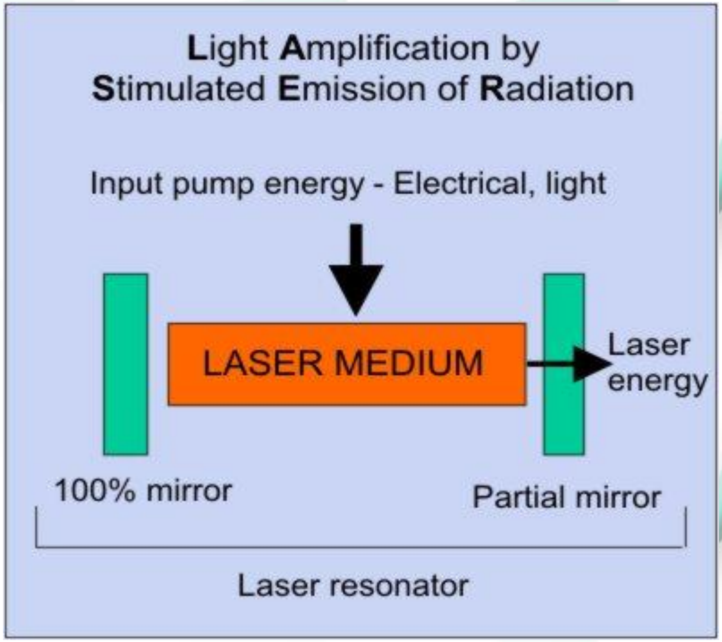
Laser Fundamentals

What is a laser..

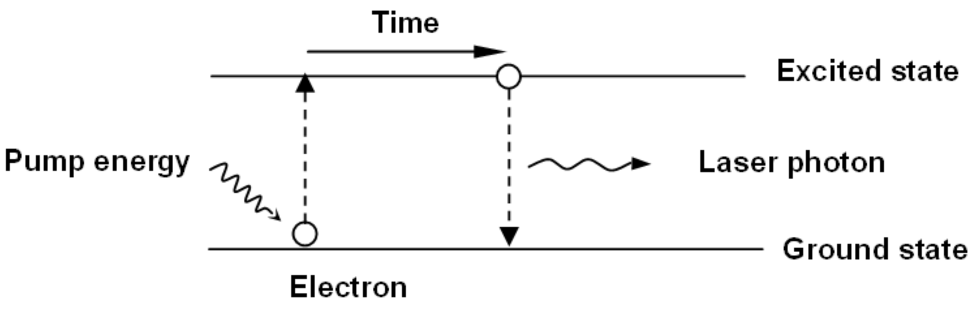
Light
Amplification by
Stimulated
Emission of
Radiation



- Elements of any laser
  - Laser medium
  - Pump energy for medium
  - A resonator that controls the generation and amplification of the laser

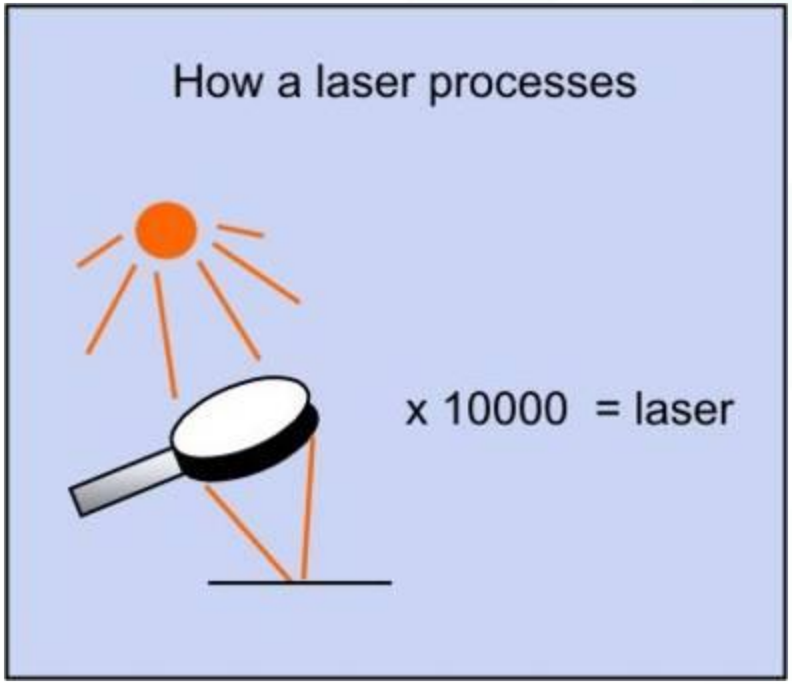
Laser Generation

1. Spontaneous emission – the seed



Processing fundamentals

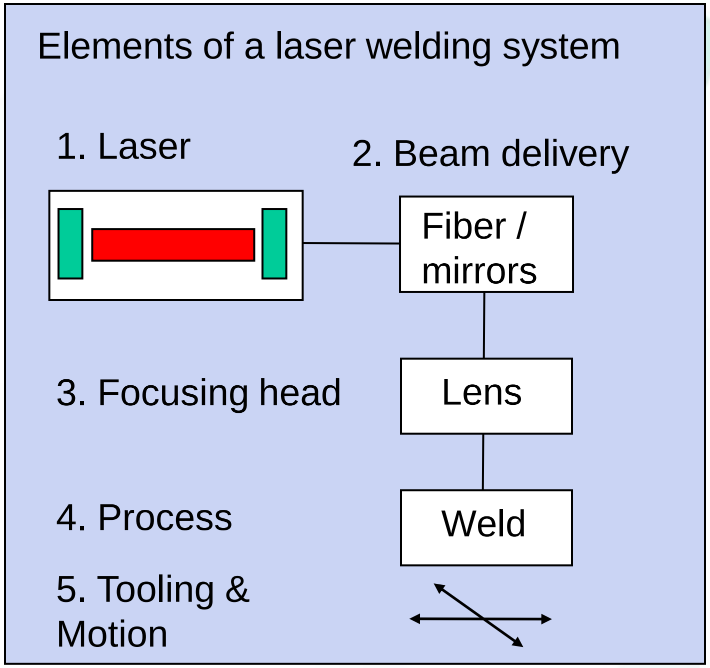
- The laser must be focused for materials processing



Elements of a laser welding system

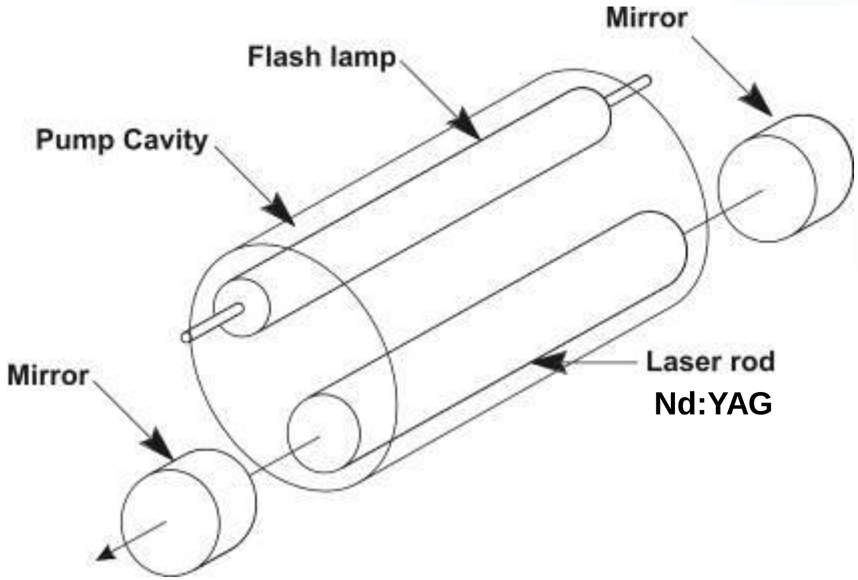
Laser Welding System

Laser
Beam delivery
Focusing head
Process
Tooling & Motion



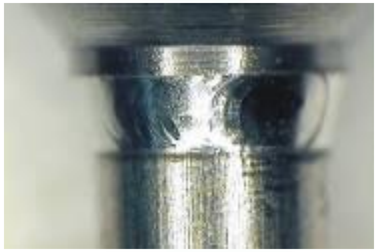
Welding Lasers

- Pulsed Nd:YAG laser
- Micro welder (<0.02” penetration)



Seam welding implantatable devices

Air bag detonator



Medical tool connect

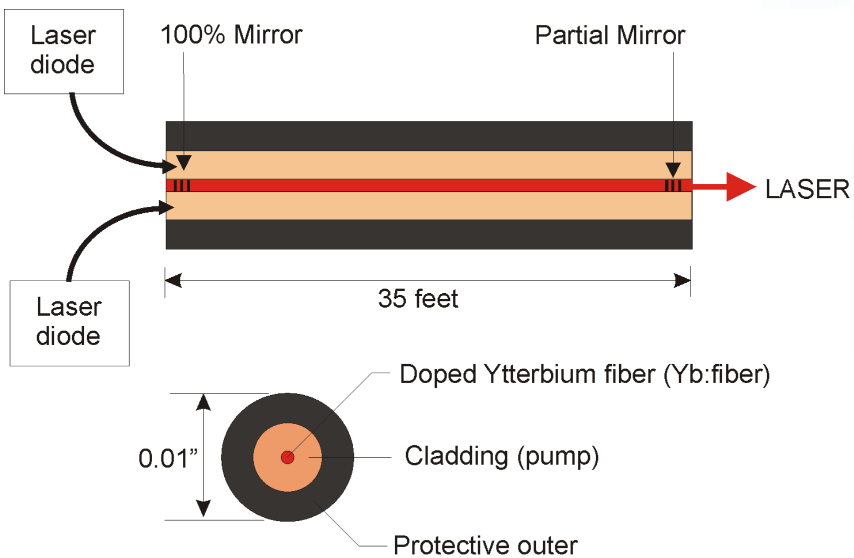
Aluminum battery

Features of pulsed Nd:YAG welders

- Very flexible
- Highly controllable
- Lowest heat input of any welding laser
- Robust industrially proven
  - Very reliable
  - Many parts field replaceable
- Energy / time share
  - Optimize laser usage, multiple welds per part
- Fiber delivery
  - Locate laser where its convenient
  - Standard fiber lengths 5,10 & 20m (longer available)

Welding Lasers

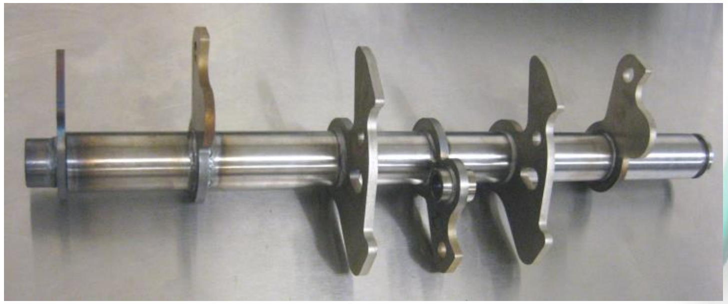
- Continuous Wave (CW) lasers
  - Fiber laser
- Penetration welder (>0.04")



Pulley wheel

Copper battery tabs

Steering column assembly



Crank case

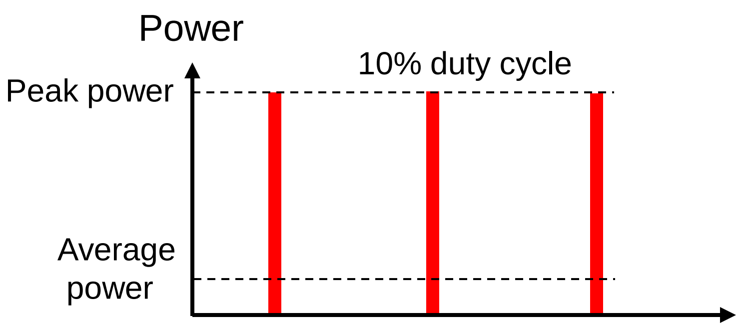
Features of Fiber laser welders

- Excellent penetration and speed performance
- Efficient welding mechanism
- Fiber delivery
  - Locate laser where its convenient
  - Standard fiber lengths 5,10 & 20m (longer available)
- Wall plug efficiency up to 30%
- Energy / time share
  - Optimize laser usage, multiple welds per part

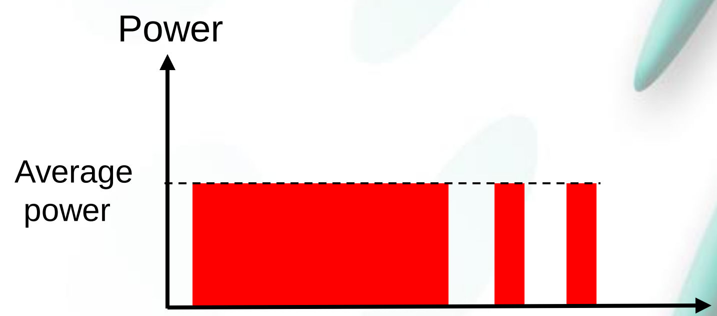
Comparison of pulsed and CW lasers

- Pulsed Nd:YAG lasers
  - Micro spot welder
  - Fine control of weld energy
  - Pulse durations typically 0.1 – 10ms
  - Peak power up to 250 times average
    - 25W laser provides 6kW peak power
    - Average power = heat input, welding speed
  - Large welding spot size (400-600 microns)

- Continuous wave
  - Penetration welder
  - High speed seam applications
  - Power range 1 – 5 kW
  - Peak power is the same as average power



Pulsed Nd:YAG output



Continuous wave or gated output

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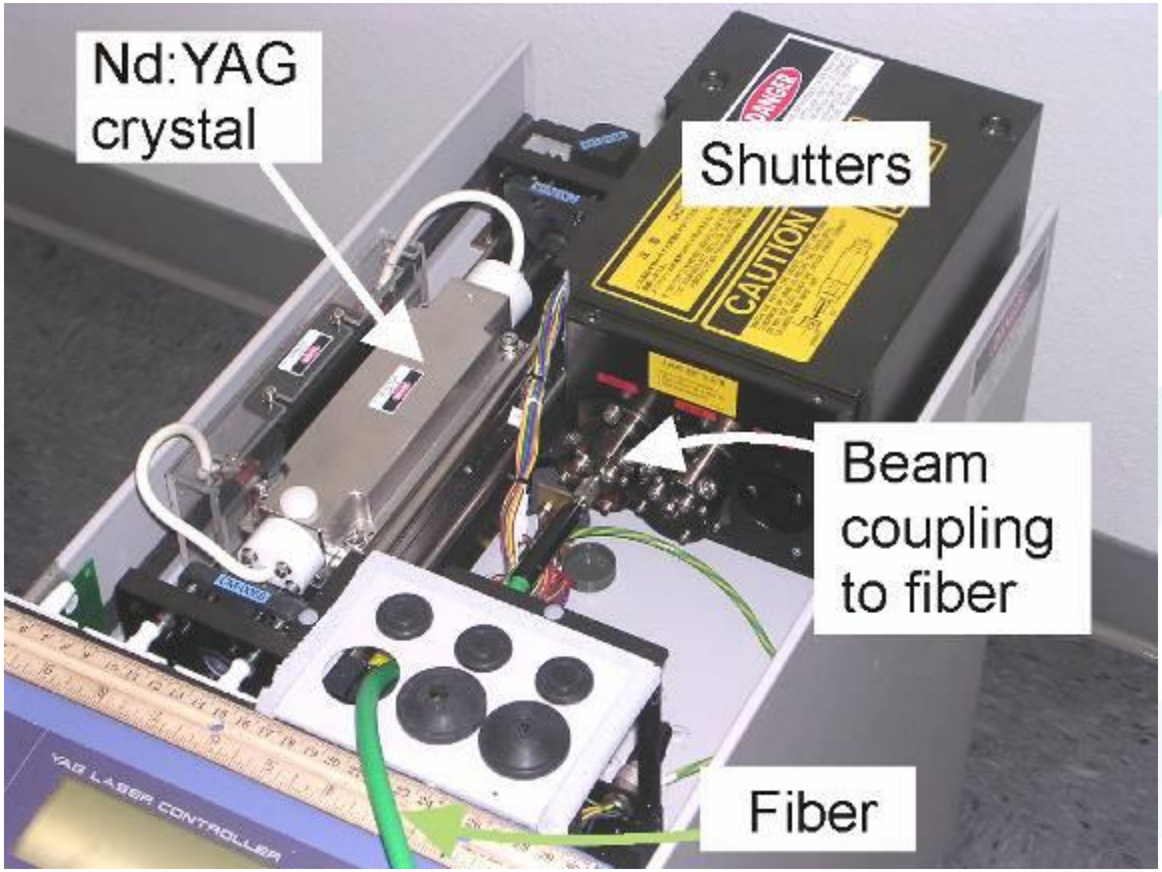
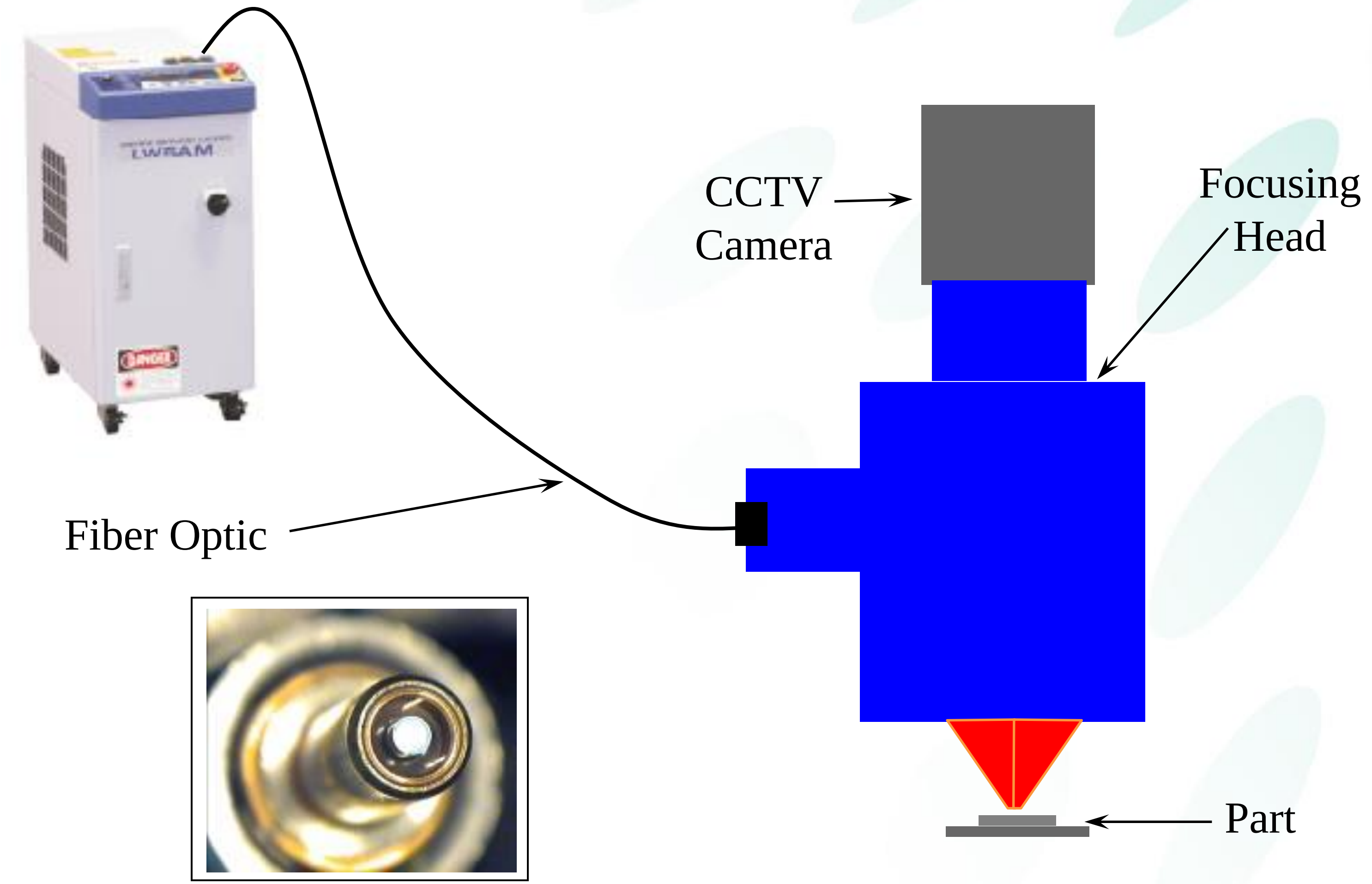
Laser Beam Delivery

Delivering the laser to the workpiece

The laser – where it starts

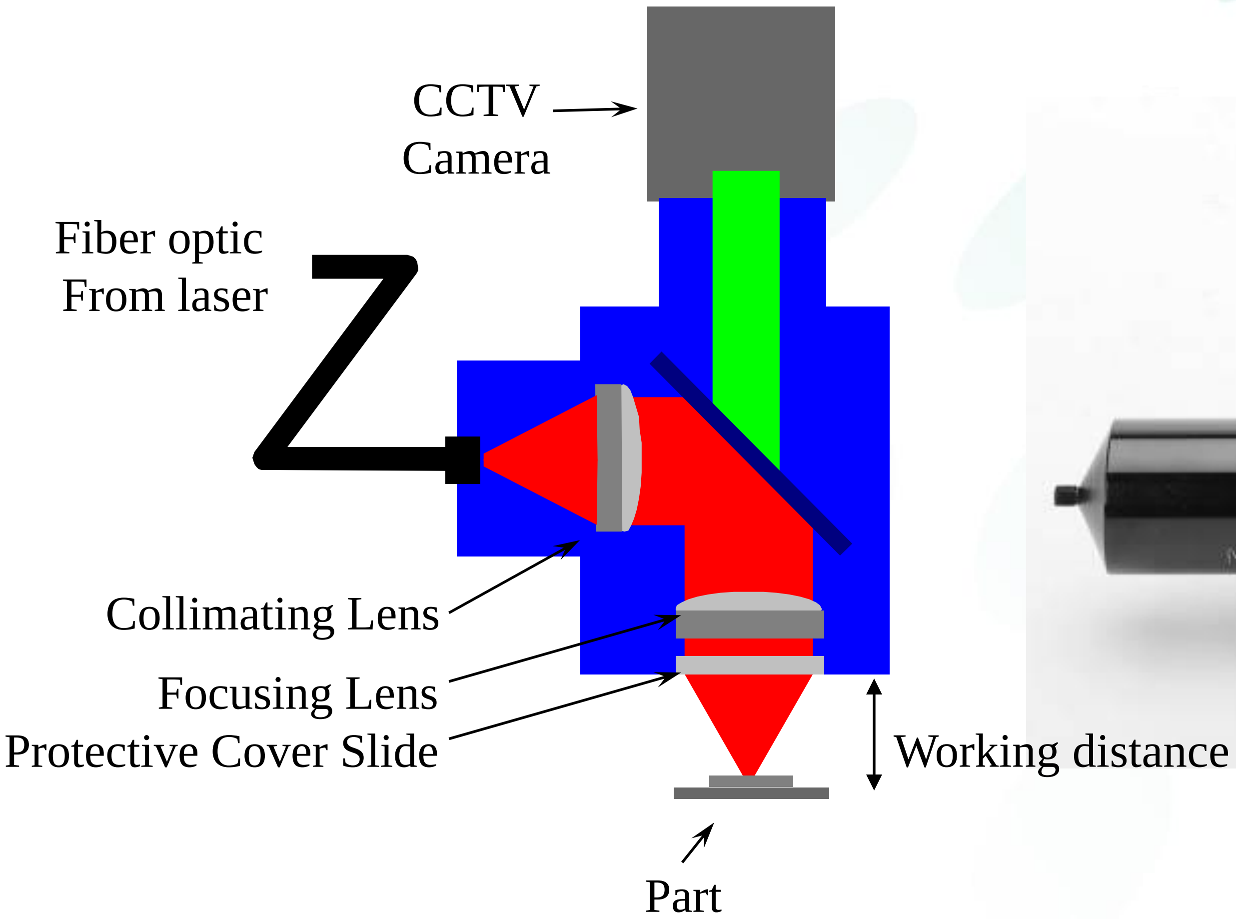


Fiber Optic Delivery + Focus head



Fiber Optic end

Focus head



Part

The Route to a Successful Weld

Design for Laser Welding

Defining the requirements of the weld

Materials, Joint geometry, Penetration, Cycle Time

↓

Part tolerances, Fit-up, Laser parameters

↓

The Required Weld

The Required Weld

- What is the purpose of the weld
  - Mechanical / electrical / sealing
- Inspection techniques
  - Weld cross section
  - Pull/peel testing
  - Pressure testing
  - Resistance
  - Hermeticity
- Optimizing penetration requirements
  - Reduce laser size
  - Increase speed

Material selection for pulsed Nd:YAG Welding

Material	*Comments*
Aluminum	Welding is limited to certain grades such as 6061 to 4047 or 4032, 1050, 1100, 3003 and 5005. High energy levels required to overcome surface reflectivity. Other aluminum alloys should be tested thoroughly for joint design and crack sensitivity.
Beryllium Copper	Good welds. Alloys containing less copper are best due to reduced reflectivity. A safety hazard exists from the toxic beryllium oxide fumes
Carbon Steel	Good welds, carbon content should be less than 0.12%.
Copper	Generally limited to spot welds. High energy levels required to overcome surface reflectivity.
Hastalloy-X	Good welds
Kovar	Good welds
Molybdenum	Good welds, slight brittleness.
Nickel	Good welds
Phosphor Bronze	Good welds
Stainless steel	304 & 304L produce excellent welds 316 & 316L are ok provided Cr/Ni ratio is greater than 1.7 Other 300 series require testing, though 303 should be avoided 400 series require testing for crack sensitivity.
Titanium	Good welds, gas shielding is key

Material selection – size of laser & process speed

Material	Relative weld energy
Low Alloy Steel	1
Titanium	1.5
Stainless Steel	1.5
Aluminum	3.5
Copper	5+

Material selection

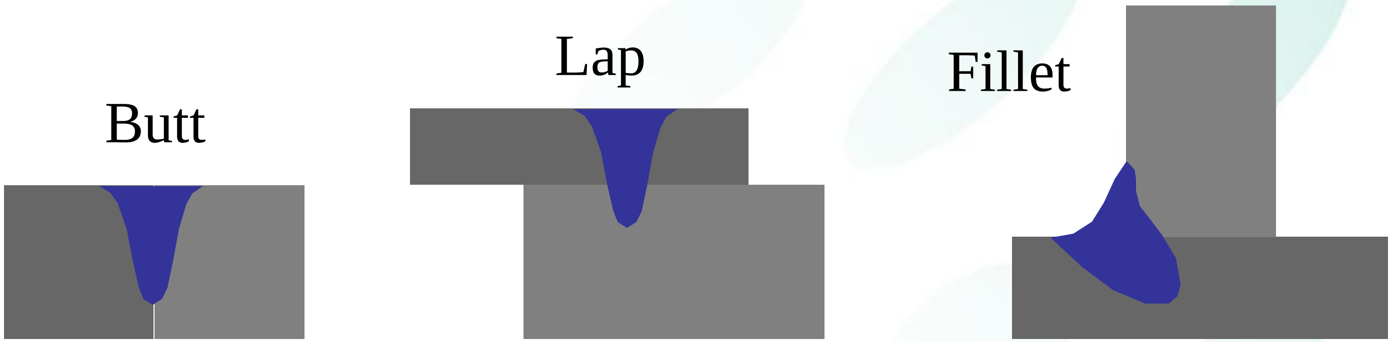
- Stick to your recommended vendors!

Material plating

- OK
  - Nickel coated
  - Gold coated (to around 1 micron)
  - Electrolytic process
  - Zinc (weld spatter)
  - Tin (weld spatter)
- Bad
  - Thick plating
  - Electroless plating process

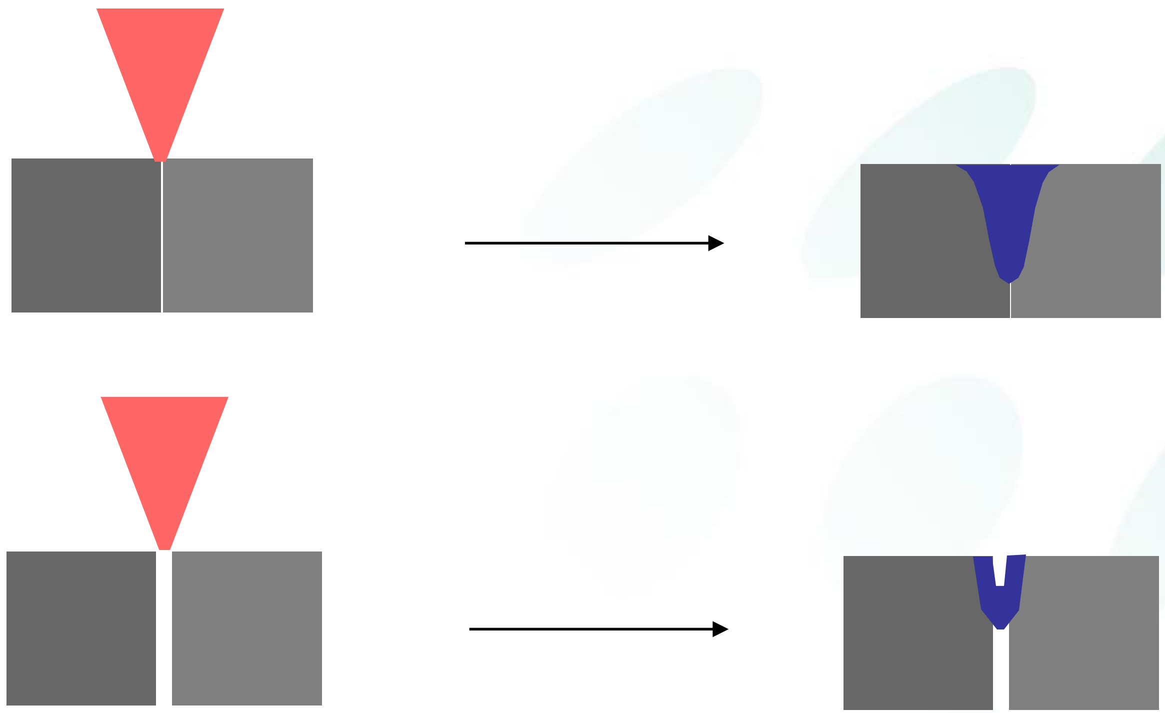
Material generally welds better without plating

Joint Geometry & Fitup



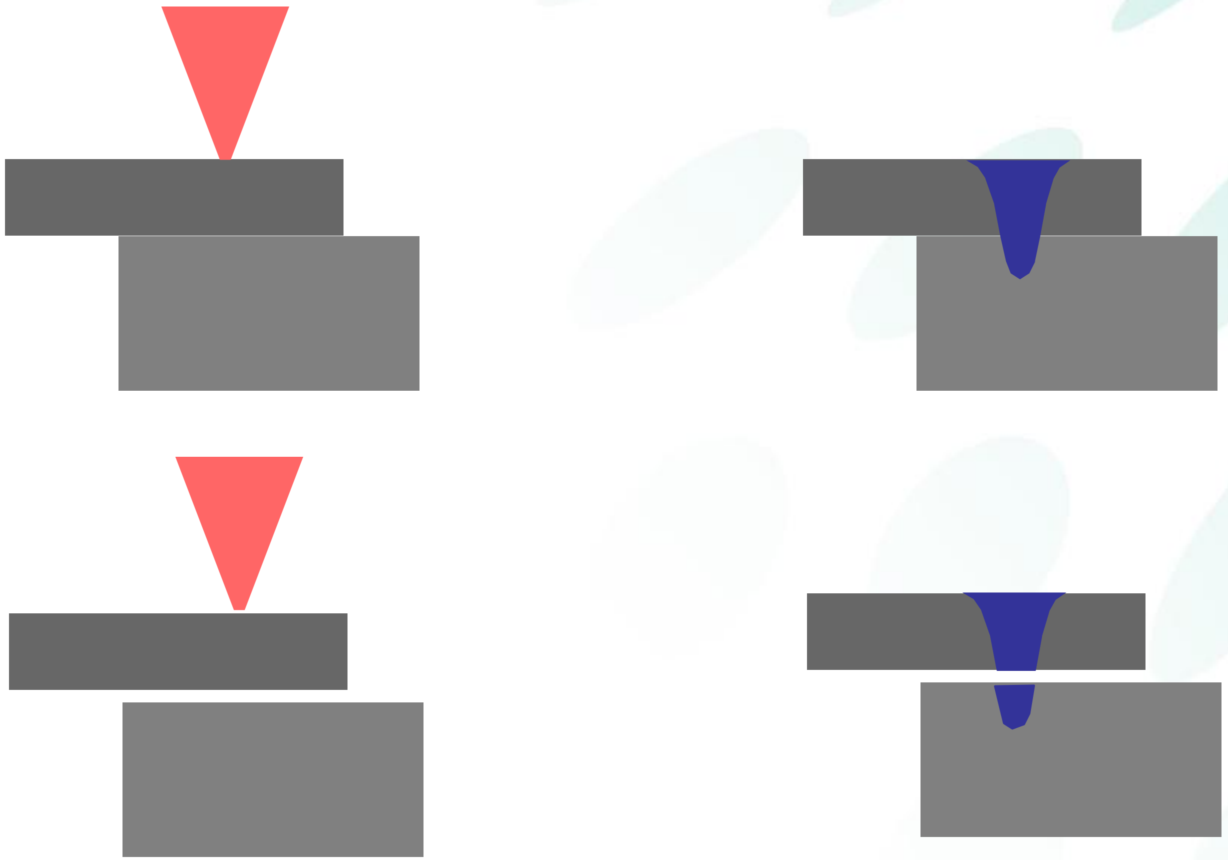
- Select for efficiency
  - Tolerance to fit-up, speed, strength
- For best results - **NO GAP between parts**!

Butt weld



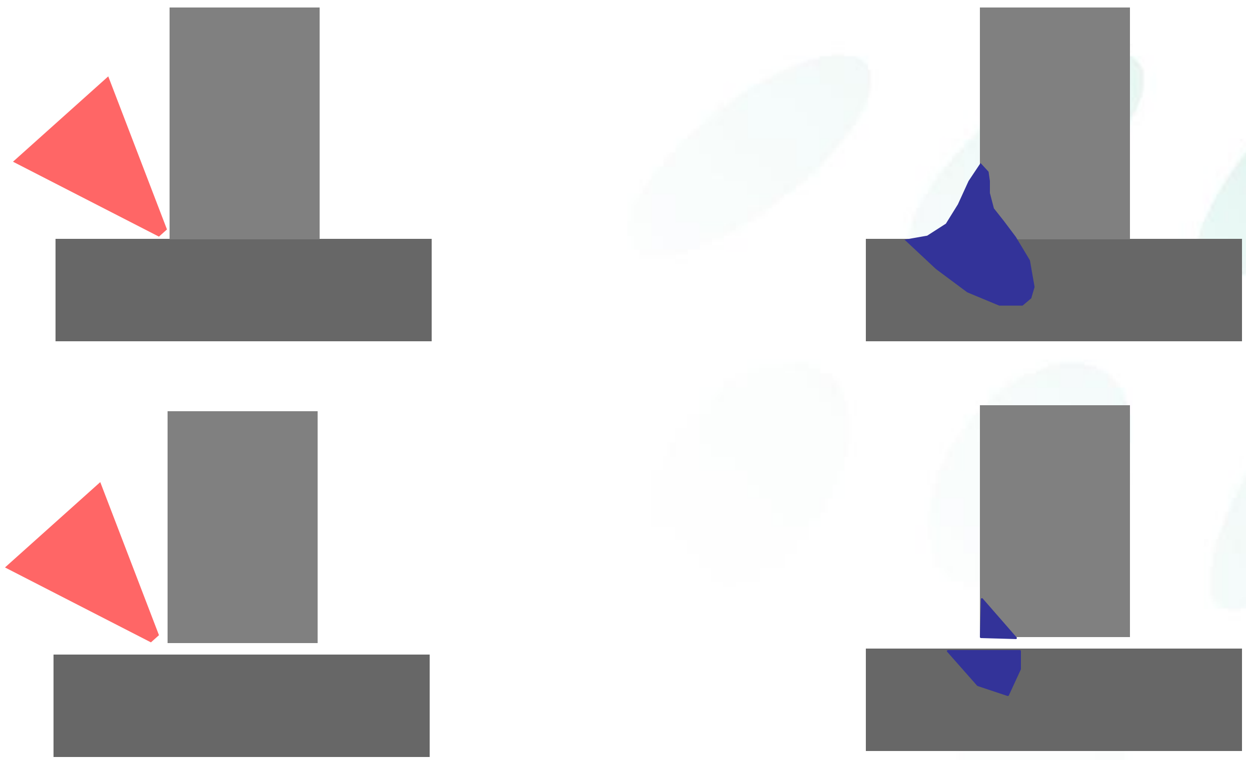
- Gap allowed around 10% of beam diameter

Lap weld



- Gap allowed around 25% of beam diameter

Fillet weld

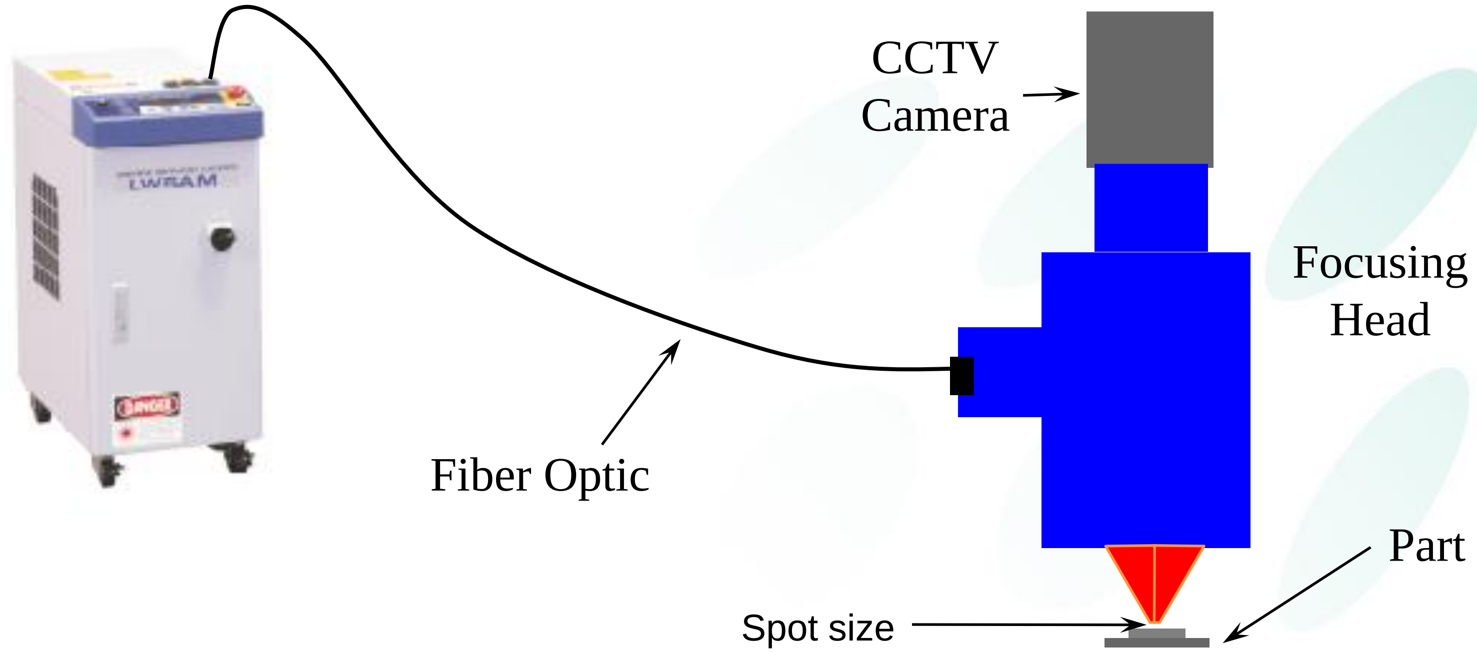


- Gap allowed around 15% of beam diameter

The Process

Fiber and focus head selection

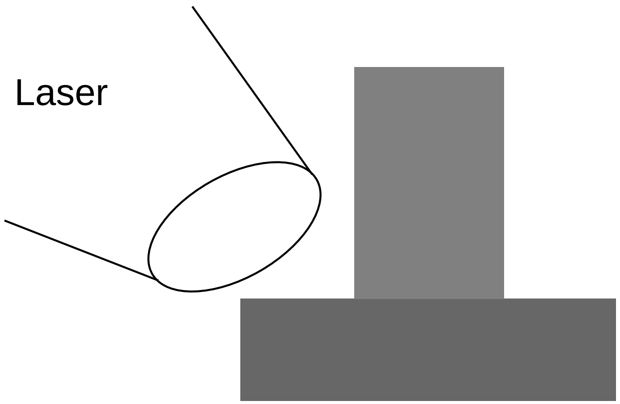
Selecting Fiber and Focus head for Application



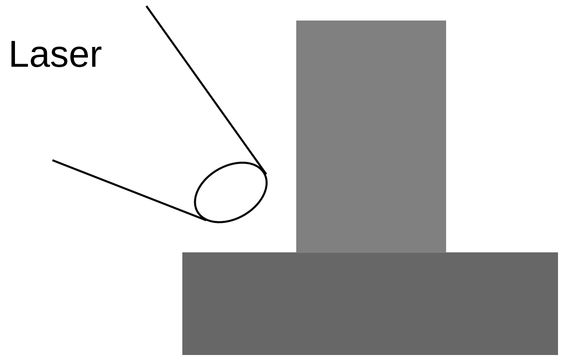
Spot size = core diameter of delivery fiber x $\frac{\text{focus lens}}{\text{collimator lens}}$

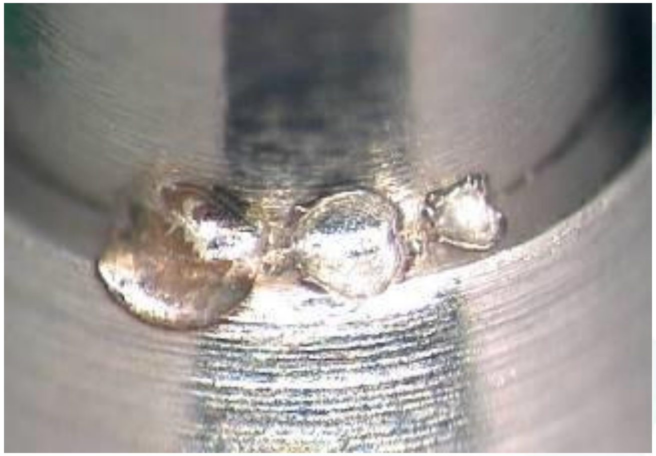
Size of Parts

- What makes sense, size to component & joint



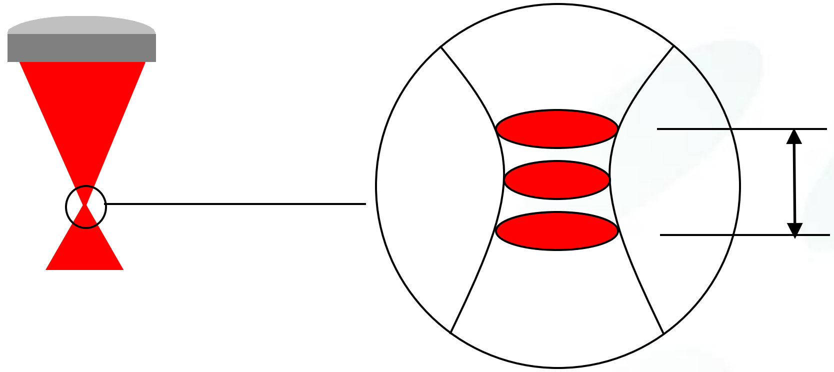
Spot size too large





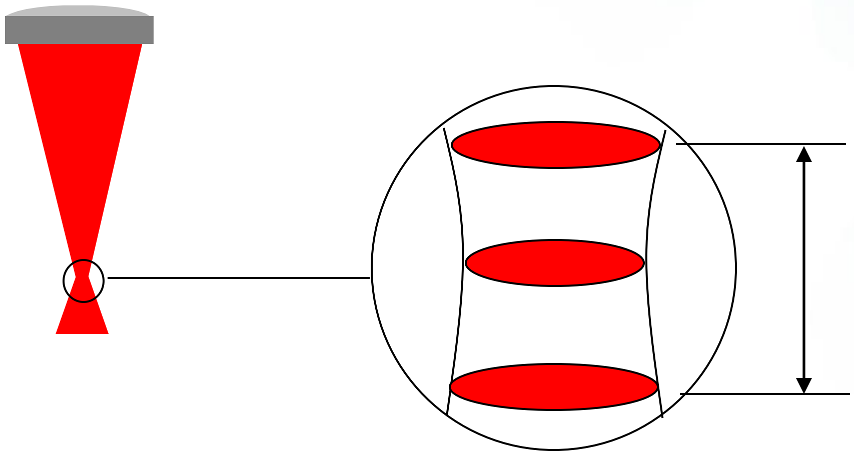
Depth of focus

75mm Focal length



Small spot size, small vertical tolerance

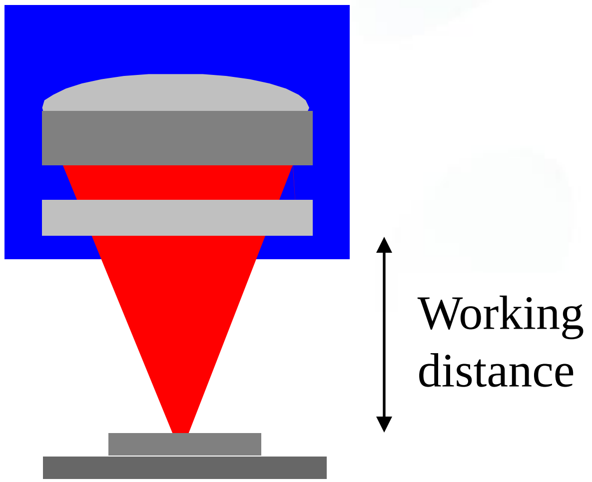
125 mm Focal length



Large spot, large vertical tolerance

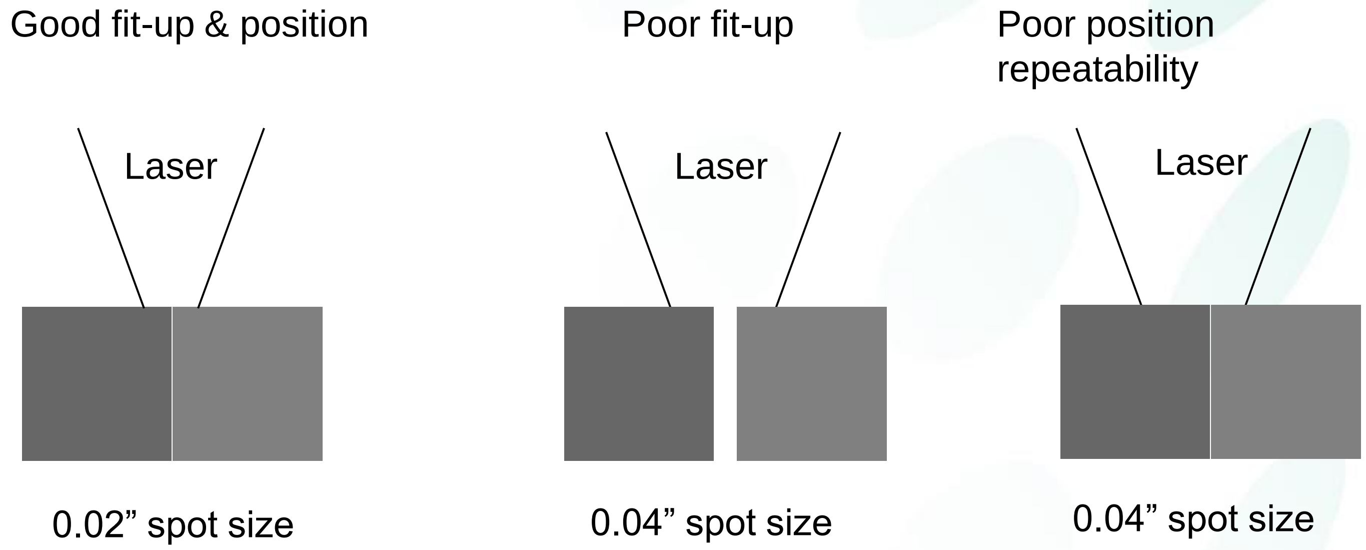
Working distance

- Accommodation of tooling / peripheral equipment



Fit up tolerances

- Gap between parts & positional variance



Weld stability

- Increasing spot size increases weld stability
- Aluminum key material
  - Disturbances in weld pool are magnified by low viscosity
  - Large spot size = large melt pool = more damping effect
    - Throwing a stone into a bigger pond!

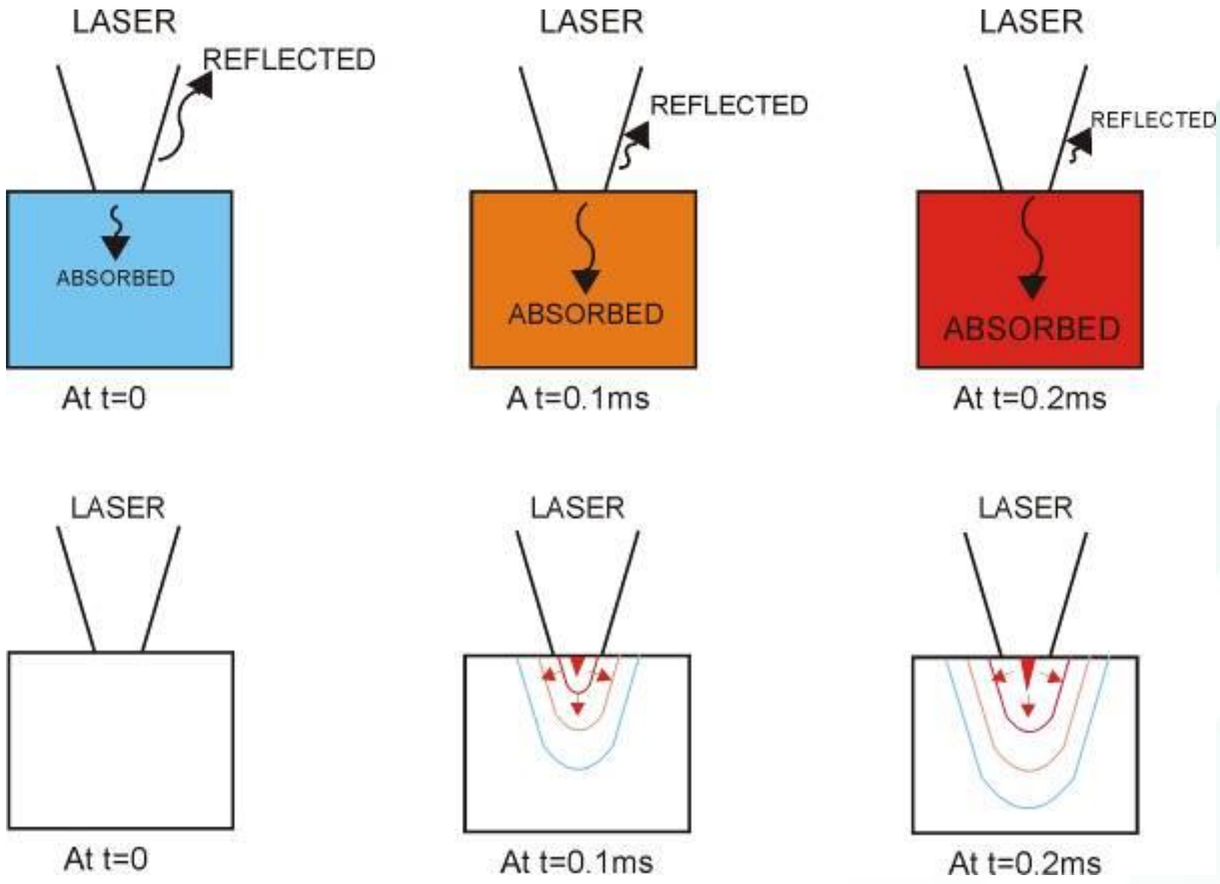
Summarizing the optics selection

- Define required spot size
  - Select focus lens for working distance
  - Select fiber core diameter for power (pulsed Nd:YAG laser only)
  - Select collimator to fit

The Process

Laser parameters

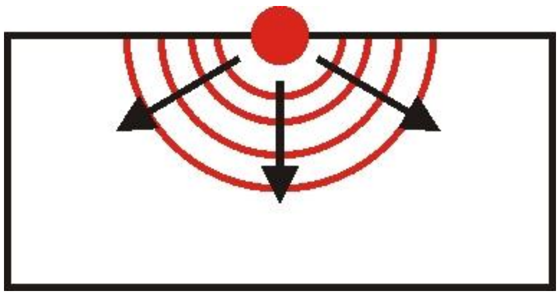
Heating with a laser – The big picture



Welding modes

CONDUCTION

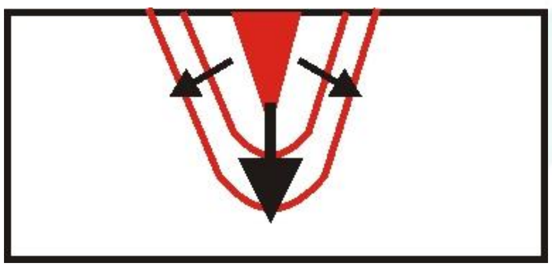
- Low energy density heat source relies on conduction from the surface



- Shallow welds
- Large heat input

KEYHOLE

- High energy density heat source such as laser welding produce an internal heating effect by the creation of a vapor filled element know as a keyhole welding to increase penetration

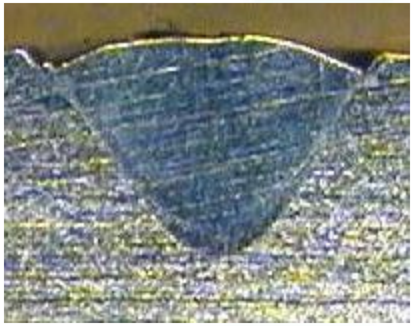


- Narrow deep welds
- Small heat input

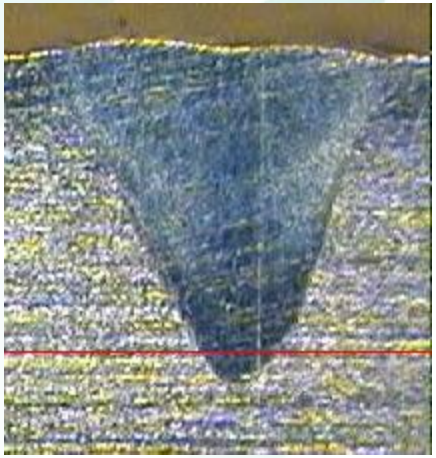
Welding with a laser - Welding modes

Conduction

Partial Keyhole



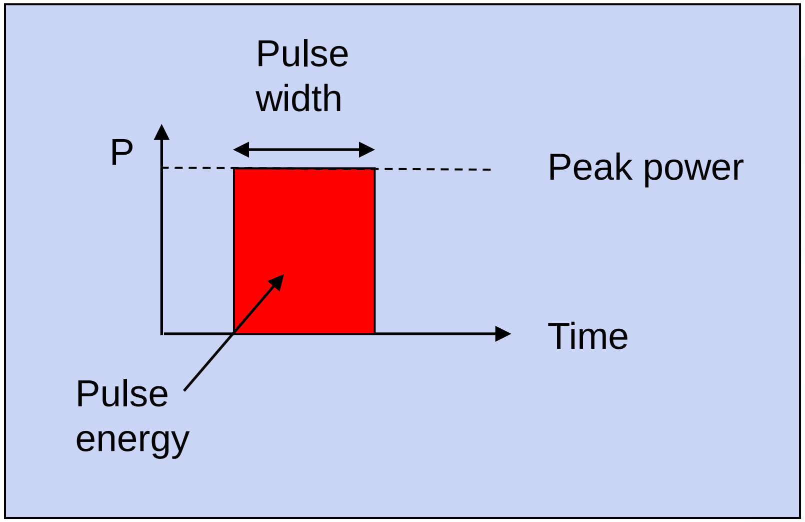
Full Keyhole



Increasing laser power density →

Pulsed Nd:YAG Laser Parameters

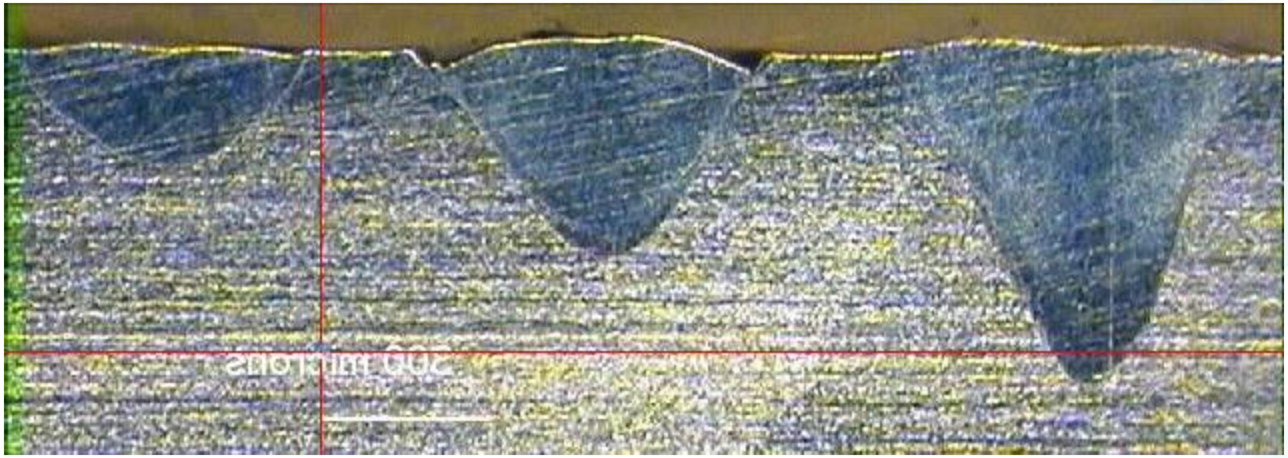
- Peak Power (kW) – Main parameter that determines weld penetration.
- Pulse Width (ms) – Effects width and penetration
  - Pulse Energy (J) – Peak power x pulse width.



Effect of Peak Power

- Controls penetration depth
  - Too high causes porosity & drilling

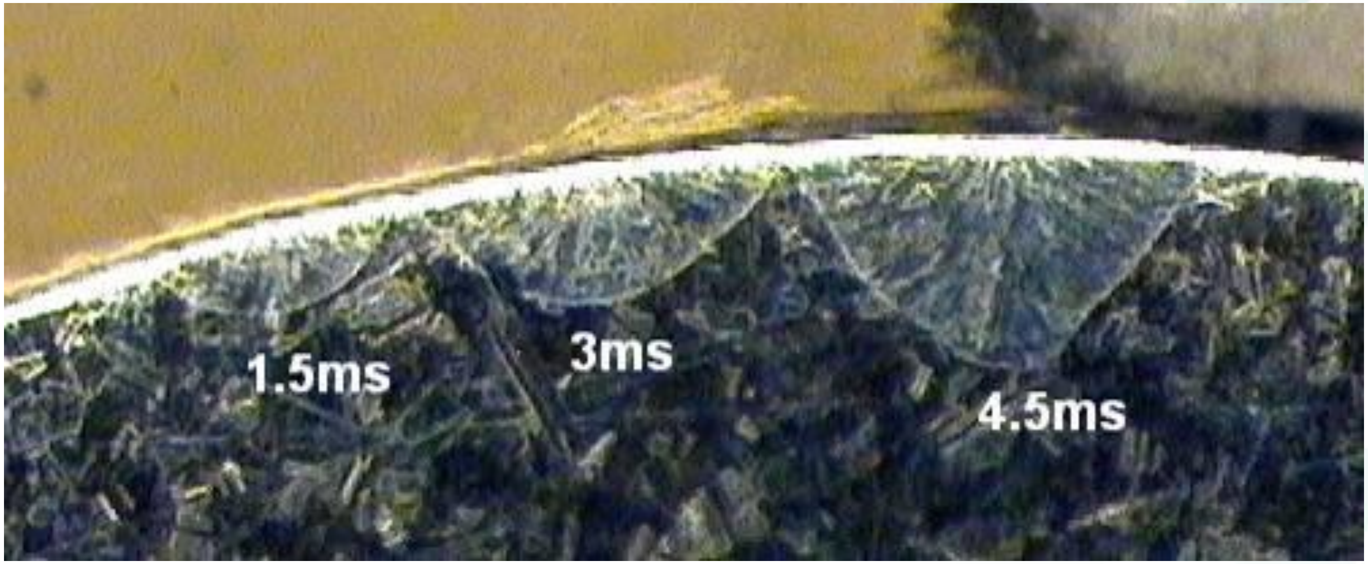
1kW 1.5kW 2kW



Increasing peak power →

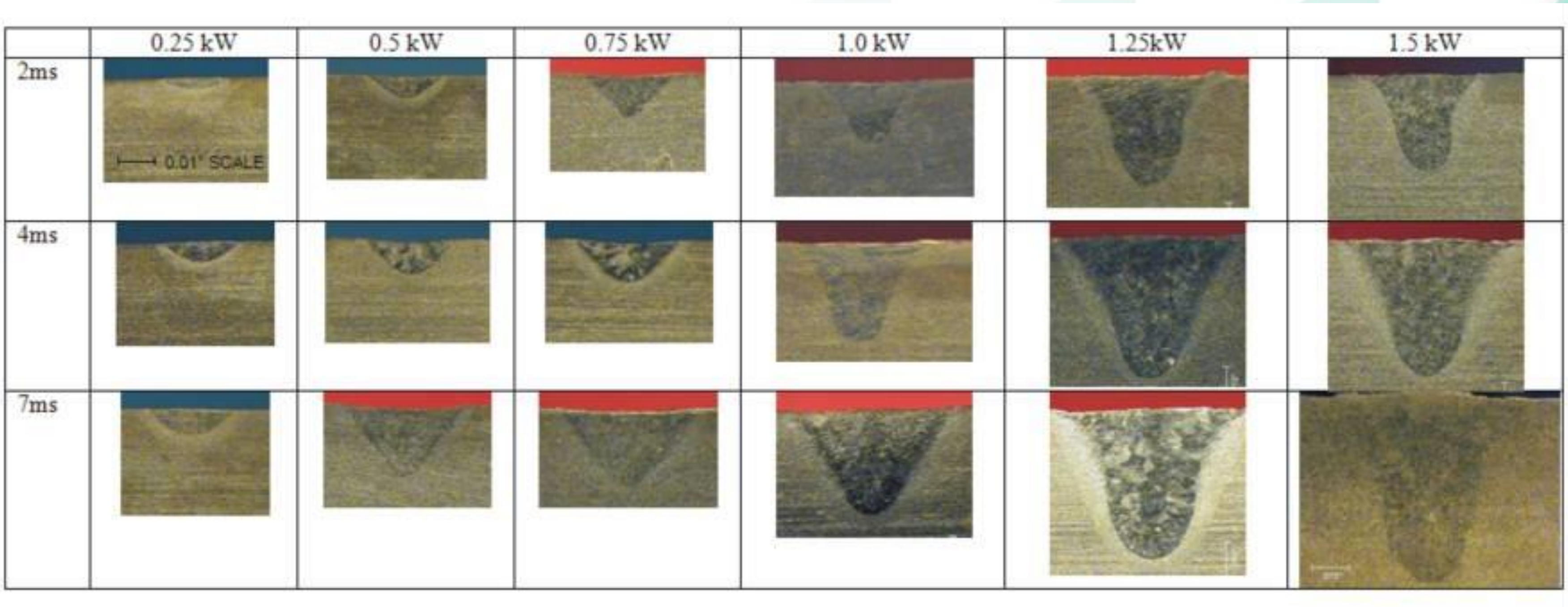
Effect of Pulse width

- Increases width and depth



Effect of Peak power & pulse width

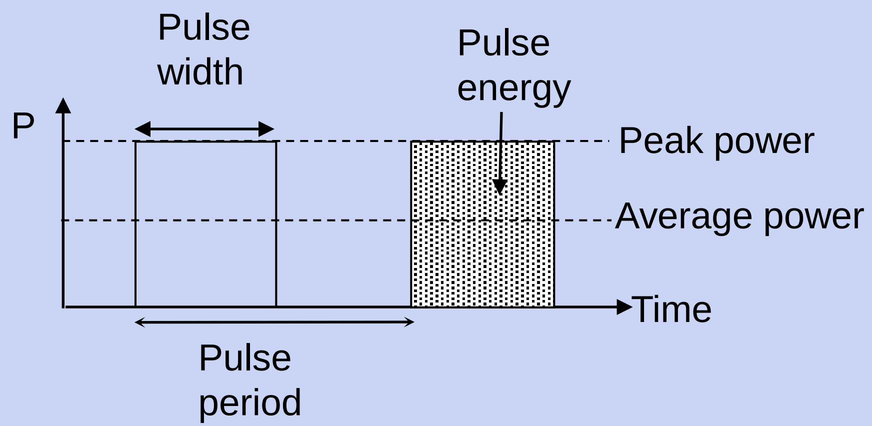
Material: Titanium (0.02” spot size)



0.02”

Seam Welding Laser Parameters

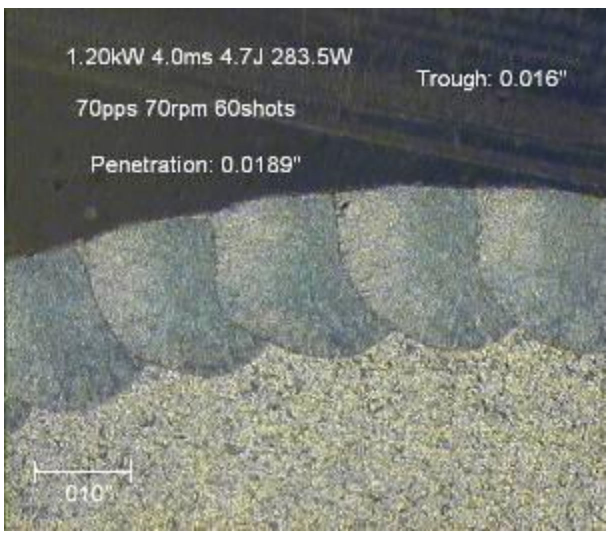
- Pulse Repetition rate (Hz) – number of pulses that the laser fires per second
- Pulse overlap (% of weld diameter) – how much subsequent pulses overlap
  - Average power (W) - peak power x pulse width x repetition rate.



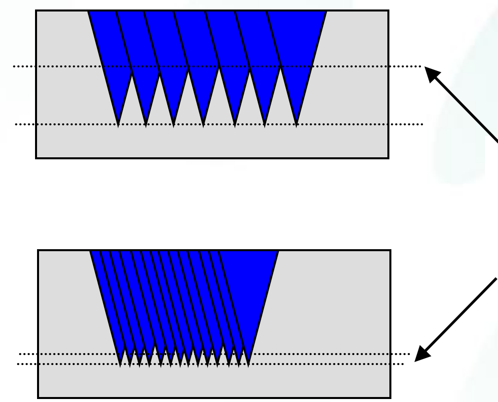
Pulse repetition rate or Frequency = 1/ pulse period

Overlapping spots

- Overlap % - function of speed, pulse repetition rate and weld spot diameter
- Rule of thumb settings
  - 60-70% spot overlap for strength
  - 80-90% spot overlap for hermaticity
  - Small laser can seam weld, just slower



50% overlap



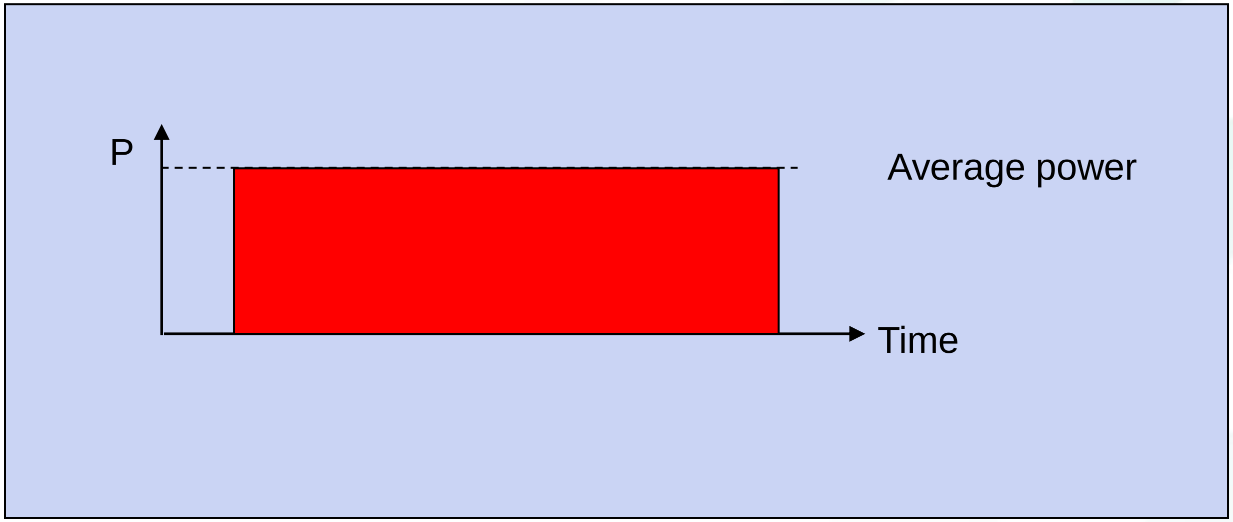
85% overlap

Sizing the laser

- Lasers are described in average power
  - A 400W laser can provide 400W average power
  - Example: Weld requires 4kW at 5ms = (4kW x 5ms) = 20J
    - How fast can we pulse with a 400W laser?
    - 400W / 20 J = 20 Hz (20 times per second)
    - Welding speed = (1 - overlap) x spot size x frequency

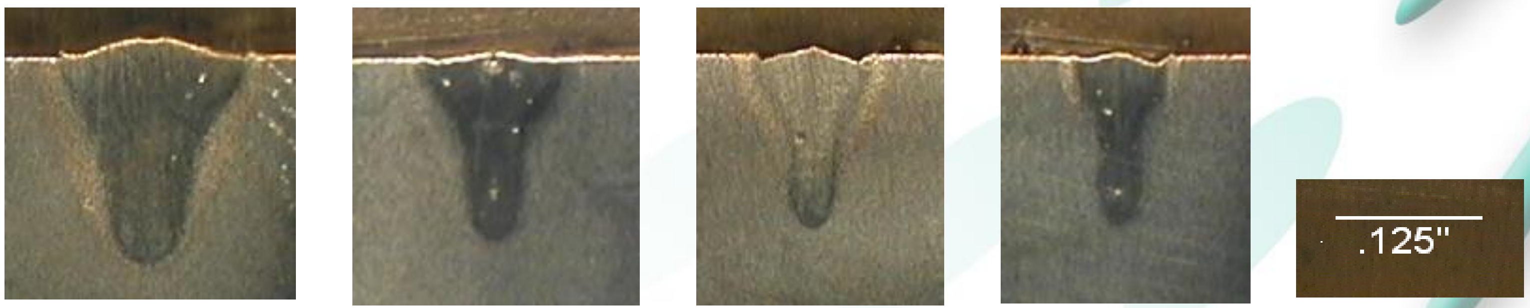
Fiber Laser Parameters

- Average Power (kW) – Main parameter that determines weld penetration.
- Spot size selection important



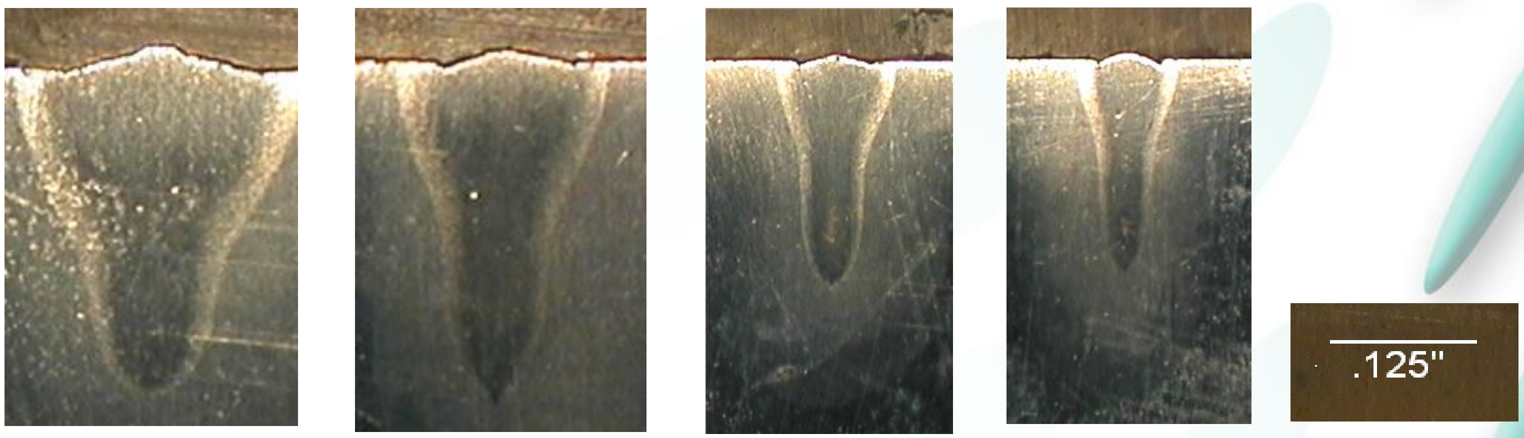
Power vs Speed for Fiber Laser

3kW



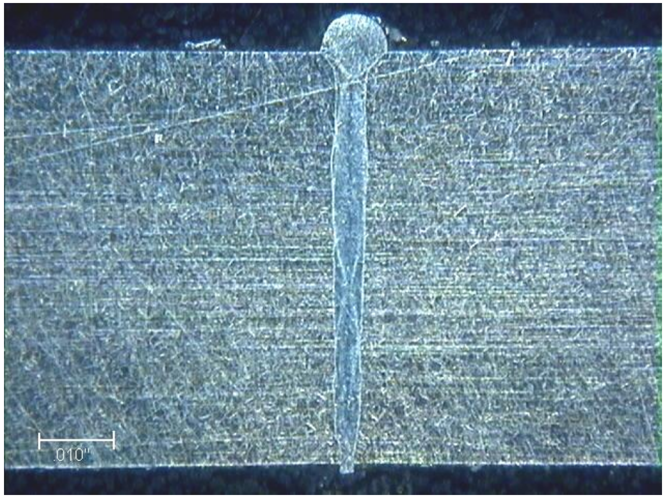
40ipm 60ipm 80ipm 100ipm

5kW



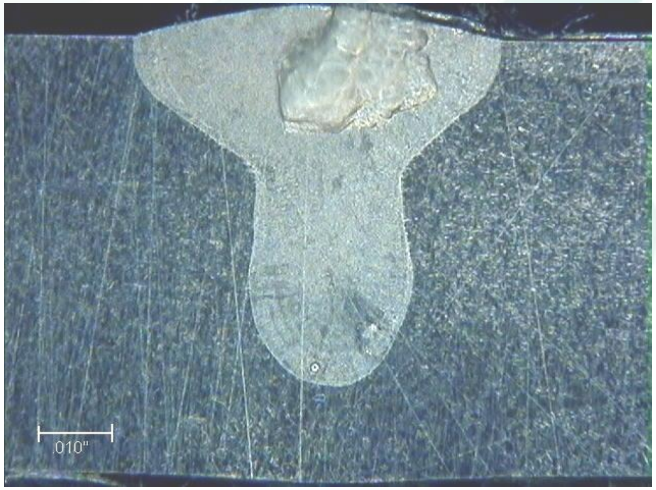
Single Mode and Multi Mode fiber lasers; the importance of spot size

- 500W single mode laser



- 1.5mm thick steel at <u>300ipm</u> with 30 micron spot size

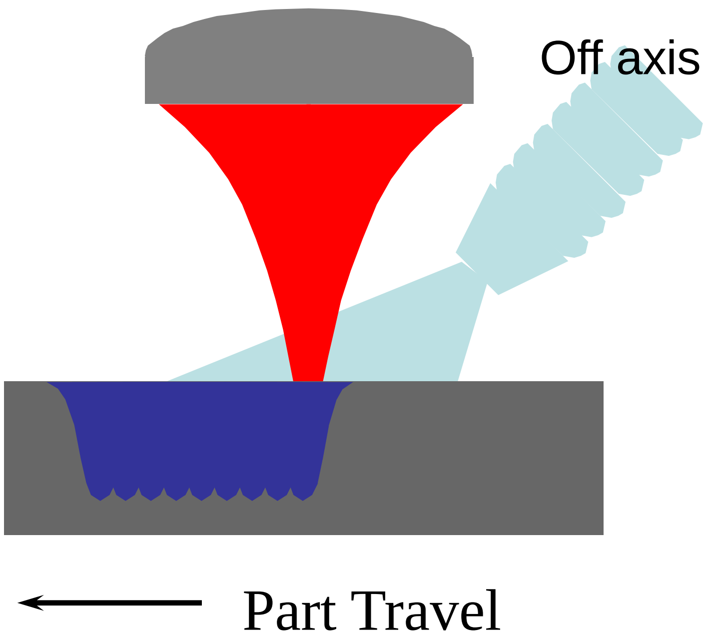
- 1kW multi mode laser



- 1.5mm thick steel at <u>40ipm</u> with 200 micron spot size

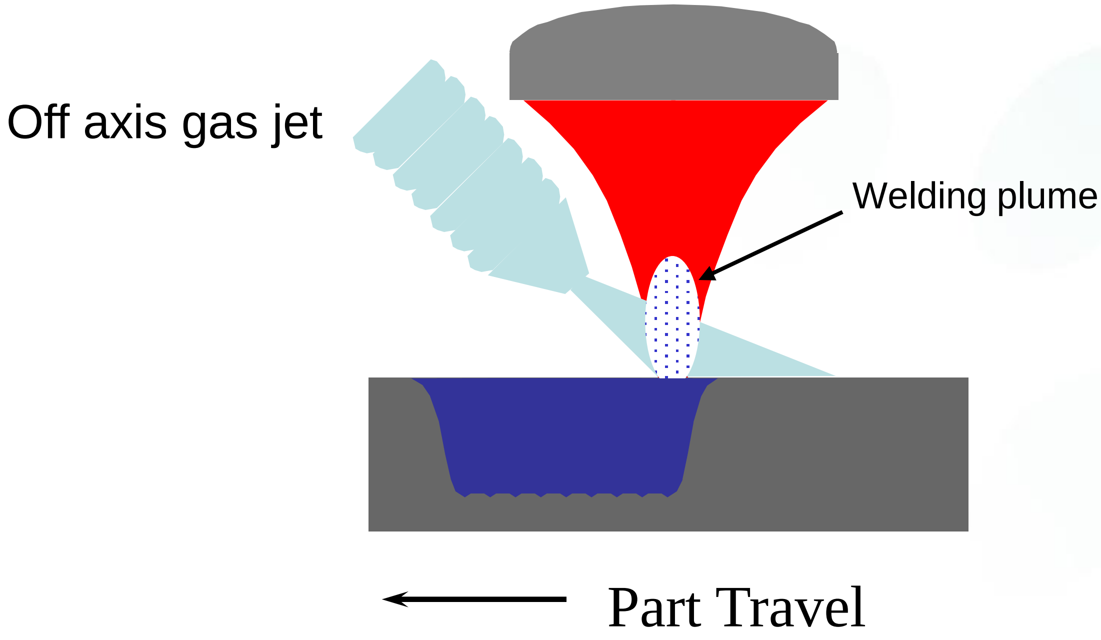
Role of Shielding gas for pulsed Nd:YAG laser

- Prevents oxidation
- Produces aesthetic shiny weld
- Required for titanium, inconels,
- Laminar flow



Role of Shielding gas for fiber laser

- Prevents oxidation
- Welding plume suppression
- Active gas pressure

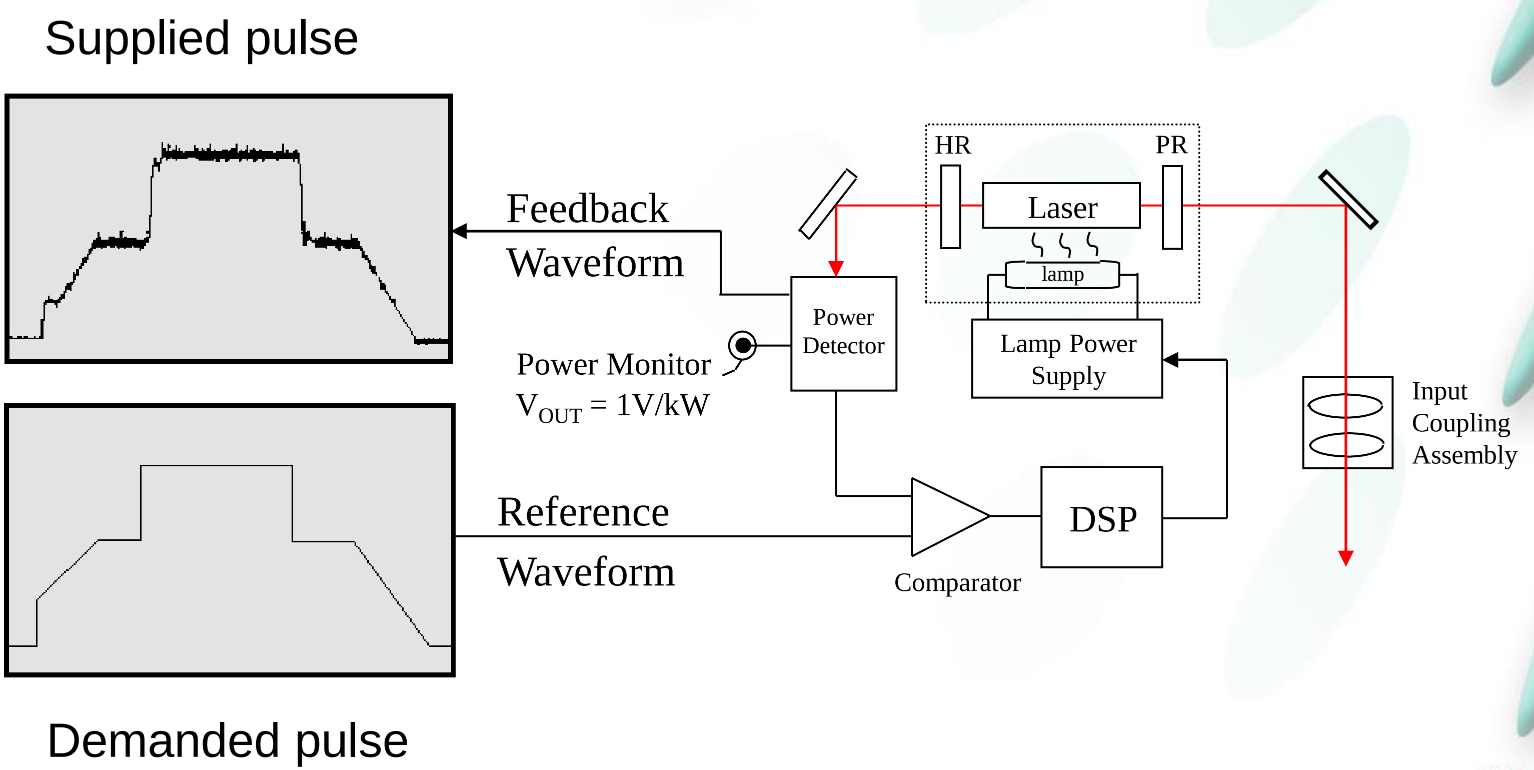


Laser Process & Integration features

- Real time power feedback
- Energy/Time share – multiple outputs
- Excellent pulse to pulse stability
- Pulse Shaping (Fix and Flex Modes)
- Laser Power Ramping (seam welding)

Internal Laser Power Feedback at Work

- All Miyachi pulsed Nd:YAG and fiber lasers
- Same power delivered to workpiece every time, all the time



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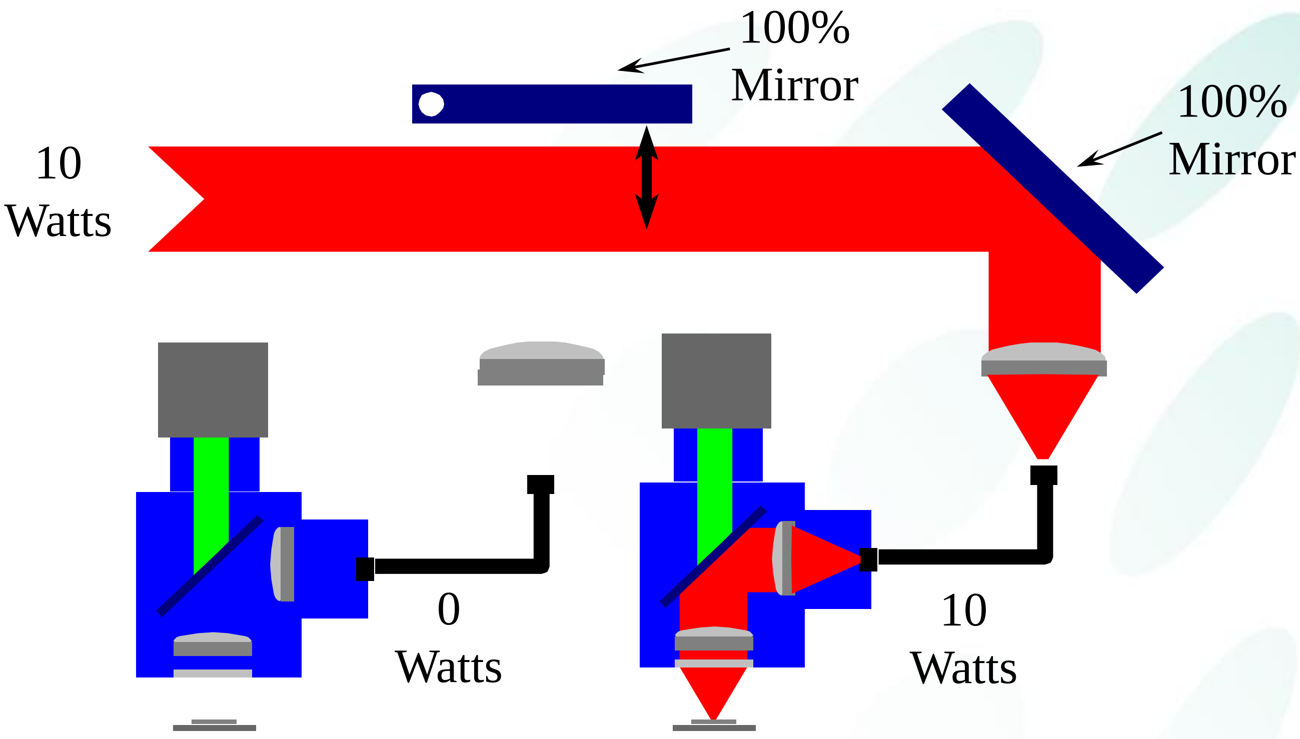
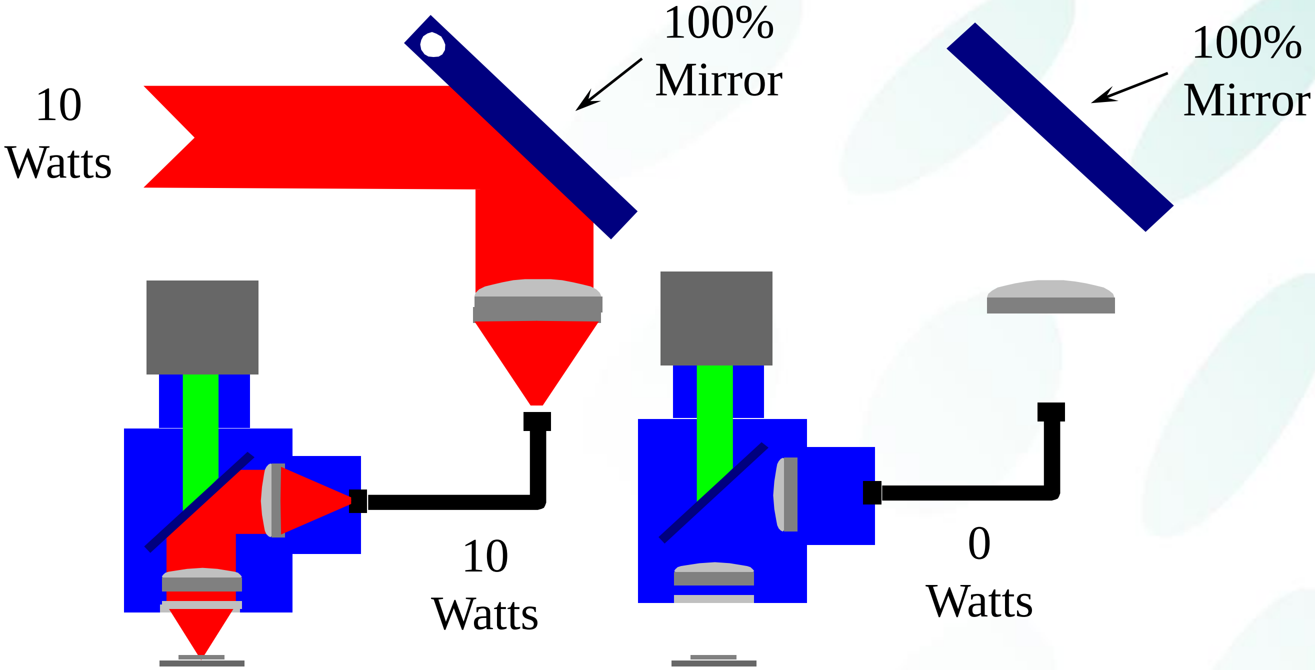
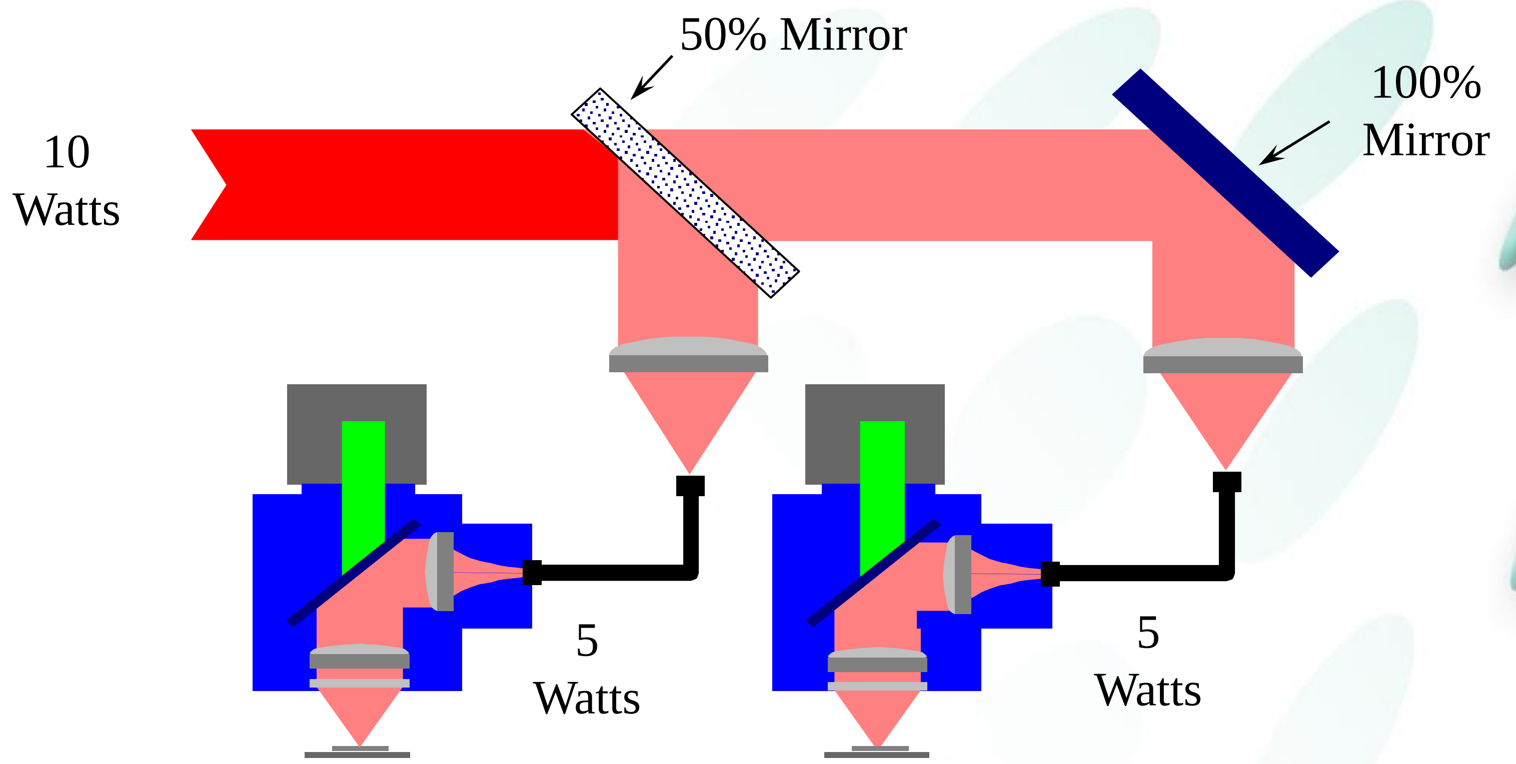
The Laser - *Time Share: Welds Sequentially*



***The Laser** - Time Share: Welds Sequentially*



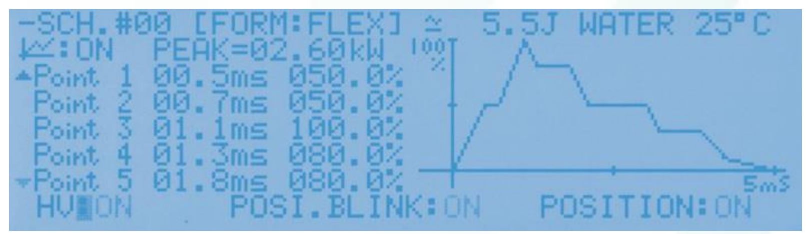
***The Laser** - Energy Share: Welds Simultaneously*



Pulse Shaping

- Pulse Shaping
  - FIX Mode
    (3 segments)

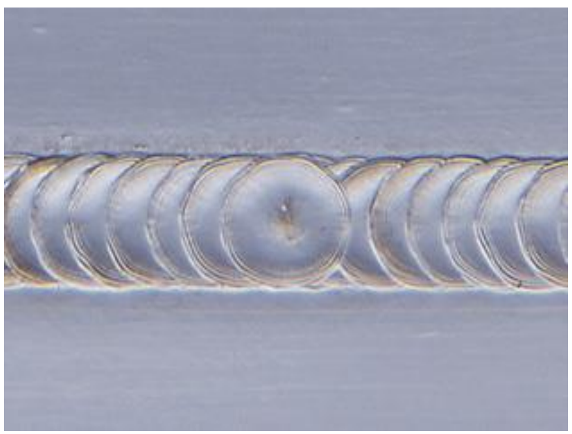
  - FLEX Mode
    (20 segments)



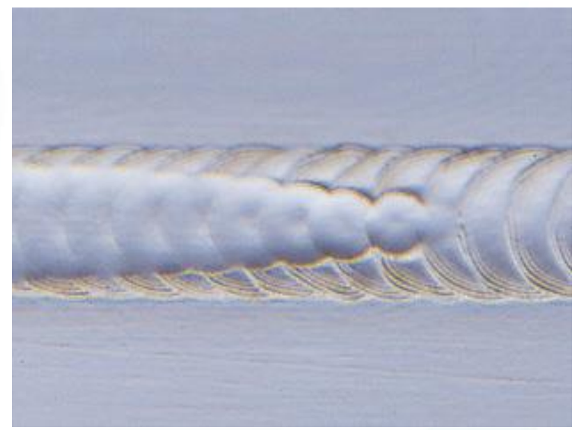
- Applications; welding aluminum, crack alleviation

Laser Power Ramping

- Available in all LW50A – LW600A Lasers, FL fiber lasers.
- Example of Power Ramping:



Without Power Ramping

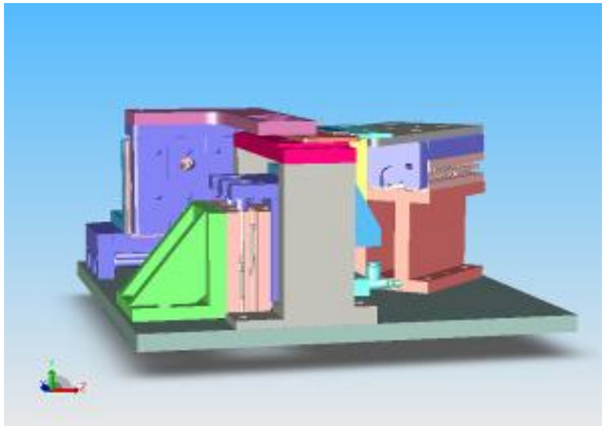


A series with Power Ramping

Tooling & Motion

Tooling (you can't weld air)

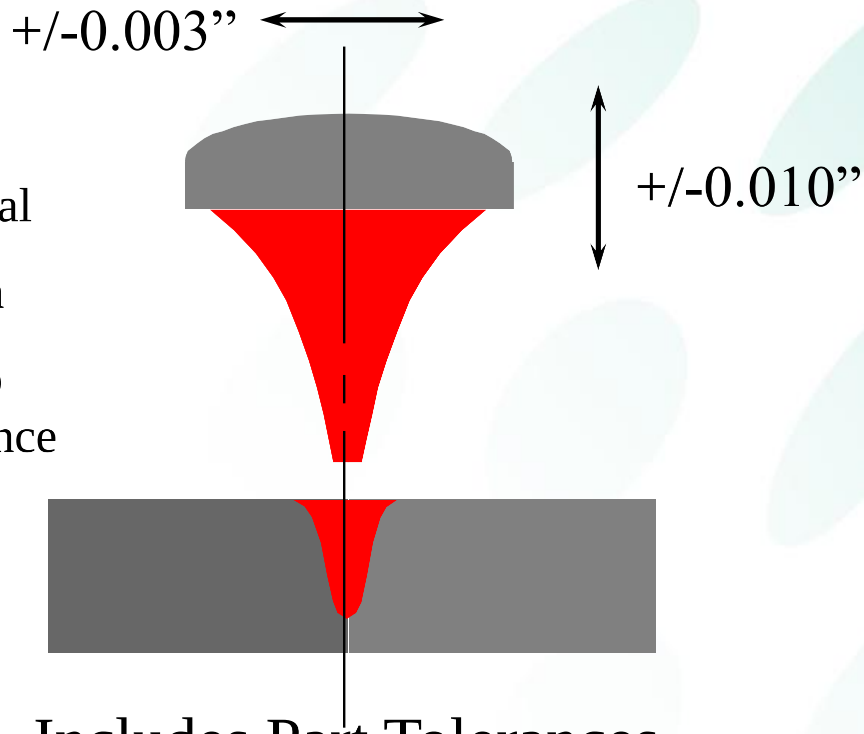
- Tooling functions
  - Clamp parts with minimal gap at the weld interface
  - Consistent positioning under laser
  - Flexibility
  - Ease of use
  - Heat sink
- Modeling



Part Alignment & seam tracking - Nominal Values

Variance in:

- X direction is critical
- Y is travel direction
- Z is forgiven due to large focusing tolerance



Includes Part Tolerances

Motion

- How many axis are required to weld the part (s)
- How accurate does the positioning need to be
- How fast do the stages need to move
- Does the laser or the part move

Putting It All Together

Process Requirements - define the required weld

Materials, joint geometry, cycle time, part fit-up,
part tolerances

↓

Laser Settings:

- Peak Power / Pulse Energy
- Pulse Width
- Pulse Repetition Rate

Beam Delivery:

- Fiber Core Diameter
- Focus Head Collimating Lens
- Focus Head Focus Lens

↓

Average Power ,Spot Size, Power / Energy Density,
Spot Overlap (Seam Welding)

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A FULLY UNDERSTOOD & CONTROLLED WELD!!!!!

Welding in Production

- Bench mark weld
  - Visual, penetration, sensitivity
- Standardize set-up procedures
- Power checks
- Troubleshooting
  - Work from the material backwards