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Laser sources and equipment

State of the Art

Laserdagarna, Luleå, 2011-05-12

Niklas Malmberg

Content

- Laser sources
  - The laser medium
  - Fiber
  - Disk
  - Direct Diode
  - CO_2
- Applications and Solutions
  - Cutting
  - Quasi Continues wave
  - Small process window – problem
  - Dual beam
  - Laser angle
  - Humping & Spatter
  - Deep penetration welding
  - Remote welding
  - Hybrid welding
- Modeling/Simulation
- Optics
  - Problems
  - Dual spot and custom spot
  - Reflective optics

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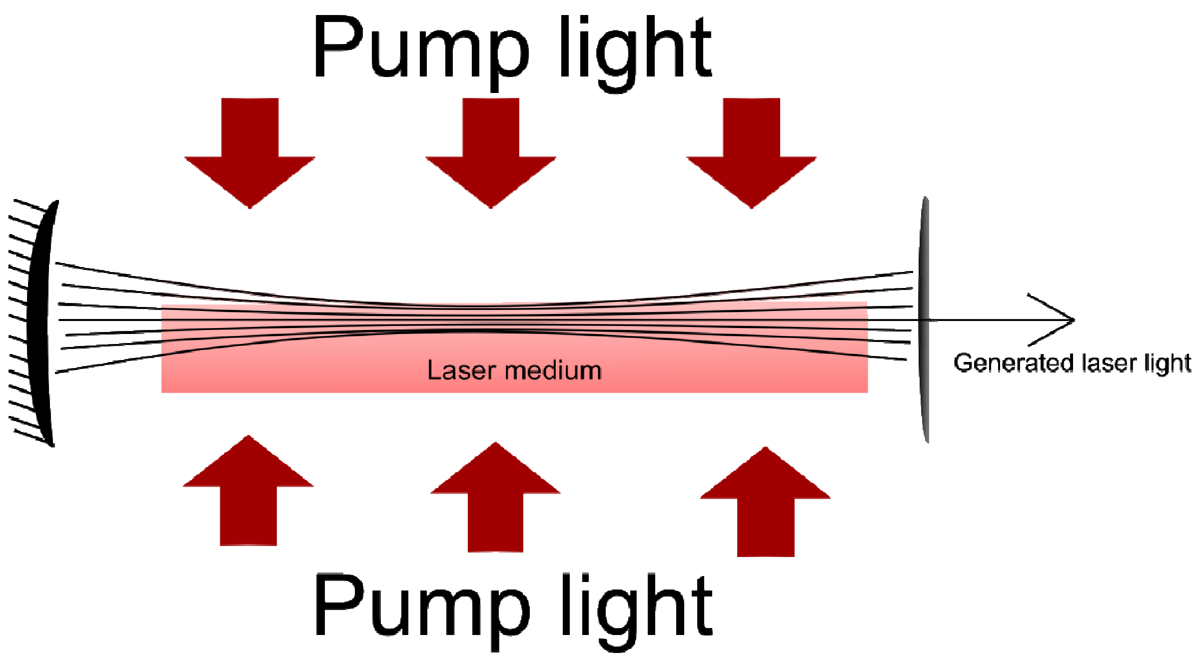
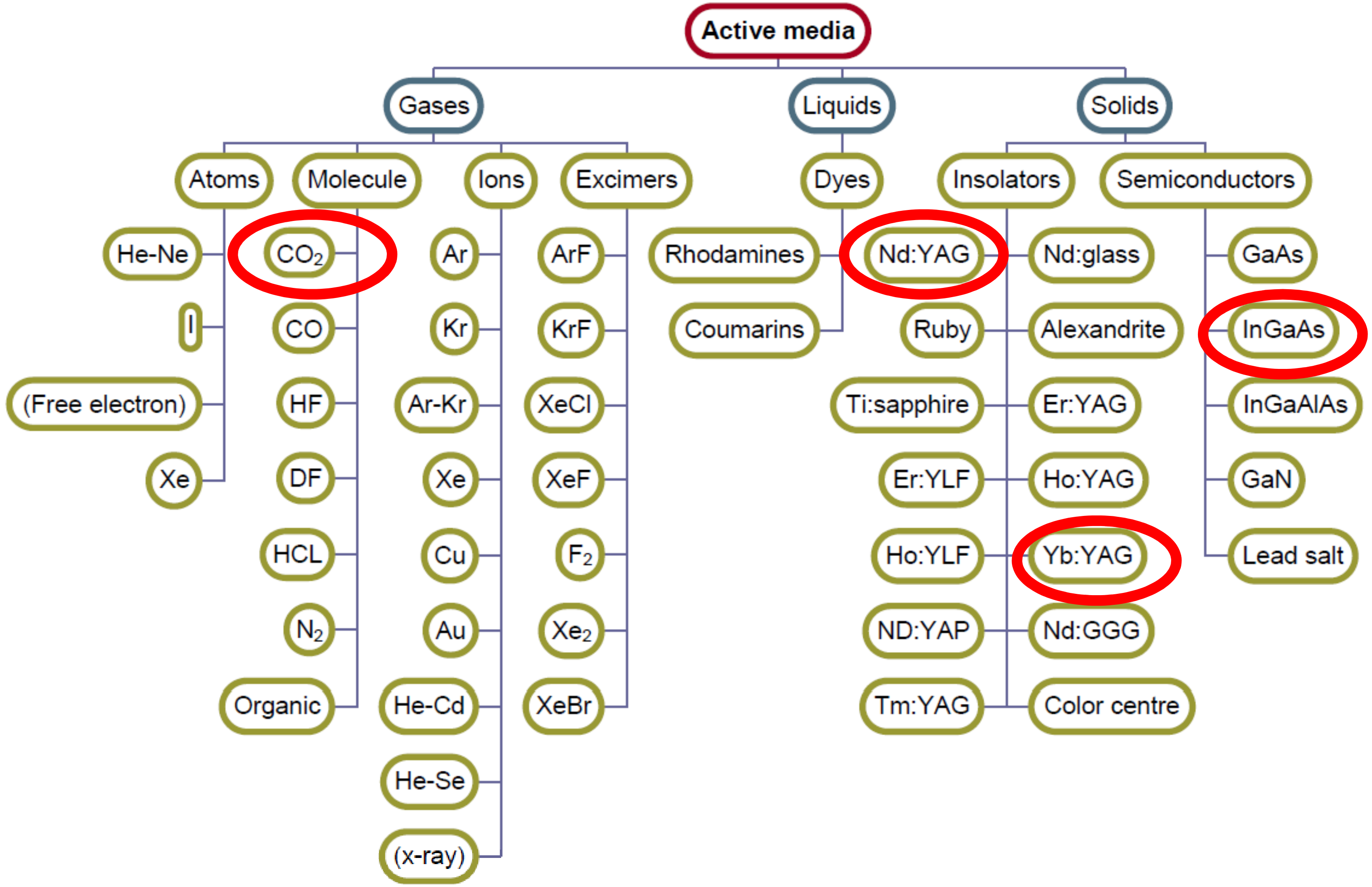
How laser light is made



The laser medium



What does the names mean?

CO_2

CO2 is the laser medium

Laser wavelength = 10.6 µm

Stav (Rod)

The rod is the **shape** of the laser medium. The material is often Nd:YAG.

Laser wavelength = 1.06 µm

YAG

YAG is the laser medium material (Nd:YAG)

Laser wavelength = 1.06 µm

Lamp pumped, diode pumped

Fiber

Fiber is the **shape** of the laser medium. The material is often Yb doped optical fibers.

Laser wavelength = 1.06 µm

Disk

Fiber is the **shape** of the laser medium. The material is often Yb:YAG.

Laser wavelength = 1.06 µm

Difference between 10.6 and 1.06 μm

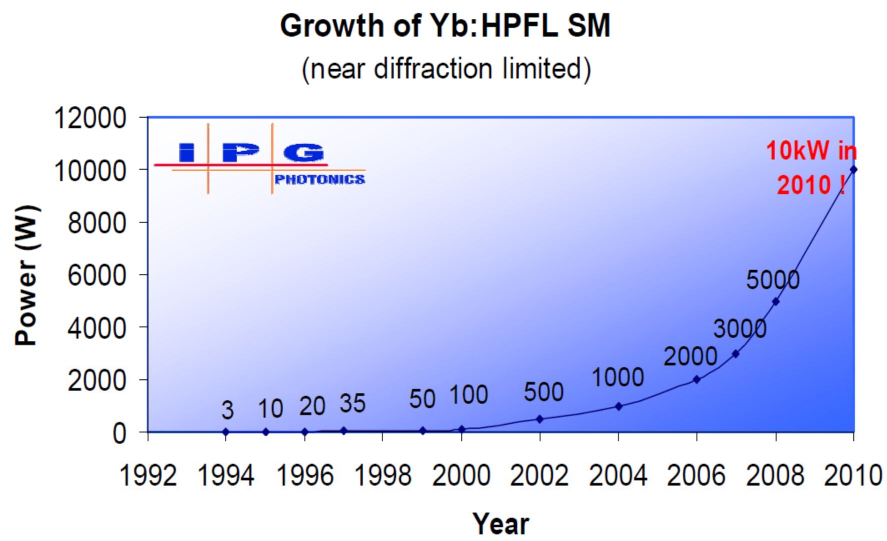
- The absorption of the energy is different
  - Base Material
    - Generally, 1 μm light is absorbed better
    - For reflective materials, e.g Cu and Al, 1 μm light is the only solution
  - Plasma
    - 10 μm light is absorbed in plasma

Higher power and brightness

- Generally, the power is (was) increasing
- The brightness (energy density) is increasing
- The beam quality is increasing
  - Disk and fiber lasers, close to maximum quality
  - Single mode fiber up to 10 kW have maximum quality (M^2=1)

- Has the development in terms of power and beam quality stopped?

Fiber laser



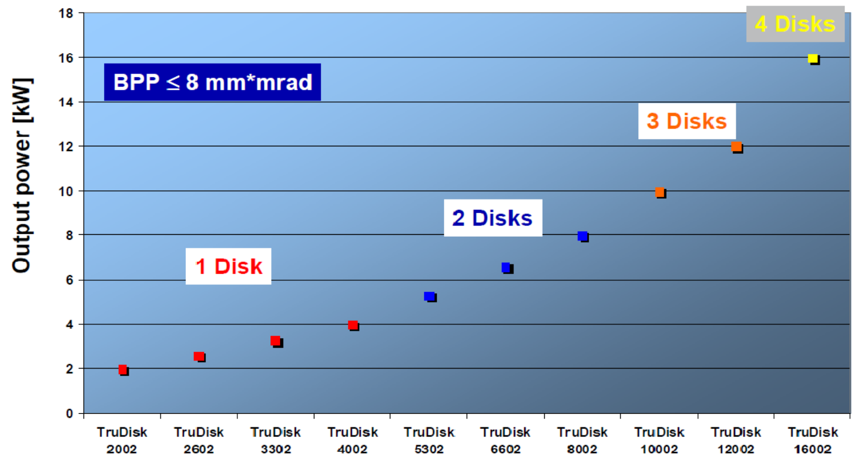
- Multimode up to 50 kW
- Single mode up to 10 kW
- Very high beam quality
- Wall plug efficiency up to 30%
- Quasi Continuous wave [QCW] (long pulse single mode)
  - On the market but still heavily developed by IPG
- Single mode – $M^2 \sim 1$

[8] [9]

Disk laser

- Up to 16 kW (4 disks * 4kW)
  - Possible to connect several laser sources
- Wall plug efficiency is 25-30%
- Beam quality up to 2 mm*mrad (8 and 12 BPP most common)
  - Boeing show that M^2 ~ 1 possible

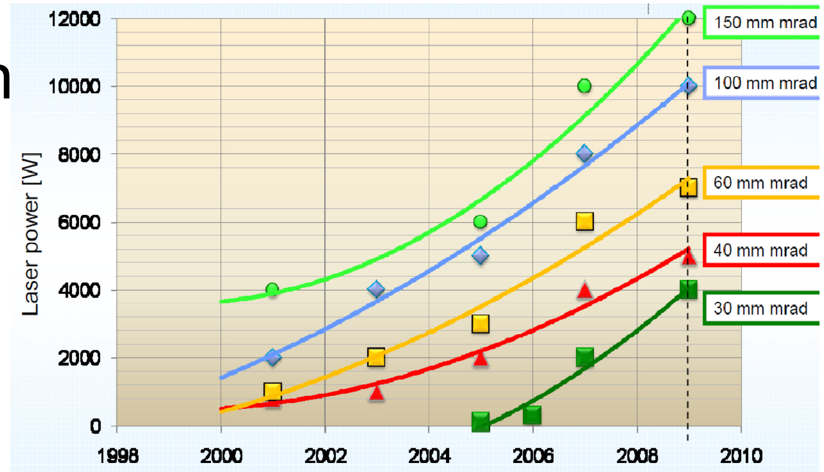
- 5.5 kW / disk in lab
  - Smaller equipment



[13] [14] [15]

(Direct) Diode laser

- Use the pump devices directly
- Beam quality increasing – But still far from fiber and disk
- Wall plug efficiency up to 50%
- Power increasing
- Diode lifetime at least 40.000 h
- 12 kW available (Laserline)
- 4 kW (Trumpf)



[1] [17] [18] [19]

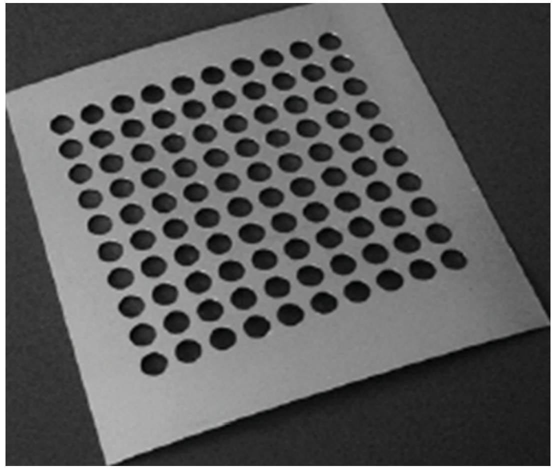
CO_2 laser

- Most common laser source in cutting applications
- Still popular in welding due to a stable process
- Limited research at universities (unfortunately)
- Cheap
- Very good for organic materials (10 µm wavelength)

Content

Cutting

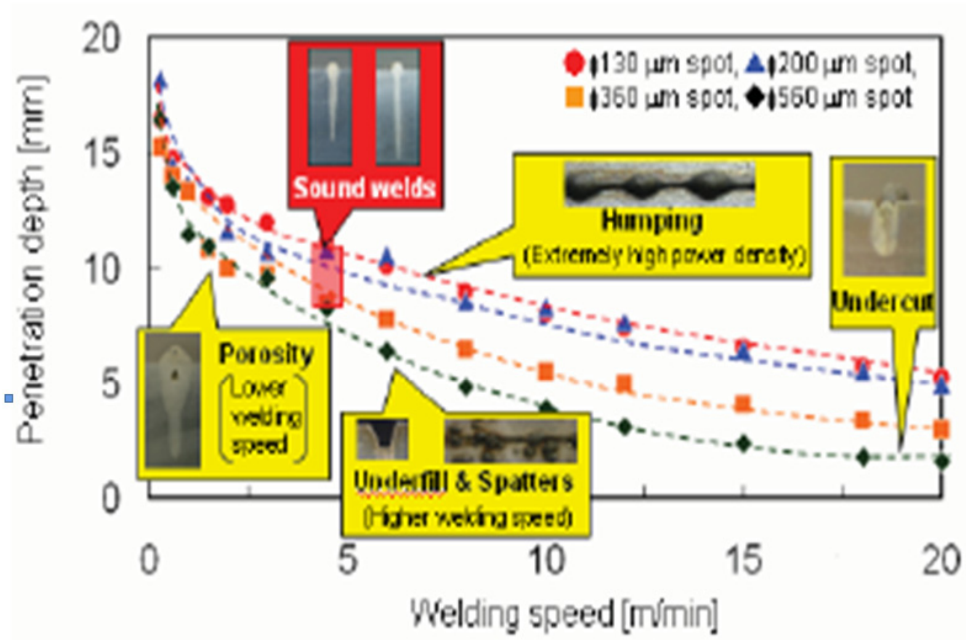
- Solid state lasers
  - Faster in thin (< 5mm) materials
  - Use for reflective materials, e.g. Al and Cu
- CO_2 lasers
  - For thicker materials
  - For mixed production (thick and thin)
- Remote cutting up to 1 mm possible
  - For very thin materials, remote cutting can highly increase productivity



[9] [13] [21]

Welding – small process windows

- General process stability is a big problem and it increases with high power/brightness
- The laser light wavelength is the main problem (1 vs. 10 µm)
- IPG claim that higher brightness from single mode lasers improves the process stability

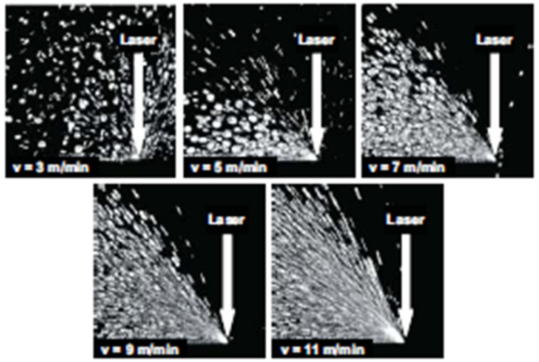


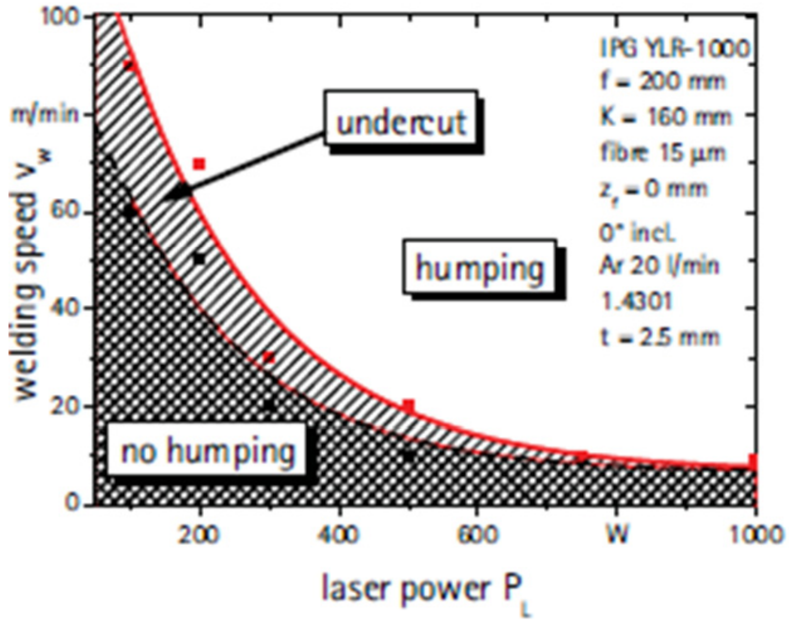
Example with 10 kW fiber

[22] [23] [9]

Spatter and Humping problem

- Illustrate how spatter depends on welding speed
- High speed welding, humping and undercut windows

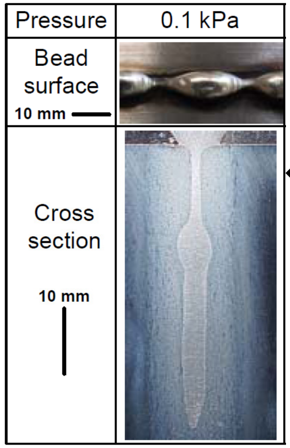




"It is shown that the spatter formation can be reduced by an increase of the inclination angle of the keyhole in forward direction (caused by an inclination of the laser beam) or by a variation of the focal position"

[27] [28]

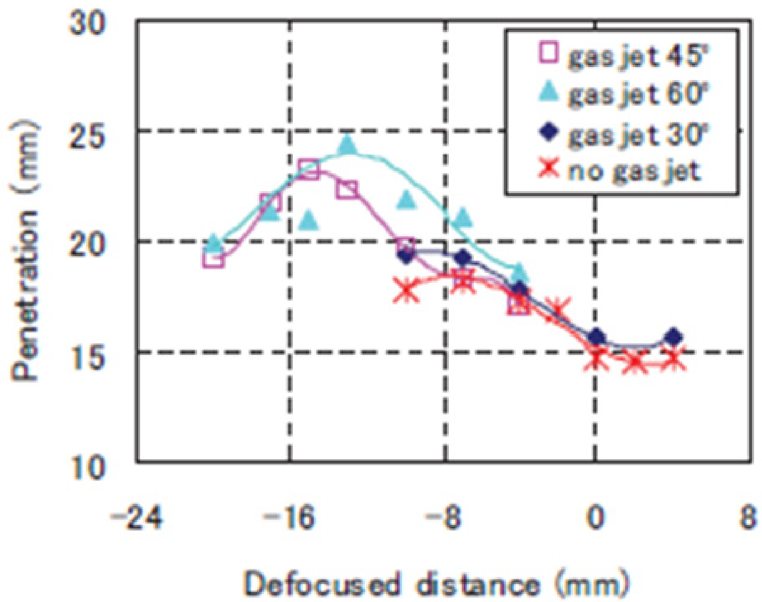
Deep penetration

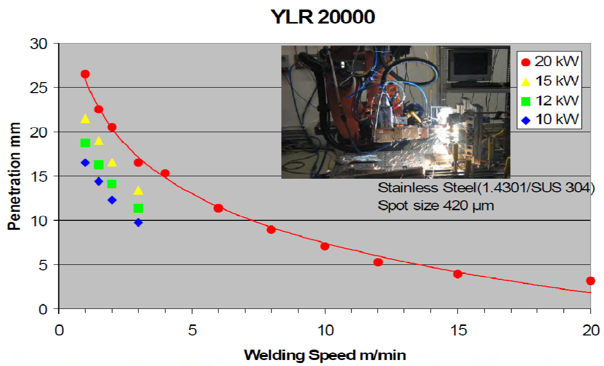


43 mm with 16 kW disk laser, using vacuum

24 mm with 10 kW fiber

@ 0.3 m/min





26.5 mm with 20 kW @ 1 m/min

[20] [29]

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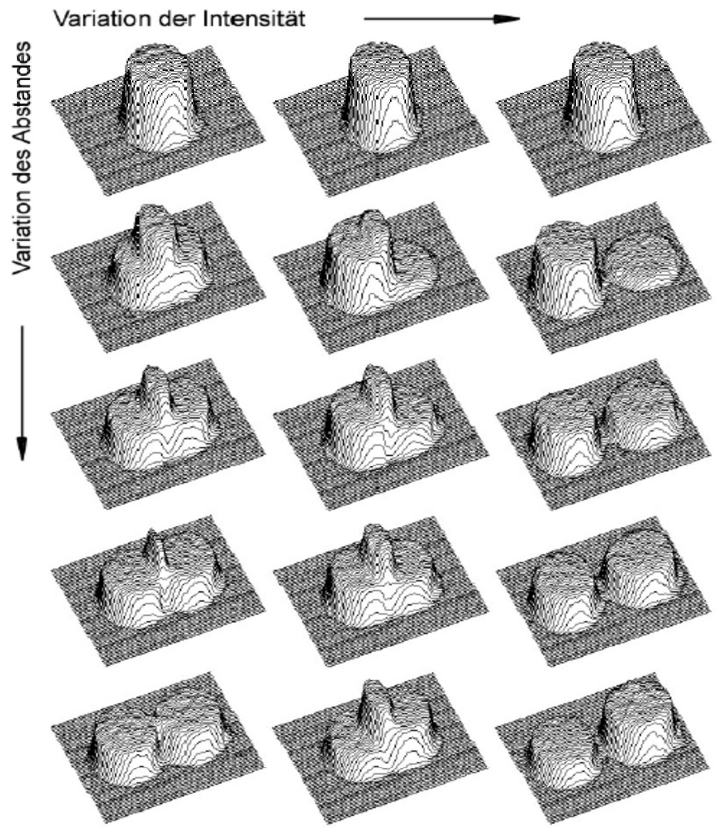
Optics – dual spot

- Standard equipment from most optical head suppliers

- Several solutions of dual spot welding available
- Fixed and adjustable beam spot properties



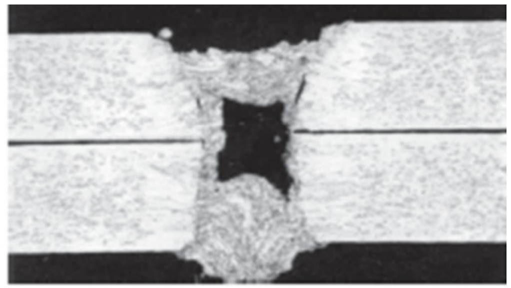
Example From HighYAG

[2]

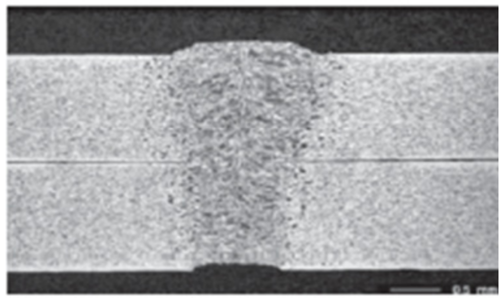
Dual beam/spot

- Dual/split beam gives more stable process in many applications

- Zn coated steel
- Aluminum
- Magnesium



(a) Single beam laser weld



(b) Dual beam laser weld

[24] [25]

Remote welding

- ”Common” in the car industry
- Moving towards robot controlled
- Increased speed
    - Require high volumes
- The market and technique is expanding

Trumpf Programmable Focusing Optics PFO 33.

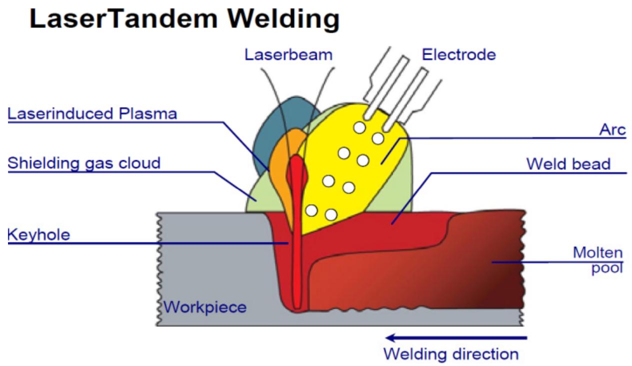
Kuka remote welding head
Focal length 270-1500 mm

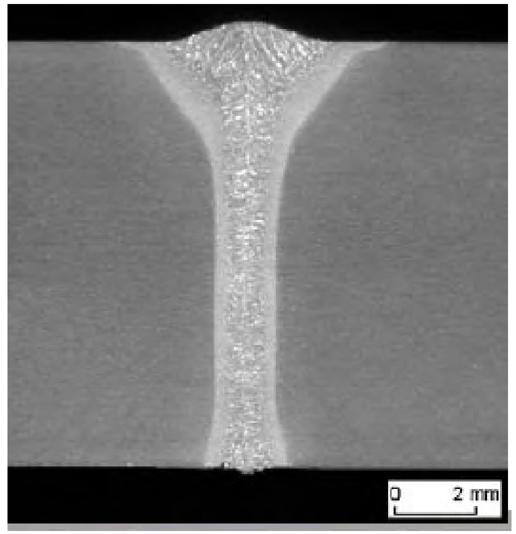
[30]

Laser hybrid

- Combines the best parts of two processes
- Increase the tolerance acceptance

- Example of hybrid welding with high power laser, 10.5 kW
- Fronius Laser-Tandem, example





Deep penetration laser hybrid example

[21]

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Laser hybrid Nov 2010

- Lincoln Electric and Esab had press releases at November 2, 2010
- The start of laser hybrid welding for the masses?

HYBRIO™ LIGHTS THE WAY
TO RADICALLY LOWER COSTS AND HIGHER QUALITY

Florence, SC – The launch of ESAB Welding & Cutting Products' pioneering Hybrio™ technology marks the entry of the first commercially available automated laser welding system on the global market. Welding at three to ten times the speed of conventional processes, with 80-90% less heat input, enables breakthrough performance gains unseen in a generation of welding process developments. Available in gantry, robotic and specialized ...ated solutions, ESAB now has a system configuration well suited to many industrial applications. All ... adaptive welding process control and an easy to use human-machine interface.

During the 2010 Fabtech show, Lincoln Electric and IPG Photonics announced a strategic partnership for the development of HLAW welding systems. The promotion of HLAW by one of the world's largest arc welding companies suggests a positive shift in how industries view the process.

History of HLAW

Having traditional welding companies embrace a laser based technology has not occurred overnight. The combination of a laser with an arc process to address some of the short comings of the technology is almost as old as laser processing itself. Bill Steen published a paper titled "Arc

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Optical problems

- High energy density – problem in the optics (focal shift)
- The problem has been reduced, but not eliminated

- The solution could be to use Reflective optics

  or ZnS (or other optical materials)

Ways to prevent the focal shift

1. Avoiding laser light absorption in the material by selecting the optical material which is best suited.
2. Preventing additional laser power absorption on the optical elements, for example, due to dirt or dust, and hence reducing the interfaces visible to the user. **Keep the optics clean!**
3. Protecting the interfaces, for example by means of protection glasses, crossjets or soiling monitoring components which can be easily changed and checked.
4. Reducing the number of optical elements used.
5. Adapting the optical system to the laser beam parameters.

[2] [9] [41] [43] [44] [45]

Optics – custom spot design

- ZnS is a newer material that can be easily machined
- ZnS have better thermal properties
- Possible to make real custom designs

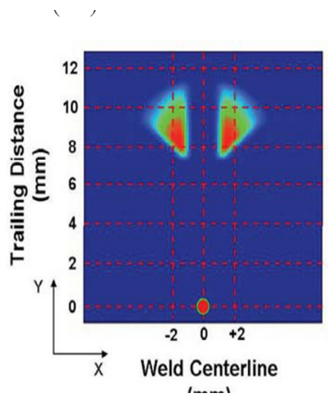
Transmissive Materials for 1 µm Optics

		BK7	Fused Silica	MS ZnS	ZnSe
Mechanical Properties	Density (g/cm^3)	2.51	2.203	4.09	5.27
	Poisson's Ratio	0.208	0.17	0.27	0.28
	Hardness (Knoop)	610	500	150-165	105-120
	Rupture Modulus (dyne/cm^2)	1.65E+08	5.00E+09	6.90E+08	5.50E+08
	Young's Modulus (dyne/cm^2)	8.2E+11	7.3E+11	7.45E+11	6.72E+11
Thermal Properties	Linear Expansion Coef (x10^-6/°C)	7.1	0.55	6.5	7.57
	Specific Heat (J/g/°C)	0.858	0.703	0.527	0.356
	Thermal Conductivity (W/cm/°C)	0.0111	0.0138	0.272	0.18
Optical Properties	Scatter Coefficient at 1.08 µm (/cm)	ND	ND	< 3%	< 0.5%
	Scatter Coefficient at 0.6328 µm (/cm)	ND	ND	< 10%	< 3%
	Index of Refraction @ 1.06 µm	1.5066	1.4496	2.287	2.483
	Temp. Change of Refractive Index(x10^-6/°C) @ 1.08 µm	1.2	11	42	70
	Bulk Absorption (/cm) @ 1.07 µm	~ 0.001	~ 0.0001	< 0.0005	< 0.001
	K-Values For Lenses: Plano/Convex Lens	0.07112	0.08094	0.02888	0.02840
	Positive Meniscus Lens	0.08573	0.07792	0.02051	0.01758
	Equi-Convex Lens	0.10280	0.11642	0.05484	0.05164

Multi-Spectral (MS) ZnS is the only material for NIR and IR freeform optics.

Courtesy II-VI Inc.

[43]



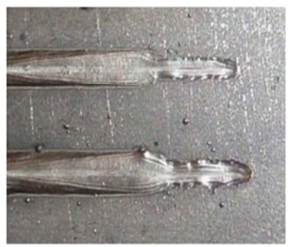
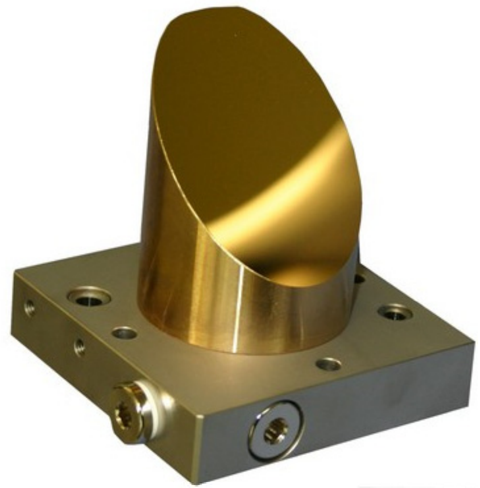


Figure 9. Weld End Craters from Custom Optic Welding Trials

Figure 10. Weld from Single Pass of Custom Optic

Reflective Optics - Mirrors

- Copper
- Better cooling
- Slightly higher energy losses
- Not as good focusability (compared to transmissive optics)



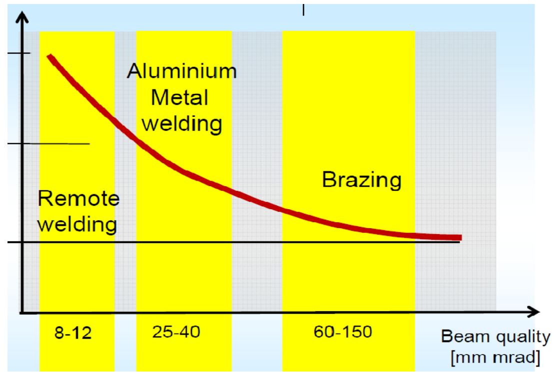
- Both Trumpf and IPG mention mirrors as a solution for high brightness systems

[9] [23] [46]

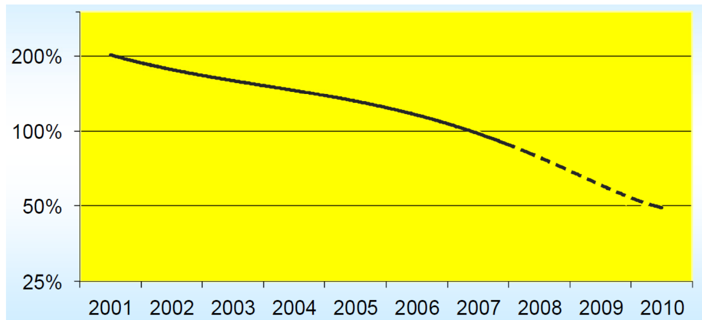
Economy

- Important to know what beam quality that one need. Do not buy higher beam quality than you need.

- Prices are decreasing fast. The economically barrier will hopefully be smaller to increase the general utilization of laser materials processing



Price as a function of beam quality (Laserline)



Price development for Laserline's diode lasers

[1] [13]

Summary

- The high brightness laser processes are more uncontrollable than ordinary weld processes
- The process windows are generally very small for high brightness welding
- Laser beam quality is generally increasing
- Multi mode fiber lasers are available up to 50 kW
- Single mode fiber lasers are available up to 10 kW
- Disk lasers are available up to 16 kW
- Direct Diode lasers are available up to 12 kW
- Many optical components are not constructed for the high energy density
- The Wall plug efficiency is increasing
- Twin-Spot welding stabilize the process
- The laser inclination angle is an important parameter
- Penetration depth of 43 mm has been achieved
- Reflective optics are used in high power installations
- There are much development in new spot shape designs and optical materials
- The price of the laser sources are decreasing
- Typical beam qualities in mm*mrad are:

Single mode fiber:	0.3
Multi mode fiber:	2-10
Disk laser:	2-12
Diode laser:	30-150

Thank you for the attention

Questions and comments?

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