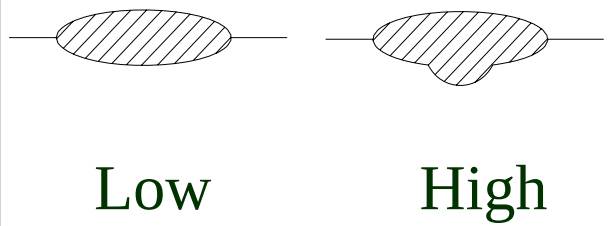
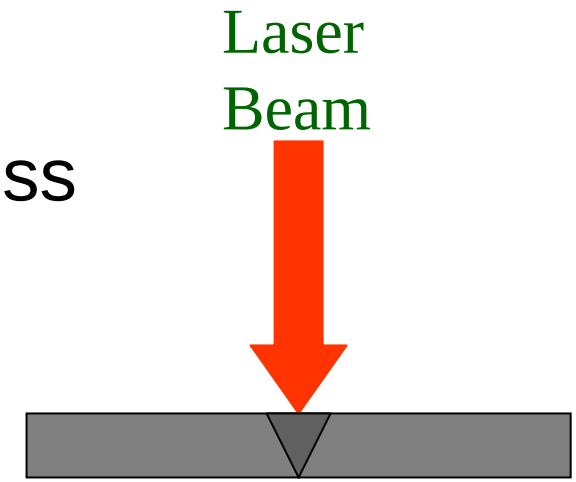
Modern Manufacturing Processes

Laser Welding

Why Laser Welding ?

Welding Process	Heat Source Intensity W/cm^2	Fusion Zone Profile
Gas Shielded Arc (TIG/MIG)	$5 \times 10^2 - 10^4$	 Low High
Plasma Arc	$5 \times 10^2 - 10^6$	 Low High
Laser or Electron	$10^6 - 10^8$	 Defocus Focus

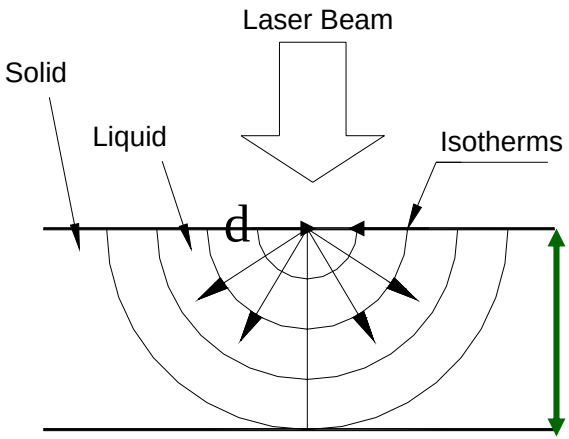
- Types of Laser Welding Process
  - Conduction welding
  - Keyhole welding
  - Hybrid laser welding



Laser Welding of workpiece

1. Laser Conduction Welding-

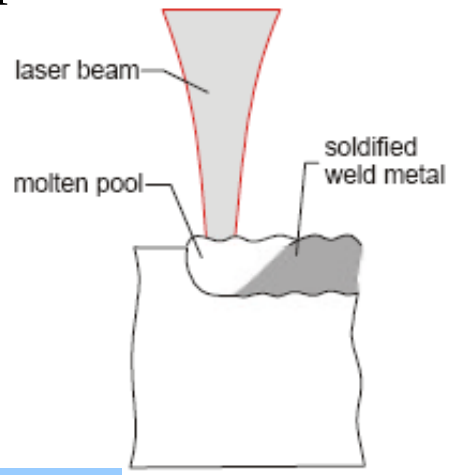
* Joining of thin metal sheets
* Laser power densities: Relatively low $\leq 5x10^5$ W/cm^2.
* Two metal surfaces melt and
* Full thickness melts due to heat conduction from top hot surface.



Conduction Welding

$t=2\sqrt{\kappa\tau}$

κ- Thermal Diffusivity



τ- Laser Interaction Time = Laser pulse duration
= Laser dwell time = Beam diameter d/Welding speed v

In conduction welding the depth to width aspect ration is about 1.5.

2. Deep Penetration / Keyhole Welding

Thicker sheets (>3mm):

Higher Laser Power

At intensities $\geq 10^6$ W/cm^2, a small amount of metal vaporizes & plasma is formed.

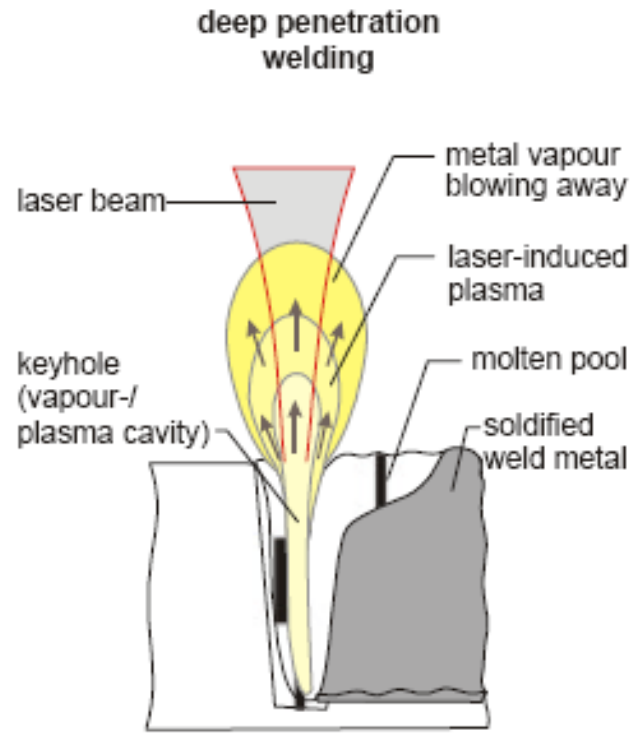
Escaping vapour exerts a recoil pressure on the molten pool creating a key hole

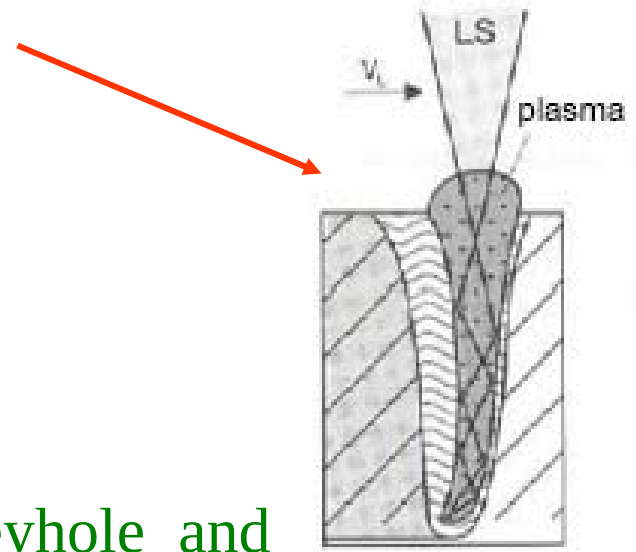
Laser beam is absorbed in the hole in multiple reflections and in metal vapour plasma and heat is transmitted to the work-piece through the walls of the hole.

Deep penetratio Welding

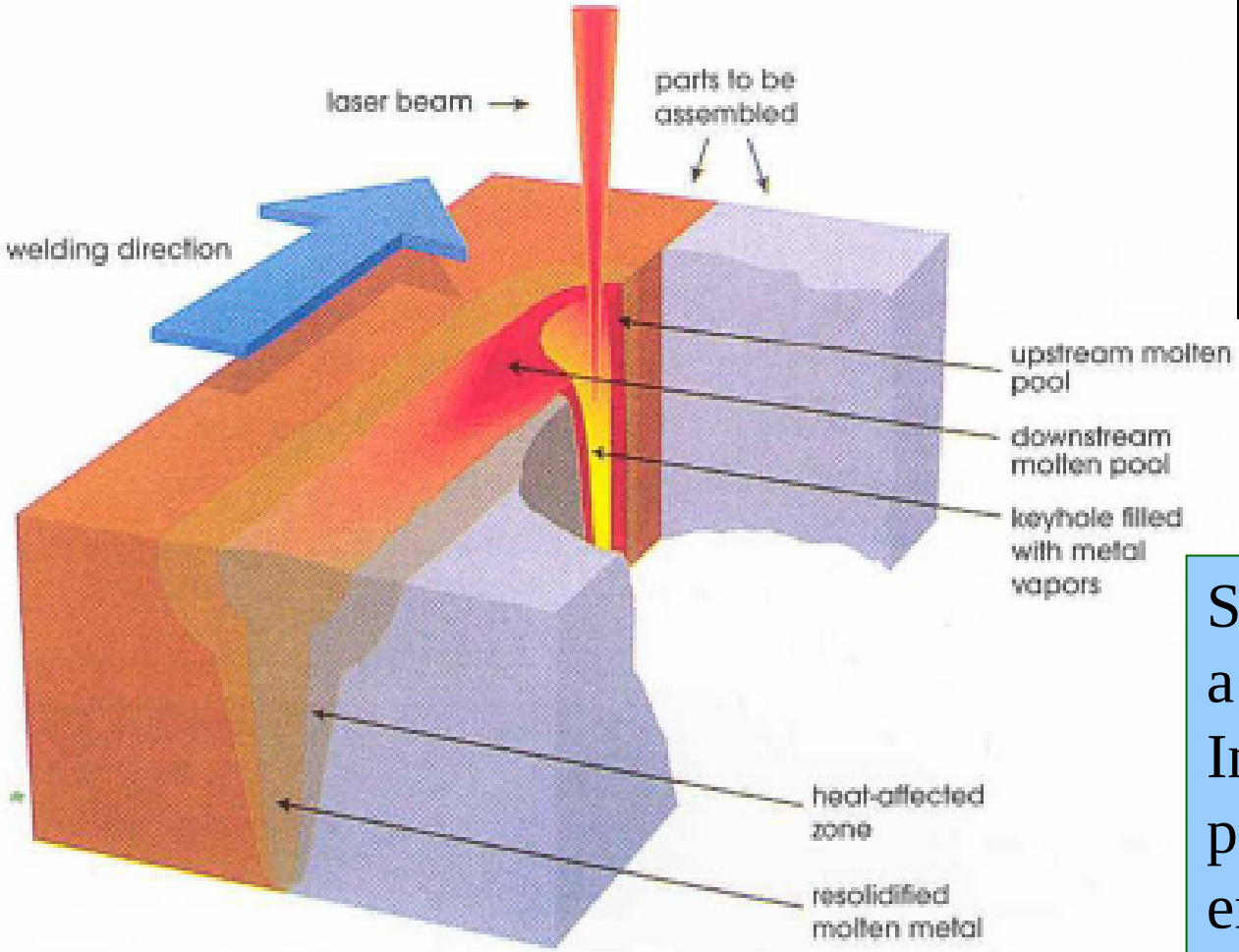
Aspect ratio in Keyhole welding = 3-5

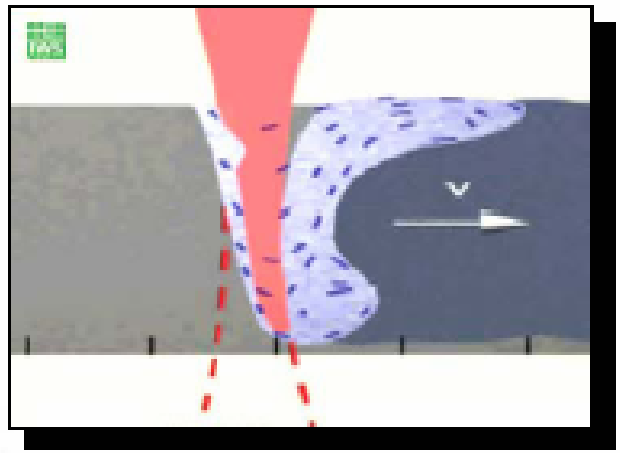
Scan velocity determines the shape of keyhole and cooling rate determines the microstructure of weldmet





Laser Keyhole Deep Penetration Welding



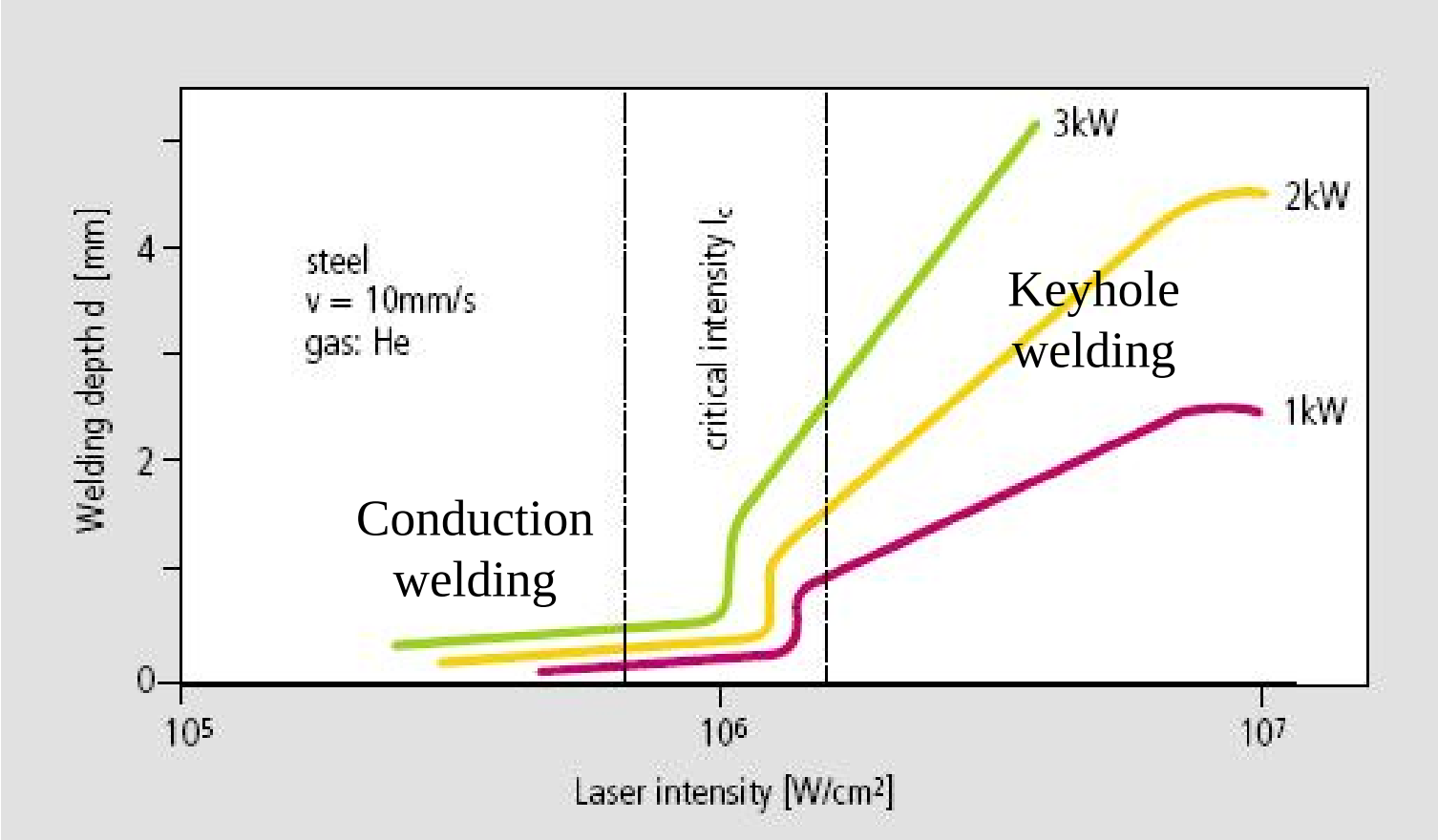


Stability of keyhole is a major issue : Instability causes partial penetration & entrapment of gas bubble- porosity

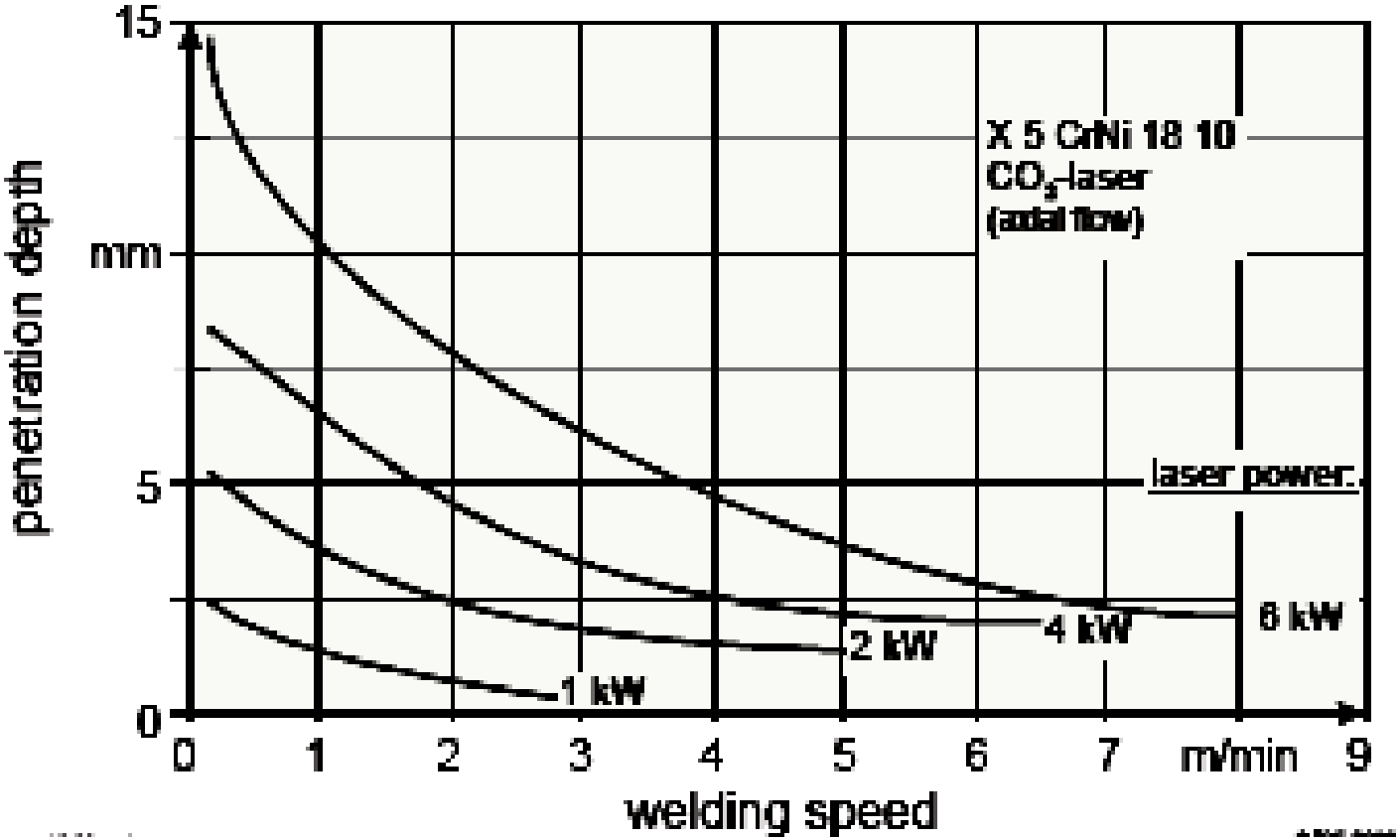
Operating parameters

- Beam characteristics
  - Beam Power & Power Density
  - Beam Power distribution, i.e. Mode
  - Polarization
  - Mode of operation: CW, Pulsed
- Process Parameters
  - Beam diameter & focus
  - Welding Speed
  - Shielding / Shroud gas
- Material Properties
- Joint Geometries: Butt, Lap…
- Gap Tolerance

Parameter effect: Laser Power Density



Beam Power & Scan speed

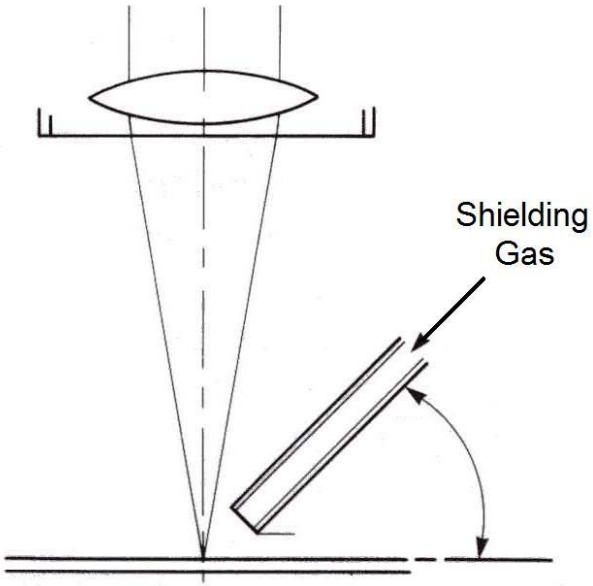


1 kW of laser power per mm thickness is needed to weld at 1 m/min.

Energy Balance Equation: $A.P_L(1-R) = V.w.t.(\rho.C_p.T_m + L_f)$

where A = 0.48 to account for conduction loss; V-Welding speed, w-weld-width, t-weld-thickness & others are material properties.

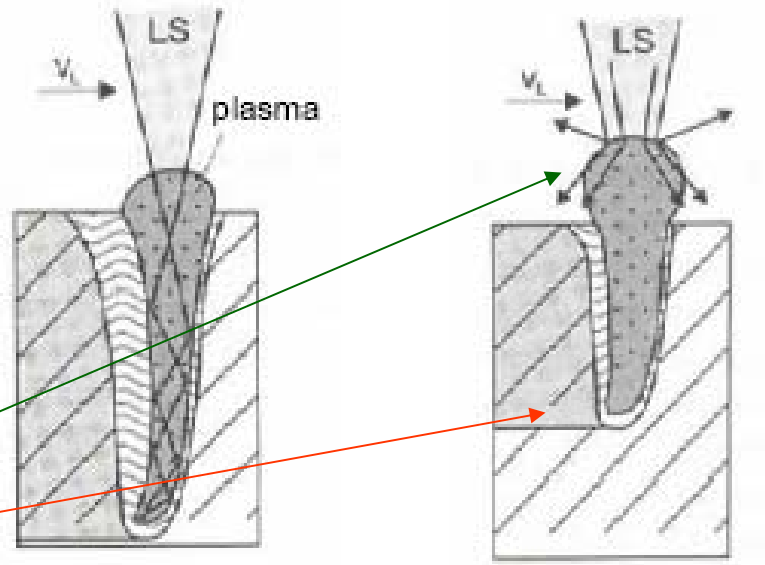
- Shielding gas properties
  - Gas composition, design, pressure, etc



Gas	Ionizing potential
Helium	24,46 eV
Argon	15,68 eV
N_2	15,51 eV
CO_2	14,40 eV
Fe	7,83 eV
Ni	7,61 eV
Ti	6,81 eV
Cr	6,74 eV
Al	5,96 eV

deep penetration welding

Plasma shielding

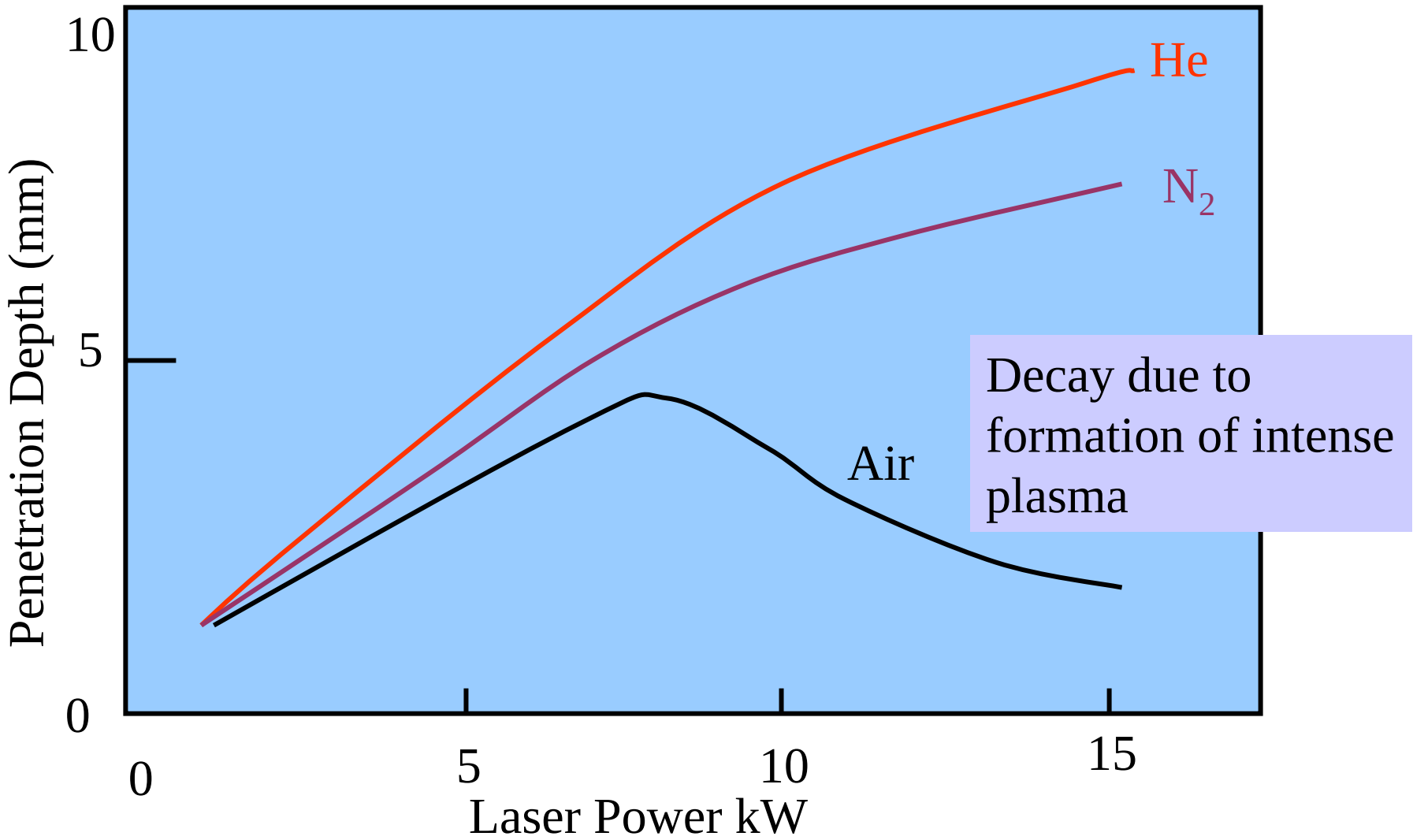


At higher laser power densities
> $10^6 W/cm^2$

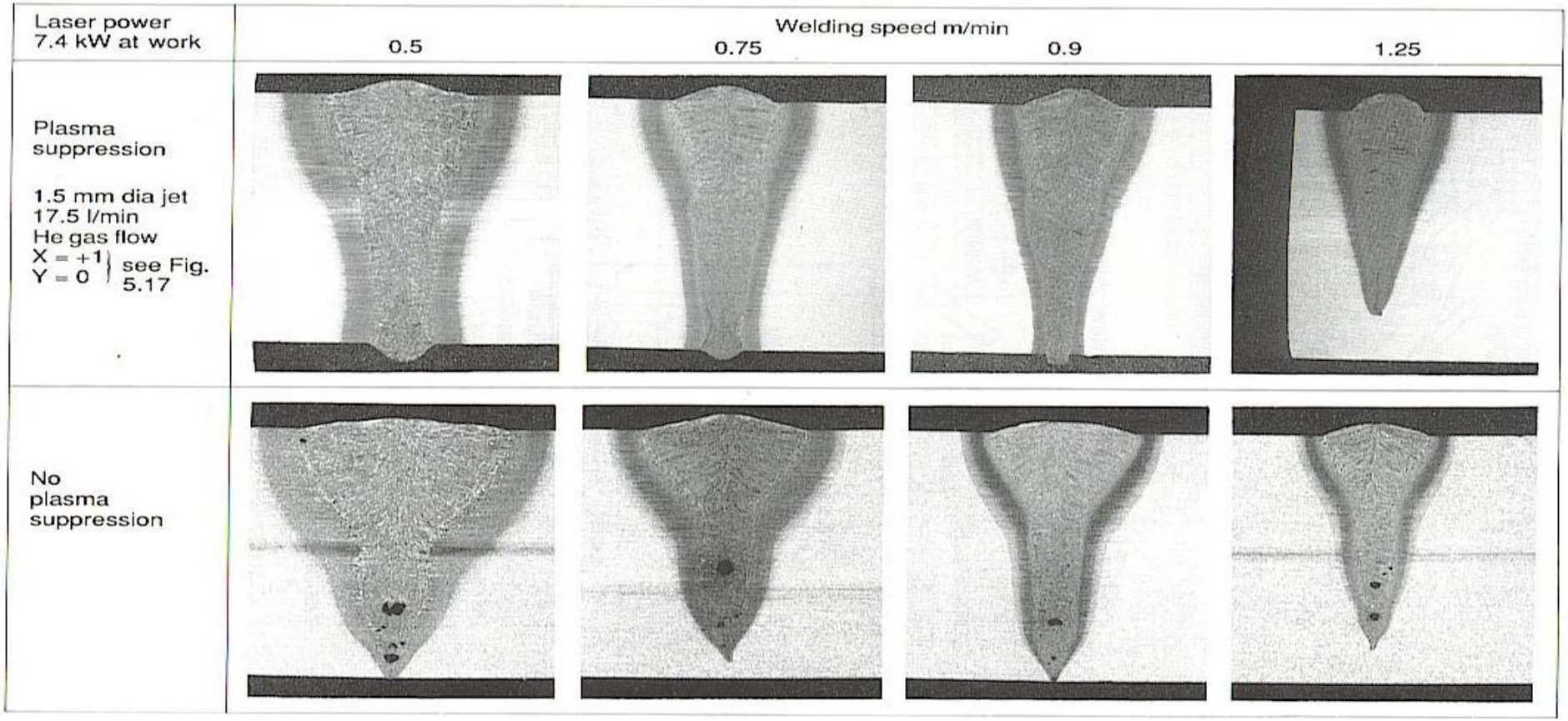
More intense (larger electron density) plasma, Expand away from keyhole

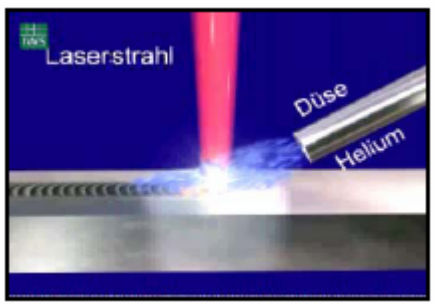
Laser power absorbed in plasma head, thus can't reach to work-piece: shallower weld-depth

Effect of Shielding / Shroud Gas

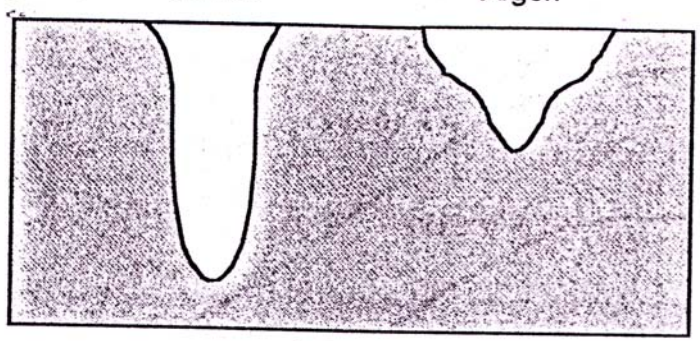


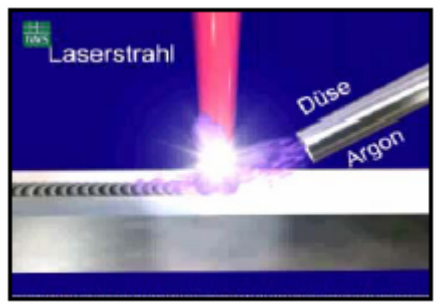
Parameter effect: shielding gas





Protective gas = Helium Argon

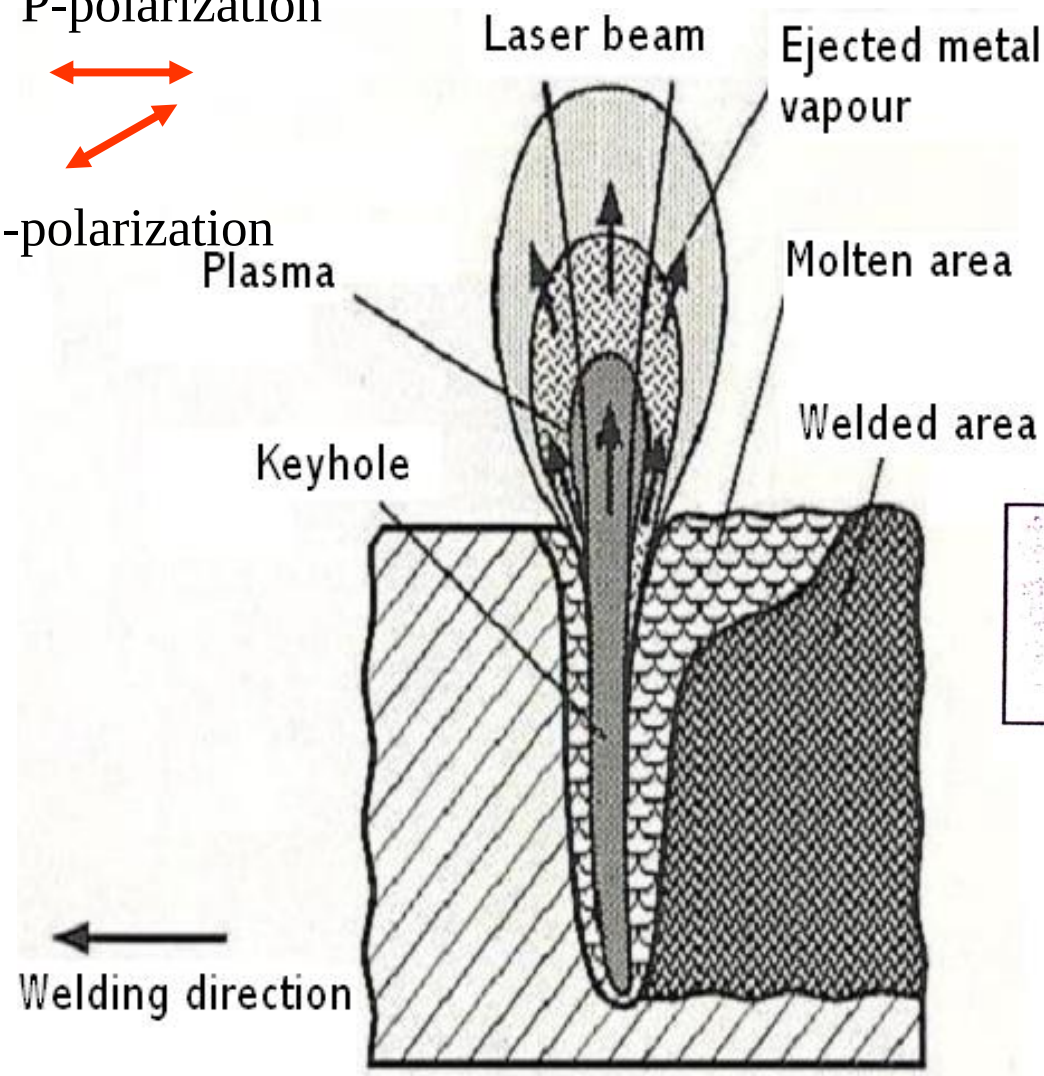


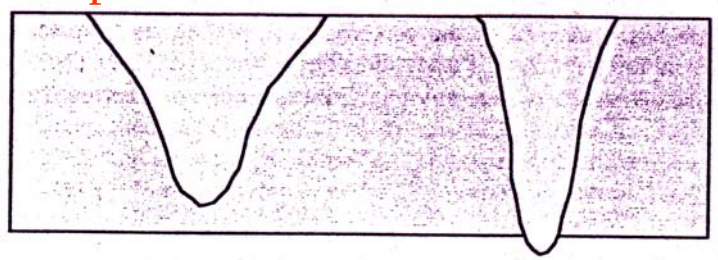


Effect of Polarization

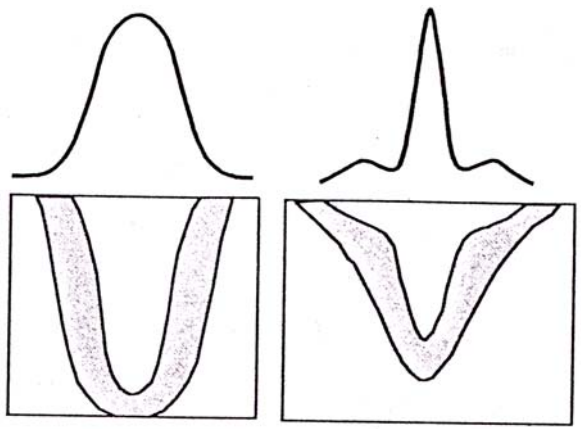
P-polarization

S-polarization



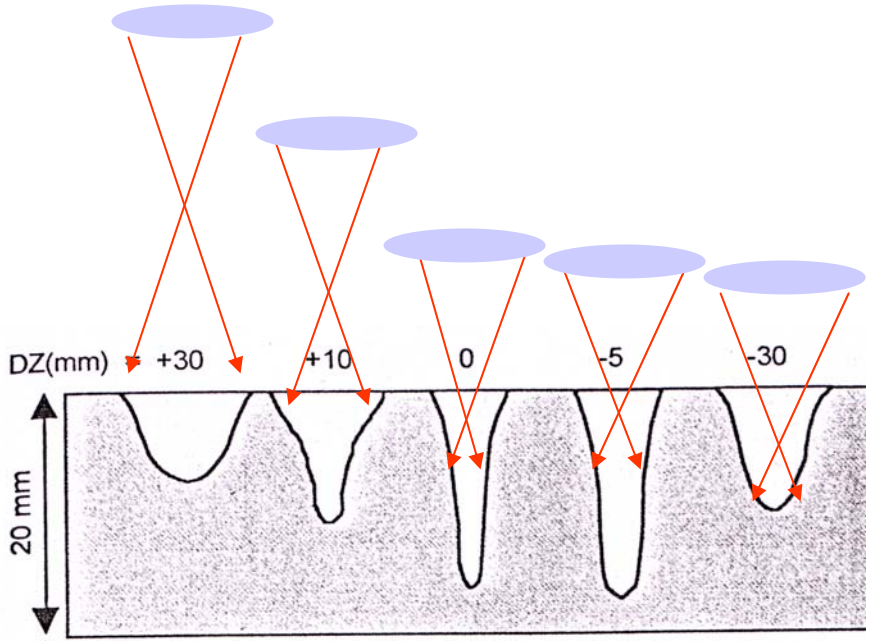


Beam Quality



TEM $_{00}$ TEM$_{10}$

Focal point position



Laser Weld / Joint Geometries

All different types of weld geometries possible with laser:

Butt Joint

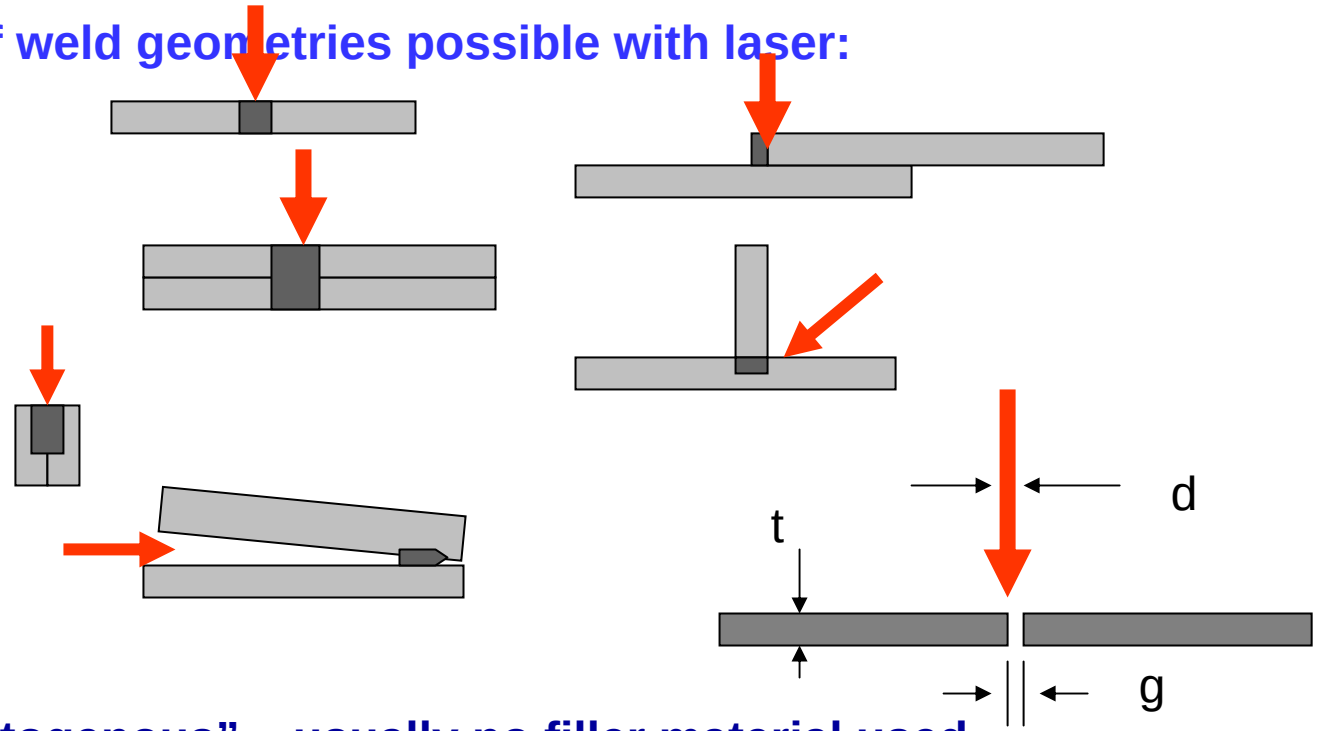
Lap Joint

Spot /Lap Weld

T-Joint

Flange Joint

Flare Joint



Gap Tolerance:

Laser Welding: “Autogenous” – usually no filler material used

Gap between two parts: Less than half of the laser beam diameter for efficient laser power coupling, $g < 0.5d$

Minimum fall in weld level:

- Weld width
- Weld Thickness
- Welding Temperature
- Thermal Expansion Coefficient

Thumb Rule: Gap less than 10% of weld thickness, $g < 0.1t$

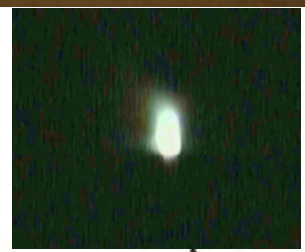
Typical shape of Laser Weld

Inverted Wine-bottle shape

Top part- Effect of Conduction,

Plasma formation & heat conduction

Marangoni Force due to variation of surface tension with temperature.



Surface Shear force due to change in Surface Tension, σ (MT^{-2})

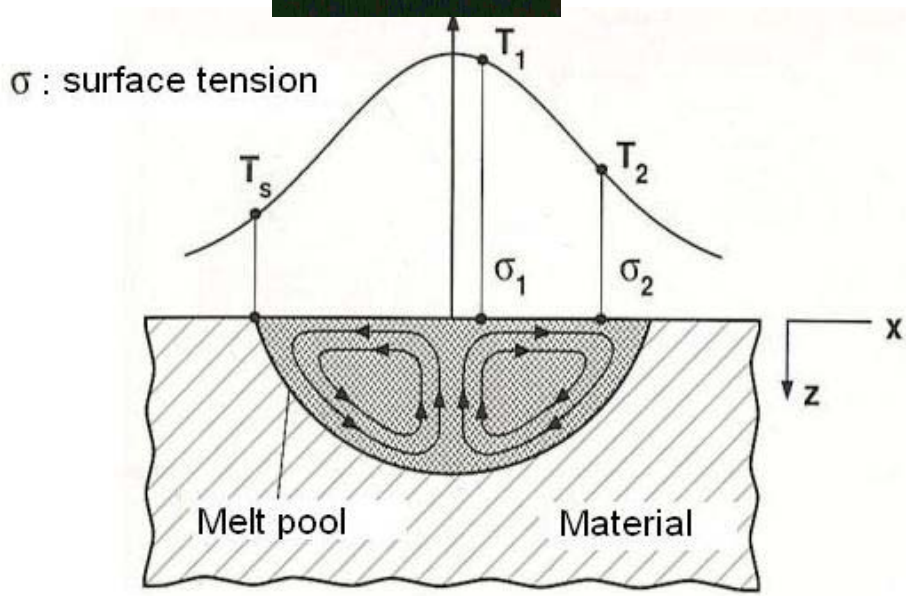
$F_s = \partial\sigma/\partial x = \partial\sigma/\partial T . \partial T/\partial x$,

For Ni: $\partial\sigma/\partial T$ = 0.38ergs/ $^0C/cm^2$

$\partial T/\partial x$ = 2.5×10^4 $^0C/cm$

Shear Force = 10^4dynes/cm = 10^3 Pa = 0.01 atm.

This can produce ~10G acceleration in a small layer of molten pool



Alloys	**Laser Welding Characteristics for Different Alloys**
Steels	O.K.
Al-alloys	Problems : 1. Reflectivity-requires at least 1kW, 2. Porosity, 3. Excessive fluidity-leads to drop out
Ti-Alloys	Better than slower process due to less grain growth
Heat resistant Alloys e.g. Inconel 718 (Ni-based alloy)	O.K. but 1. Weld is more brittle, 2. Segregation problem, 3. Tendency of crack

Weldability of metallic pairs

	Al	Ag	Au	Cu	Pd	Ni	Pt	Fe	Be	Ti	Cr	Mo	Te	W
Al	◆													
Ag	○	○												
Au	○	◆	◆											
Cu	○	○	◆	◆										
Pd		◆	◆	◆										
Ni	○		◆	◆	◆	◆								
Pt		○	◆	◆	◆	◆	◆							
Fe			○	○	●	●	●	◆						
Be			○	●	○	○		○						
Ti	○	○	○	○	○	○	○	○		◆				
Cr			○		●	●	◆	◆		●				
Mo						○	◆	●		◆	◆			
Te					●	●	○	○		◆		◆		
W					○	○	●	○		○	◆	◆	◆	◆

◆ = excellent ● = good ○ = satisfactory

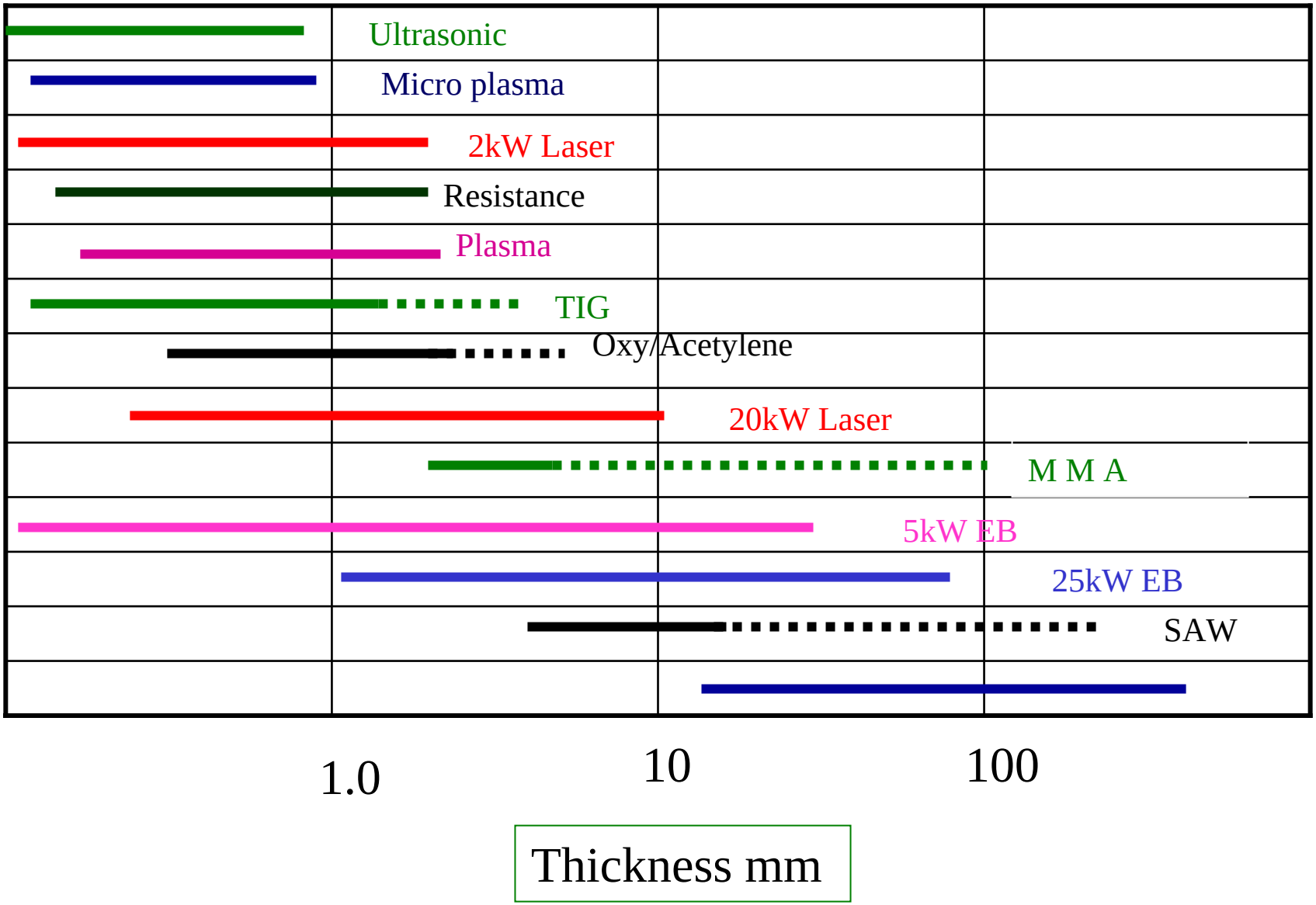
Laser Welding Advantages

- Can be used in open air
- Can be transmitted over long distances with a minimal power loss
- Narrow heat affected zone (HAZ)
- Low total thermal input
- Welds dissimilar metals
- No filler metals necessary: Autogenous Weld
- No secondary finishing necessary
- Extremely accurate
- Welds high alloy metals without difficulty

Laser Welding Limitations

- Rapid cooling rate may cause cracking in certain metals
- High capital cost
- High maintenance cost

Laser Welding capability & Comparison with other Welding Processes

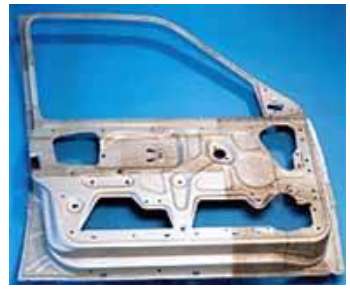


Advantage & Disadvantage of LW

Quality	Laser	Electron Beam	TIG	Resistance	Ultrasonic
Rate	**G**	**G**	**B**	**G**	**B**
Low heat input	**G**	**G**	**B**	**G**	**G**
Narrow HAZ	**G**	**G**	**B**		**G**
Weld bead appearance	**G**	**G**	**B**		**G**
Simple fixturing	**G**	**B**	**B**		
Equipment reliability	**G**		**G**	**G**	
Deep penetration	**B**	**G**		**B**	
Welding in air	**G**	**B**		**G**	
Welding magnetic material	**G**	**B**	**G**	**G**	**G**
Weld reflective material	**B**	**G**	**G**	**G**	**G**
Weld heat sensitive material	**G**	**G**	**B**	**B**	**G**
Joint access	**G**			**B**	**B**
Ergonomics	**G**	**G**	**B**	**B**	**B**
Equipment Cost	**B**	**B**	**G**		

Applications

Automobile Sector – (> 65%)

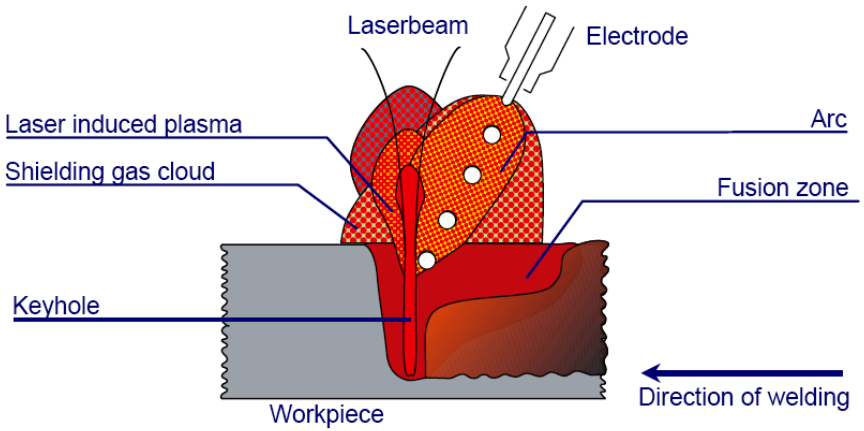


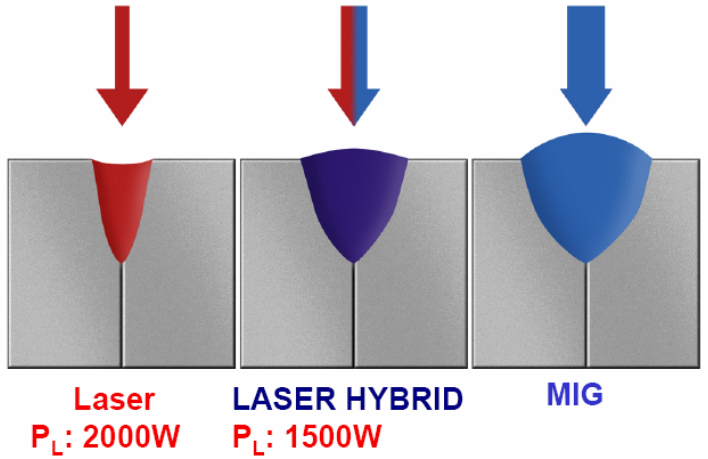
- Tailored welded blanks for automobile body blanks.
- Welding of Transmission components – gears, viscous coupling & differentials

Specialized applications

- Hydraulic bearing thrust units
- Joining of Diamond or WC impregnated steels to tool tips.
- Welding of thin fins to high finned tube heat exchangers.
- Welding of pipelines
- Welding of bimetallic saw blades
- Repair of nuclear boiler from inside
- Spot welding in TV tubes
- Welding of heart-pacemaker

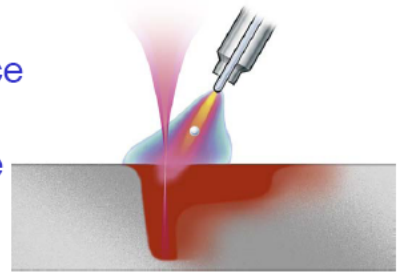
Laser Hybrid Welding





ARC

Low-cost energy source
Gap bridgeability
Microstructure can be influenced



LASER

High penetration
High welding speed
Low heat input
High tensile strength

HYBRIDPROCESS

Better metallurgical quality
Higher welding speed, large throat thickness
Saving expensive laser energy
Low distortion
Improved gap bridging

High joining quality through suitable additives