Laser Welding

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Introduction

The Sun and the stars are the most powerful sources of electromagnetic radiation. But they emit in-coherent radiation, wave lengths ranging from kilometres to fractions of an Angstrom. "LASER" "Light Amplification by Stimulated Emission of Radiation" gets its name from its function i.e. that it can amplify light. The most important characteristic of a laser is its ability to generate coherent electro-magnetic radiation at either infra-red or light frequencies. Waves of coherent energy are uniform in length, extremely well collimated and are in phase in the same direction over the entire section of the beam in contrast to incoherent electromagnetic radiation which consists of waves of varying lengths propagating in wild disorder. This makes laser lend itself to pin-point focussing with simple lens system.

Production of coherent energy is made possible because of the ability of some materials to absorb energy in the form of electro-magnetic radiation and then re-emit them as electro-magnetic radiation. When the re-emitted radiation is in the optical range of the spectrum, the phenomenon is called "Fluorescence." Fluorescence is an atomic reaction. When the electronicstructure of an atom of a fluorescent material is stimulated by radiation the atom is said to be in the excited state. When the stimulus is cut off, the atom returns to its original state of energy, in the process emitting energy in the form of electro-magnetic radiation. Each fluorescent material is stimulated by light of certain colours (wave lengths) and emits light of the same or other wave lengths.

It was in 1958, the search for and development of coherent energy began when it was theoretically predicted by A. L. Schawlow and C. H. Townes that laser action is possible. In 1960 Maiman succeeded in producing laser action in a rod of ruby i.e. aluminium oxide doped with $Chromium^{+3}$. The new laser technology was then born.

Atomic theory explains that atoms and ions exist in states with certain allowed energy. If an atom or ion shifts from a state with energy E1 to another state of energy E2, it can do so by making up the difference in energy by absorbing or emitting a photon. The transition frequency of the photon may then be given by :—

$$y_{12} = \frac{E_2 - E_1}{h}$$

where 'h' is Planck's constant.

As shown in fig. 1, if an atom or ion is initially in the state of lower energy, a photon is absorbed from

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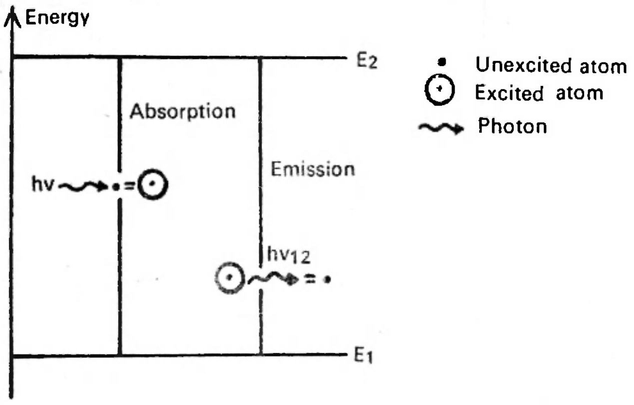

Fig. 1. The two energy levels of an atom or ion.

incident electro-magnetic wave and the result is an excited atom or ion with higher energy. If the atom or ion in the excited state i.e. with greater energy, is stimulated by the electro-magnetic field to make the transition to the state of lower energy it emits in the process a photon. In the laser the electro-magnetic field in the resonator which is formed by two parallel mirrors stimulates the atoms or ions to emit photon adding *hy* of energy to the resonator micro wave cavity for each photon emitted. The photons emitted are in phase with the wave that induced emission thus reinforcing it. The rate of addition of photons to the resonator is, therefore, proportional to the number of atoms or ions in the state of higher energy i.e. if there is a large excess population of atoms or ions in that state subject to inducing electro-magnetic wave, a large number of photons is emitted. It is possible to have a sufficient density of active atoms or ions to augment considerably the wave that induces the emission. Energy can be supplied to the resonator rapidly enough to overcome the losses, resulting in spontaneous emission. This mechanism is the basis of laser operation.

The laser works because the atoms or ions in a laser cavity can be induced to emit photons so that they reinforce the electro-magnetic field in higher order of modes of an optical cavity. When energy is fed into the cavity to overcome the losses, the laser can be made to amplify and to oscillate. The condition of excess population of atoms in the upper energy state is a non-equilibrum situation and some effort must be expended to maintain it. By using suitable techniques, it is indeed possible to attain this situation which is called inverted population.

As shown in fig. 2, in a laser a resonant cavity is the first requirement which is formed by two precisely oriented mirrors one of which is slightly transparent.

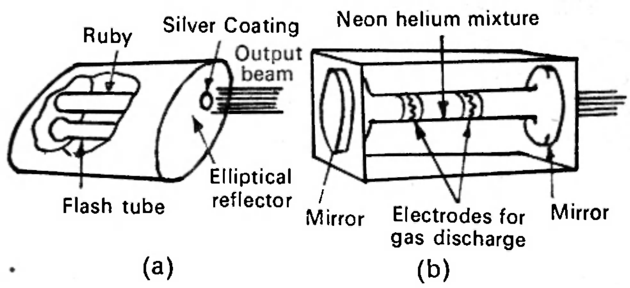

Fig. 2(a) Essential elements of solid state Laser Mirror material with active ions (ruby), and means of exciting the material (flash tube)

2(b) Neon-helium gas laser. The helium excites the neon atoms which supply the resonator made by parallel mirrors.

Resonant modes exist between mirrors at frequencies for which the spacing is an integral number of half wave lengths. The laser material which may be either a gas or solid is placed between the mirrors.

Ruby-Chromium System

In the ruby chromium system, electrons are normally in the ground state or the E level—Fig. 3. The electrons are then "excited" by absorbing green light from a pump usually Xenon flash lamp. When the electrons absorb light they are excited to a higher energy state E_3 level. This is an unstable state with an average life time of about 0.05 microsec. The electrons quickly decay to a meta stable state in level E_2. Under normal conditions the electrons remain at this for about 1 m sec and then fall back to the ground state spontaneously emitting photon energy as they decay. In the laser, the first photons emitted by chromium ions returning to the ground state serve as triggers that stimulate other excited chromium ions to emit photons. The result is an intense flash of red light.

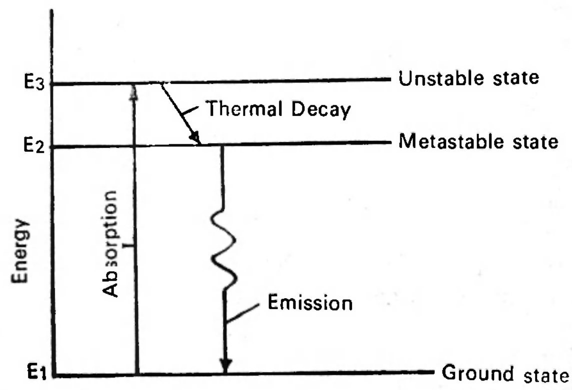

Fig. 3. Energy level diagram of three level laser.

Of all the solid laser devices, only pink ruby assembly has been extensively used. The ruby is a rod ranging from 1/8″ to 1/2″ in diameter and 3″ to 8″ length. It is a matrix of Al_2O_3 and 0.05% chromium (Cr^{+3}) added as an active ion. Chromium gives ruby its characteristic red colour. The greater the amount of chromium the darker is its colour. Chromium ions have a property of emitting red light when stimulated by green light. The aluminium oxide transmits green and red light and is inert in so far as fluorescence is concerned. It merely serves as a lattice for the chromium ions. When ruby is pumped through a strong green-light, chromium atom may emit a photon of red light. When the photon is propagating, it might strike another chromium atom still in the excited state and cause in turn emission of a photon in the same direction and in the same phase. This is the principle of stimulated emission. Once the stimulated emission is achieved, it is necessary to provide for extensive amplification of the wave and an opportunity to propagate the wave from laser in a coherent manner which is accomplished by polishing both the ends of circular laser rod optically flat. A wave is eventually built up parallel to the axis of the crystal (fig. 4). The laser beam coming out of the partially polished end face can be focussed by simple lenses into small area giving controllable power densities that have not been previously available to man as monochromatic light. Any known material can be vaporised melted or welded with a laser beam.

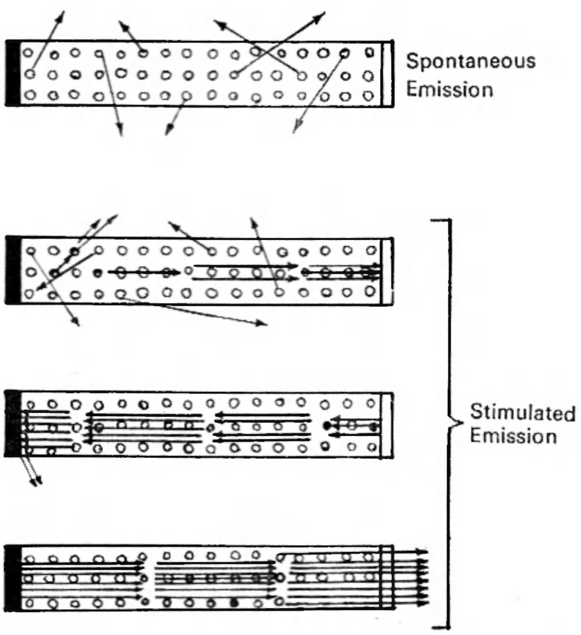

Fig. 4. Amplification of photon wave by stimulated emission.

Laser output is greatly improved by cooling the ruby rod. For this reason ruby lasers are cooled to liquid nitrogen temperatures (—163°C) during their operation. This doubles the output.

Impact of Laser on Fusion Welding

The laser like electron beam is a high intensity, lower momentum surface heating device. The laser technology therefore, had its natural impact on fusion welding. Like electron beam, laser offers potential capability for precise control of energy and location that cannot be approached by conventional sources such as arcs and flames. Further, under optimum conditions of operation, there is little thrust on the material being worked. However, the extreme intensity of laser expressed as power per unit area presents problems and advantages when viewed from the point of view of local melting in fusion welding. Among the conventional welding heat sources, electric arc provides the most concentrated high intensity heat. At the intensity levels of electric arc, the tendency when applied to metals having high thermal conductivity, is to conduct the heat of the weld region almost as fast as it is supplied. In other words, the 'melting efficiency' i.e. the fraction of the total heat delivered to the metal that is used for melting is generally below 50%. Since the melting efficiency is related directly to the intensity of the heat source, as the intensity of source increases, melting efficiency also increases. For the intensity levels attainable with laser or electron beam the melting efficiency almost approaches 100%. It will be no exaggeration to state that very few basic scientific discoveries in history have been applied as fast as laser to metal working. Many scientists consider the laser as a wonder tool that emits the most intense radiation energy known to man and will revolutionise the metal processing techniques.

Comparison of thermal events

If we compare the thermal events that occur in arc welding, electron beam welding and laser welding processes, the analogy of the three welding processes in so far as the movement of liquid metal during welding is concerned can readily be seen in fig. 5. In the low density arc process, liquid is moved toward the rear of the pool at relatively slow rate and acts a coolant to remove heat from beneath the arc source. In the electron beam, the motion is more violent. Similar conditions exist with a laser where the concentrated emergy in single overpowering pulse causes the liquid to move away from the point of energy impingement.

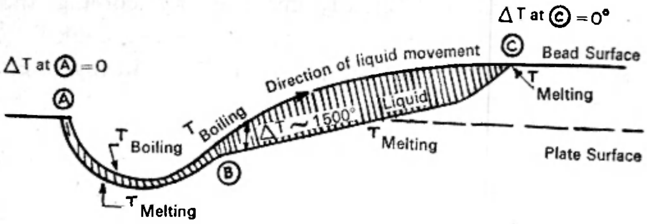

Fig. 5. Liquid movement during welding.

Key Variables and Mechanism

The three things which are essential for laser action are suitable materials, appropriate energy (pump) sources and designs that promote stimulated emission. The laser material must have the following properties to undergo stimulated emission :—

(1) It must luminesce when excited by optical, electrical, radio frequency or some other type energy.

(2) The emission transition must have a long spontaneous emission time so that the population inversion can be achieved.

(3) The absorption properties of the material must be such that a fraction of exciting energy is absorbed and is effective in producing a population excess in the upper level of emission transition.

(4) The spectral width of the emission transition must be relatively small so that sufficient gain per pass can be obtained to overcome the losses through the partially reflecting end surfaces.

(5) The optical quality of the crystal must be sufficiently good so that scattering caused by imperfections and inhomogenieties does not result in excess loss of emitted rediation.

A number of solids meet these requirements. Among solids, chromium, uranium and several rare earths have turned out to be best suited for stimulated emission. These materials are doped in minute quantities i.e. less than 0.5% in host materials. The purpose of the host materials is primarily to keep the active atoms apart from one another and to remove the unwanted heat. Single Crystal ruby i.e. aluminium oxide in which some atoms are replaced by Chromium is the most widely used solid state laser material.

Laser action in solids is not limited to single crystals only. Glasses are also used as hosts for active rare earth elements. Glasses have a potential advantage over the single crystals in that they do not suffer from size or shape limitation.

TABLE 1

Solid Laser Materials Crystals

Material	*Temperature deg K*	*Output wave-length*	*Pulsed or continuous operation*
$Al_2O_3Cr^{3+}$ (0.05 wt.%)	4.2-300	0.69	p
$Al_2O_3Cr^{3+}$ (0.01 wt.%)	77	0.6934	c
$Al_2O_3Cr^{3+}$ (0.5 wt.%)	77	0.701	p
$Al_2O_3Cr^{3+}$ (0.05 wt.%)	300	0.704	p
CaF_2U^{3+}	4.2-300	0.6929	p
		2.5	p
		2.6	p c
		2.24	p
BaF_2U^{3+}	77	2.6	p
SrF_2U^{3+}	4.2-90	2.4	p
$CaWO_4$ Nd^{3+}	77.300	1.06	p c
$SrWO_4$ Nd^{3+}	77-300	1.06	p
$SrMoO_4$ Nd^{3+}	77-300	1.06	p
$CaMoO^{3+}$	77.300	1.06	p
$PdMoO_4$ Nd^{3+}	300	1.06	p
CaF_2Nd^{3+}	77	1.05	p
SrF_2 ND^{3+}	77-300	1.04	p
Baf_2 Nd^{3+}	77	1.06	p
LaF_3 Nd^{3+}	77-300	1.06	p
		1.04	
$CaWo_4HO^{3+}$	77	2.05	p
		2.06	p
CaF_2Ho^{3+}	77	2.09	p
$CaWo_4Tm^{3+}$	77	1.91	p
Sr F_2Tm^{3+}	77	1.97	p
$CaWO_4Fr^{3+}$	77	1.61	p
$CaWO_4Pr^{3+}$	77	1.05	p
$SrMoO_4Pr^{3+}$	20	1.0	p
CaF_2SM^{2+}	4.2	0.7083	p
Sr F_2Sm^{2+}	4.2	0.6967	p
CaF_2 Dy^{2+}	77	2.36	p c
CaF_2 TM^{2+}	4.2	1.12	p

* Output power as high as 500×10^6 watts has been reported for ruby operated in the giant spike mode. Energy output in excess of 50 joules have been reported for normal pulsed operation.

Table 1, 2, 3 & 4 show some solid and liquid laser materials with some of their properties. Table 5 shows gaseous laser materials along with some of their properties. There are advantages and disadvantages to the various type of laser. The gas is superior in frequency stability and non-chromaticity, but has very low efficiency i.e. less than 0.1%. Solid lasers are comparatively more efficient.

Perfect ruby has an efficiency upto 10% but will not transmit continuous wave. Given the laser material and the energy source, how effictively the energy is "Pumped" into the laser material determines largely the strength and the duration of the output beam. Fig. 6 shows the typical laser welding system. The ruby crystal rod and the flash tube are located at the foci of an elliptical cavity lined with reflective material. This design has proven quite successful because the cavity wall focusses large portion of the flash tubes output into crystal. In place of a flash lamp with Xenon, scientists have substituted an exploding wire. The wire that is vapourised by an electrical discharge is one of the most brilliant sources of light and is capable of furnishing extremely high input to a laser.

TABLE 2

Solid Laser Materials Glasses

Ion	*Host glass*	*Temperature deg K*	*Output wave-length microns*	*Pulsed or continuous operation*
Nd^{3+}	American Optical Barium Crown	300	1.06	** p c
Nd^{3+}	Eastman Kodak Optical Glass	300	1.06	p
Nd^{3+}	SiNaCaATSb	77	0.018	p
Yb^{3+}	LiMgAlSi	77	1.02	p
Gd^{3+}	LiMgAlSi	77	0.3125	p
Ho^{3+}	LiMgAlSi	77	1.95	p
Nd^{3+}	LiMgAlSi	77	1.06 & 1.02	p

** Output energies in excess of 50 joules and efficiencies in excess of 2 per cent have been reported for pulsed operation of nd-glass.

TABLE 3

Solid Laser Materials-Organic Compounds

Material	*Temperature deg K*	*Output wave-length*	*Pulsed or continuous operation*
Benzophenonenaphthalene	77	0.47	p
EU^{3+}TTA Chelate	77	0.6130	p

TABLE 4

Liquid—Laser material

Material	*Solvent*	*Temperature deg K*	*Output wave-length microns*	*Pulsed or continuous operation*
Eu^{3+} Benzoyl-aceto nate chelate	Methyl-ethyl alcohol	100	0.6130	p

TABLE 5

Gaseous Lasers

Gas composition	*Output wavelength microns*	*Output power milliwatts*	*Pulsed or continuous operation*
HeNe	0.6328	4	c
	0.6301		c
	0.6293		c
	0.6118		c
	1.0798		c
	1.0845		p
	1.1143		p
	1.1177		p
	1.1390		p
	1.1523	20	c
	1.1601		c

TABLE 5—*Contd.*

	1.1614	1	c
	1.1767		c
	1.2066		
	1.4276		c
	1.304		c
	1.4321		c
	1.4330		c
	1.4346		c
	1.4368		c
	1.5231	3	c
	3.3913	10	c
	2.0603	3	c
	1.1523	1	c
	2.1010	1	c
	5.40		c
	17.88		c
	1.6180		
	1.6941	0.5	c
	1.793		
	2.0616	1	c
	12.14		
	1.6900		
	1.6936		
	1.7834		
	1.8185		
	1.9211		
	2.1165	1	c
	2.1902	1	c
	2.5234		
	7.06		
	2.0261	5	
	5.5738	Very strong	c
	2.0261	10	c
	2.3193	weak	c
	2.6269		c
	2.6511	strong	c
	3.1069	weak	c
	3.3667	strong	c
	3.5070	very strong	c
	3.6788	weak	c
	3.6849	strong	c
	3.8940	weak	c
	3.9955	strong	c
	7.3147	strong	c
	9.0040		c
	9.7002		c
	12.263		c
	12.913		c
A-Q[3]	0.8446	1	c
Ne-02	0.8446	1	c
Cs	7.1821	0.025	c

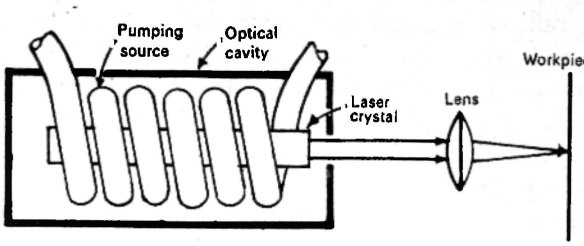

Fig. 6. Typical laser welding system.

Laser output is measured in joules (watt second). Output of laser ranges from a fraction of a joule upto 30 to 40 joules for the largest unit available. The energy losses in laser system are high. For power input of a 10,000 joules the laser output may be of the order of 30 joules. This is readily understood because only the light in the green region of the spectrum initiates the laser action. Nevertheless, these energy losses are acceptable because the focussed spot of light from laser is millions of times more intense than the light from the flash lamp that initiated the laser and is in fact many times more intense than the light of that wave length emitted from an equivalent area of the surface of the sun. By focussing, high power intensities i.e. 10^5 to 10^8 watt/sq. cm can be achieved. Table 6 given the relative intensitites obtainable by conventional welding processes, electron beam and the laser. The optimum laser output for welding depends on the

TABLE 6

Comparison of Heat Source for Welding

Heat Source	*Power intensity w/mm²*
Laser	Upto 10^9
Electron beam	Upto 10^9
Electricarc (Argon 200 amp)[a]	1.5×10^4
Oxy acetylene flame[a]	10^3
Oxy hydrogen jet burner[a]	3×10^3
Black body radiation °K[b]	
6,500	10^4
11,500	10^5
20,500	10^6
36,500	10^7
65,500	10^8
115,000	10^9

a Experimentally determined for heat transferred to flat surface
b Calculated

absorptivity, thermal conductivity, density, heat capacity, melting point and surface condition of the material to be joined and the duration of the pulse. The maximum temperature that can be maintained at the surface of a metal is its boiling point which limits the heat conduction into the metal. Surface boiling in most of the common metals occurs at a power intensity of 10^5 to 10^6 watt/sq. cm. which is still below the capability of laser. Therefore, care is required to be taken to avoid exceeding the intensity that produces surface boiling. It is done by increasing the pulse duration. In more advanced laser welders automatic selection of pulse duration for any given output is available.

The most important considerations in determing the welding parameters are the following :—

(1) Selecting the number of capacitors and corresponding voltage to obtain the desired energy input level.

(2) Proper selection of optics to control size and shape of the beam.

(3) Selection of beam focal point either on or above the metal surface.

The laser equipment must consists basically of power supply and a laser head assembly. An accurate positioning table supports the work piece during operation. The power supply has a typical range of 800 to 8000 V that makes the energy capacity of about 25,000 joules which is switched into the load with an ignition. Pulse rate control can be raised from 0.25 to 12 pulses per minute.

Fig. 7 shows the typical laser head for welding. The ruby rod at the centre is enclosed in a transparent glass tube. Cold nitrogen gas is circulated over the surface of the ruby rod and returns outside the glass tube. Between the glass tube and a helical flash lamp

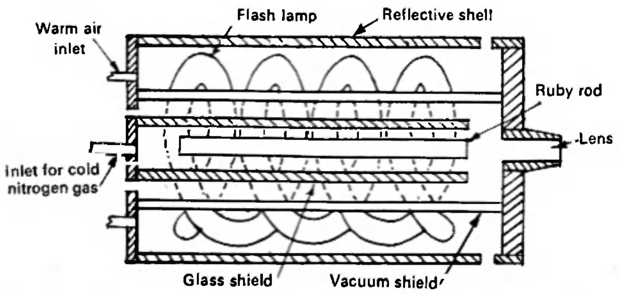

Fig. 7. Typical laser head for welding cold nitrogen gas flows over ruby ; warm air flows over flash lamp.

is a vacuum bottle. The vacuum bottle contains liquid nitrogen that supplies cold gas that is carried to the laser head by an insulated hose. The vacuum bottle prevents heat from the flash lamp from being transmitted to ruby rod but like the glass tube it does not significantly affect the transmission of the light. The entire assembly is enclosed in a metal shell. A suppressor prevents arcing between flash lamp and the shell. Since the flash lamp is most efficient when it is warm and to prevent arcing hot air is circulated continuously over the flash lamp. The laser welding system must have provision for the part movement and since the welding is accomplished by pin pointlight beam, the tooling to hold the object is critical in that part rotation, hesitation or out of roundness can seriously affect the weld quality and the weld seam can be missed.

Comparison with Electron Beam Welding

Compared to electron beam welding which is also capable of joining thick to thin materials and of welding dissimilar materials, laser has some important differences pointing its unique role.

(1) it requires no vacuum chamber.

(2) there is no discernible temperature rise in points close to the laser beam so that welding can be close to the heat sensitive materials.

(3) with laser welding it may not always be necessary to protect reactive materials, refractory alloys of tungsten or molybdenum from atmospheric contamination.

(4) The cost of acquiring, operating and maintaining laser equipment is less than that for electron beam.

(5) No pressures are required and the surface contaminants are vaporised during welding.

One of the important short comings of laser welding is its inability to weld extremely thick sections. Current indications are that thickness that can be welded by laser are 0.02 to 0.03" max. The thickness range cannot be increased by output because of the danger of vapourisation. Further, continuous pumping sources are not available.

The present costs for welding are much more with laser. The cost range is 2 to 5 cents per laser pulse. A laser welding system will cost from $2,500 to $25,000

TABLE 7
Properties and Processing Data for Wire to Wire Laser Weld

Material	*Wire Dia in* *	*Joint type*	*Processing Data* — *Laser output joule*	*Pulse Duration millisec*	*Joint Properties Max Load lb*	*Resistance ohm* +
301 Stainless Steel	0.015	Butt	8	3.0	21.3	0.003
		Lap	8	3.0	22.8	0.003
		Cross	8	3.0	25.0	0.003
		Tee	8	3.0	23.2	0.003
	0.031	Butt	10	3.4	31.8	0.002
		Lap	10	3.4	34.6	0.002
		Cross	10	3.4	40.0	0.002
		Tee	11	3.6	40.1	0.002
	0.015-0.031	Butt	10	3.4	24.3	0.003
		Lap	10	3.4	24.8	0.003
		Cross	10	3.4	25.6	0.003
		Tee	11	3.6	22.6	0.003
	0.015-0.031	Tee	11	3.6	26.4	0.003
	0.031-0.016	Tee	11	3.6	19.6	0.001
Copper	0.015	Butt	10	3.4	5.1	0.001
		Lap	10	3.4	5.2	0.001
		Cross	10	3.4	4.3	0.002
		Tee	11	3.6	3.2	0.001
Nickel	0.020	Butt	10	3.4	12.2	0.001
		Lap	7	2.8	7.8	0.001
		Cross	9	3.2	6.8	0.001
		Tee	11	3.6	12.5	0.001
Tantalum	0.015	Butt	8	3.0	11.5	0.001
		Lap	8	3.0	8.8	0.001
		Cross	9	3.2	9.3	0.001
		Tee	8	3.0	10.8	0.001
	0.025	Butt	11	3.5	14.9	0.001
		Lap	11	3.5	12.9	0.001
		Tee	11	3.5	17.0	0.001
	0.015	Butt	10	3.4	11.0	0.001
	0.025	Cross	10	3.4	9.2	0.001
	0.015	Tee	11	3.6	12.6	0.001
	0.025	Tee	11	3.6	11.4	0.001
Copper Tantalum	0.015	Butt	10	3.4	3.8	0.001
		Lap	10	3.4	5.3	0.001
		Cross	10	3.4	4.1	0.001
		Tee	10	3.4	4.0	0.001

*When only one size is given both pieces are the same diameter ; when two sizes are given, the first diameter is that of the top member of a cross joint or the cross bar of a tee joint.

+joint resistance represents the difference between the resistance of a given weldment plus wire lead, and the resistance of the wire alone.

depending on the sophistication and the power capacity. Laser welding has been used to produce similar and dissimilar metal joints with copper, stainless steel, nickel, aluminium alloy, iron nickel base alloy. Most welds with these metals have been of the wire to wire type, butt joints and several other types of welds. In the wire to wire type of laser welding there are four basic configurations i.e. butt, lap, cross and tee. Table 7 shows the properties and processing data for wire to wire laser welds in 301 stainless steel, copper, nickel, tantalum, copper alloy for the different joint types and in different diameters.

Wire to ribon type combination has also been used for electronic application and the weld is usually penetrated through the ribbon into the under lying wire. When fabricating molecular semi conductor devices, molecular blocks, integrated circuits, functional electronic blocks etc. it is often necessary to attach very small diameter lead to small area on the substrate of the devices.

Recently laser welding has been attempted to attach 0.005″ gold wire to substrate of silicon and Aluminium coated silicon. Laser welds in these applications have been found to be extremely reliable. Successful laser welds have also been achieved in ribbon to ribbon type lap joint. Lap joints between tungsten and Aluminium alloy sheet have been done. Nickel conductor ribbon 0.002″ thick has been successfully welded to copper clad fibre reinforced epoxy circuit boards. Sound welds can also be made between parts that vary considerably in size or mass. Welding potential of laser has been demonstrated in some difficult to join metals such as columbium, molybdenum. The weld joint efficiency varies in the range of 90 to 100%.

Continued progress in development of continuous moving heat source capable of attaining significant increases in pulse repetitive rates and pulse duration will widely broaden lasers potential usage.

Application and Future Potential

It is the view of some people that practical application for optical maser or laser welding probably will be found in the welding of minute structures such as watch parts. It is also felt that laser will probably never lend itself to large scale welding operations because it is expensive. Fine scale work may turn out to be competitive with laser than other methods. The use of laser welding in extremely fine work of exotic space age technology may be the only field of application.

There are others who seem to disagree with this view. Fig. 8 shows a high temperature bearing laser welded where gas tungsten arc, resistance seam and electron beam welding processes had failed and the laser accomplished this successfully. Though the joint is of a simple design, there was an extreme difference in joint material thicknesses. The lower heavy bearing acted as an infinite solid while the shield metal welded was only 0.010″ thick.

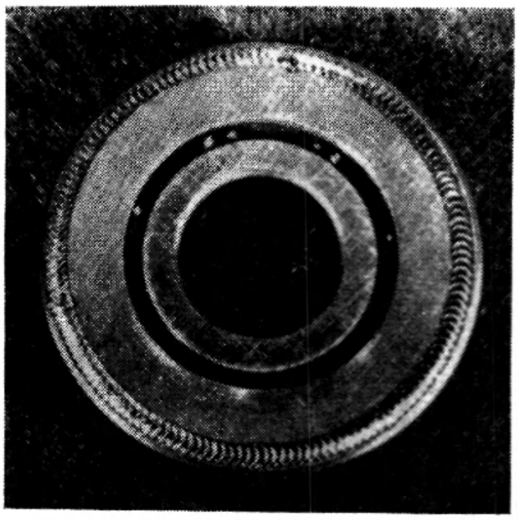

Fig. 8. Hot gas bearing assembly with continuous circumserential weld in the welded condition. Tie-in of the weld was made in top right quarter.

Another example of successful application of laser has been in the welding of electronic sensor configurations fig. 9. Several other joining processes including epoxy bonds had failed in this application. Laser welding has proved to be extremely reliable for this application, when either aluminium alloy or gold is used for insert and outer member housing 0.0002″ diameter insulated copper wire winding.

Making seal welds in close proximity to ceramic glass seals very sensitive to heat is another fabrication application in which lasers have been utilised. Owing to the package limitation, the final closing weld could not be moved away from the ceramic seal assembly. Welding can be done by laser within 0.05″ from the ceramic seal without providing any heat sink as required in other processes viz gas tungsten arc electron beam or brazing fig. 10.

From these examples, it appears that laser welding is making progress. The developments currently underway in the field of laser are :—

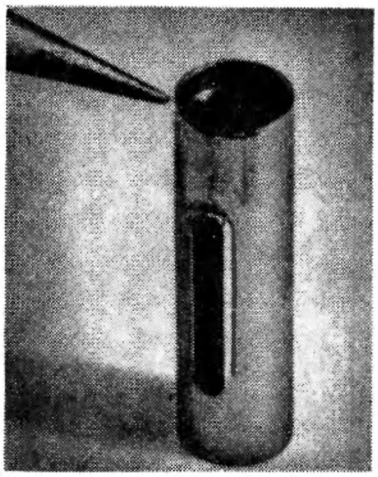

Fig. 9. Laser weld of gold sensor package having uniform and gas right surface.

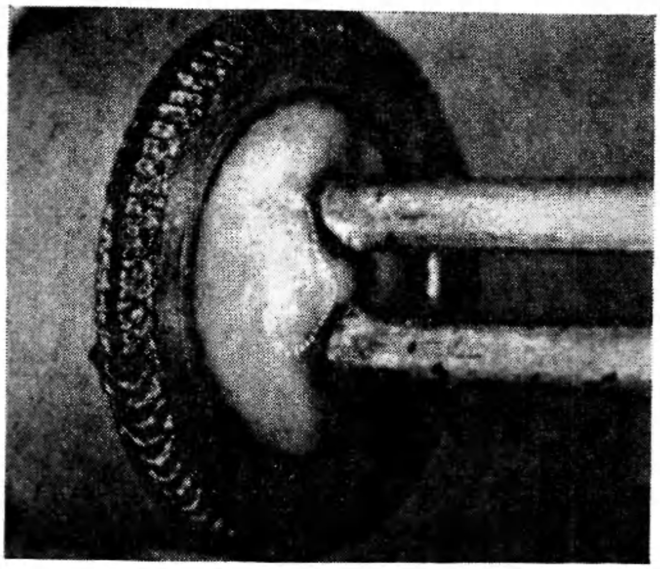

Fig. 10. Laser weld of an electrical feedthrough in a thermistor enclosure. The ceramic is within 0·050-in. of the weld which was successfully made without heat sinks as required by gas-tungsten-arc or electron-beam welding or brazing (X25).

(1) A few years ago ruby crystal was not much bigger than a cigarette. To-day laser rods 3 ft. in length and longer are available. Glass with small traces of neo-dymium is being tried as a laser material.

(2) Higher reproduceability and better distribution of energy is being attempted. Welds which took 7 to 8 secs to perform can now be done in 1 sec.

(3) New carbon dioxide lasers with 1000 watt energy output are a possibility that can be operated either continuously or pulsed.

(4) Improving power supplies and flash lamps to achieve longer pulse length.

It is now possible to alter the duration of pulse from 0 to 60 msec in 3 msec steps.

The laser may assist metal fabrication where conventional welding processes have met with problems such as :

(1) Control of heat affected area, (2) control of weld penetration (3) control of metallurgical properties at the 'high quality' level.

The laser has been tried and proved on special welding jobs. However, the point of standardised methods and set ups has not been reached, but it is not too far distant.

References

(1) A. L. Schawlow and C. H. Townes, "Infrared and Optical Masers," Phy. Rev., 112, 1940 (December 1960).

(2) T. H. Maiman, "Stimulated Optical Radiation in Ruby Masers," Nature, 187, 493 (August 1960).

(3) A. Yariv and T. P. Gordon, "The Laser," Proc. IEEE, 51, 4 (January 1963).

(4) G. C. Dacey, Science, 135, (3498), 135 (January 1962).

(5) S. A. Collins. Jr., "Lasers" Electro Technology," 64-69 (March 1963).

(6) W. N. Platte, and T. F. Smith "Laser Techniques for metal joining", Welding J, Research Suppl., 81-5-4895 (November 1963).

(7) A. L. Schawlow, Sci. Amer. 204, (6), 60 (June 1961).

(8) K. J. Miller and J. D. Nunninkhoven, 'Production Laser welding for specialised applications, welding J., 480-485 (June 1965),

(9) Mel. M. Schwartz "Moder Metal Joining Techniques".