KAPTRON

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FINAL REPORT

AUTOMATION OF FIBER-OPTIC PIGTAILING PROCESS:
LASER WELDING DEMONSTRATION PROGRAM

Contract Number: N00014-88-C-2050

DATE: 5-26-89

TO: Mr. M. Musselman
Naval Research Laboratory
4555 Overlook Ave. SW
Washington DC 20375-5000
Attn: Code 6503

DCASMA San Francisco
1250 Bayhill Drive
San Bruno, CA 94066-3070

FROM: Dr F. C. Unterleitner
Kaptron, Inc.
2525 E. Bayshore Rd.
Palo Alto, CA 94303 Ph# (415) 493 8008 x38
FAX (415) 493 8924

LASER WELDING DEMONSTRATION PROGRAM
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Automated Semiconductor Laser Pigtailing Utilizing YAG Laser Welding

Demonstration Program

ABSTRACT

This demonstration program is intended to demonstrate the feasibility of coupling a commercially available Nd:YAG laser with the Kaptron POLYTROPE 3000 automatic alignment system for the production of single mode fiber pigtailed semiconductor lasers. It has been demonstrated that 30 watts of Nd:YAG laser power can produce repeatable welds of 0.18mm thick Kovar saddles to gold plated substrates of the type used for semiconductor laser modules. It has also been shown that beam geometry stabilization by passing the beam through a step index fiber (or reflective tube channel) is essential for reliable and repeatable welding with this type of multimode laser. Laser and delivery system requirements for a production Nd:YAG laser welding accessory for the Polytrope 3000 have been defined, and recommendations for such an accessory are included in this report.

1. INTRODUCTION

The automated production of fiber pigtailed semiconductor lasers will become increasingly important as fiber optics becomes more widely used in office and factory networking, necessitating high production volume, low cost methods. At present, laser pigtailing primarily uses manual alignment and soldering of a metalized fiber ferrule to a pad in the semiconductor laser housing in order to maintain alignment between the fiber and the laser chip. This technique is slow and has a low yield of good devices because of the compensation needed to correct for the differential thermal expansions as the molten solder solidifies and the laser substrate cools to operating temperature. Ultraviolet curing cements have also been used in order to avoid the temperature cycling problems associated with soldering. However, the cements have long term creep, high thermal expansion coefficients, and tend to outgas in hermetically sealed packages.

For these reasons, spot welding with a laser pulse as the heat source is becoming the accepted method for fixing the position of fiber ferrules. The method has the advantage of minimizing heat deposition in the semiconductor laser substrate during the welding process and minimizing mechanical perturbation of the package. The production of simultaneous welds in symmetrical positions on fiber saddles further reduces the mechanical deformations during the welding process, as discussed in more detail in section 6.0 below. This demonstration phase program was intended to determine the conditions required to produce satisfactory welds with saddle and substrate configurations required by semiconductor laser pigtailing operations, thereby defining the Nd:YAG laser requirements for a welding accessory.

2. EXPERIMENTAL ARRANGEMENT

2.1 Nd:YAG LASER

The Nd:YAG laser was selected as the primary choice for the source of optical power for welding for two reasons:

a) The emission wavelength of 1,064nm is efficiently transmitted through (and imaged by) conventional optics, including high silica fiber optics. It is also relatively efficiently absorbed by the thermally stable nickel alloys which are favored for use as fiber mounting saddles.

b) Nd:YAG laser systems have been used in production welding and drilling systems for about 20 years. They are well characterized and reliable products with multiple vendors and readily available components, such as pump lamps, laser crystals and pump cavities.

The 50 watt CW laser which has been used for the demonstration program utilizes a 75mm long YAG crystal and a single Krypton arc lamp. The lamp is imaged onto the laser crystal by a highly reflective elliptical cylinder, with one focal axis of the ellipse at the center of the lamp and the other focal axis at the center of the YAG rod. The end plates are highly reflective flat surfaces, improving the optical efficiency of the pump cavity.

Cooling of both the arc lamp and the laser rod is accomplished by circulating deionized water through the pump cavity. The deionized water is in a closed loop containing an ion exchange filter, and is cooled by a heat exchanger in the water reservior. This arrangement has proven reliable, because it permits water cooling of the electrode ends of the lamp as well as the quartz envelope. The low electrical conductivity of the deionized water avoids electrode errosion during operation.

The arc lamp operates stably over an input power range of about 1kW to 3.5kW. which covers the laser output range from near threshold to about 70 watts of CW multimode laser power. A single phase 240 volt line with 30 ampere capability is adequate for operation of such a laser.

The laser cavity has an internal shutter which consists of a steel rod which drops into the optical path by its own weight when the solenoid coil is not activated. When the interlock solenoid is activated, the rod is pulled up into the solenoid, and the optical path is cleared. This provides a very failure safe method of insuring that an active command must be given to permit laser power to be generated within the cavity and emitted to the external apparatus.

The laser specifications and more detailed description are included as Appendix A to this report.

2.2 LASER SAFETY MEASURES

All personnel in the laboratory had to wear laser protective goggles when the laser pump lamp was on, as indicated by the power console panel lamp, since there was no protective enclosure for the laser beam. The laser interlock shutter with its yellow warning light was left engaged, and had to be switched on to permit the laser to oscillate and power to be emitted from the resonator, thus providing some level of warning that laser exposure was possible. Furthermore, alignments requiring observation of the laser beam were done with pump power only slightly above thershold, to minimize the chances of injury from stray reflection or direct contact with the beam.

2.3 LASER PULSE CONTROL

The initial analysis of laser welding indicated that a higher optical power at the beginning of the pulse would help to rapidly bring the workpiece surface to temperatures near the melting point, where the emissivity increases significantly, permitting more efficient coupling of laser power. Once this temperature is reached, power density at the surface needs to be reduced to minimize vaporization of metal from the surface while the heat penetrates through the thickness of the metal sheet which is being welded. Ideally, the surface would be maintained below the boiling point of the metal during the heat diffusion phase of the process. The desired time dependence of optical power on exposure time is shown in Figure 2.1.

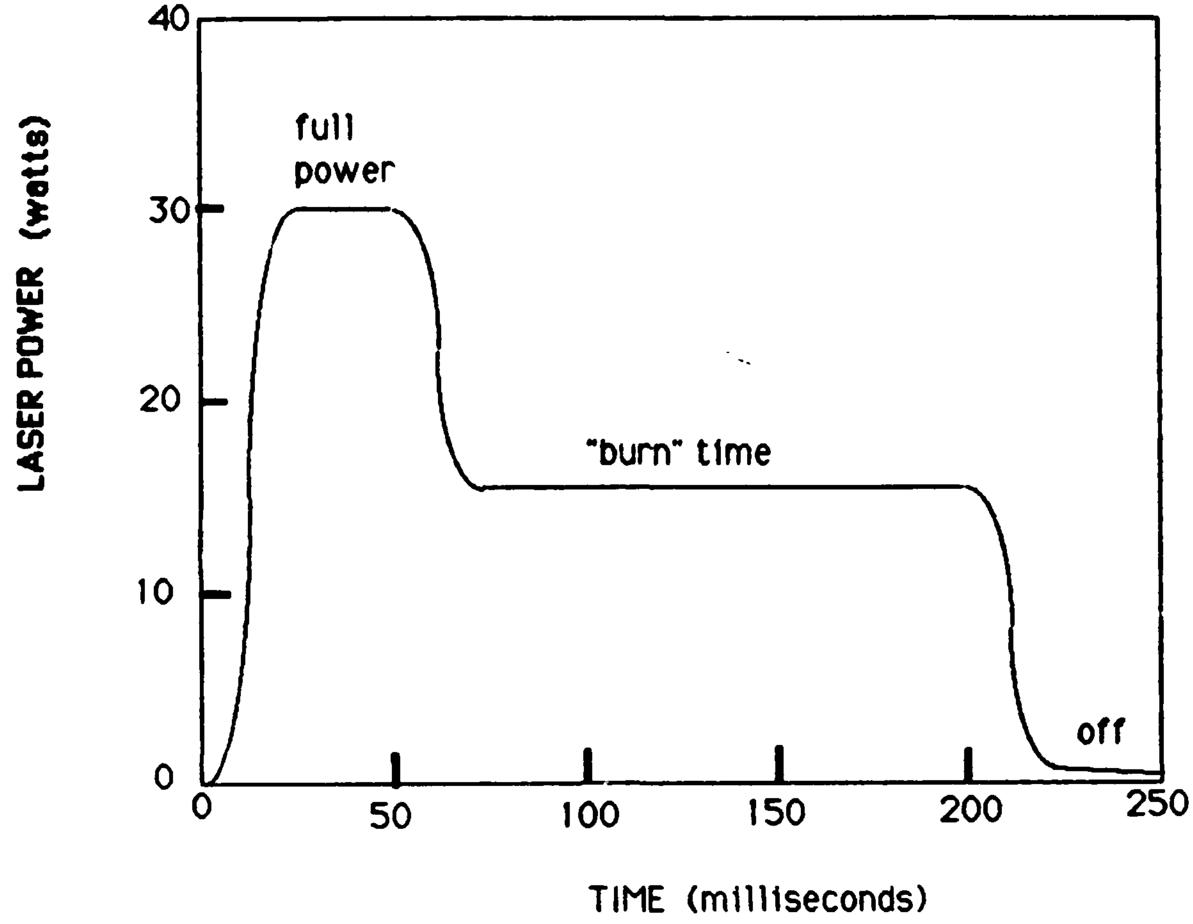


Figure 2.3.1 Desired dependence of laser power on exposure time.

A method for accomplishing the pulse shaping was selected which utilized a polarizing prism rotated by a high speed servo motor under the control of a computer generated timing sequence from a digital-to-analog converter (DAC). By inserting suitable constants for the rotational inertia of the shutter mechanism, a very reproducible pulse waveform is generated which is free of mechanical overshoot or undershoot. The value of the moment of inertia coefficient has to be specified very accurately to accomplish this critical damping (deviation by as little as +/-0.5% produced noticable degradation in the waveform). Pulses with a rise from zero to full power in 25 milliseconds were generated in this way. The full power "on" time can be set to any value above 7 milliseconds in 1 millisecond intervals, and the decrease to a specified lower power level, called the "bake" power, (polarizing prism angle less than 90 degrees) and the exposure time at that power level can also be set. A listing of the program for this function is presented in Appendix B.

The insertion of a Brewster's angle polarizer into the laser cavity, and the insertion of an external polarizing prism reduced the maximum output power of the laser to about 35 watts. This decrease is due primarily to the significant strain birefringence induced into the laser rod by the heat flux from the absorbed optical pump power. The ratio of maximum transmitted power to minimum transmitted power as the polarizer is rotated 90 degrees was measured to be in excess of 2000:1, ie. with 35 watts full power, rotation of the polarizing prism can reduce the power to less than 20 milliwatts, which has completely negligible heating effect.

Although the servo controlled polarization shutter operated sucessfully, it was later found that practical fiber saddles need to be made from relatively thick sheets of metals having low thermal diffusivity. Under these conditions, the time required for heat to penetrate to the lower surface becomes very long compared to the time required to heat the upper surface to the melting point. Thus, the fraction of the pulse energy required to do the initial surface heating is small, and the shaping of the pulse as described above has little effect on the efficiency of the welding operation. Under such conditions, a simple 'on/off' shutter with stable power ouput and accurate timing is adequate. It was found that, for pulses longer than 0.5 sec., the polarizing elements could be removed and timing accomplished by raising and lowering the intra-cavity shutter rod with computer controlled timing.

2.4 MODE DISTRIBUTION CONTROL

The most efficient power generation in the Nd:YAG laser crystal ocurrs when the largest available portion of the rod cross section is utilized for laser oscillation. Operating with high order transverse mode structure permits extraction of power closer to the edge of the rod than when operating in the lowest order transverse mode. The disadvantage of multimode operation is that the optical power distribution within the mode pattern is quite sensitive to slight thermal distortions of the laser rod, which in turn are dependent on such factors as the time between pulses and the coolant temperature. When the laser beam is imaged directly onto the piece to be welded, the mode distribution can significantly effect the apparent area of the heated region, as well as local "hot spots" within the image, resulting in transient higher vaporization rates. Initial welding tests were made with a directly imaged laser beam, and showed unpredictable variation in weld quality with repeated laser pulses of the same power and time duration on the same saddle and substrate samples.

Two methods for improving the repeatability of the laser energy delivery to the weld have been explored:

1. A thick aperture plate of highly reflective material and
2. A step index fused silica fiber about 1 meter long.

Both have the effect of "homogenizing" the light distribution over the physical output aperture, regardless of the input mode pattern. Attenuation of the laser power is minimized by selecting an aperture diameter slightly larger than the largest mode diameter in the laser beam image. An aperture hole 0.33mm in diameter in a 3mm thick aluminum plate served as a very effective beam homogenizer. The output aperture of the plate is imaged onto the test saddle, and much more reproducible welds are obtained than with the direct laser beam, under the same conditions.

Initial tests of a fiber optics delivery system were made by using a 400 micron core diameter plastic clad silica fiber manufactured by Ensign-Bickford Co. At low laser power, the desired beam homogenization was achieved, but at higher powers, such as required for welding, the plastic cladding seems to be damaged, resulting in melting of the input end of the fiber. Since the power densities involved are far below the damage threshold of fused silica, we believe that glass clad step index fiber having 400 micron core diameter would easily support the power levels needed for our welding process. While we have not located an off-the-shelf source for such fiber, several manufacturers could make a custom draw if we order at least 1 km of fiber.

2.5 WELD POWER IMAGING OPTICS

The imaging optics for the demonstration of welding fiber ferrule saddles to semiconductor laser substrate blocks used the aperture plate beam homogenizer (or mode scrambler) discussed above. The optical arrangement is shown schematically in Figure 2.4.1. The dicroic mirror at 45 degrees reflects about 98% of the 1.06 micron laser radiation, but permits most of the visible light illumination to pass through to the video camera, which is used to locate the workpiece in the desired position before initiating the weld pulse. The 18 mm focal length lenses produce a small enough image of the laser mode pattern to fall within the 330 micron diameter hole in the plate, thus losing very little

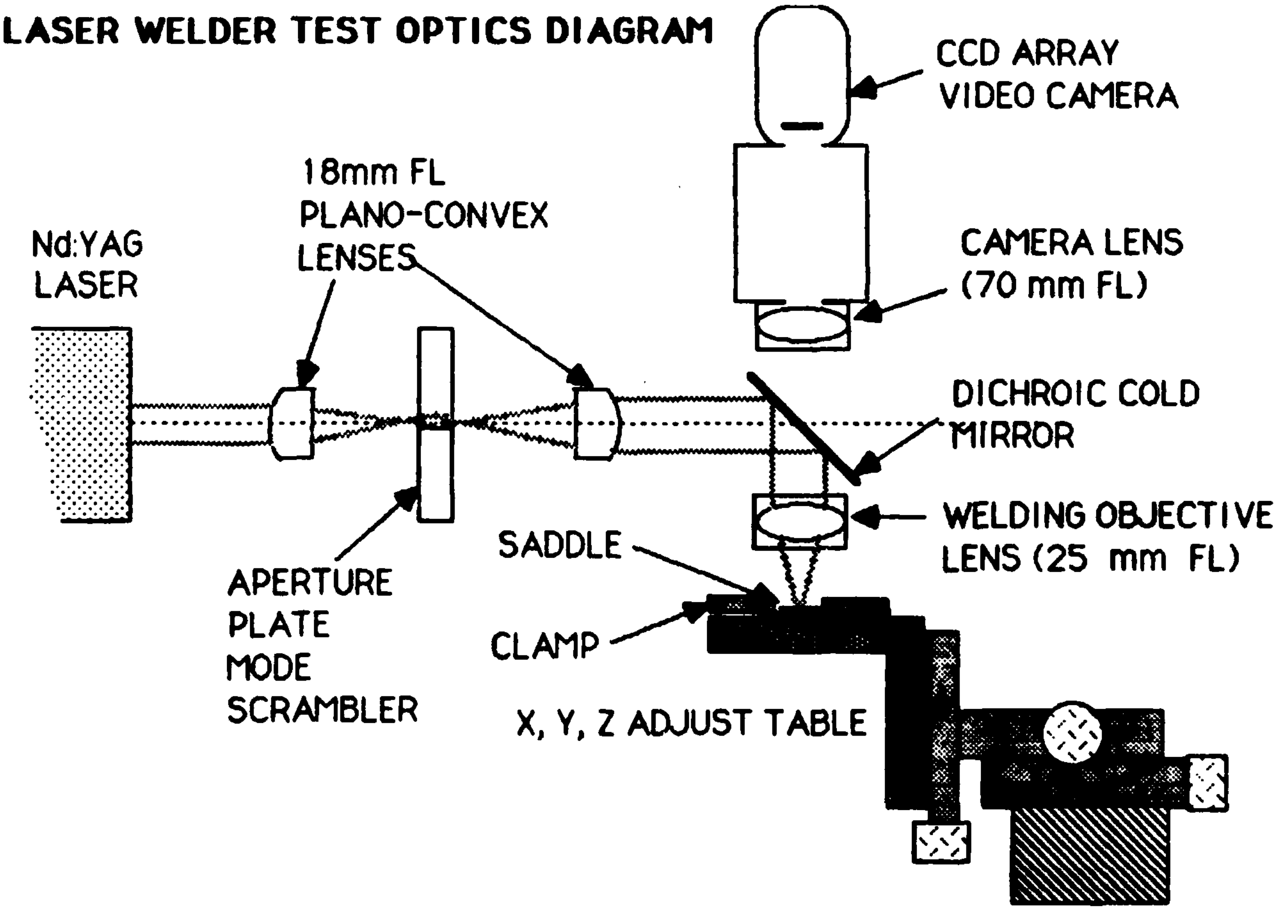


Figure 2.4.1 Experimental Imaging Optics for Welding Experiments.

light in the aperture. The 25 mm focal length welding objective was designed for use with nearly infinite conjugate input illumination, so the second 18 mm lens provides the collimation of the mode scrambling aperture output required by the objective.

3. LASER WELDING EXPERIMENTS

3.1 POWER CALIBRATION

The laser power output was measured with a standard calorimetric energy meter Model 258 manufactured by Optical Engineering, Inc., with calibration traceable to NBS. The full scale reading is 2000 Joules, with calibration lines at 20 Joule intervals. Since the laser shutter can be accurately set by the computer timing control, the energy reading can be converted to average power simply by dividing the measured total energy in Joules by the number of seconds (to the nearest millisecond) shutter ON time. The beam energy was measured after the objective lens to determine the power actually incident on the weld sample.

The mode distribution and beam position were observed with a fluorescent infrared detection screen. Beam focal position is also observed by using a collimated visible light beam passing through the laser resonator, with the pump lamp turned off and the shutter open.

3.2 WELD PARAMETER MEASUREMENTS

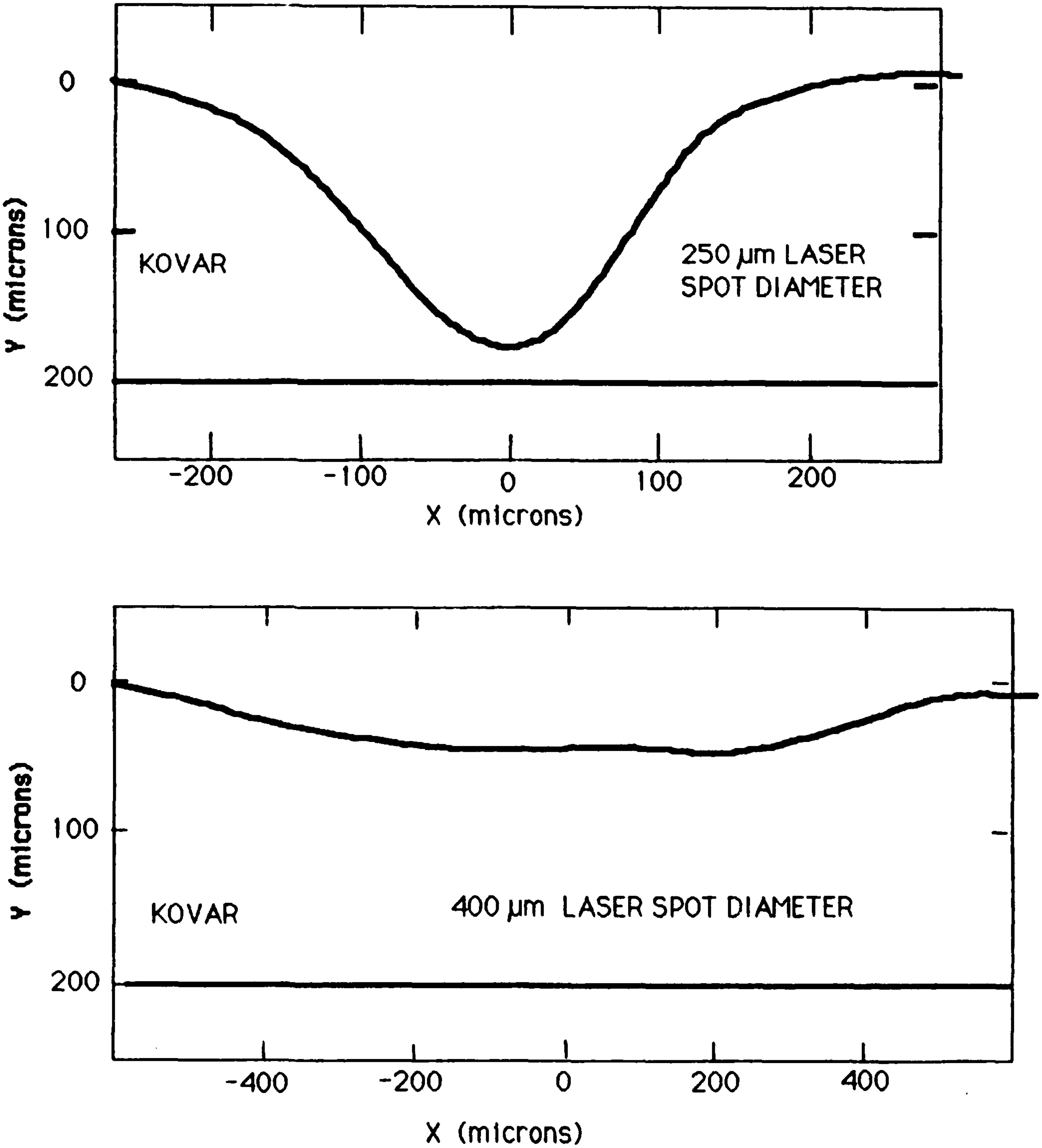
The initial welding experiments utilized the servo motor driven polarization shutter. The first successful welds were with 75 micron thick stainless steel sheet welded to 250 micron thick stainless stock. These showed that about 20 watts of "burn" power with 800 to 1000 milliseconds of exposure is required to make reliable welds with about 200 micron spot size. Pre-treatment with a lower pulse power to oxidize the surface reduced the required weld energy by about 20%, presumably due to better initial absorption of laser power.

Communication with a customer who is using the Polytrope with a 400 watt YAG laser for fiber ferrule welding revealed that the nickel alloy "Kovar", commonly used for making glass-to-metal vacuum seals, has a favorable combination of low thermal expansion, good long term mechanical stability, reasonable absorption at 1.06 um. It is also readily fabricated into complex stamped shapes. Some samples of "saddles" which are used for welding fiber ferrules to semiconductor laser substrates were supplied, and these have been used for subsequent tests. Tests with these Kovar saddle samples revealed that the rough exposure time parameter of 10 milliseconds/micron derived from the stainless steel experiments held also for the Kovar, which has approximately the same heat capacity and thermal conductivity. (See section 4 for the values of these constants for Kovar.) Imaged laser spot size proved to be a very critical factor in achieving high strength welds, and this tended to vary significantly from pulse to pulse with direct laser beam imaging, as discussed in section 2.3. We report here the results obtained using the arrangement shown in Figure 2.4.1, where the laser mode distribution is "scrambled" by a highly reflective hole in a plate of aluminum.

The rather delicate balance between welding and hole drilling is shown in Figure 3.2.1(next page), where the profiles of two "craters" produced in the same 200 um thick Kovar saddle flange, welded to a gold plated stainless substrate, are shown. Both were made with 30 watts of laser power and 2 second exposure. Clearly the smaller (250 um) spot diameter, whose "crater" cross section is shown in Figure 3.2.1(a), had too high a power density, vaporizing a significant fraction of the Kovar which had been in the hot zone, and nearly drilling a hole through the material. An estimated 5.5E-3 cubic mm of Kovar was vaporized in this case. The surface of the deep pit appears to be bare, high reflectivity metal, but an annular ring of very fine grained red oxide extends from an ID of 250 microns to an OD of 700 microns, indicating exessive temperature in the zone around the crater. A larger spot diameter (400 um) resulted in a much gentler profile, shown in Figure 3.2.1(b), and a stronger weld. The larger "crater" is surrounded by an annular ring of black oxide having a surface texture similar to the bare metal. This indicates more modest heating and little re-deposition of the vaporized material. The total volume of the crater in this case is estimated at 20E-3 cubic mm, or almost 4 times as much as in the case of the smaller spot diameter. Some of this crater depth can be attributed to the dropping of the molten area onto the substrate over the welded spot, since the contact between the saddle and the substrate is not perfect, permitting a slight gap which must be filled by molten material from the saddle. A slightly longer exposure at lower power density results in less vaporization and a better weld.

4. ANALYSIS OF HEAT FLOW DURING LASER WELDING OF PLATES

Laser welding of a flat sheet to a substrate is constrained by the fact that the heat from the optical absorption is delivered to the surface only, and must penetrate through the workpiece by thermal conduction. The laser can readily deliver power densities sufficient to raise the surface temperature of even the most refractory metals above the boiling point, thus ablating a thin surface layer. Pulsed operation in this power density regime permits "drilling" of holes with laser beams through even the hardest and most refractory of materials. When a weld is desired, removal of a significant amount of workpiece material is undesirable, since it weakens the weld area. Furthermore, in the case of welding fiber saddles to semiconductor substrates, ablation of the surface is undesirable because it may result in deposition of some of the ablated material on the semiconductor laser facet, which is usually in close proximity to the saddle location.



NOTE: VERTICAL SCALE EXAGGERATED 2X RELATIVE TO HORIZONTAL SCALE.

Figure 3.2.1 Cross-sections of laser welded Kovar sheet on a gold plated Kovar substrate. The 200 um reference depth is the level of the substrate adjacent to the welded area. Laser power: 30 W;
a) 250 um laser spot diameter at top surface of Kovar;
b) 400 um laser spot diameter at top surface of Kovar.

In order to better define the physical constraints on welding by energy deposited on the top surface of a metal sheet, as is the case in laser welding, a simplified finite element analysis of the heat flow into the metal was programmed on an IBM-PC to simulate the conditions at the focal point of the lens. The parameters used were for the nickel alloy "Kovar", which has low thermal expansion and good mechanical characteristics required for a fiber ferrule support structure. The results for other nickel alloys or most types of steel would be similar. The relevant parameters are:

Density:	8.37 gm/cc
Heat Capacity:	0.150 cal/gm/degC
Heat Conductivity:	0.060 cal/sec/cm¢2/degC/cm
Melting Point:	1453 deg C.
Boiling Point:	2750 deg C.

The thickness of the welded sheet was assumed to be 180 microns, the typical thickness of the saddle material. Other test conditions assumed were: a focal spot size of 500 microns, and that 33% of the 30 watt laser beam was absorbed at the surface. Phase changes were ignored for heat transfer, except that the surface was limited to a temperature 100 degrees Celsius below the boiling point of Kovar.

The substrate was assumed to have a thin gold layer of negligible heat capacity, on a thick base of the same thermal conductivity as the Kovar sheet. Trials with high heat conductivity substrates, such as gold plated copper or aluminum, showed that not enough heat flow can be generated in Kovar to heat these materials to a high enough surface temperature to permit bonding. Experiments confirm this conclusion: short of melting a hole completely through the Kovar sheet or tacking at the edge of the sheet, a copper substrate does not reach bonding temperature, no matter how long a laser welding pulse is used.

The results for the case of 30 watt laser power, a 0.5mm spot diameter and an exposure of 2 seconds show that at the end of 2 seconds, the interface had reached the melting point of kovar, but melting had not yet progressed into the substrate. 250 milliseconds later, after the laser beam had been shut off, the thermal energy stored in the molten overheated puddle succeeded in melting 25 microns into the substrate. Thus, the analysis confirms the experimental conclusion that the time required to achieve a weld, when the top surface is held near the boiling point, is about 11 seconds/mm of thickness. This duration is primarily set by the thermal diffusion rate in the Kovar. (The only way to significantly alter this result might be by "drilling" a small diameter hole through the Kovar sheet before applying the longer, lower power, melting pulse.)

The heat affected zone was shown to reach a size of approximately 1.5 mm diameter, in rough agreement with the experiments, as determined by the oxidation of the kovar adjacent to the weld.

The computations were very slow, since many iterations were required over a rather fine mesh in order to obtain accurate simulation. Even though accuracy is limited by not including energy involved in phase changes or the temperature dependence of heat conductivity and heat capacity, the results are in good agreement with experiment. We believe that refinement of this analysis on higher speed computers would be helpful in permitting the prediction whether selected combinations of materials would be suitable for laser welded components, and for specifying the approximate laser power density and pulse duration required to produce good welds.

5. CONCLUSIONS

1) The experiments have established the conditions required for Nd:YAG laser welding of fiber ferrules in Kovar saddles to semiconductor laser substrates, and have demonstrated that the use of step index fiber optics for delivery of the laser beam to the weld should provide controllable and reproducible conditions for welding using a relatively simple multimode Nd:YAG laser.

2) Optimum conditions for a single weld of 180 micron thick Kovar with a CW YAG laser are:
30 watts of CW laser power at 1.06 microns
2 seconds of exposure time
0.5 mm diameter focal spot

3) A substrate having thermal conductivity close to that of the Kovar must be used to achieve laser spot welding of Kovar sheet. High thermal conductivity materials, such as copper or aluminum, will not work.

6. RECOMMENDATIONS

6.1 PROCEEDE WITH WELDING ACCESSORY DEVELOPMENT

The present demonstration program has shown that an effective laser welding accessory for the Kaptron POLYTROPE 3000 automatic alignment system can be designed using a standard CW multimode Nd:YAG laser and an optical fiber delivery system. Because such a system promises to significantly improve the yield and reduce the cost of fiber pigtailing of single mode semiconductor lasers, such an accessory should be developed. This conclusion finds further confirmation in the successful utilization of the POLYTROPE 3000 with in-house developed laser welding accessories by several of our customers.

6.2 DESIGN DUAL FIBER DELIVERY HEAD

Mechanical displacement due to thermal expansion can be minimized by simultaneous welds placed symmetrically with respect to the fiber saddle axis. For this reason, a dual fiber delivery head should be designed for the laser accessory. Two welds can be produced simultaneously on fiber saddles similar to the ones used in this demonstration program with the existing single pump lamp laser, provided that low loss optics are incorporated into the dual beam delivery system. The laser power supply console will require modification to run at higher lamp currents for short periods, so that up to 100 watts of multimode laser power can be produced. If AR coated optics are used and a high efficiency turning mirror is incorporated, up to 40 watts would be available at each of two focal spots for the simultaneous welding of two symmetrical positions on a saddle. This would be adequate even under worst case conditions.

6.3 PROVIDE VIDEO CAMERA INTERFACE

An interlocking safety enclosure must be designed for the work area, and observation should be only by video camera. A video digitizer board should be used to permit computer input of weld position information. This will facillitate future enhancement of automation to include coarse pre-alignment of the fiber to the laser chip and placement of the welds on the saddle, which are currently done under operator control.

6.4 EVALUATE PYROMETRIC FEEDBACK OPTION

If greater laser weld uniformity and repeatability should prove to be required, it is possible to incorporate feedback from a short wavelength pyrometric sensor, observing the blue-green spectral emission of the weld spot, to provide real time feedback to a laser modulator (eg. an accousto-optic crystal) to limit the surface temperature to a value below the boiling point, at about 2,700C. However, the welding demonstrations done in the course of the present program indicate that beam characteristics can be made sufficiently reproducible with a fiber delivery system that such a feedback system should not be needed, thus keeping down cost and eliminating an additional maintainance item.

APPENDIX A

Nd:YAG LASER SEPCIFICATIONS

1-1 General System Description:

The LRI Model 50CE is a CW laser system using neodymium as the lasing atoms in a crystalline host of yttrium aluminum garnet ("YAG"), lasing at 1.06 microns, with a continuous power output capability up to 50 watts.

The basic laser system consists of two units:

1. The Power Station--containing the krypton arc lamp power supply and a water-to-water heat exchanger.
2. The Head Assembly--consisting of the laser pump cavity, associated mirrors and mounts, and optional equipment, such a safety shutter, linear polarizer and pulse modulator.

1-2 Laser Head Assembly:

The single lamp head contains a linear krypton arc lamp which is focussed by means of a gold plated elliptical cavity onto a neodymium doped YAG (yttrium aluminum garnet) rod mounted parallel to the lamp. Cooled distilled water, pumped from the external heat exchanger (Figures 1A, 1B) flows through a system of jackets and couplings, carrying away heat from the rod and lamp in series. The basic head structure has been machined from a unitized block of plastic and contains water channels and rod holders; the optical pumping cavity; and the electrical connections and lamp holders. The head is sealed by means of 'O'-rings. The elliptical cavity itself is precision machined and polished; the reflecting surfaces are heavily electroplated with 24 karat gold. The optical path is protected from dust by removable flexible boots.

The laser head unit is mounted on a carriage, which rides on the optical rail and clamps to it by means of a singlescrew. The other optical components are mounted to this rail in similar fashion.

1-3 Power Station:

The main power station contains the high voltage power supply for the krypton arc lamp; and the water-to-water heat exchanger that provides cooling to the laser head.

The regulated DC power supply provides operating power for the krypton arc lamp in the laser head, at 10 to 22 amperes. In addition, it supplies an ignition pulse in the form of a positive-going spike of 26,000 VDC peak, of about one microsecond duration, followed by a booster discharge of

1000 volts. The booster discharge period is about one millisecond.

The power supply output current, at any setting, is maintained at a constant value within close tolerances by a feedback regulating circuit operating the gates of two SCR's that comprise part of the main bridge rectifier. Output current at 20 amperes, for instance, is held constant within +/-1% for any variation of output load from 2 to 6 ohms; and held within 5% for an excursion from zero load to 5 ohms, in a total correction time of no more than 250 milliseconds.

The "Functional Block Diagram" of the power supply is shown in Figure 1.

The cooling system consists of an internal deionized water (D.I.) to external tap water heat exchanger. All components of the internal cooling system are either plastic, stainless steel, or some other material which will not ionize the cooling water. Two filters are embodied in the external circuit; a mechanical particle filter, and a deionizing filter.

The pump for the internal circuit is of the closed, plastic impeller, centrifugal type, with a total pressure capability of 60 psi. In this system, it normally operates at about 35 psi, with a flow of 3 to 5 gallons per minute.

The operating temperature maintained by the internal D.I. water is regulated by means of a solenoid valve that admits or blocks the flow of external water to the heat exchanger. This solenoid is controlled by a temperature sensing probe in the internal water passing through the head; when the temperature of the internal D.I. water rises beyond set limits, the supply of external tap water is turned "on"; when the internal water cools to a preset value, the external water turns "off".

1-4 External Mirrors and Mirror Mounts:

The dielectric mirrors are in mounts that provide direct adjustment of the mirror angle with independent X-Y angular positioning. A threaded cylindrical mirror holder permits easy interchange of mirrors.

1-5 Options:

The Model 50CE can be optionally equipped with an accousto-optical Q-switch, single mode selector, power monitor, mechanical safety shutter, HeNe alignment laser, Brewster polarizer and polarizing pulse modulator (Model 50PM). Additional carriages, which mount to the optical rail by a single clamping screw, are available for special components and accessories.

YAG LASER (CONT'D)

SPECIFICATIONS FOR THE MODEL 50CE LASER

Laser Medium:	--- Nd:YAG 4x75mm
Wavelength:	--- 1.06 microns
Mode Structure:	--- multimode
CW Power Output:	--- 50 watts multimode
Beam Diameter:	--- 2.0 mm nominal
Beam Divergence:	--- 6 mradians multimode
Mirrors:	--- dielectric plano
Optical Cavity:	--- one 3.5kw krypton arc lamp one Nd:YAG rod in a single ellipse polished gold cavity
Safety Shutter:	--- attached to output coupler mirror holder. Provides "hold off" of laser with 2 millisecond response time
Power Supply:	--- current regulated 220VAC 50 or 60 Hz 25 amps nominal fuse for 35 amps
Mechanical:	--- Power Station: 31"H x 22"W x 25"D Optical Rail: 7"H x 7"W x 32"L
Cooler:	--- Mounted in power supply cabinet. Complete with particle filter and deionizer. Heat Exchanger requires 2 to 3 GPM external water flow. D.I. reservoir holds 3.5 gal.

SAFETY PRECAUTIONS

Although the LRI Model 50 CE incorporates features that provide maximum safety consistent with other requirements, they can--like any other equipment employing electrical voltage and emitting intense optical radiation--cause serious damage and injury if improperly handled. The following safeguards should, therefore, be observed at all times.

Electrical System:

- Disconnect main power line before working on any electrical equipment, and before changing the lamp.
- Allow at least five minutes, after disconnecting the power, before opening the cabinet or housing; this period is required for the capacitors to discharge completely through their protective bleeder resistors.
- Always use only approved, insulated tools when working on high voltage circuits.
- Short circuit terminals of all capacitors with suitable jumpers before working on or near them.
- Do not short or ground the power supply output; the power supply is not electrically isolated from the power line. Positive protection against possible hazards, however, requires proper connection of the ground terminal on the power cable, and an adequate external ground. Check these at time of installation, and periodically thereafter.
- Ground the metal cases of any test instruments used while working on the power supply. (Special precautions must be taken when using an oscilloscope to measure the trigger pulses to the SCR's. The oscilloscope must be powered by an isolation transformer.)
- Never work alone on high voltage systems; have an alert associate at hand in case of an emergency.
- Read and adhere to the specific additional WARNINGS AND CAUTIONS which have been inserted where applicable throughout this manual.

Optical System

- Never permit unbriefed, unauthorized or inexperienced personnel to adjust or have access to the Laser System
- Keep personnel in the area to a minimum. Permit no one but authorized maintenance personnel in the laser area during setup and maintenance operations.

* The Model 50CE is a CDRH Class IV laser. No one should be allowed to view or be exposed to possible lasing output without wearing approved protective goggles, unless the laser output has been so confined as to not permit human visual access consistent with the definition of Class IV Laser Systems.

* The Model 50CE is an OEM laser designed for incorporation into a user's complete system. The designer of the user's system is responsible for providing all of the safety features required for the class of laser equipment being designed.

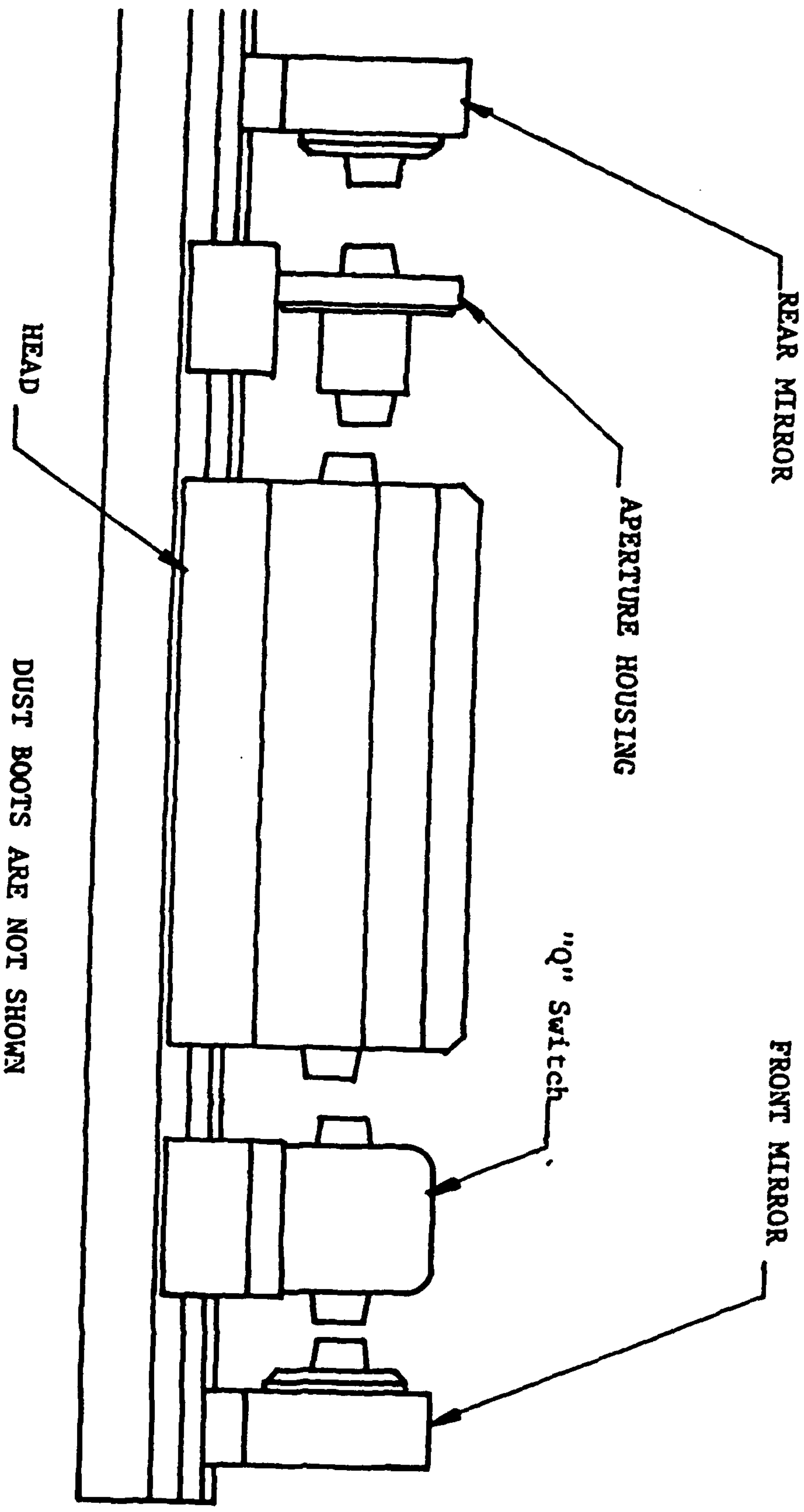
* General Recommendations:

If possible, visually isolate the area in which the laser is to be operated.

Provide visual and/or audible warning that the laser is in operation to anyone seeking admittance to the laser area.

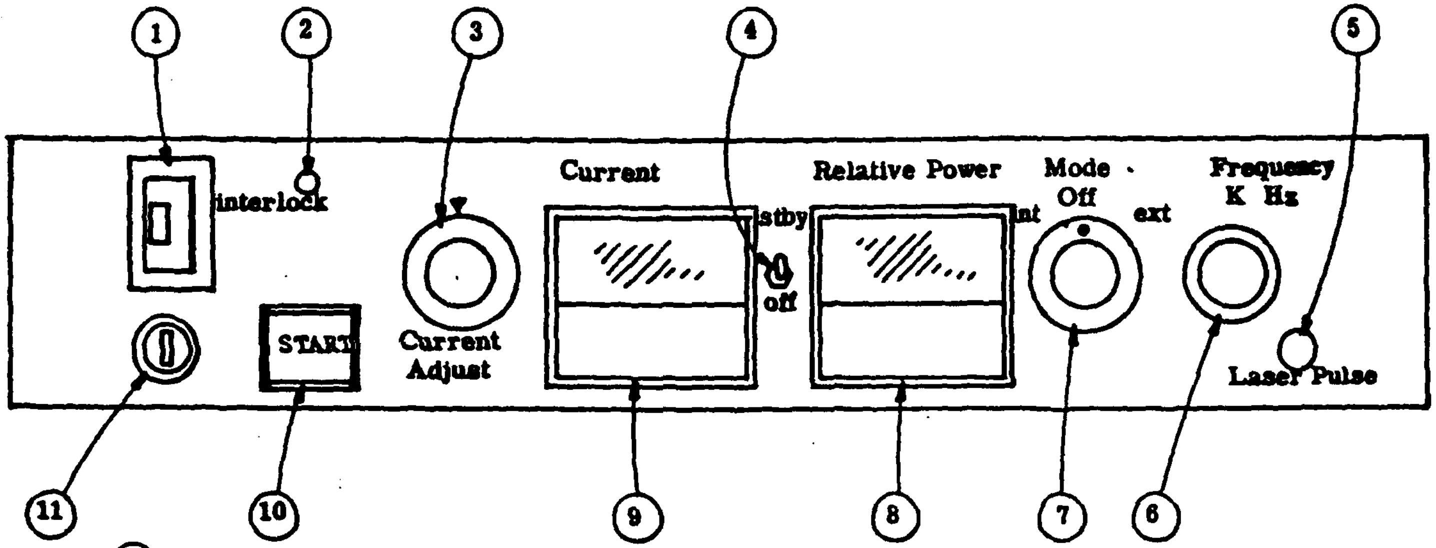
Permit access to the laser area only if the entrant is wearing approved safety goggles.

All possible reflective surfaces in the laser area should be diffuse in order to prevent specular reflections.

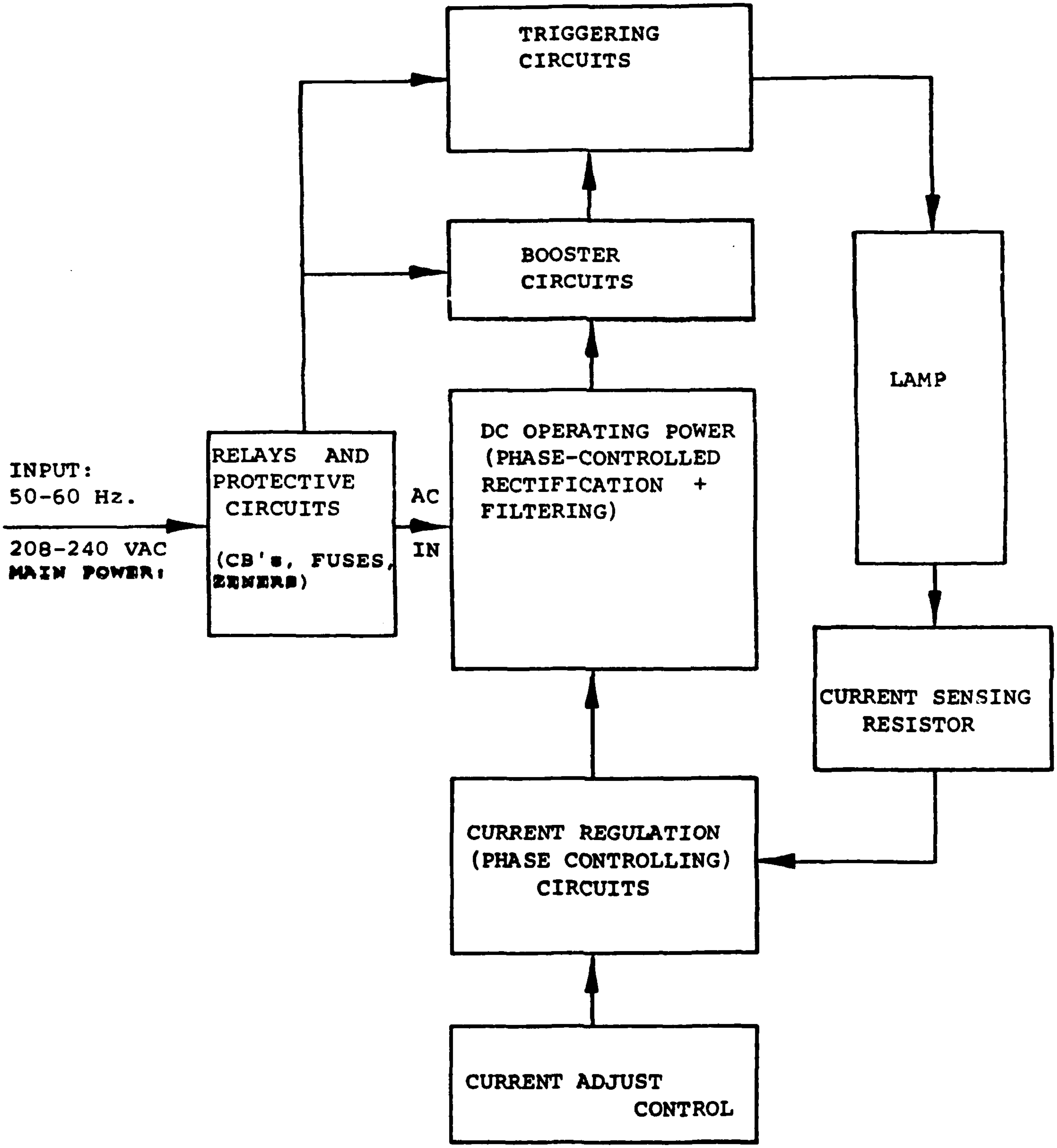


Optical Components of the Laser System

Control Panel for Systems Using Solid State RF Driver



① — Power Rocker Switch
② — Interlock Indicator Light
③ — Current Adjust Potentiometer
④ — Standby Toggle Switch
⑤ — Laser Pulse Connector
⑥ — Internal Trigger Freq. Control Pot.
⑦ — Modulation Mode Selector Switch
⑧ — Relative Power Meter
⑨ — Current Meter
⑩ — Laser Push Button
⑪ — Key Switch



<u>POWER SUPPLY: FUNCTIONAL BLOCK DIAGRAM</u>

APPENDIX B

POLARIZATION SHUTTER PULSE CONTROL PROGRAM

```
10 'For driving 8 bit DAC from parallel port with PRINT CHAR$(X)
20 '0 to 255 corresponds to -5 to +5 volts.
30 'DAC driver program for YAG laser shutter control

50 DEFINT I-L
60 DIM V(55)
70 LPRINT CHR$(128);: 'SET DAC TO ZERO VOLTS

110 PRINT CHR$(26)"SHUTTER DRIVER PROGRAM"
120 PRINT "2-1-89                       F. U.
125 PRINT:PRINT "SERVO ACCELERATE TIMES:"
130 PRINT "     TIME IN MILLISECONDS FOR OFF TO FULL ON=T1"
140 PRINT "     TIME IN msec FOR 'BAKE' = T2
150 PRINT:PRINT"SETTLED 'ON' TIME =TA"
160 PRINT"SETTLED 'BAKE' TIME =TB
170 PRINT "ACCELERATE TO DECELERATE TIME RATIO = R"
180 INPUT"RETURN TO CONTINUE.";A$

200 PRINT CHR$(26)
210 PRINT "* * * MAIN MENU * * *
220 PRINT:PRINT"1. ENTER NEW TIME VALUES"
230 PRINT: PRINT "2. START A PULSE OUTPUT SEQUENCE"
235 PRINT:PRINT"3. TO RUN CALIBRATION CURVE"
237 PRINT:PRINT"4. SAVE THE PRESENT SET UP DATA TO FILE"
238 PRINT:PRINT"5. READ SETUP DATA FROM A FILE"
240 PRINT:INPUT"ENTER THE NUMBER OF YOUR CHOICE.  ";N
250 ON N GOTO 300,400, 2000,4000,4200

300 PRINT CHR$(26);"* * * TIME ENTRY MENU * * *"
310 PRINT:INPUT"FIRST ACCELERATE TIME T1 IN msec ";T1
320 INPUT"DROP TO 'BAKE' TIME T2 IN msec ";T2
330 INPUT"FULL 'ON' TIME IN msec. TA IS:";TA
335 INPUT"      FULL ON VOLTAGE IS: ";VF
340 INPUT"'BAKE' ON TIME IN msec. TB IS:";TB
345 INPUT" BAKE VOLTAGE IS: ";VB
350 INPUT"ACCELERATE TO DECELLERATE TIME RATIO R IS:";R
355 INPUT"      SHUTTER OFF VOLTAGE IS: ";VO
360 PRINT:INPUT"IF ALL VALUES ARE CORRECT, ENTER 'Y', ELSE ENTER 'N'.";A$
370 IF A$="Y" THEN 200 ELSE 300

390 'START THE PULSE SEQUENCE * * * *
400 T = T1
410 V = 5:'DAC TO +5V
420 GOSUB 1000:'RUN TIME DELAY FOR T1 MSEC
430 T = T1 * R
440 V = -5
450 GOSUB 1000: ' RUN TIME DELAY FOR T1*R MSEC
460 T = TA:V= VF
470 GOSUB 1000: ' PREHEAT FOR TA MSEC.

490 'START * * BAKE * *  SEQUENCE
```

```
500 T = T2: V = -5
510 GOSUB 1000: ' ACCEL TO BAKE
520 T = R * T2: V = +5
530 GOSUB 1000: ' DECEL TO BAKE
540 T = TB: V = VB
550 GOSUB 1000: ' SIT AT BAKE POWER FOR TB MSEC.

590 'RETURN TO ZERO POSITION * * *
600 T = T2: V = -5
610 GOSUB 1000: 'ACCEL TO ZERO
620 T=1000: V = VO
630 GOSUB 1000: ' SET TO OFF CONDITION
640 GOTO 200

1000 'TIMER
1002 IF V¶=5! THEN V=4.96
1003 IF V§=-5! THEN V=-4.96
1005 LV= V*-25.6 + 128:'CONVERT VOLTS TO BYTE FOR DAC
1010 LPRINT CHR$(LV);:'PRINT "START OF LOOP"
1015 IF T ¶ 11000 THEN 200
1020 FOR I= 1 TO T:NEXT I
1030 RETURN

2000 'CALIBRATION TEST
2010 FOR I1 = 0 TO 255 STEP 5
2020 LPRINT CHR$(I1);
2025 PRINT"CHAR =";I1;:II=I1/5
2030 INPUT"TYPE IN VOLTAGE READING FROM DAC OUTPUT.  ";V(II)
2040 NEXT I1
2050 GOSUB 3000
2060 GOTO 200
2490 STOP

2500 FOR J = 0 TO 51:'ARTIFICIAL DAC DATA GENERATOR
2510 V(J)= -5 + .2*J
2520 NEXT J
2530 GOSUB 3000
2540 GOTO 200

3000 'WRITE DATA FILE
3005 OPEN "O",1,"DAC_CAL"
3010 FOR J=0 TO 51
3020 PRINT#1,5*J;",";V(J)
3030 NEXT J
3035 CLOSE #1
3040 RETURN

4000 'Generating a setup file
4005 INPUT"ENTER A 2 DIGIT SETUP FILE NUMBER.  ";N$
4010 OPEN "O", 2, "SETUP" + N$
4020 PRINT#2,T1;T2;TF;TB;R;VA;VB;VO
4030 CLOSE #2
4040 GOTO 200
4200 'READ SETUP FILE
4210 INPUT"ENTER 2 DIGIT SETUP FILE NUMBER.  ";N$
```

```
4220 OPEN "I", 2, "SETUP" + N$
4230 INPUT#2,T1,T2,TF,TB,R,VA,VB,VO
4240 CLOSE #2
4250 GOTO 200
4300 END
```

POLARIZING MODULATOR:

DESCRIPTIONS AND SPECIFICATIONS

1-1 General System Description:

The LRI Model 50PM is a servo motor driven Glan-Laser Polarizer assembly designed to regulate the output of polarized CW visible and near infrared lasers up to 50 watts maximum. The use of a servo motor permits computer control of the polarizer angle and, thereby, computer control of the percentage of transmission of the laser beam without upsetting the mode pattern of the laser.

1-2 Polarizer:

The Glan-Laser Polarizer consists of a Schlieren grade calcite polarizer equipped with an exit window so that the rejected polarization may escape the crystal. Rotation of the crystal through a 90 degree angle allows the transmitted polarization to be varied from 0% to 100%. Selection of intermediate angles allows partial percentages to be selected. The transmission follows a sinusoidal profile. Thus, 0 degrees corresponds to 0% transmission while 90 degrees corresponds to 100% transmission. An intermediate angle, such as 30 degrees, would select 50% transmission.

All surfaces of the calcite polarizer are AR coated for the wavelength region selected. Fresnel losses are typically less than 1%.

The calcite polarizer is mounted in an axle equipped with bearings and a sprocket for a zero backlash plastic chain. Mechanical stops are provided to prevent the rotation of the polarizer from exceeding 95 degrees. The rejected laser beam passes through the side of the axle and strikes an absorbing block.

1-3 Servo System:

The servo motor used to drive the polarizer consists of a low inertia cup armature DC motor equipped with a DC tachometer.

The servo motor is driven by a linear DC servo amplifier board capable of delivering +/-24 volts at 10 amperes maximum current. The servo amplifier can deliver 3 amperes continuously. The motor delivers approximately 60 oz-in of torque at maximum current. A higher power servo amplifier can be supplied as an option which will provide up to 30 amperes of peak current and, thereby, up to 180 oz-in of peak torque.

Angle feedback is provided by use of a 2 Kohm servo potentiometer attached to the motor shaft.

POLARIZING MODULATOR (CONT'D)

A zero backlash plastic drive chain is used to convey mechanical power from the motor to the polarizer axle. The chain and sprockets have a reduction ratio of 1:2. Thereby, a 180 degree motor rotation results in a 90 degree polarizer rotation.

SPECIFICATIONS

Maximum Power: --- 50 Watts CW (250 W/cm2)
Maximum Beam Diameter: --- 6 mm
Maximum Transmission: --- 99% (depends on degree of polarization of laser)
Minimum Transmission: --- 0.1% (depends on degree of polarization of laser)
Risetime (to 70% transmission): --- 10 milliseconds
Input Signal: --- 0 to +5 volts
Dimensions: --- Polarizer:
10"H x 5"W x 7"L
Servo Amplifier:
7"H x 19"W x 7"L
Mounting: --- Polarizer:
Saddle mount on Model 50CE YAG laser rail
Servo Amplifier:
19" panel rack

APPENDIX C

AUTOMATION OF FIBER OPTIC PIGTAILING PROCESS:

LASER WELDING ACCESSORY FOR KAPTRON POLYTROPE 3000
S.B.I.R. FEASIBILITY DEMONSTRATION PROGRAM
CONTRACT NUMBER N00014-88-C-2050

CERTIFICATION OF LABOR BY JOB CATEGORY

LABOR CATEGORY:

Research Scientist	361.0
Electrical Engineer	51.0
Mechanical Engineer	26.0
Technician	366.5
TOTAL HOURS:	804.5