PL-TR-95-1153

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COMPACT, INTEGRATED LASER/TELESCOPE/DETECTOR FOR REMOTE WIND SENSING

Thomas J. Kane

Lightwave Electronics Corporation
1161 San Antonio Road
Mountain View, CA 94043

November 1995

Final Report

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PHILLIPS LABORATORY
Lasers and Imaging Directorate
AIR FORCE MATERIEL COMMAND
KIRTLAND AIR FORCE BASE, NM 87117-5776

PL-TR-95-1153

This report has been approved for publication.

MICHAEL ALLEN
Project Officer

FOR THE COMMANDER

NICHOLAS R. PCHELKIN, GM-15
Chief, Semiconductor Laser Branch

ROBERT A. DURYEA, Colonel, USAF
Director, Lasers and Imaging Directorate

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	November 95	Final Mar 95 - Sep 95

4. TITLE AND SUBTITLE
COMPACT, INTEGRATED LASER/TELESCOPE/DETECTOR FOR REMOTE WIND SENSING

5. FUNDING NUMBERS
C: F29601-95-C-0110
PE: 65502F
PR: 3005
TA: CO
WU: CJ

6. AUTHOR(S)
Thomas J. Kane

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Lightwave Electronics Corporation
1161 San Antonio Road
Mountain View, CA 94043

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Phillips Laboratory
3550 Aberdeen Ave SE
Kirtland AFB, NM 87117-5776

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
PL-TR-95-1153

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

We have identified a military market for a low-energy laser radar. This market is very sensitive to cost, power and cooling requirements and ruggedness. We have developed a design proposal for a compact, rugged, and integrated laser radar transceiver which we think meets these requirements. This design is based on diode-pumped Thulium:YAG lasers.

We have experimentally investigated the causes of dimensional creep in our laser structures, have found solutions, and have tested and implemented them in manufacturing.

We have done about half the work necessary to finish a good computer model of the alignment sensitivity of the laser design we have proposed.

14. SUBJECT TERMS
Diode-Pumped, Thulium:YAG, Laser Radar, Helicopter

15. NUMBER OF PAGES
18

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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I. Technical Goals

The overall goals of this contract were first, to design a laser-radar transceiver which contained all critically-aligned optical components on a single, highly-stable platform, and then to study the issues which will affect the long-term stability of the platform in a challenging environment where hands-off operation is required.

Initially, we were considering a transceiver with output energy in the 3-10 milliJoule (mJ) range. For operation at long range, such a system would require a large telescope. Figure 1 shows this original concept. Our goal was for the entire package to fit in a volume of 8" x 6" x 24" or 1152 cubic inches. This package would have contained the Q-switched laser and the telescope, but not the pump laser diodes, which would be remoted via optical fiber. It was assumed that two 20-Watt cw fiber-coupled laser diodes would have provided the power. When all required cooling is added to this system, it was expected to have a power draw of about 300 Watts. (Each 20-Watt diode will draw about 50 Watts, and about twice this much is required for cooling.) Dissipation of this amount of power required either forced air or flowing coolant. This cooling would have been required only at the remoted pump diodes, which was one of the reasons for locating them remotely. The powerful diodes and large telescope of the system of Figure 1 makes it expensive. The likely cost for parts is about $50,000, so the sales price must be well over $100,000 for it to be a viable product. The part cost is dominated by the laser diodes (2 units at $10000 each) and the telescope mirrors ($10000 each.)

Lightwave Electronics has a history of cooperation with the Honeywell Corporation on laser-radar projects. Honeywell would like to produce a system, with Lightwave as the manufacturer of the transceiver subsystem. Early in the contract period, Honeywell met with representatives of McDonnell-Douglas helicopter of Phoenix, Arizona. Honeywell learned of an application for a short-range laser radar which would be used at low altitudes. This device would improve the accuracy of munitions fired from helicopters by determining the wind velocity at the launch tube and 1000 feet beyond, which is out of the helicopter downwash.

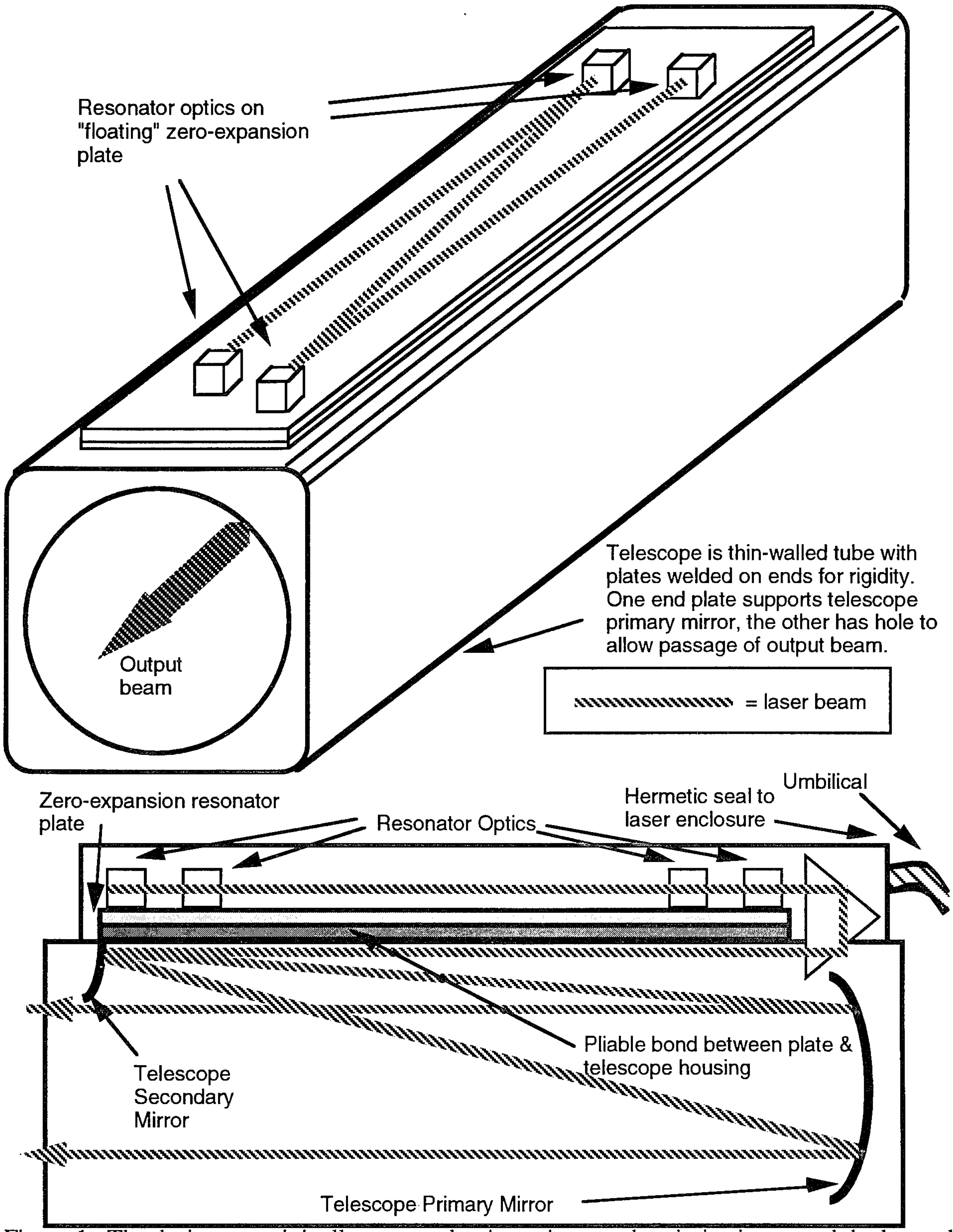

Figure 1. The design we originally proposed to investigate and optimize integrated the laser, the detector, and the telescope into a package which has its size dominated by the size of the telescope. CW lasers (pumps and local oscillators) were to be remoted with fiber optics.

McDonnell-Douglas stated that low cost was of paramount importance to creating a successful laser radar for this application. Liquid or forced-air cooling were not possible, and low power consumption (100 Watts or below) was desired. However, this application requires only very low pulse energy, because the range is short; the altitude is low, so the atmospheric return (beta) is high; and achieving usable signals 100% of the time is not critical to the overall utility of the system. Also, the telescope need not be large, because of the close range. It is a property of laser radars that increasing telescope diameter only increases signal in the far field of the telescope aperture. With 2 μm light, a 2-centimeter-diameter beam is all that is needed to place the far field beyond 1000 feet.

Honeywell and we determined that an 0.33 mJ laser radar, with a 2 cm aperture, operating at 80 pulses per second, could provide useful data for the helicopter application well over 95% of the time. Honeywell also concluded that the helicopter application was significant, in that the number of units required was large and benefits were important. Thus we decided to focus this research project on the particular application of a short-range, ground-level coherent laser radar.

A low-energy system has a number of advantages over the high-energy systems required for most applications.

1. Cost is reduced very substantially, since only a single, non-fiber-coupled laser diode is required for pumping, and the telescope optics are small. The cost of the single diode is $1500 and the cost of the 2-cm telescope is less then $500.

2. Since the average output power of the laser is only 27 mW (80 Hertz rep rate x 0.33 mJ) the laser is within a factor of two of being truly eye-safe at all ranges. Current ANSI standards define eye-safe as being 13 mW for 2-μm cw lasers. Watt-level 2-μm lasers are safe in only a relative sense, as compared to shorter wavelength lasers with the same power. They will be a substantial eye hazard even at a range of several kilometers for a collimated beam.

3. The thermal dissipation of this laser will be about 10 Watts, so conduction cooling is not difficult.

II. Transceiver Design

Figure 2 shows the design approach we developed for the helicopter application. All components, including the laser diode, and the cw local oscillator, are on a single plate. The Q-switched resonator is made compact by multiple folding mirrors. The telescope (not shown in the figure) is simply an additional pair of components on the plate. The plate dimensions are 5" x 6", and the enclosure is 2" high, so the total volume is 60 cubic inches. The pump diode is a single 2-Watt diode running at reduced duty cycle, since only an 80 Hertz repetition rate is required. Table 1 is a comparison of the originally-proposed unit and the design we developed

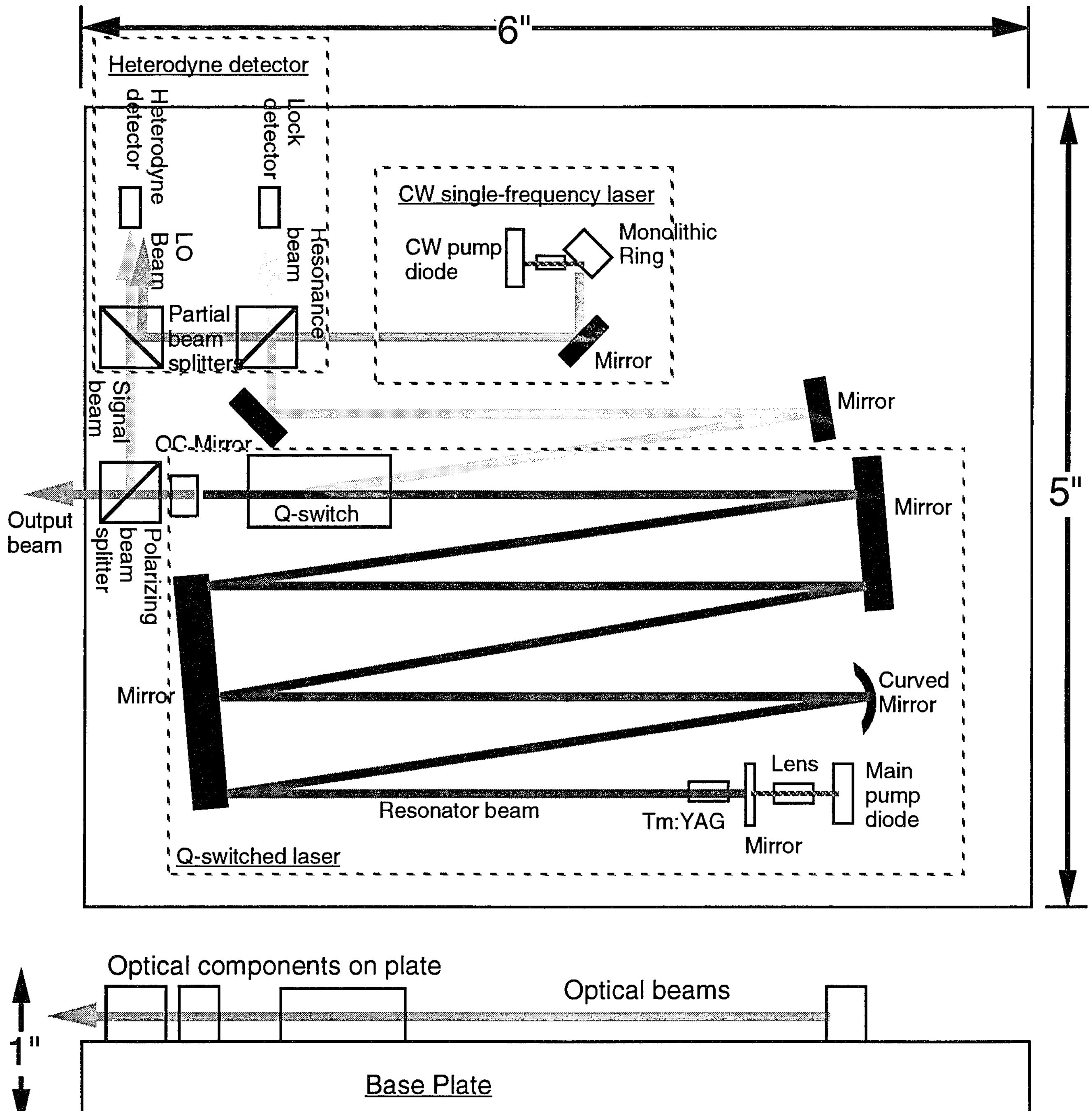

Figure 2. The low-energy, compact design contains all components, including pump and local oscillator laser, on a single platform. The Q-switched resonator is made compact by multiple folding mirrors. Cooling is by conduction. The telescope is an additional two lenses to be placed on the platform.

for this contract. For reasons of cost, size, and thermal and power management, the later design is much more attractive for the helicopter application.

TABLE 1: Comparison of original, high-energy design with later design optimized for helicopter application

Characteristic	Original design	Later design
Pulse energy	5 mJ	0.33 mJ
Pulse rep rate	300 Hertz	80 Hertz
Average power	900 mW	27 mW
Pump diode	2@ 20 Watt, fiber-couple	1@ 2 Watt
Pump diode duty cycle	100%	25%
Pump diode cost	$20000	$1500
Pump diode power draw	100 Watts	2 Watts
System power draw	300 Watts	10 Watts
System dimensions	8" x 6" x 24"	6" x 5" x 2"
System volume	1152 cubic inches	60 cubic inches
Telescope aperture	12.5 cm	2 cm
Telescope cost	$10000	$500
Telescope far-field	6 km	157 meter
System cooling	Fluid or forced air	Conductive

III. Design of Stable Platforms

Our proposal called primarily for a theoretical analysis of platform stability. In fact, the work completed was a combination of practical and theoretical work. Lightwave produces commercial lasers which are similar in their platform requirements to the laser radar system, in that the overall dimensions are about the same, and in that we are using the same "plate" approach to mounting the optics. These lasers are known as the Lightwave 200 series. They are diode-side-pumped lasers with power in the 2 to 10 Watt range. We have environmentally stressed these lasers and found problems.

The most serious problems we have found are ones which are non-recoverable, that is, where returning the environment to its original state does not result in the laser returning to its original state. We find that many lasers, after periods of a few weeks of thermal cycling of ±25°C, lose up to half of their output power. This power can in all cases be recovered by re-aligning the laser. However, our goal is to build lasers that never have to be re-aligned. Thus the need for re-alignment indicates an unacceptable change in the relative positions of some of the components.

The kind of theoretical analysis we had planned is most useful for understanding small *elastic* deformations of the type which are completely recoverable, that is, for which the system returns to the same state when the environment is returned to the same state. Non-recoverable deformations are much harder to study theoretically. We sought practical approaches to these problems.

Part of our problem of non-recoverable dimensional change was traced to creep of the aluminum plate. We sought experts in fields where similar problems have been dealt with. Roger A. Paquin is a mechanical engineer with experience in the construction of lightweight telescopes. He recommended a process for the construction and treatment of large aluminum parts which must not creep after machining. We have adopted this approach for the 200 series and it appears that the new units are more stable. Appendix 1 is a copy of the report in which he described the process.

Another practical source of component creep turned out to be the process of bonding optics to the aluminum plate. An old approach consisted of gluing optics to metal carriers, and then gluing glass blocks to the aluminum plate, then gluing a ceramic resistance heater to the glass block, and finally soldering the optic and its carrier to the metallized surface of the resistance heater, using a current applied to the heater as a source of heat. In some cases this approach was observed to creep unacceptably after time or after temperature cycling. The large number of glue bonds and components makes it hard to determine exactly what was creeping. We sought a much simpler structure, with a minimum number of glue bonds.

Silicon mounting & soldering technology

Lightwave Electronics makes extensive use of soldering of optics in our products. Soldering is inexpensive and is re-workable. It is also quite stable. In many of our products, our pre-existing approach to soldering is adequate. For larger resonators, such as the one we hope to use for laser radar, unacceptable levels of dimensional creep have been observed. We don't know exactly which components were creeping. We decided to design a new soldering structure which made use of no epoxies, and which used the minimum number of materials, and which used only well-characterized, widely-available materials. Figure 3 shows the approach we have developed.

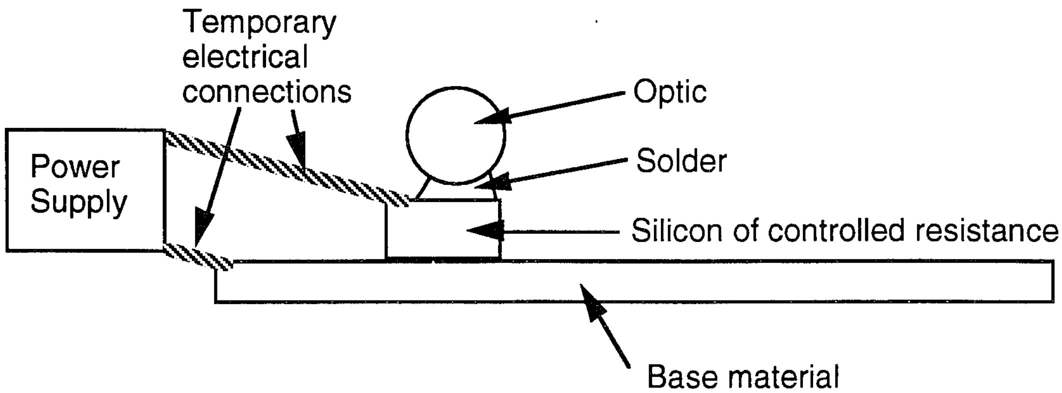

Figure 3. Newly developed and tested approach to soldering optics in place on platform.

This approach uses as its primary supporting element a piece of doped silicon. The top and bottom surfaces of the silicon are metallized. The bottom surface is attached by soldering to the aluminum bench, which is nickel-plated for solderability. A contact which touches the top surface of the silicon can cause a current to flow through the silicon. The electrical conductivity of the silicon is chosen so that for a reasonable current and voltage, the silicon heats to the point where the top solder melts. Once the solder melts, an optical component with metallization on one surface can be placed into the molten solder, aligned, and when the current is removed, remain permanently attached. This simple approach has already been tested successfully, and we are using it on the large-resonator lasers produced by Lightwave.

IV. Theoretical analysis of platform response to Environment

1. Platform structures.

When we started this program, we expected that the telescope mirror would a very large component, and that designing the telescope into the structure would be one of our largest challenges. Now we are focused on the short-range helicopter application which our partner Honeywell has identified. This application requires a much smaller telescope aperture than is needed for longer-range applications. The telescope is likely to be a simple telescope, with a lens or mirror of only two centimeters. The dominant goal now is low cost. This has caused us to focus on simple approaches, such as plates.

The two approaches which we are comparing are shown in Figure 4.

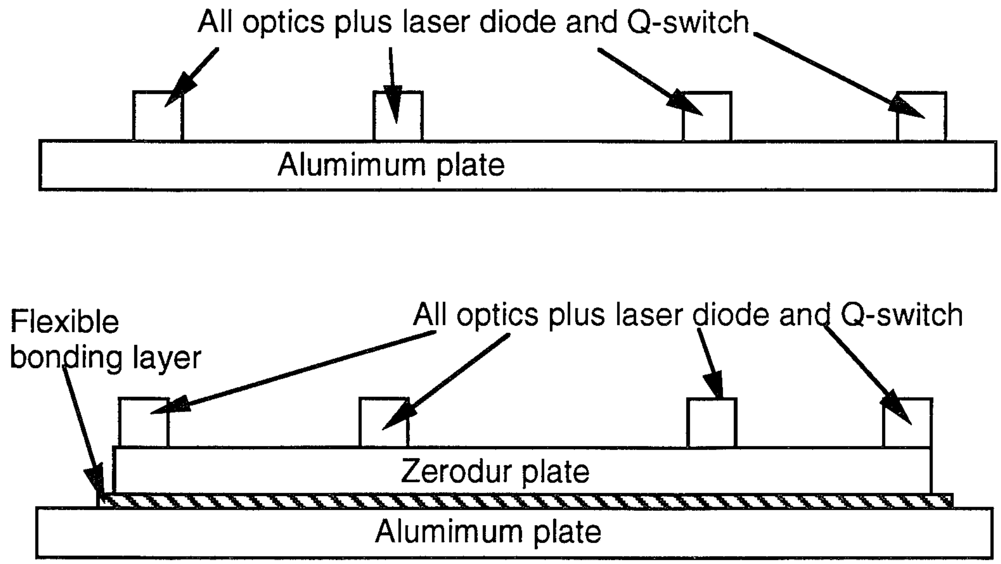

Figure 4. Top approach is to simply attach all optics to a plate which also acts as a pressure surface and a heat sink. This is cheap and simple but pressure and heat may distort plate unacceptably. Bottom approach is to use a thermally and mechanically isolated zerodur plate. This will create a platform of near-perfect dimensional stability, but heat sinking is complicated and cost is increased.

The first approach is a simple aluminum plate. All optical components are attached onto the plate, so any flexing of the plate moves the optical components. The plate has multiple functions in addition to an optical bench. Since the laser diode and the Q-switch are mounted to the plate, it must act as a heat sink for those components. Since the optics are to be in a hermetic enclosure, the plate also acts as one surface of a pressure vessel. Both heat and pressure differences will distort the shape of the plate to some degree.

The second design uses an optical bench which is not used as a pressure vessel surface or as a heat sink. This surface is mounted using a flexible bonding material to another supporting surface. Gaps in the bond equalize pressure on both sides of the optical bench. The optical bench material could be something inexpensive, such as aluminum, or it could be a zero-thermal-expansion material, such as the glass-like material zerodur. Zerodur plates such as the one we would need are only about $300 and have thermal expansion about 1/400 of that of aluminum, and are of equivalent mass and rigidity. We expect that this second mounting scheme will have essentially perfect dimensional stability for our purposes. This design is more expensive, and it complicates the problem of heat-sinking. Some sort of flexible heat-sink must carry away the heat from the laser diode. One option is flexible heat-pipes and another is close-coupled surfaces which transfer heat via an intermediate gas layer.

Mathematical Analysis

We have found simple expressions for the deformation of plates. Our reference is "Formulas for Stress, Strain and Structural Matrices," by Walter D. Pilkey, (Wiley-Interscience) This has allowed us to estimate the deformation of the laser plate due to pressure and temperature.

We have derived or looked up all of the equations and written about half of the computer program which is needed to calculate the effect of optics misalignment. This program takes as one input the plate deformation, given as a quantity of spherical bulge, cylindrical bending, or non-uniform compression along either axis, or as a wedging deformation along either axis. The other set of inputs are the nominal positions of each optic. It then calculates the motion of each optic. Then it finds the new position of the beam produced by the Q-switched resonator caused by this motion. The resonator beam and the local oscillator beam are then propagated through the system to the heterodyne detector.

One output of the model is the degree of misalignment of the local oscillator beam and the (conjugated) output beam from the Q-switched laser. This misalignment can be very simply converted to a system sensitivity loss, since the theory of heterodyne detectivity is straightforward. The other output is the amount of motion of the beam in the Q-switched resonator relative to the diode pump beam. This motion will lead to power loss from the Q-switched laser, but the exact amount cannot be calculated, since their is no theory of laser performance with enough accuracy. Nevertheless, if the sensitivity of laser power to pump misalignment is measured for one configuration, it can be used to provide the coefficient which can then be used in the theory.

V. Conclusion & Recommendations

We have done three things during this Phase I:

1. With our partner Honeywell, we have identified a military market for a low-energy laser radar. This market is very sensitive to cost, power requirements and ruggedness. We have then developed a design proposal which we think meets these requirements.

2. We have experimentally investigated the causes of dimensional creep in our laser structures, have found solutions, and have tested and implemented them in manufacturing.

3. We have done about half the work necessary to finish a good computer model of the alignment sensitivity of the laser design we have proposed.

In our opinion, a single-platform LIDAR based on a single laser diode is technically possible. We believe that this technology will be cheaper, simpler and more robust than larger, higher-energy designs. Of course, low energy will limit the range of applications. But if low-energy applications can be identified, we strongly recommend that our compact design be tried, since the reduced complexity relative to higher-energy designs gives an improved chance of success.

MANUFACTURING PROCESS SPECIFICATION

Aluminum Bulkhead P/N 4-1539

A. INTRODUCTION

This document defines the procedures for fabricating aluminum (Al) bulkheads (P/N 4-1539), in production quantities, for use as the optical bench for a hermetically sealed solid state laser. The process steps provide for rough machining, heat treating, finish machining and thermal cycling prior to hard anodizing.

B. MATERIAL SPECIFICATION

The bulkheads will be fabricated from Al plate, alloy 6061-T6 or 6061-T651 (UNS No. A96061). Other specificationds for this material are AMS 4025 and ASTM B209. The plate is to be furnished with a minimum of 0.150" per surface over finish maximum dimensions.

D. MACHINING AND STRESS RELIEF

The Al plate will be machined and stress relieved in accordance with the following process steps:

1. Machine tooling holes as required.
2. Rough machine to 0.050"/0.150" per surface over finish dimensions.
3. Clean and degrease.
4. Solution treat by heating rapidly to a temperature of 985°F ±10°F; hold for one hour and immediately quench into room temperature solution of 30% UCON Quenchent A[1] in water.
5. Partial age at 320°F ±10°F for 10 hours and air cool. 340°F for 5 hrs
6. Machine to finish dimensions with progressive machining cuts for final 0.040".
7. Stress relieve at 320°F ±10°F for 10 hours and air cool.
8. Thermal cycle two complete cycles of the following:

   Cool to -40°F and hold 15 minutes at temperature
   Heat to room temperature and hold 15 minutes at temperature
   Heat to 200°F and hold 15 minutes at temperature
   Cool to room temperature and hold 15 minutes at temperature
9. Clean and degrease.
10. Hard clear anodize 0.0015"/0.0020" all surfaces except tapped holes and surfaces noted on drawing. Do not apply sealing agents.
11. Surface treat as required
12. Repeat step 8.

Prepared by: R. A. Paquin

Roger A. Paquin 7/3/95

[1] Polyalkaline glycol polymer distributed by Tenaxol Corp. and described in Union Carbide Brochure SC-955 (1988)

DISTRIBUTION LIST

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DTIC/OCP Cameron Station Alexandria, VA 22304-6145	2 cys
AFSAA/SAI 1580 Air Force Pentagon Washington, DC 20330-1580	1 cy
PL/SUL Kirtland AFB, NM 87117-5776	2 cys
PL/HO Kirtland AFB, NM 87117-5776	1 cy
Official Record Copy PL/LIDA Sylvia Mancha	2 cys
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