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Center for Night Vision and Electro-Optics

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FINAL REPORT

HIGH RADIANCE PULSED LASERS

LASER DIODE, INC.
1130 SOMERSET STREET
NEW BRUNSWICK, NJ 08901
AUTHORED BY: STEPHEN KLUNK

CNVEO-DELNVL-L (Trussell)

JULY 2, 1987

CONQUEST OF DARKNESS

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The objective of this contract was to design, develop, test, and deliver six (6) pulsed laser modules. These devices combined 10 to 12 pulsed GaAlAs injection lasers into a compact package using fiber optic coupling to achieve a high radiance. The delivered devices had a nominal peak power of 100 watts in a 40 ns pulse at a repetition rate up to 50 kHz. The emitting aperture was 0.010 inch square. The devices were designed to be driven by a Power Technology model ILM pulser.

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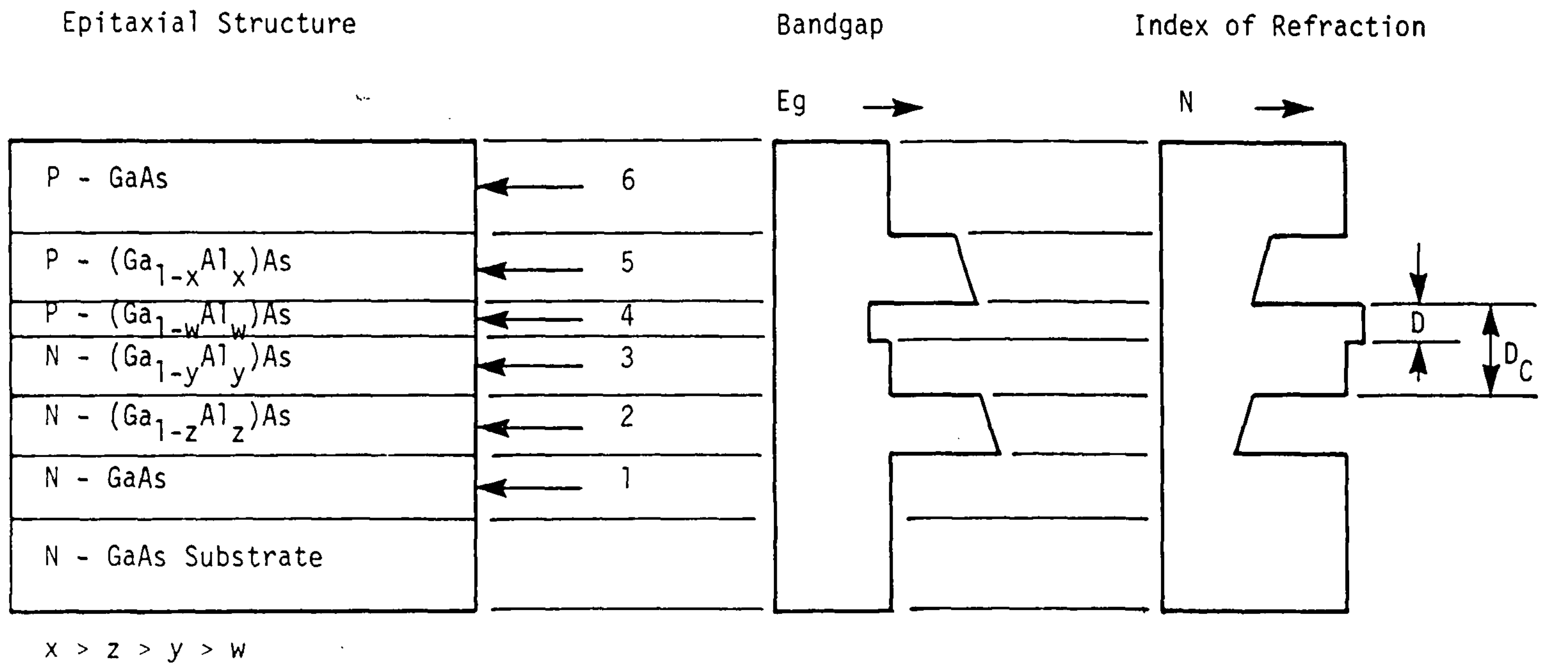
OBJECTIVE:

The objective of this contract was the design and fabrication of six (6) high radiance pulsed semiconductor laser sources which emit in the near infrared. These compact, fiber coupled sources were required to emit 100 watts of peak power from a source of 0.010 inch by 0.010 inch at a duty cycle up to 0.2 percent. The lasers were designed to be operated by a Power Technology ILM series current pulser. Two pulsers, as specified in the contract, were delivered with the lasers.

LOC STRUCTURE:

Large Optical Cavity (LOC) lasers, similar to material currently used for commercial high power lasers and arrays, have been used to meet the requirements of DAAK-20-85-R-0030. Devices fabricated from LOC wafers exhibit low thermal impedance, moderately low threshold current density, high quantum efficiency and acceptable beam divergence. LOC lasers performed well at the required pulse width range (35-70 ns) and frequency (up to 50 KHz).

The LOC structure is shown schematically, along with energy bandgap and refractive index profile, in figure II.1. This structure was grown in a single liquid phase epitaxial process on a GaAs single crystal (100) substrate. The first layer grown was an n-type GaAs Buffer. It acted as an interface between the GaAs substrate and the (GaAl)As second layer. While this first layer was not necessary to the operation of the LOC structure, it served to absorb submicron substrate damage and provide a flat, uniform surface for growth of subsequent layers.



Schematic Representation of GaAs-GaAlAs LOC Structure

FIGURE II.1

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The second layer was n-type (GaAl)As. It confined the stimulated radiation and lasing mode to the optical waveguide, Dc. Layer three formed the passive part of the waveguide Dc. It was n-type (GaAl)As.

Layer four was the active region of the waveguide. It made up the second part of the waveguide. To meet the requirements of DAAK-20-85-R-0030, it was p-type (GaAl)As. By adjusting parameters such as thickness, Al concentration, and carrier concentration of layers 3 and 4 it was possible to adjust such laser parameters as threshold current density, wavelength, catastrophic damage threshold and beam pattern.

Layer 5 was p-type (GaAl)As. It formed the upper boundary of the optical cavity. It also served to confine injected electrons to the active region, layer 4, thus increasing the efficiency of the lasers.

The final layer, layer 6, was a p^+ GaAs cap. It was grown to facilitate ohmic contact to the p side of the structure. While this layer, as the buffer layer, was not essential to the structure it provided a surface which allowed low resistance, p-type ohmic contact. Contact resistance was further reduced by a shallow Zink diffusion (~0.5 um) to the p-cap layers.

Devices fabricated from this structure exhibited beam divergences, perpendicular to the junction, of $\sim 25^{o}$. The catastrophic damage threshold was ~1.5W per mil of junction for uncoated junctions and threshold current densities were 7-11,000 A/cm^2.

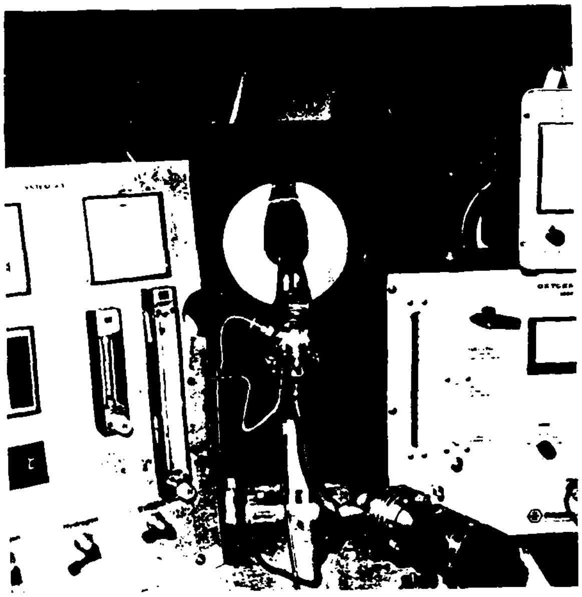
LIQUID PHASE EPITAXIAL PROCESS:

There were several factors of prime importance for optimal Liquid Phase Epitaxial (LPE) material growth. First, to obtain maximum yield of devices having the same electrical and optical properties. Second, growth reproducibility from wafer to wafer. Third, the surface of the grown wafer must be flat and free of residue to facilitate wafer processing operations.

Using MLD's LPE system, figure II.2 we were able to obtain uniform layer thickness over areas greater than 2.8 cm^2 for structures with as many as eight consecutively grown layers of GaAs/(GaAl)As. Desired layer thickness in such a structure can range from 0.1 um to 15 um. Thickness variations for such a structure are typically less than 5% for layers 1.5 um thick and no more than 10% for layers 1.5 um thick. This high degree of growth uniformity is due to the following:

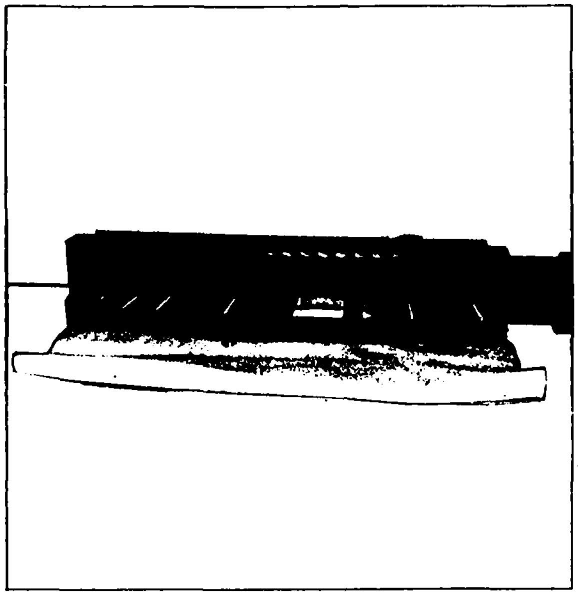
a. Selection of the highest quality substrates from our GaAs crystal facility. All substrates selected had an etch pit density of <1000 cm^{-2} .u

b. Elimination of temperature gradients, both vertical and horizontal. This was accomplished by using a roller mounted, resistance heated furnace incorporating an isothermal heat pipe. Using this type of furnace allows a flat temperature zone of 20" in a 30" furnace, insuring uniform temperature over the entire LPE boat, figure II.3.



LIQUID PHASE EPITAXIAL SYSTEM

FIGURE II.2



LPE BOAT

FIGURE II.3

c. It is well known that oxygen in the growth ambient causes problems such as changes in growth rate,layer defects and changes in layer composition. In order to reduce the oxygen caused problems, all LDI LPE systems have facilities for vacuum evacuation of reaction chamber prior to introduction of purified hydrogen. Pumps are of the sorption type to eliminate oil backstreaming during evacuation. Oxygen content is monitored during purge and growth operations and is typically ~0.3 parts per million.

d. Furnace temperature and cool rate were controlled by a programmable power supply capable of providing a thermal growth cycle reproducible to within $\pm$ 0.1 ^{o}C. This was important for reproducible layer thickness and composition.

Material growth was accomplished by loading the substrate wafer into the slider well of a high purity, high density graphite boat. When the appropriate dopants and gallium charges have been added to the growth bins, the boat was loaded into the growth tube. The system was sealed and purged with high purity nitrogen. The system was evacuated to >10^{-2} torr. High purity, paladium diffused hydrogen was introduced into the reaction chamber. System oxygen level was monitored. When the oxygen level was below 0.3 parts per million, the furnace was rolled on to the reaction tube.

After the furnace stabilized at the growth temperature (845 ^{o}C), one hour was allowed to insure complete melt saturation. Epitaxial growth proceeded along a time-temperature program. Each layer was grown, in sequence, by advancing the substrate from bin to bin for a controlled time interval. Wafer positioning under a melt was controlled by an indexing feature incorporated in the design of the LPE boat. Surface morphology of grown wafers was such that no processing is necessary prior to metalization of the epitaxial side of the wafer.

Grown wafers were metallurgically inspected for surface damage. A sliver was cleaved from the wafer and an SEM photograph was taken to measure layer thickness and uniformity. Acceptable wafers are then sent on for Zn diffusion.

WAFER PROCESSING:

After Zn diffusion, P-side metals (Ti/Pt/Au) were sputter deposited. Wafers were back lapped to a final thickness of 3.5 mils before N-metals (Au-Ge/Au/Pt) were applied. Contacts were sintered, in vacuum, at 450 Degrees Centigrade for two minutes. Both contacts were overlaid, p-side (Pt/Au), n-side (Pt/Au/Pt). Overlap and sintering were performed in the sputter system.

Metalized wafers were cleaved, using automated scribe and break equipment employed for commercial lasers. Cleaved slivers were loaded, with facets exposed, into a coating fixture. The coating fixture was placed into our E-Gun vacuum system.

A six (6) stack, all dielectric, reflector was deposited on one facet. Typical reflectivity of the stack was >90%. The fixture was rotated and a 1/2 wave passivation coating was deposited on the other facet.

Representative slivers were fabricated into devices to characterize the wafer. Evaluation diodes were manufactured using LDI's standard processes for commercial laser diodes.

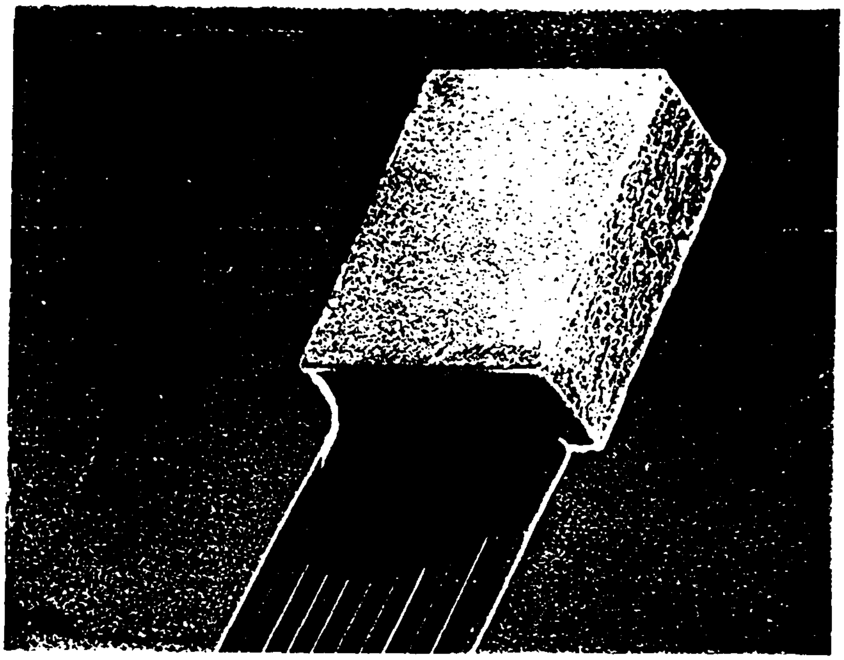
DEVICE ASSEMBLY:

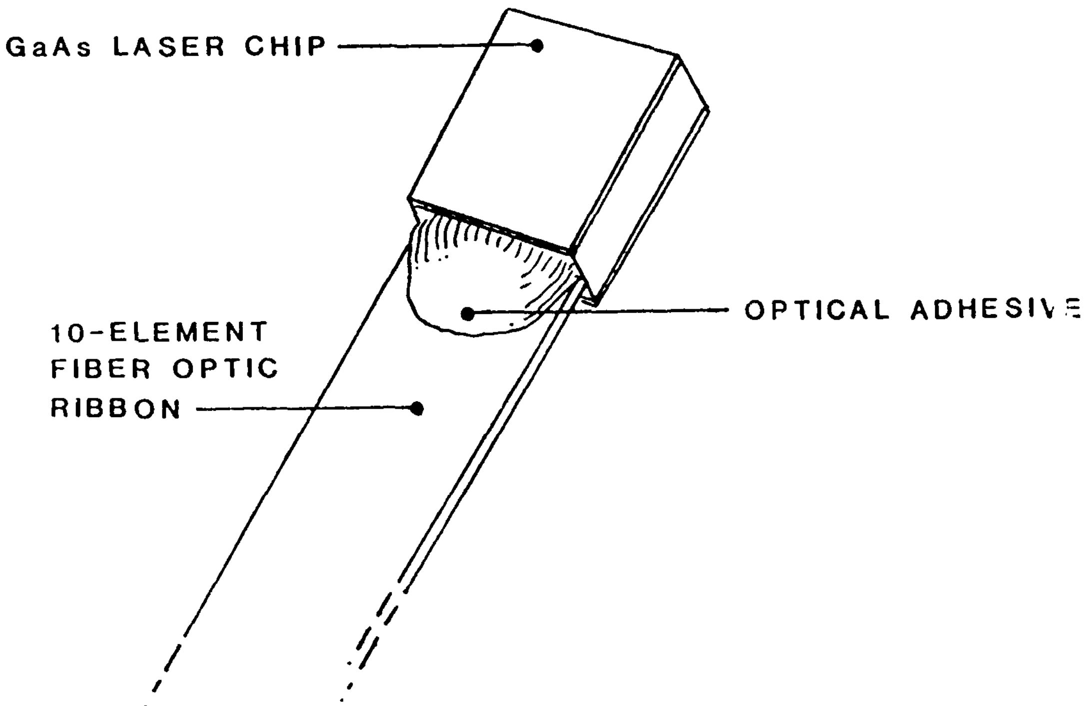
The high radiance pulsed laser arrays were formed by combining the outputs of ten separate GaAlAs laser diodes into a single high radiance source. Each laser chip had its output coupled to a custom fiber optic ribbon as shown in Figure III.1. During the design phase, both clad and unclad fiber ribbons were used to couple the output from the lasers. Both the clad and unclad fiber had cross sections of 0.001 inch by 0.010 inch. During assembly of the arrays it was noticed that the clad fiber was excessively brittle and broke easier then the unclad fiber. At this time the decision was made to use unclad fiber in the delivered units.

Each laser diode chip was mounted on its custom heat sink and while the laser was operated at 30 ns pulse width, 30 Amps peak power current and 1 KHz PRF, the ribbon fiber was aligned to the laser using a X, Y, Z micromanipulator stage. The alignment of the fiber was adjusted for maximum power coupled through the fiber.

When maximum output power is achieved, the fiber is epoxied to the heat sink. Epotec UV cured optical epoxy is used to maximize the coupling between the fiber and the laser.

During the assembly of the heat sinks to form the 10 diode in series array, a problem was found which we have not been able to explain. After alignment and attachment of the fiber, the





LASER DIODE CHIP- F/O
RIBBON INTERFACE (150x MAG.)

FIGURE III.1

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output power of the individual fiber is measured. After assembly of the array, before bundling of the fibers, the output of each fiber is again measured. In some arrays we have experienced losses of output power as high as twenty percent. When the array is disassembled and the individual subs are again checked, the output power returns to the original value. No reasonable explanation for this phenomenon has been found.

After the array is formed, the heat sink assembly is mounted in the aluminum frame. The ten ribbon fiber free ends are then bundled together, as in Figure III.2, to form an optical source 0.010 inch by 0.010 inch.

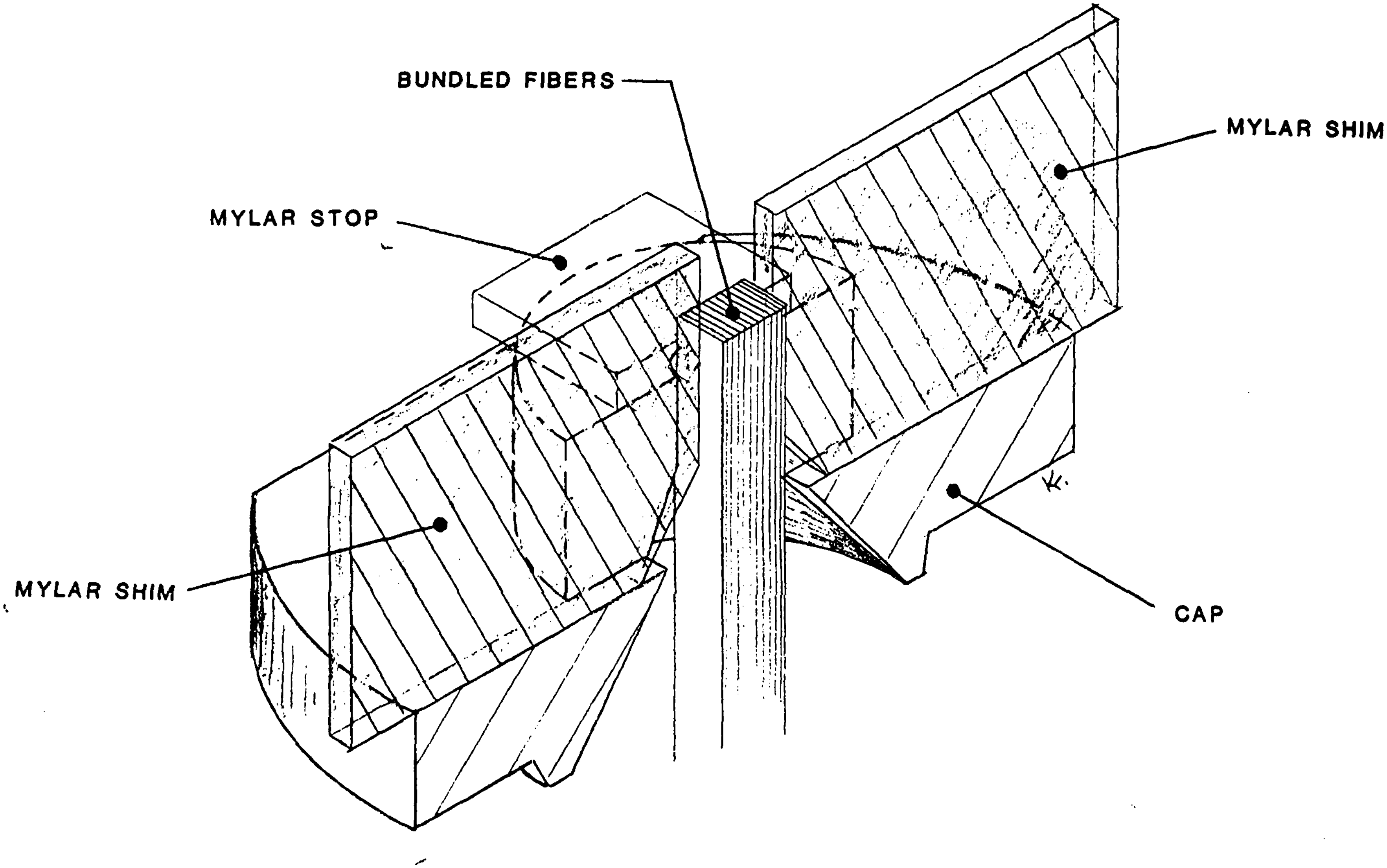
The optical epoxy that is used as cladding for the ribbon fibers is then injected into the fiber assembly. Extreme care is taken during this step to insure that no air gaps exist that could cause fiber breakage or a power loss.

The assembly is then potted using Stycast 2857. After curing the epoxy compound, the bottom of the array is lapped to provide a good surface for heat transfer, and the fiber optic output is polished. Source size is measured and each fiber is checked to insure it has an output.

TEST RESULTS:

All of the lasers fabricated had the output wavelength measured. The wavelengths were in the range of 835 nm to 840 nm.

Two of the arrays were burned-in at 30 Amps, 40 ns, 10 KHz. One array was burned-in for 72 hours at room temperature. This array had a power loss of 7.4 percent. The other array was



CAP CROSS SECTION SHOWING SHIM PLACEMENT

FIGURE III.2

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burned-in for 192 hours at room temperature. Its power loss was 2 percent.

The delivered lasers were tested for output power using the Power Technology pulser and an LDI LPD-2 high speed detector. The LPD-2 is a peak power detector whose calibration is NBS traceable through a calibrated ITT F-4000 -S1 Photo Diode. The peak output power of the delivered arrays was determined to be:

Serial #	P_o at I_p = 35 Amps DF = 0.2%
8	86 watts
12	102 watts
13	105 watts
19	77 watts
11	88 watts
21	100 watts

Some of the delivered arrays could not be driven to the maximum power output. This was due to the inability of the Power Technology pulser to deliver sufficient drive current to the laser.

The Power Technology ILM series pulser utilizes discrete transistors as current amplifiers. The rise time of the pulsers is generally slow with respect to the pulse width and the current monitor calibration was found to be off by as much as 20 percent. Also, the peak current varied considerably as a function of pulse width. These problems could be corrected by redesigning the pulser. This redesigned model should utilize power FET's in the output stage of the driver.

Another factor that limits more effective utilization of the fast rise times that diode lasers are capable of, is the size of the individual heat sink plates used. In the delivered fiber coupled arrays, the heat sink plates are 0.572 inch long, 0.383 inch wide, and .020 inch thick. Using heat sink plates half as wide as the present size, initial test results with a high speed FET driver, show that rise times under ten nanoseconds are possible, however, reducing the size of the plate reduces the thermal capacity of the array. If duty cycles of up to 0.05 percent, instead of 0.2 percent were the objective, rise times of less than ten nanoseconds can be achieved.

<u>CATASTROPHIC FAILURE:</u>

Five lasers from wafer lot LOC-A-405 were mounted on TO-18 headers for test. Threshold current, power, and line quality were measured.

Condition Unit#	PRF-10kHz Ith	Pulse Width 30 ns Pom at 25 Amps	Line Quality
1	8A	10.5 watts	good
2	7A	7.2 watts	many dark spots
3	7A	12.6 watts	one dark spot
4	7A	12.1 watts	good
5	7A	11.0 watts	good

The units were then tested at 45 ns pulse width, 10 kHz PRF at currents up to 35 Amps with the following output powers:

#1: 17.1 watts, #2: 10.8 watts, #3: 18.9 watts,

#4: 18.7 watts, #5: 18.0 watts. There was no indication of degradation or power rollover under these conditions.

The units were then tested at 60 ns pulse width, 10 kHz PRF at currents up to 35 Amps:

#1: Degraded after 30 seconds operation at 35 Amps.

#2: Degraded after 30 seconds operation at 34 Amps.

#3: Drove to 45 Amps at 23.1 watts.

#4: Degraded after 30 seconds operation at 34 Amps.

#5: Slowly degraded at 40 Amps operating current.

With this information, we can see that the units are degrading at 35 Amps peak current at 60 ns pulse width. Assuming good reliability is expected, the safe operating current for 80 ns pulse width is 25 to 30 Amps. Then applying similar criteria used to calculate overdrive and burn-off power in single heterostructure lasers

$$I\ \mathrm{drive}\ (t)^{1/2} = I\ \max\ (t\max) \qquad \text{Ref (1)}$$

From this we can derive:

$$I\ \mathrm{drive} = Im \left(\frac{80}{\text{Selected pulse width}}\right)^{1/2}$$

Where I drive = drive current at selected pulse width,

Im = safe operating current at 80 ns pulse width.

Several of the arrays were tested at duty cycles from 0.008 percent to 0.2 percent by varying the PRF from 2 kHz to 50 kHz while the laser was driven at 30 to 35 Amps at 40 ns pulse width. Table 1 shows how the output power changed. On average, the power drop from the lowest duty cycle to the highest was only 10 percent.

CONCLUSIONS AND RECOMMENDATIONS:

The GaAlAs LOC laser characteristics are such that when coupled to ribbon fiber and driven at narrow pulse widths and high pulse repetition frequencies, peak powers in excess of 10 watts per diode are attainable. Peak power of 100 watts at a duty cycle of 0.2 percent was obtained with selected lasers. The lack of availability of a current source capable of higher drive currents prevented achieving 100 watts in all the devices.

LDI would recommend that NVL fund development of a driver that will utilize power FET's in the output stage. Initial results from some internally funded developments show that it is possible to design a driver that will drive a fiber coupled array at pulse widths of 30 to 50 nanoseconds with rise and fall times of 20 ns or less at peak currents up to 60 Amps. Further effort in development of these drivers, will enhance the performance capabilities of the laser.

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RCA Laboratories