Characteristics of high power GaAlAs laser diodes
useful for space application

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Single quantum well laser diode arrays with emitting apertures of 200 um have operated up to 8 W cw. Monolithic multi-element arrays with emitting apertures of 1 cm are capable of cw operation up to 76 W cw.

Devices fabricated using MOCVD epitaxial growth techniques and highly efficient single quantum well active region structures have exhibited high cw power and high efficiency. Catastrophic power limits of 8 W cw have been demonstrated by a 20 emitter multistripe laser diode with emitting aperture of 200 um. Similar structures consisting of 10 emitters in a 100 um aperture have operated to 6 W cw. (Fig. 1)

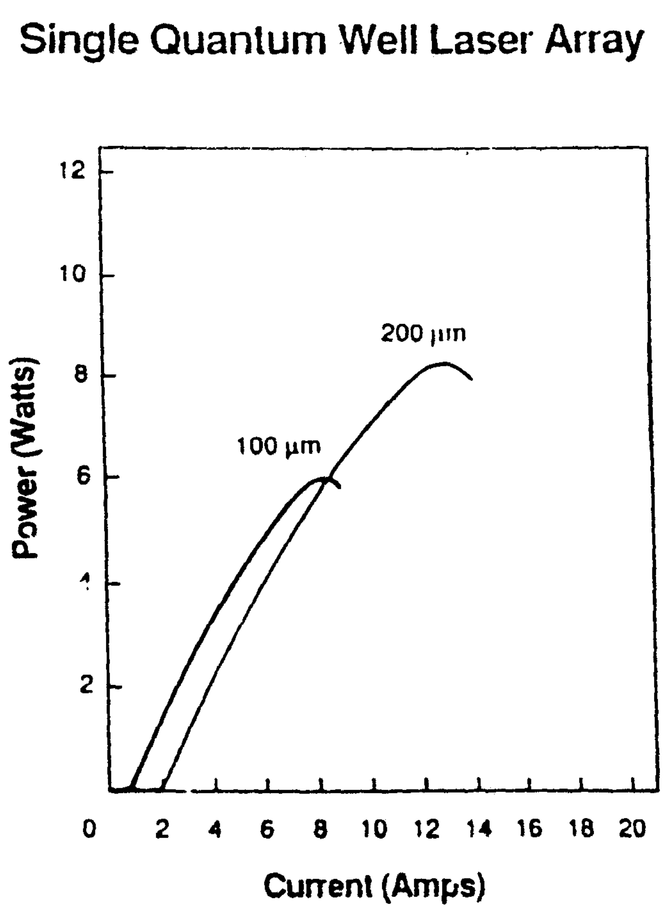


Fig. 1

The fabrication process for high power gain guided laser diodes is shown in (Fig. 2) MOCVD cladding, guiding layers on a GaAs wafer. the wafer is cut into sections one cm on a side, and proton implantation through a photoresist defines a gain guided stripe structure. Typical geometry is 10 or 20 individual emitting stripes on 10 µm centers.

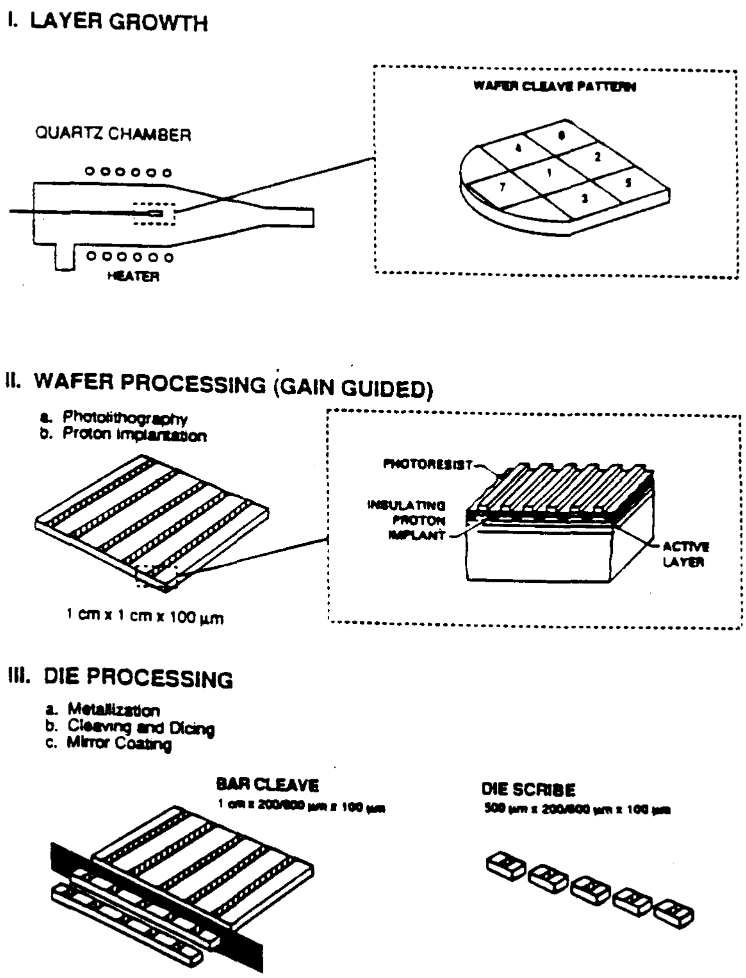


Fig. 2

Following further processing and metallization, the 1 cm square wafer section is cleaved into "bares" one cm long. The thickness of the bar is 100 um, and laser cavity length is typically 250 to 400 um. For commercial laser diode production, the 1 cm bars are sawed into individual die, each of which are bonded to separate heat sinks.

The relatively simple photolithographic stripe defining process permits the number of stripes to be changed easily. However, even with devices bonded with the "p" side (active layer side of the substrate) down against a high thermal conductivity heat sink, thermal spreading is the limiting factor for high average power devices. For this reason, a new class of lasers has been defined, those capable of operating with high peak power in a quasi-cw mode. Quasi-cw bars operate in relatively long pulses, but with duty factor of 1 % to 2 %, limiting average power dissipated. Due to the lower thermal load, this class of devices can be built with high emitter packing density, approaching 100 % Individual emitters are spaced on 10 um centers, allowing approximately 1000 emitters in a 1 cm bar (Fig. 3). These bars can be stacked up to 3 layers for a total peak power of 160 W. The energy per pulse is up to 32 mili joule as a commercial product.

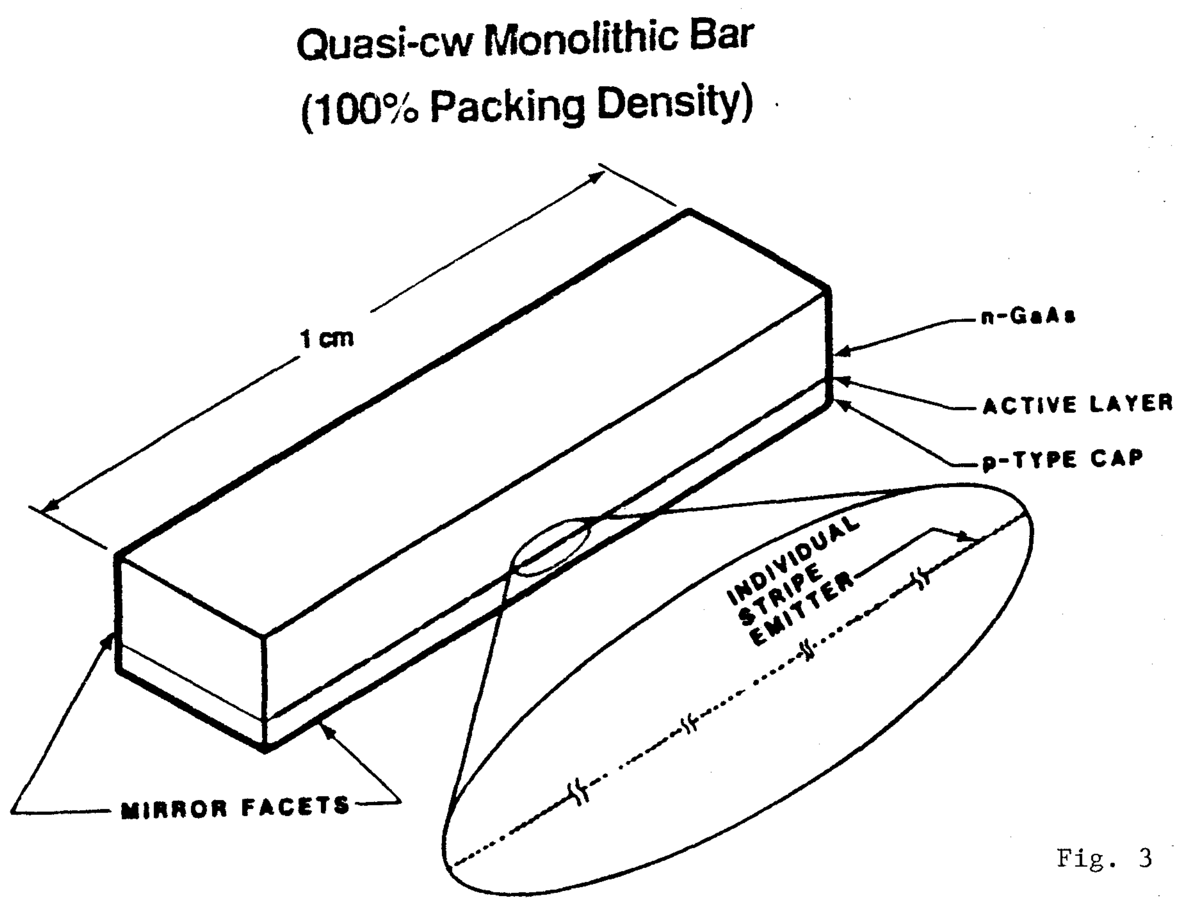


Fig. 3

High cw operation from 1 cm monolithic arrays can be achieved with satisfactory reliability only when heat sources are spread along the bar. Recently reported is a 1 cm aperture monolithic device with 2 mm total active aperture which achieved 38 W cw optical power from one facet. The efficiency of this device reached 28 %.
This bar had (Fig. 4) twenty 10 stripe lasers spaced on 500 um centers, each with an aperture of 100 um. Thus, 20 % of the bar was electrically pumped for laser emission. A high reflectivity coating was applied to the back facet, with a low reflectivity coating on the output facet. The bar is bonded P side down to a copper heat sink. (Fig. 5) is a plot of output power versus drive current from a new 1 cm bar with 30 % packing density. The power hereby was up to 76 W and efficiency grater then 45 %.

Linear array emitters can be utilized in several ways. Direct coupling of 1 cm arrays to solid state laser rods or slabs has been demonstrated. The spectral width of monolithic arrays is within the efficient absorption band of Nd doped YAG, YLF or glass host materials. Optical to optical efficiency greater than 30 % has been achieved.

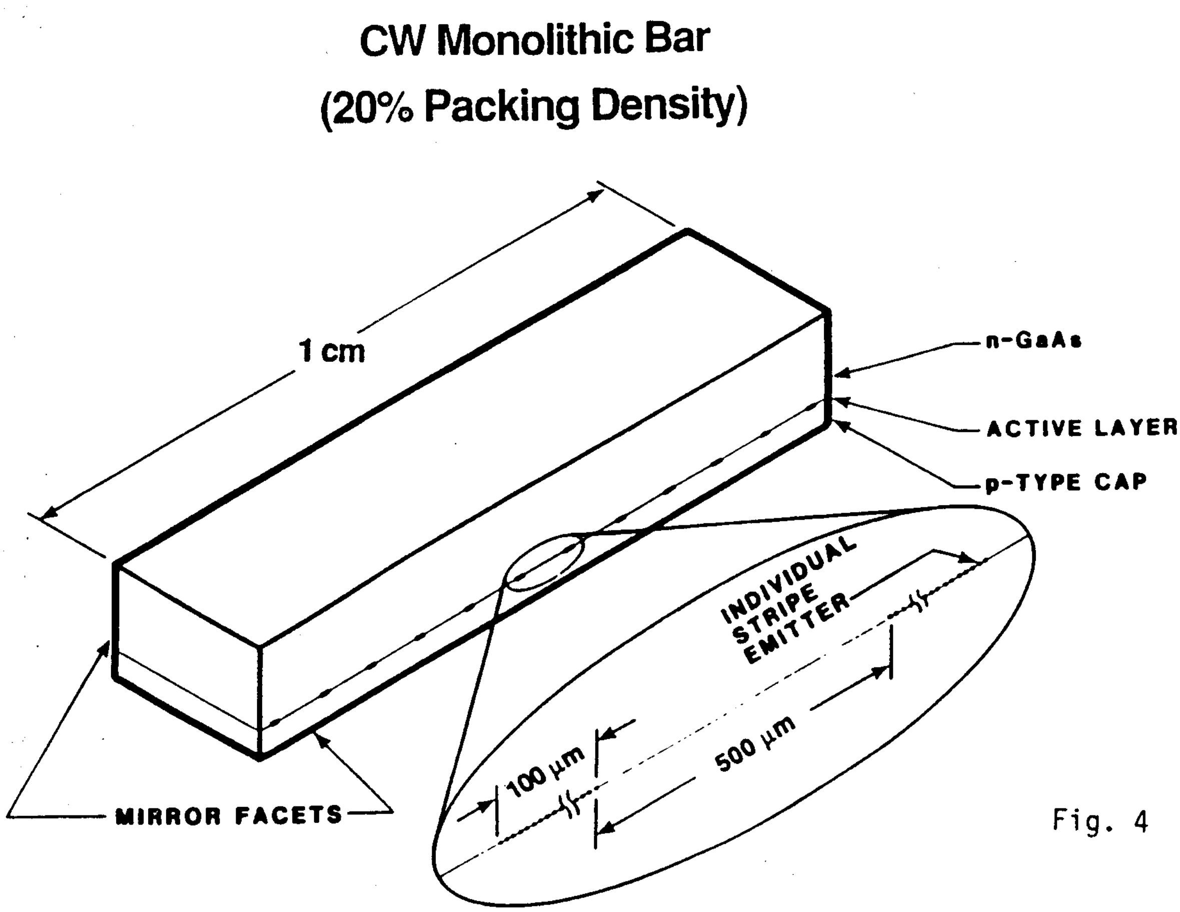
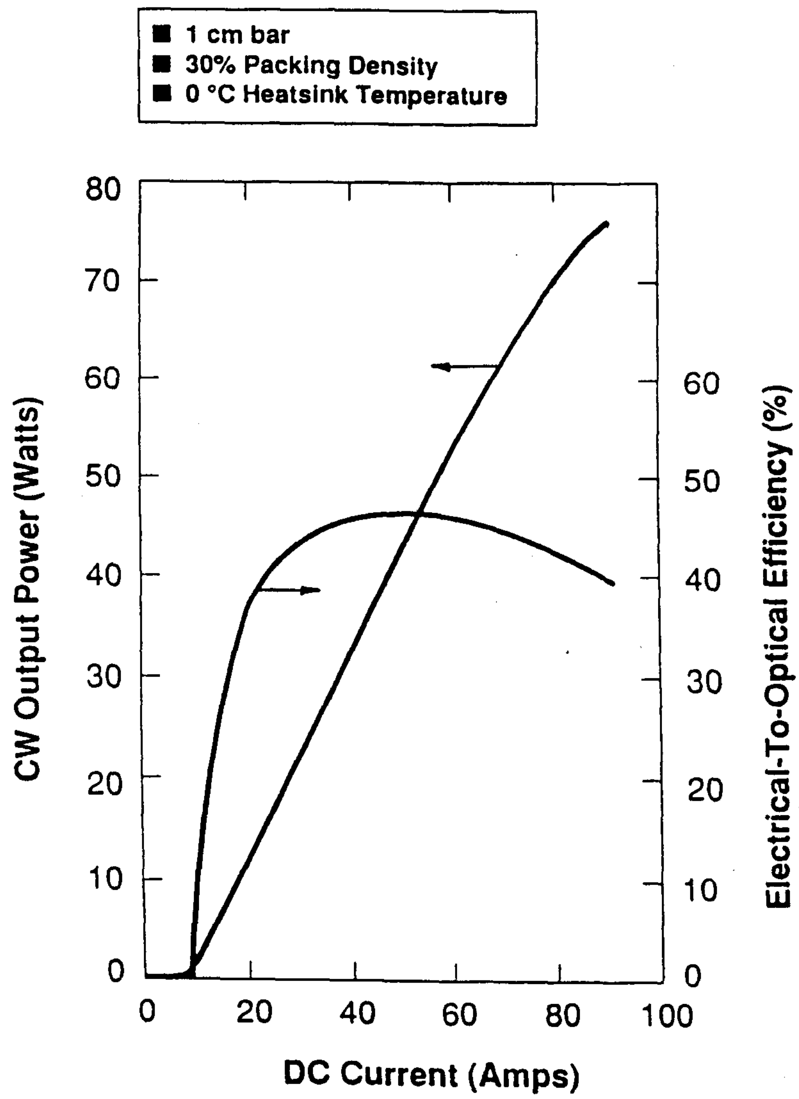


Fig. 4



1 cm bar
30% Packing Density
0 °C Heatsink Temperature
80
70
60
50
40
30
20
10
0
CW Output Power (Watts)
60
50
40
30
20
10
0
Electrical-To-Optical Efficiency (%)
0
20
40
60
80
100
DC Current (Amps)

Fig. 5

On the common design of axial YAG pumping (Fig. 6) there are limitations because of thermal effects beyond 300 mW at 1.064 nm. An alternative is tightly folded cavity design (Fig. 7), where the beam path is a zig-zag through the rod. By pumping with 11 W cw bar we achieved already 3.8 W IR diffraction limited beam (Fig. 8). This design and the variations are applied for patent (Fig. 9/10).

Linear to circular fiber bundles offer an efficient method of changing the aperture format of linear arrays (Fig. 11): A commercial bundle consisting of about 50 relatively large core diameter fibers was coupled to a quasi-cw 100 % packed linear array. The bundle output was formed into a circular cross section. Nearly 75 % of the energy emitted from the linear array was coupled out of the bundle (Fig. 12).

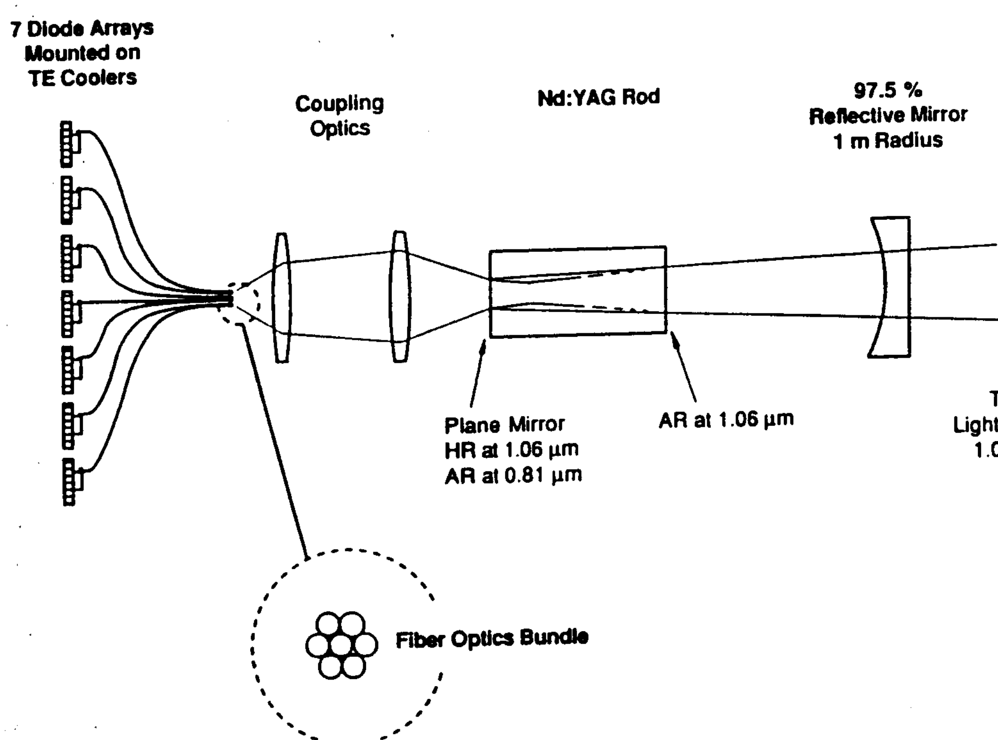
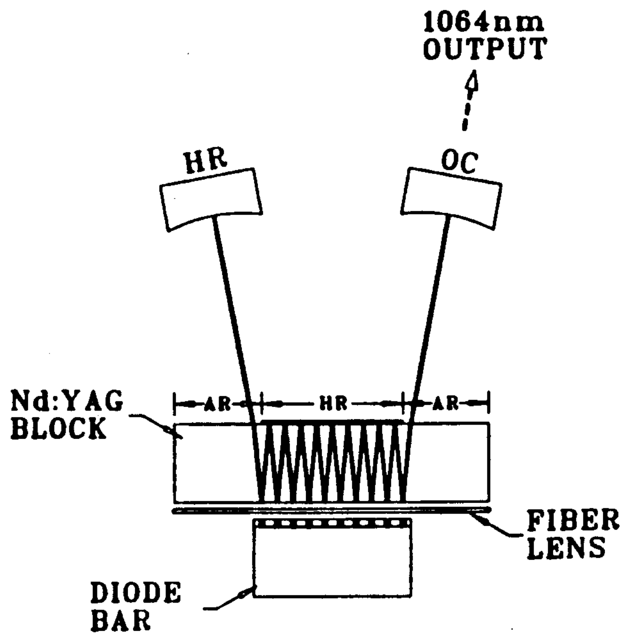
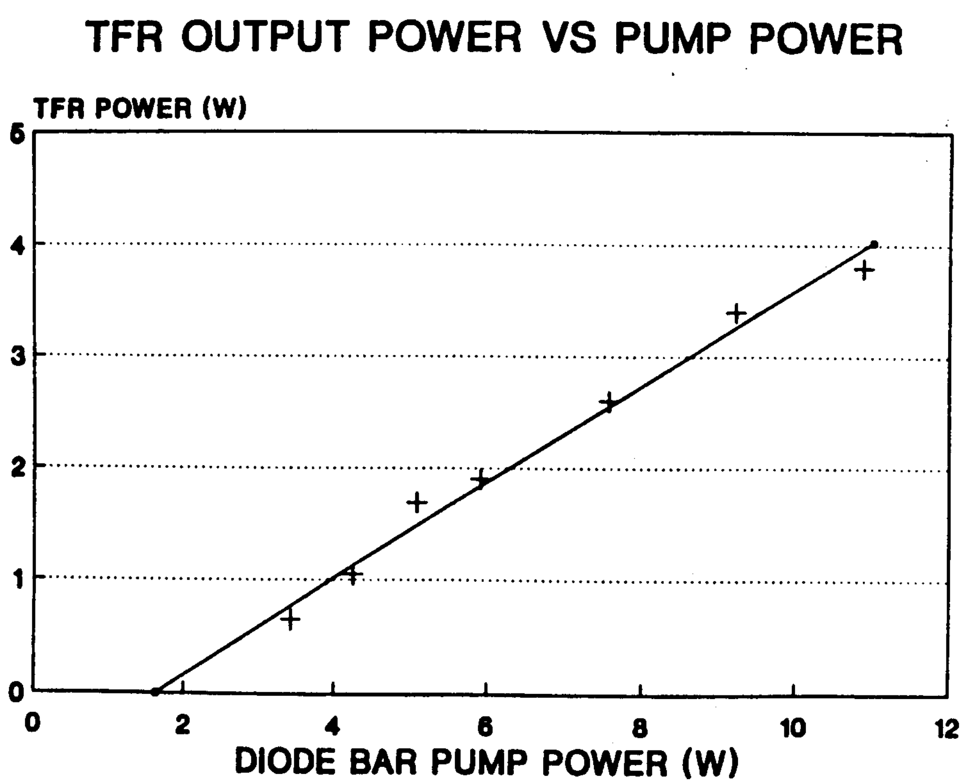


Fig. 6



1064nm
OUTPUT
HR
OC
Nd:YAG
BLOCK
AR
HR
AR
FIBER
LENS
DIODE
BAR

Fig. 7



TFR OUTPUT POWER VS PUMP POWER
TFR POWER (W)
5
4
3
2
1
0
0
2
4
6
8
10
12
DIODE BAR PUMP POWER (W)

Fig. 8

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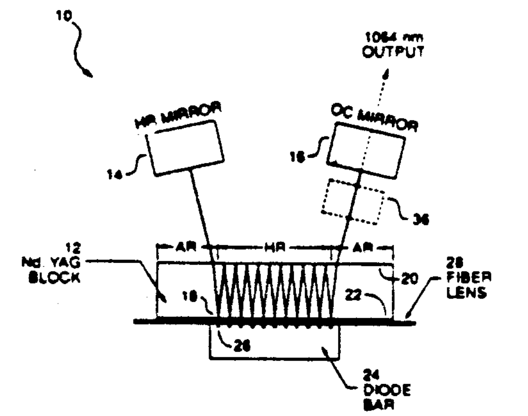

FIGURE 1

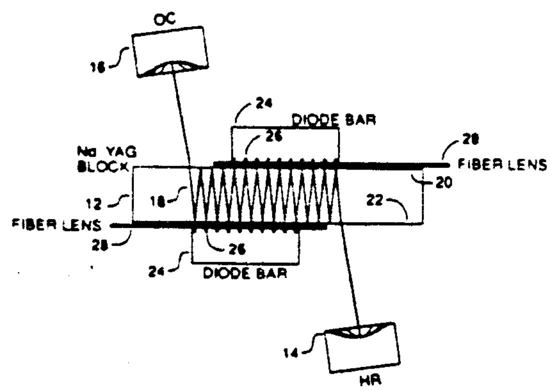

Fig. 9

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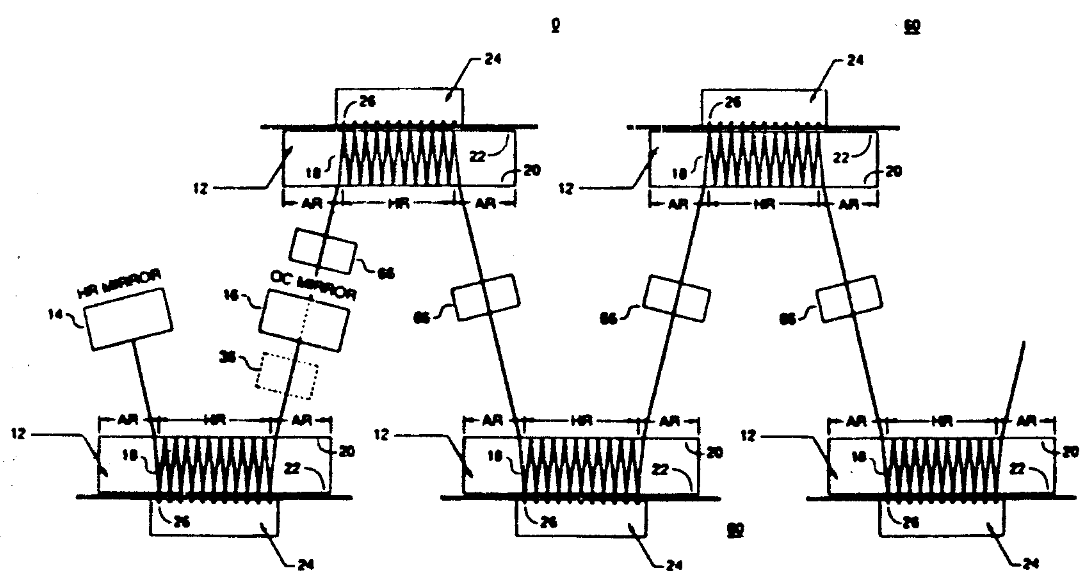


Fig. 10

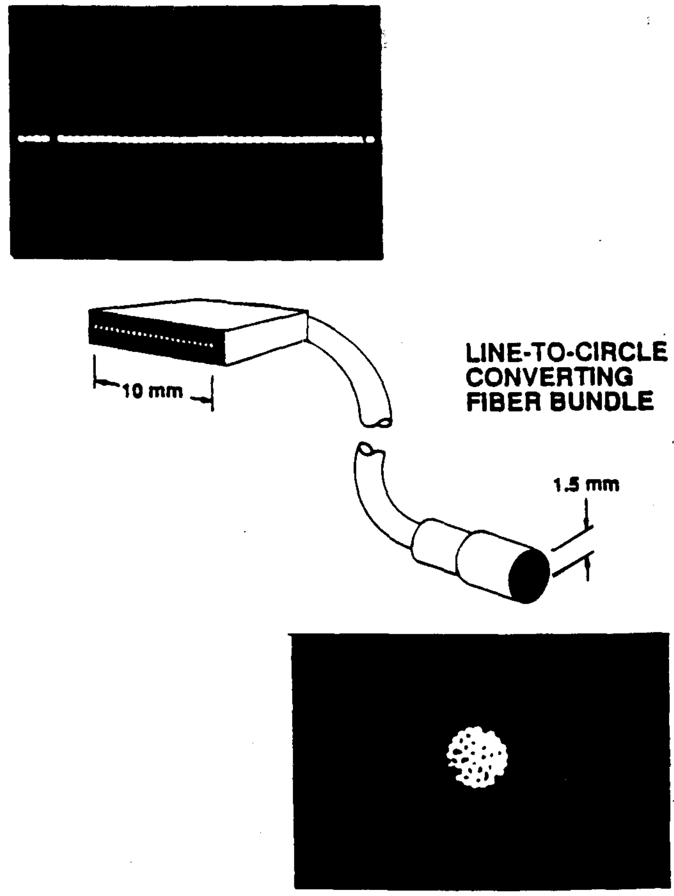

LINE-TO-CIRCLE
CONVERTING
FIBER BUNDLE
10 mm
1.5 mm

Fig. 11

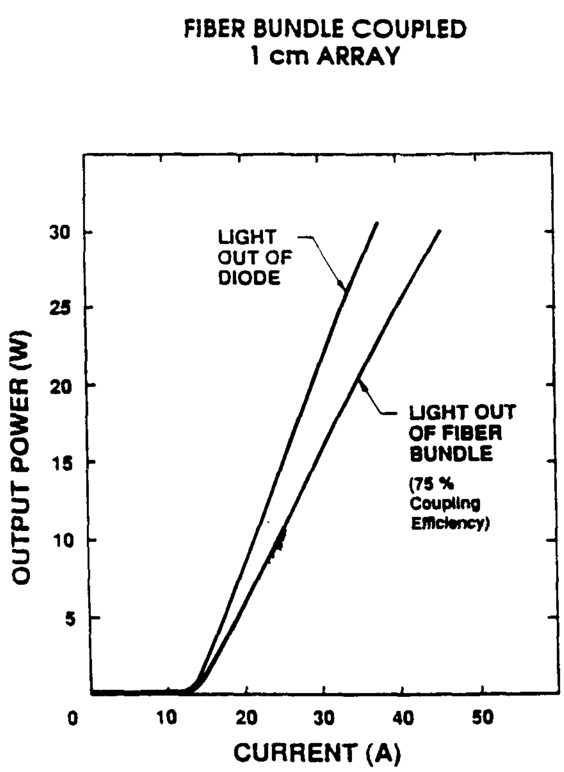

FIBER BUNDLE COUPLED
1 cm ARRAY
OUTPUT POWER (W)
CURRENT (A)
LIGHT
OUT OF
DIODE
LIGHT OUT
OF FIBER
BUNDLE
(75 %
Coupling
Efficiency)
0
10
20
30
40
50
5
10
15
20
25
30

Fig. 12

The system concept of a number of such linear to circular bundles is shown in Fig. 13 and Fig. 14. Flat linear fiber arrays are coupled to linear laser sources mounted conveniently on a multi-layer heat sink. Individual fiber arrays are bundled into a "super bundle" and the coupled optical energy is mixed into a highly uniform beam in a proprietary beam homogenizer. Such a system is capable of operation using either cw or quasi-cw array sources.

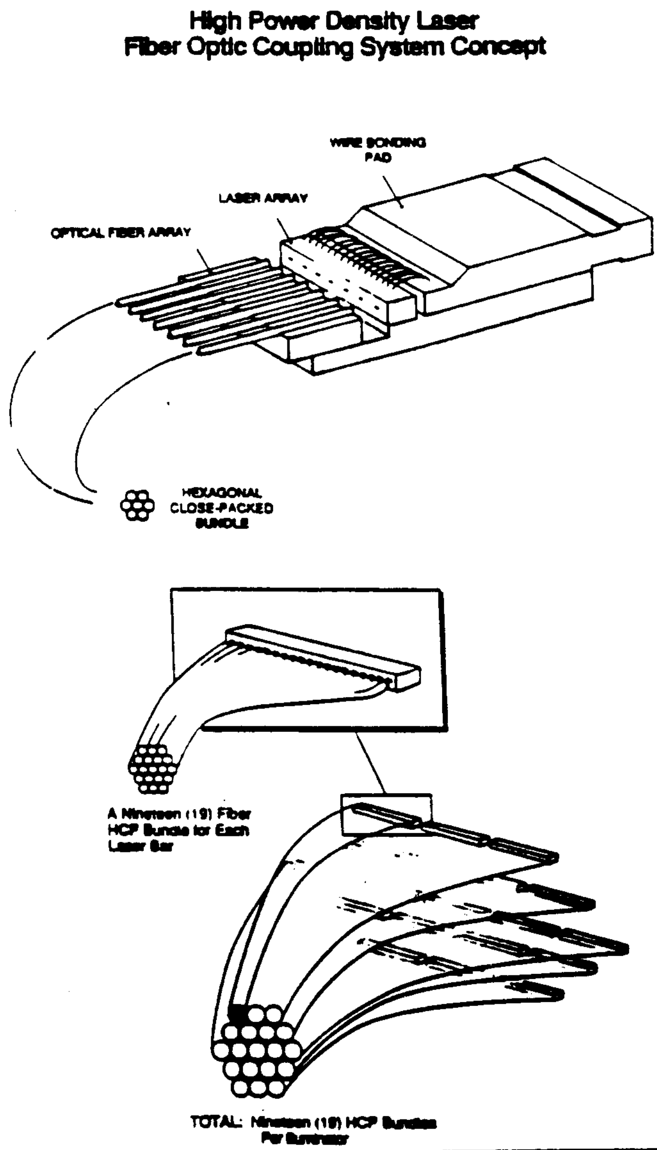


Fig. 13

Fiber Coupled Stacked Array

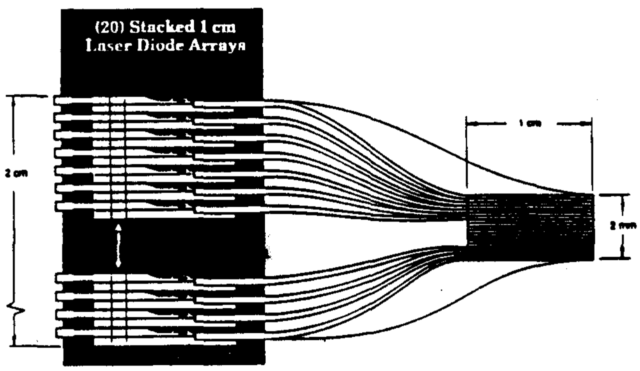


Fig. 14

In conclusion, the power available from moderate aperture linear arrays is increasing rapidly. Methods of efficiently using the optical energy directly from such sources has been achieved. Optical fiber bundles also offer efficient methods of convenient aperture change, or power delivery systems for many applications (Fig. 15, Fig. 16). As a result commercial products up to 1 W cw 10 W bar 160 W quasi cw are available.

- **SPACE**

SATELLITE COMMUNICATIONS
PYROTECHNICS INITIATION
YAG PUMP
INJECTION LOCKING

- **AEROSPACE**

PYROTECHNIC INITIATION
HYDRAULIC VALVE CONTROL
VELOCIMETER
LIDAR

- **MILITARY**

RANGING/PROXIMITY DETECTOR
NIGHT VISION ILLUMINATION
WEAPONS SIMULATION
HOMING/LANDING
TARGET DESIGNATION
LARGE SCREEN DISPLAY

- **INSTRUMENTS**

3-D IMAGING
FIBER SENSOR
FIBER POWER TRANSMISSION
OPHTHALMOLOGY
STREAK CAMERA TIMING

Fig. 15

- **INDUSTRIAL**

THYRISTOR TRIGGER
ROBOT VISION/RANGING
MEDICAL
PARTICLE DETECTION/SIZING
PHOTO TYPESETTING
YAG PUMP - SEMICONDUCTOR PROCESSING

- **COMMERCIAL**

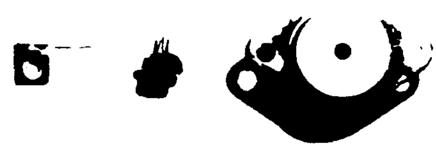
DISPLAY SYSTEMS
YAG PUMP
OPTICAL DATA STORAGE
PRINTING
OTDR
LAN, POINT-TO-POINT

Fig. 16

As a commercial product there is also an index quided cw single mode GaAlAs laser diode of 100 mW available (Fig. 17).

By direct doubling with potasium niobate we achieved 5 mW of diffraction limited output power at 427 nm. 10 mW is expected in near future.

100 mW CW SINGLE MODE GaAlAs LASER DIODES



SDL-5400 SERIES

- **Diffraction Limited Beam**
- **TEM_{00} Single Transverse, Single Longitudinal Mode**
- **50 or 100 mW CW Power**
- **1 x 3 μm Source Size**
- **Less Than 10 MHz Spectral Width***

High power in a diffraction limited, single mode beam is provided by the SDL-5400 Series laser diode. The index guided laser emits single frequency cw power up to 100 mW in the 820-860 nm wavelength range.

High resolution applications including optical data storage, spectral analysis, printing, point-to-point communication, and frequency doubling require diffraction limited sources. Faster writing, wider dynamic range and better signal-to-noise ratio may be achieved with the high power SDL-5410.

This advanced laser diode combines a quantum well structure and a real-refractive-index single lasing waveguide to provide high power, low astigmatism, narrow spectral width, high modal stability and a gaussian far field. The SDL-5400 Series is capable of cw operation or modulation rates greater than 2 GHz. Low astigmatism, low divergence and 1 x 3 μm emitter dimensions allow high energy concentration into diffraction limited spots.

Useful packaging options include heatsink, SOT or TO-3 packages, internal photodiode, thermoelectric cooler and wavelength selection.

**Special features include single-frequency operation with 25 db side mode suppression, less than 10 MHz spectral width and no longitudinal mode hops to greater than 50 mW output. These characteristics are ideal for heterodyne detection systems, Bragg cell applications and ranging. Testing and selection for these and other optical parameters is offered as an extra-cost option and is described further on page 7.*

Fig. 17

Also a space qualifiable diode is available (Fig. 18).

25 mW CW SPACE QUALIFIABLE GaAlAs LASER DIODE

SDL-2441-R2

- **Designed to meet MIL-883-L**[4]
- **25 mW CW Power**
- **Space Qualifiable**
- **High Efficiency MOCVD Quantum Well Design**
- **250,000 Hour MTTF**[4]

The SDL-2441-R2 is designed and manufactured to meet the demanding space qualifications of MIL-883-L.[4] High power and very high reliability are features of this unique laser diode.

A highly efficient MOCVD grown quantum well multistripe laser diode provides over 25 mW cw optical power. The hermetically sealed package includes a monitor photodiode and is capable of modulation rates over 1 GHz. The optical output is a 72 μm core, multimode, step index fiber which circularizes the beam and provides a symmetrical spatial output.

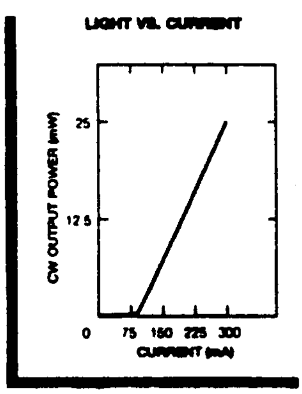
High reliability at high power is a unique attribute of the SDL-2441-R2. The laser test program documents over 25 years MTTF at 15 °C and full operating power. This laser is available with commercial specifications, or specific testing procedures may be defined by the customer. The small, rugged package is useful for military, aerospace, and high reliability commercial applications.

SPECIFICATIONS
(Typical values at 25 °C and 0.5 NA collection optics)

CW Output Power	25 mW
Differential Quantum Efficiency	0.30 mW/mA
Total Conversion Efficiency	25%
Fiber Core Diameter	72 μm
Beam Divergence θ	30° FWHM
Fiber Numerical Aperture	0.3
Threshold Current	90 mA
Operating Current	300 mA
Series Resistance	4 Ω

ABSOLUTE MAXIMUM RATINGS

CW Output Power	40 mW
Reverse Voltage	2.4 V
Case Operating Temperature	-20 to 50 °C
Storage Temperature Range	-56 to 80 °C
Lead Soldering Temperature	180 °C



NOTES

1 Other Specifications
   a Duty Factor of 100%
   b Spectral Width is 2 nm FWHM
   c Temperature coefficient of wavelength is approximately 0.27 to 0.3 nm/°C
   d Temperature coefficient of threshold current can be modeled as
   $I_{TH2} = I_{TH1} \exp[(T_2 - T_1)/T_0]$ where
   T_0 is a device constant of about 150
   e Temperature coefficient of operating current is approximately 0.5 to 0.7% /°C.
   f Recommended case temp. is 0 to 30 °C

2 Forward Voltage is typically:
   $V_f = 1.5\,V + I_{op} \times R_s$

3 Wavelength range of cw laser diodes is approximately 790 to 840 nm. Contact factory for wavelength availability and cost.

4 MIL 883-L is a modified test procedure developed for a particular customer. Similar to the standard MIL 883 procedure, it specifies a test program useful for precisely defining the operating and lifetime characteristics of GaAlAs laser diodes. Test procedures for specific applications should be discussed with Spectra Diode Labs.

Fig. 18