Since the laser mode locking was self-starting, short pulse generation was possible without active modulation or synchronous pumping, which require expensive and extremely stable radiofrequency electronics for driving acousto-optics. The wide tunability of this system, its use of solid-state, room-temperature gain medium, and its relative simplicity and low cost suggest that this technology will be an attractive alternative to short-pulse dye laser systems in this wavelength range.

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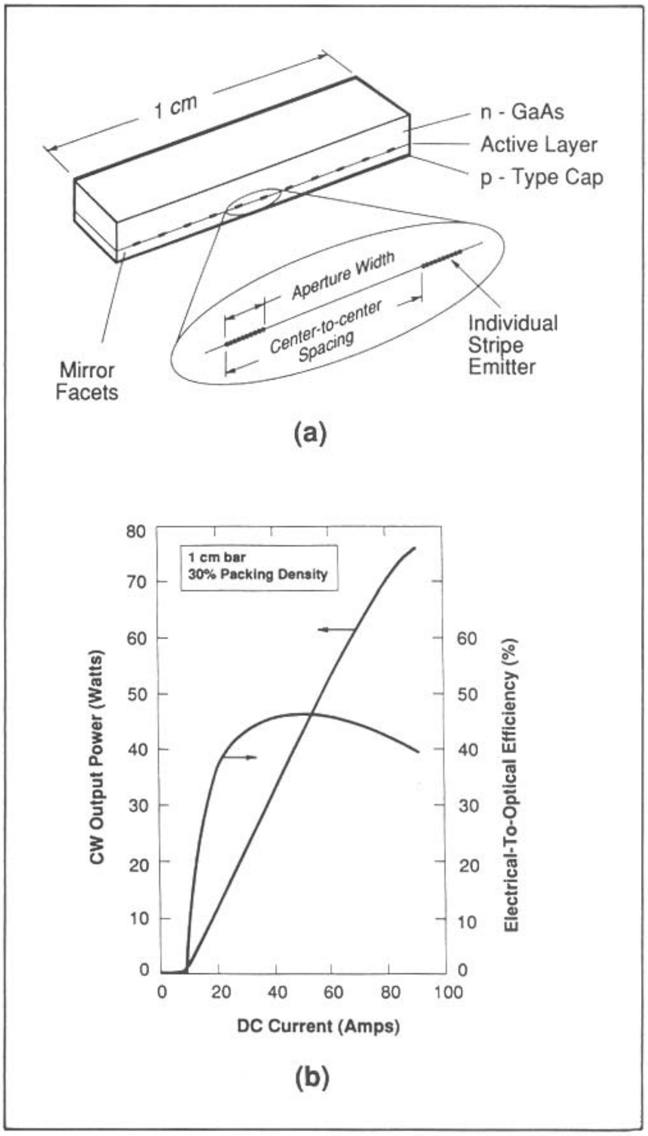
High power, long life continuous-wave monolithic laser diode arrays

M. Sakamoto, D.F. Welch, J.G. Endriz, D.R. Scifres, and W. Streifer, Spectra Diode Laboratories

Multistripe monolithic AlGaAs laser diode arrays show considerable promise as sources of high power, high efficiency narrow bandwidth optical energy. Examples of applications include: a) optical pumping of solid state laser media, b) infrared illumination, c) laser soldering, and d) eye surgery. Power levels of 38 W have been demonstrated at room temperature under continuous-wave (cw) conditions for twenty 10-stripe lasers spaced along a 1 cm bar (2 mm total aperture width).[1] We report cw operation up to 76 W and 55 W from 1 cm laser diode arrays with aperture widths of 3 mm and 2 mm, at heatsink temperatures of 0° C and 23° C, respectively. We also show that a projected lifetime in excess of 5,000 hours is obtained at 10 W at 20° C heatsink temperature.

Three types of device structures have been investigated: 20×10, 15×20, and 30×10 structures. The 20×10 structures has twenty 10-stripe lasers spaced on 500 μm centers, each occupying 100 μm of the facet length. In this case, 20% of the bar is electrically pumped for laser emission (20% packing density). The 15×20 and 30×10 structures have fifteen 20-stripe, and thirty 10-stripe lasers, respectively. In either case, 30% of the bar is used for emission (30% packing density). The laser structures were grown by metalorganic chemical vapor deposition (MOCVD) and employed single quantum-well separate confinement heterostructures (SQW-SCH).



(a) Schematic diagram of a monolithic laser diode array structure. (b) Output power vs. current for a high power cw laser with a thirty 10-stripe structure (30% packing density) at 0°C heatsink temperature.

Completed devices were tested under cw conditions at 0° C. A plot of output power versus current for one of the devices with a 30×10 structure is shown in the figure. The threshold current was 8 A and the slope efficiency was 1.0 W/A up to approximately 65 W of optical power. The output power reached 76 W at 91 A before catastrophic degradation of the device. To the best of our knowledge, this is the highest cw power level reported to date from any monolithic semiconductor lasers of any aperture width. The electrical-to-optical power conversion efficiency was 46% at an output power of 40 to 50 W and was 39% at 76 W.

A similar test was performed on one of the devices with a 20×10 structure at room temperature. The output power reached 55 W. The threshold current and the slope efficiency was 8.5 A and 0.83 W/A, respectively. The electrical-to-optical conversion efficiency was 39% at an output power of 30 W and 34% at 55 W.

To assess operational reliability, constant power life tests at 10 W cw were performed on two of the lasers with 30% packing density at 20° C heatsink temperature. These particular arrays had wavelengths of around 810 nm at 10 W cw. One laser array with the 15×20 structure has been operated for 1,500 hours and the other with the 30×10 structure, for 3,000 hours. These two lasers seem to follow a similar degradation curve. By defining the end of laser life as a 50% increase in the operating current, a projected lifetime of over 5,000 hours is obtained. Ten W cw laser diode arrays are now commercially available (SDL-3490S).

One application of laser diode arrays is for pumping solid state lasers. A TEM_{00} output power of 3.18 W and a slope efficiency of 44% from a Nd:YAG laser was demonstrated when pumped with a 10.9 W from one of our diode arrays with a 20% packing density (10×20 structure).[2]

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Low threshold electrically-pumped vertical-cavity surface-emitting micro-lasers

J.L. Jewell, A. Scherer, S.L. McCall, Y.H. Lee, S.J. Walker, J.P. Harbison, and L.T. Florez, AT&T Bell Laboratories

Vertical-cavity surface-emitting lasers[1,2] show promise for a variety of applications. Use of large coherently-coupled arrays could provide high power, cheap laser sources. Smaller arrays could accomplish high-speed communication between electronic chips, overcoming a bottleneck that presently limits the speed of computers. In the longer term, arrays of laser logic gates may be used for photonic switching in communication networks or for general purpose computing. For information processing applications, minimizing the threshold current is essential. The lowest threshold edge-emitting lasers[3] contain a single quantum well and require ~0.55 mA. Minimum thresholds will be attained by minimizing the volume of active material in the laser, which in turn requires high-reflectivity mirrors.

GaAs-AlAs mirrors grown by molecular beam epitaxy have achieved extremely high reflectivity (>99%), high enough to achieve optically-pumped lasing in a vertical cavity with an 80 Å single quantum well active layer[4]. Chemically-assisted ion beam etching can form waveguiding pillars in such heterostructures with micron dimensions, and optically-pumped lasers with 1.5 μm diameters were demonstrated.[5] Use of these technologies is appropriate for fabricating ultra-small, ultra-low threshold micro-lasers.

We have constructed more than one million electrically-pumped vertical-cavity surface-emitting semiconductor lasers with dimensions of a few μm (μ-lasers) on a single GaAs chip.[6] Cylindrical μ-lasers have diameters 1, 1.5, 2, 3, 4, and 5 μm with heights about 5.5 μm (see figure). Device density is around two million per square cm with a typical chip size about 7×8 mm. Square devices 5, 10, 25, 50, 100, and 200 μm across were also tested. Two wafers were tested containing active regions of three quantum wells (3QW), each 80 Å thick, and a 100 Å single quantum well (SQW), of $In_{0.2}Ga_{0.8}As$. Lasing wavelengths were typically 960–980 nm. All experiments were performed at room temperature. In most of the 3QW chips tested, the 5-μm in diameter devices have yields around 95–100%. Lasing was observed in 3QW μ-lasers as small as 1.5-μm in diameter. The active material volume was <0.05 μm³ compared to well over 1 μm³ for edge emitters and >10 μm³ for all previous surface emitters.

The 3-μm-diameter 3QW μ-lasers had a typical pulsed threshold about 1.3 mA and the measured single-facet differential quantum efficiency was about 16%, despite some absorption of the laser output in the doped substrate. For 4-μm SQW μ-lasers the thresholds were 1.1 mA with ~7% differential quantum efficiency. In all cases, the light vs. current shows sharp threshold, very low below-threshold output, and linear response above threshold. Room-temperature CW operation was achieved in SQW devices with thresholds as low as 1.5 mA. No heatsinking was applied to any of the devices.

The main heat flow was conduction through the bottom mirror into the substrate. These very low thresholds