High Power Frequency Stabilized Surface Emitting Arrays

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High power solid-state directed-energy lasers are conventionally pumped by micro-channel cooled Fabry-Perot pump bars which are stacked to form two-dimensional laser arrays. The large scale pump stacks required for weapon-class lasers are prohibitively expensive because each bar must be individually cleaved, coated, tested, and mounted on its own (and costly) cooler. Stacks of micro-coolers have other practical disadvantages, including frequent cooler failure due to cooler erosion or clogging, leakage due to o-ring failures between adjacent layers, and relatively high thermal impedance due to the edge-mounted configuration.

Monolithic two-dimensional arrays of surface-emitting pump diodes are conceptually much more attractive: complete two-dimensional arrays can be processed in parallel at wafer scale, and mounted on reliable macro-channel coolers with much lower fabrication cost, dramatically smaller part counts, and lower thermal impedance.

Several technologies exist for surface-emitting lasers and arrays, including VCSELs and grating surface emitters, but these have not provided practical devices due to issues such as high thermal/electrical impedance, extreme beam aspect ratios and stability issues. A more practical approach couples an in-plane laser to a monolithically-integrated dry-etched 45 degree turning mirror [1,2]; however, these mirrors tend to be optically rough, nonplanar, and inaccurately aligned. Dry-etching processes are also inherently damaging to the front facet of the semiconductor material and therefore can significantly reduce the reliability of these devices.

In this paper, we describe results from two-dimensional surface emitting arrays which utilize a completely dry-etch free 45 degree turning mirror fabrication process. The process makes use of a novel wet etching technique to create optically smooth mirrors with an accuracy of 0.1° or better.

Figure 1 shows a schematic diagram of a single vertical emitting laser element, which employs a front facet window geometry and a 45-degree total internal reflection (TIR) turning mirror. A distributed Bragg reflector (DBR) provides feedback from the back of the laser and the light is directed through the substrate after reflection from the TIR mirror. The DBR determines the oscillation frequency, and ensures that the entire array operates at the desired pump wavelength.

Figure 2 shows a light output power versus current (L-I) curve from a 60 element surface emitting array tested under continuous wave (cw) operation. The monolithic 2-D array consists of 3 rows with 20 elements each. The elements in the array were electrically biased in parallel and mounted on a single micro-channel cooler. About 120 W was produced at a 220 A drive where the maximum output power was limited by the power supply. The spectral width at 220 A was approximately 0.8 nm. This width is much narrower than a similar Fabry-Perot array due to the frequency selective feedback from the rear DBR mirror. In addition, the oscillation frequency has much smaller temperature dependence (~0.08 nm/ºC) than a Fabry-Perot.

Shown in Figure 3 are the cw L-I characteristics from a larger 2-D array consisting of 10 rows with 22 elements each. The array was mounted on a *single macro*-channel cooler for testing. The packaging for this array was designed such that each row of devices was electrically biased in series. A maximum output power of about 300 W was achieved at a drive current of 60 A. Figure 4 shows the emission spectrum at 50 A. The full width at half maximum is approximately 0.9 nm. The dominant limitation on the maximum power is due to thermal roll-over, therefore further optimization in the thermal design of the package is expected to increase the maximum output power of the arrays.

References

1. D.W. Nam et al., *IEEE Photon. Tech. Lett*., **5**, 281 (1993).
2. J.P. Donnelly et al., *IEEE Photon. Tech. Lett*., **5**, 747 (1993).

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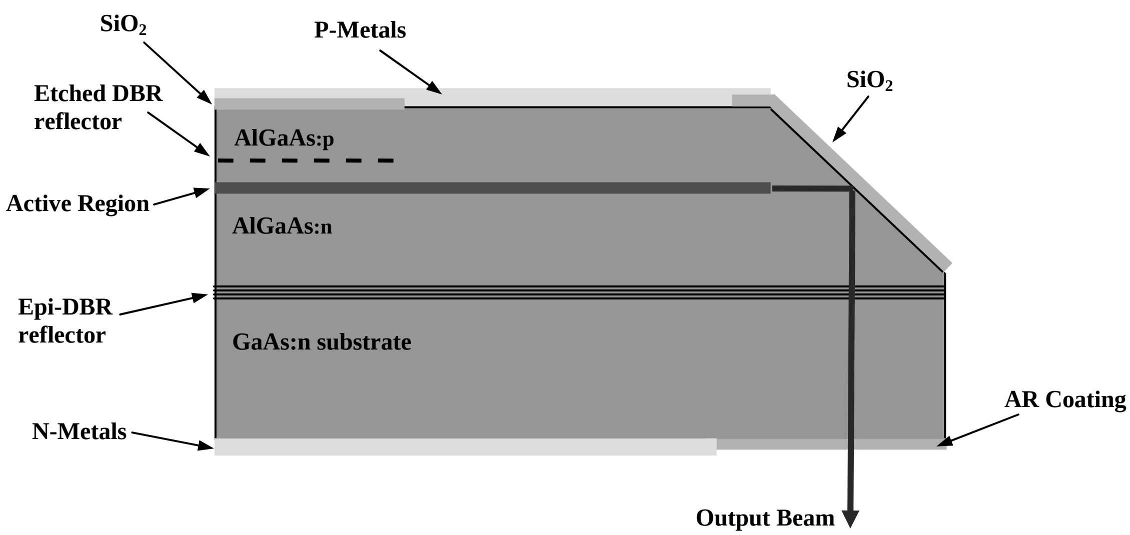

Figure1. Schematic diagram of vertical emitting laser chip.

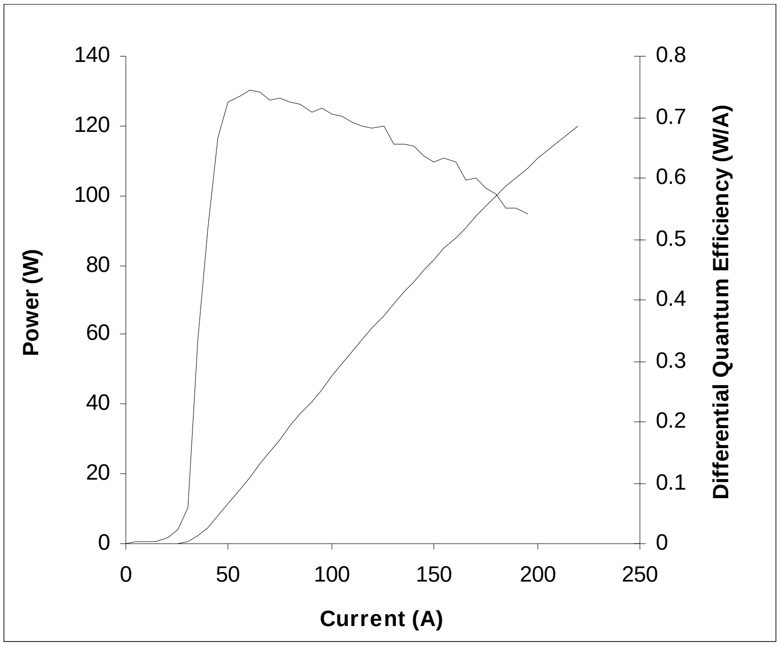

Figure 2. L-I characteristics from a 60 element 2-D surface emitting array.

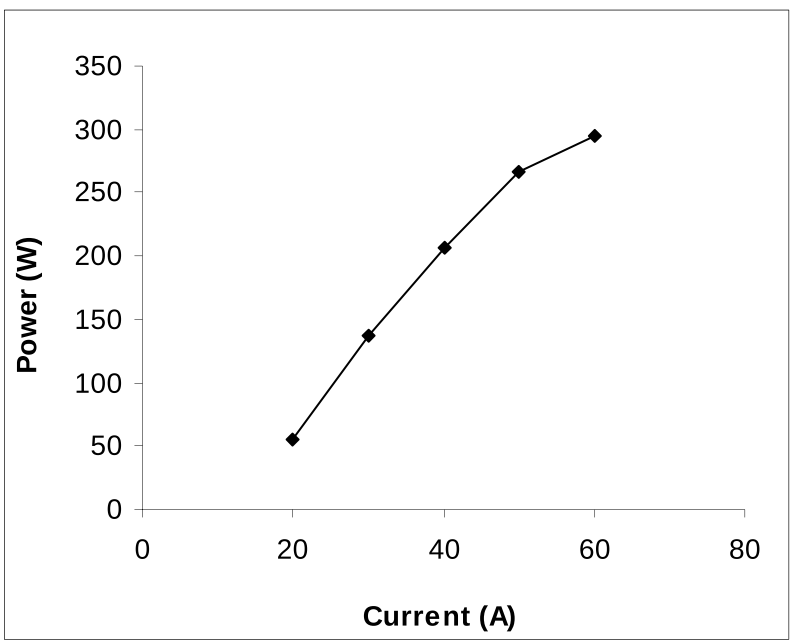

Figure 3. L-I characteristics from a 10x22 surface emitting array.

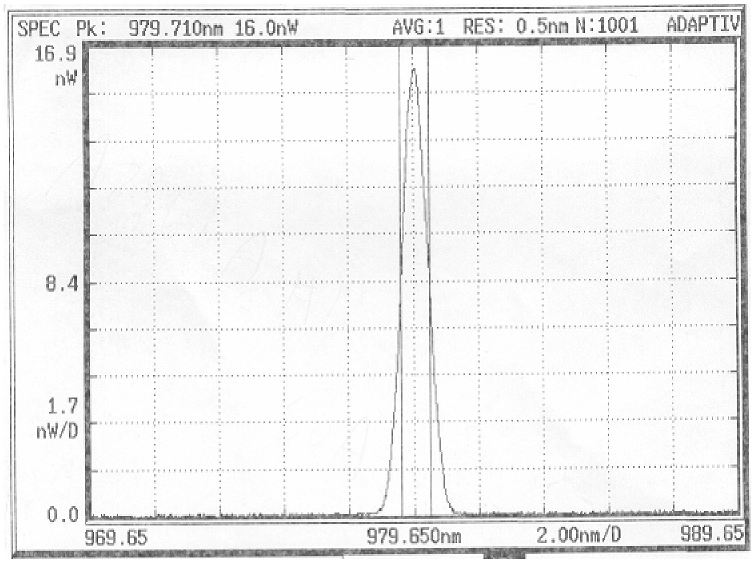

Figure 4. Optical spectrum from 10x22 array measured at 50 A. The full-width at half-maximum is approximately 0.9 nm.