Cascade Vertical Cavity Surface Emitting Laser Arrays

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Low round trip gain which is typical in vertical cavity surface emitting lasers can be overcome with multiple active regions electrically coupled by Esaki tunnel junctions [1,2]. This device structure is known as the bipolar cascade laser [3,4] and has produced near or above 100% differential quantum efficiency in edge emitting lasers [5] and VCSELs [2, 6]. High differential quantum efficiency is desirable for analog or digital optical fiber links with gain [7], low noise applications, and high output power. However, incorporation of highly doped yet thin layers to form a tunnel junction within the optical cavity can lead excess optical loss and the tunnel junction impedance typically increases with larger bandgap energy. Another simple approach to achieve cascade laser diodes is to lithographically series connect individual devices. VCSELs are particularly amenable to this since close packed 2-dimensional arrays have been demonstrated [8]. Moreover high volume/low cost VCSEL manufacture implies that low cost analog optical link with gain could be feasible. We report the first lithographic cascade VCSEL arrays which exhibit > 100% differential quantum efficiency.

Figure 1 is a top and side sketch of a 1x2 cascade VCSEL array. The selectively oxidized VCSELs emit at nominally 850 nm from 5 GaAs quantum wells and are grown on semi-insulating substrates by metal organic vapor phase epitaxy. Independent electrical contacts are made to the top (p-type) and bottom (n-type) distributed Bragg reflector mirrors of each VCSEL. The square VCSEL mesas are 20 μm on a side, have oxide apertures of approximately 5x5 μm, and are spaced 40 and 55 μm apart. The VCSELs are electrically isolated from each other by an etched trench. Using via holes through a planarization film, arrays of 1x2, 2x2, and 2x3 VCSELs are electrically interconnected in series as depicted in Figure 1.

Figure 2 is a plot of the light output into a broad area detector versus injection current into the cascade VCSEL arrays. As evident in this figure, the output power increases approximately linearly with the number of array elements, and arrays with 4 or more VCSELs exhibit > 100% differential quantum efficiency (see also Table 1). The nearly identical behavior for arrays with 40 and 55 μm pitch indicate that thermal cross talk does not influence the array performance, and arrays with even small pitch should be possible. As shown in Table 1 the series resistance of our cascade arrays are also found to scale linearly with the number of elements, albeit to relatively high values. These initial results indicate that lithographic cascade VCSEL arrays show promise for low cost optical links.

References

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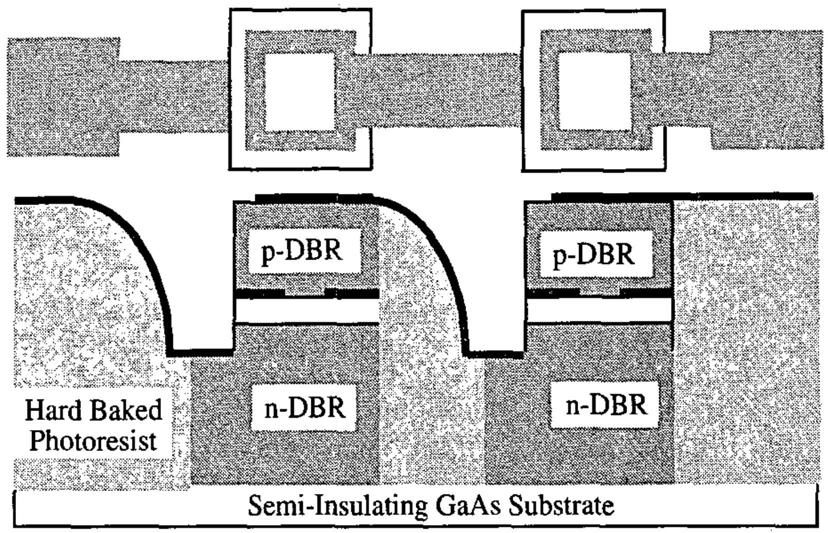

Fig. 1. Top and side view sketch of cascade VCSEL arrays.

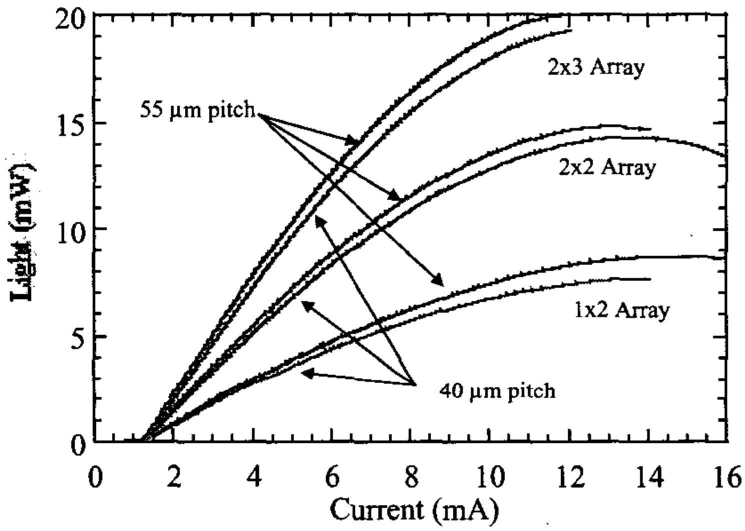

Fig. 2. Light versus current for cascade VCSEL arrays with elements separated by 40 or 55 μm.

Table 1 Summary of cascade VCSEL array performance

Configuration	Differential Quantum Efficiency		Series Resistance	
	Total (%)	Per laser (%)	Total (Ω)	Per laser (Ω)
1 x 2 (2 lasers)	65	32.5	310	155
2 x 2 (4 lasers)	120	30	540	135
2 x 3 (6 lasers)	180	30	800	133