Uniformity and Performance of Selectively Oxidized VCSEL Arrays

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Abstract

We report the uniformity characteristics of low threshold 1060 nm and high power 850 nm 8x8 individually addressable oxide-confined VCSEL arrays. Uniformity of lasing thresholds and operating characteristics are described, as well as thermal issues for 2-dimensional laser arrays.

Keywords: VCSEL, oxidation, lasers, arrays, 2-dimensional

Introduction

The apparent ease of fabrication of large 2-dimensional (2-D) arrays of vertical cavity surface emitting lasers (VCSELs) is a distinct advantage over their edge-emitting counter parts[1,2,3]. With recent advances in device performance afforded by the advent of oxidized AlGaAs current apertures[4,5], VCSEL arrays have come under scrutiny again. Applications such as free-space interconnects, displays, smart pixels and imaging will benefit from high performance 2-D VCSEL arrays. Emerging applications include the integration of VCSELs with microelectronic micromachine systems (MEMS) and other microelectronic circuitry for a wide variety of purposes. These applications require relatively low power laser arrays with high efficiencies and ultralow drive currents and voltages. All of these applications require arrays with uniform optical and electrical properties across the array as well as reliable individual devices. We report recent progress on the development of individually addressable 8 x 8 arrays of monolithic selectively oxidized VCSELs suitable for use in these applications. We also consider the thermal issues of 2-D arrays and demonstrate high power continuous wave (CW) operation appropriate for high power pump laser applications.

Device Fabrication

The 250 mm pitch 8 x 8 arrays shown in Fig. 1 were fabricated from VCSEL material grown in an EMCORE GS3200 metal organic vapor phase epitaxy rotating disc reactor. VCSEL wafers designed to emit at 1060 nm using strained InGaAs quantum wells[6] and at 850 nm using GaAs quantum wells are examined. After growth, the p-type (TiPtAu) and n-type (GeAuNiAu) contact metals are deposited. Square mesas are defined and reactive ion etched for wet thermal oxidation of the current confining aperture. After oxidation, the device is planarized with polyimide and the interconnect metal is deposited. Additional details of the device fabrication and structure are found in Ref. 5 and the oxidation system in Ref. 7. The wafer is diced and the unthinned array die are attached to the ceramic pin grid array (PGA) package using conducting adhesive.

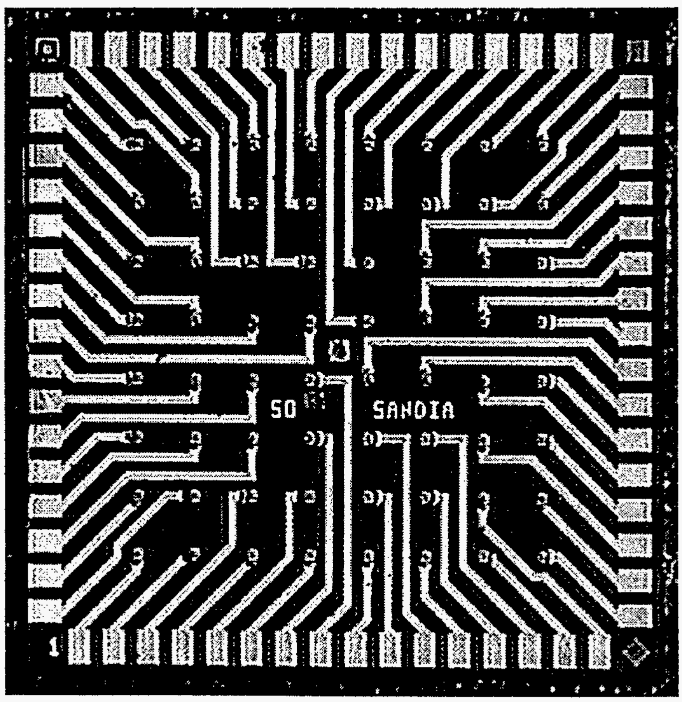

Figure 1. An individually addressable selectively oxidized VCSEL array.

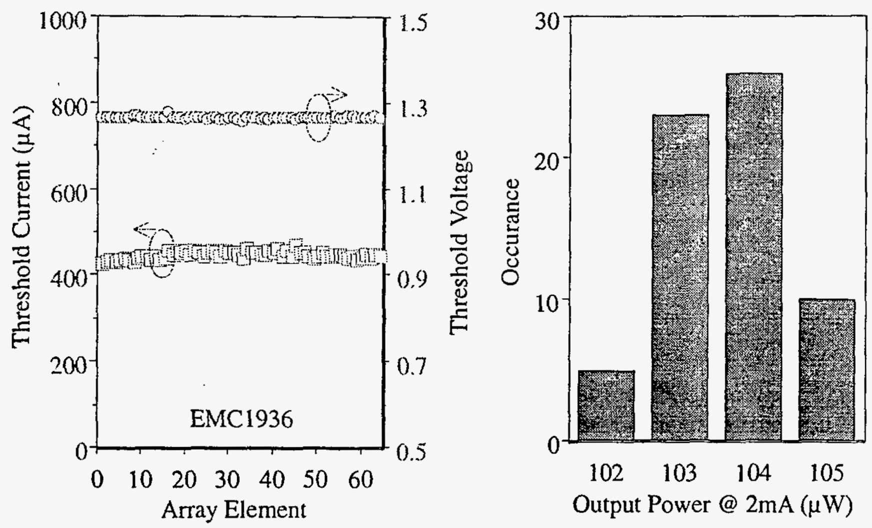

Figure 2. Plots of a) electrical and b) optical characteristics of the 1060 nm VCSEL array showing the uniformity of: threshold current = 447 ± 8 μA (±2%), threshold voltage = 1.265 ± 0.003 V (±0.2%), light output at 2 mA drive current = 103.5 ± 1 μW (±1%).

Optical and Electrical Characteristics of Arrays

Shown in Fig. 2 is the distribution of CW optical and electrical properties from each of the individual elements in an 1060 nm emitting 8 x 8 array. Each device in the array has square apertures of 5 μm on a side producing low threshold currents and voltages. The uniformity of the optical and electrical parameters are some of the best reported to date[2,3]. The uniformity of threshold currents and voltages shown in Fig. 2a and the output at a constant drive current shown in Fig. 2b should simplify the design of systems employing such devices. The uniformity of the threshold and operating characteristics of an 850 nm VCSEL array is shown in Fig. 3. The lasers from Fig. 3 have 15 x 15 μm apertures and are designed for high output power. Although the uniformity characteristics are similar to those of many discrete electronic components, the

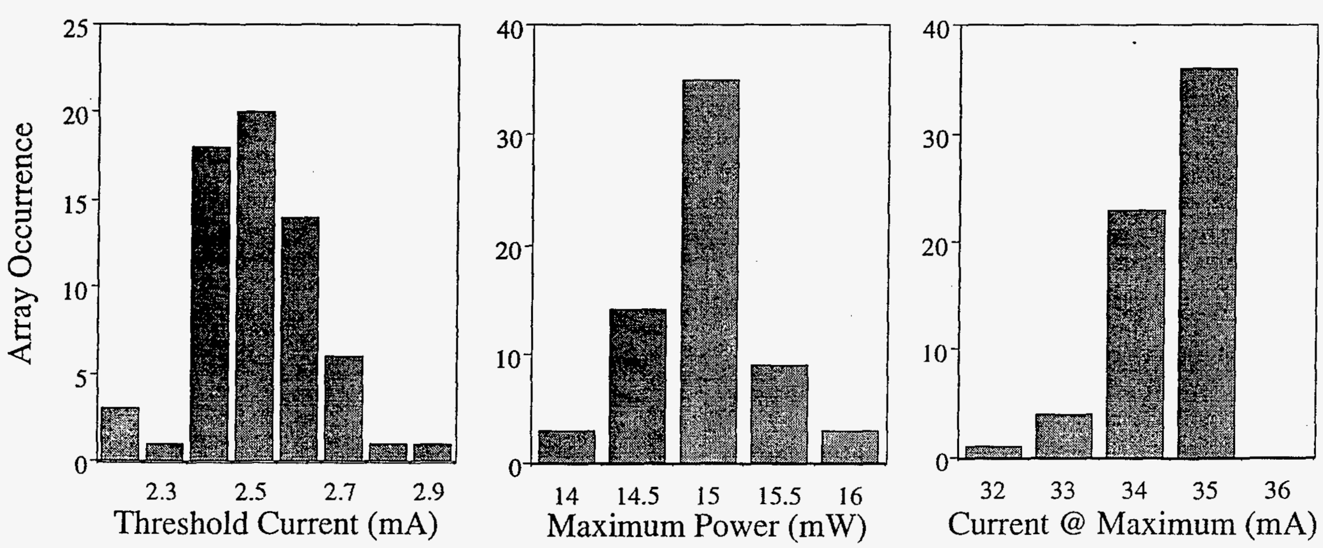

Figure 3. Uniformity of lasers across an 8 x 8 array of high power 850 nm VCSELs: a) threshold current = 2.5 ± 0.1 mA (±5%), b) peak light output = 15.2 ± 0.4 mW (±2.8%), c) drive current at peak output = 34.3 ± 0.6 mA (±1.8%).

DISCLAIMER

sources responsible for the threshold current variations are considered in the following.

Compositional variations in the epitaxial material could result in different oxidation rates across the array which would result in differing threshold currents. An indication of the uniformity of the epitaxial material was reported in Ref. 8 by determining the cavity resonance wavelength from reflectance measurements as a function of radial position on the wafer. This data showed only a ±0.2% variation across the entire 3 inch wafer. Considering that the array die are only 2 mm x 2 mm in size, the slight variation due to the growth contributes only minimally to the array nonuniformity. Thus, any nonuniformity in the optical and electrical data from the arrays must be due to the device processing.

The question of oxidation nonuniformity due to the oxidation furnace parameters has been previously addressed[7]. It was found that there was nearly a ± 2% variation across ¼ of a 3" wafer which is a combination of both the growth nonuniformity and the oxidation system gas flow nonuniformity. This variation is also very gradual across the entire surface and again should have little impact on the small array die.

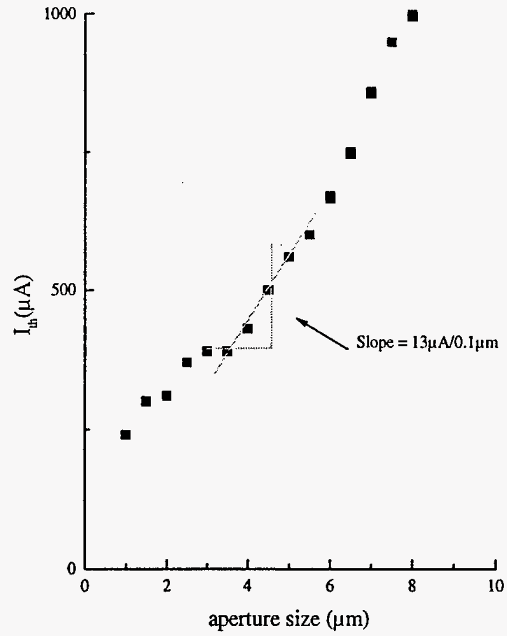

Figure 4. Threshold current as a function of oxidized current aperture size for the 1060 nm sample.

The size of the etched mesa and the oxidation extent define the oxide current aperture size. Variations in the VCSEL cross section area will translate into threshold current variations. In Fig. 4 we plot the threshold current as a function of mesa size for square VCSELs with sides that increase by 0.5 μm. At the ~450 μA threshold current corresponding to the 1060 nm lasers in the array depicted in Fig. 2, a variation in mesa size of only ± 0.1 μm corresponds to a threshold current variation of ± 13 μA. Note that this is on the order of the observed variations in the threshold current in Fig 2. Thus, the resolution of the optical lithography used to define the VCSEL mesas likely accounts for the observed threshold current variations across the array.

Thermal Issues of Arrays

Thermal cross talk between neighboring VCSELs was also investigated. Figure 5 shows the effects of operating the nearest neighbors at CW peak power on the laser characteristics of a single device in the uncooled 1060 nm array. There is no change in the threshold current or voltage and the peak power is only decreased by <10%. The thermal cross talk is more troublesome for higher output devices and as the number of operating devices is increased the overall temperature of the array increases and the efficiency of the devices begins to drop.

Applications that require relatively high CW optical power can also benefit from high efficiency VCSEL arrays. The output power of a single VCSEL scales linearly with aperture size while the threshold current scales quadratically with aperture size. Thus, using multiple high efficiency devices may be better than using a single large VCSEL for high power applications. Fig. 6 shows the CW

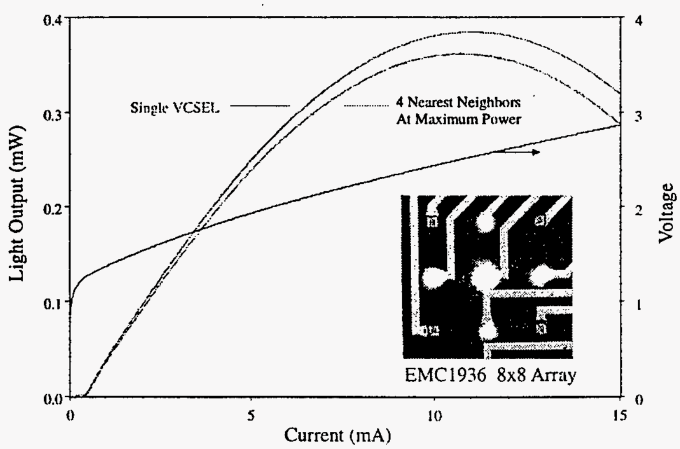

Figure 5. Only a 6% decrease in peak light output with the 4 nearest neighbors operating CW at their peak outputs and no effect on the threshold voltage or current.

output for the 850 nm array with all of the devices connected in parallel and the PGA package being actively cooled. The peak output power from the array is nearly 600 mW but it is still limited by sample heating since the average output power per pixel is only ~10 mW as compared to ~16 mW for each individual device.

Conclusions

We have reported the performance of 2-dimensional arrays of monolithic selectively oxidized VCSELs. The 1060 nm arrays exhibit:

- threshold currents of 447 ± 8 μA (±2%)
- threshold voltages of 1.265 ± 0.003 V (±0.2%)
- outputs of 103.5 ± 1 μW (±1%) at 2 mA operating current.

These uniformities should be appealing for most applications. We have found that the present tolerances in the definition of the VCSEL mesa appear to dominate the uniformity of the array's optical and electrical parameters. Thermal issues also influence VCSEL array performance. A major obstacle is thermal cross talk which can be addressed by enhanced sample cooling. Through active cooling of the package, we have demonstrated 600 mW of CW output power and are working toward output powers of >1W with improved VCSEL array packaging.

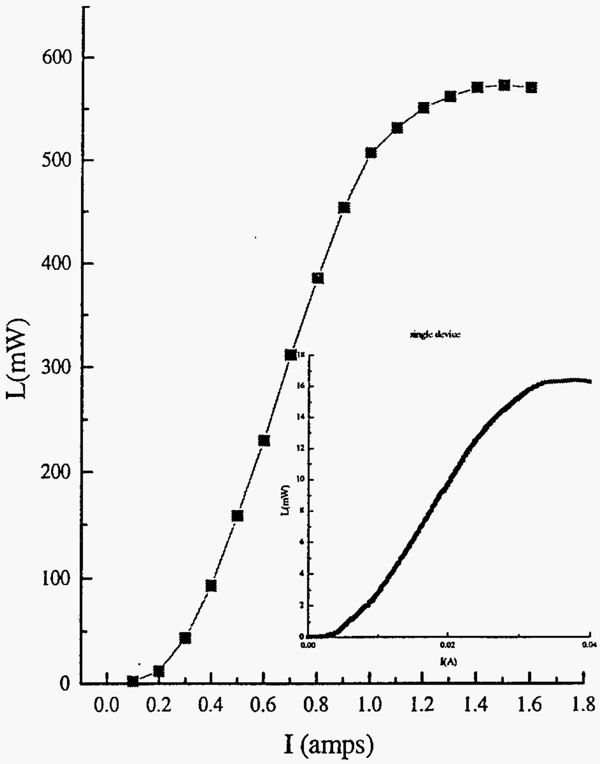

Figure 6. The light output from an 8 x 8 array with all devices connected in parallel reaches almost 600 mW corresponding to ~10 mW per device. The inset is data for a single device with ~16 mW peak power.

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