Low Thermal Resistance, Low Current Density, High-Speed 980 and 850nm VCSELs

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Abstract— **Copper plated, vertical cavity surface emitting lasers with thermal resistance up to 50% less than previously published values exhibit increased power, modulation current efficiency factor (MCEF), and maximum modulation bandwidth including 18GHz at 8kA/cm^2.**

I. INTRODUCTION

Higher data rate, directly modulated vertical cavity surface emitting lasers (VCSELs) are of interest for many communications applications from short distance LANs to chip-to-chip optical interconnects. In addition to parasitic capacitance and other circuit effects, junction heating is another extrinsic effect that can limit VCSEL bandwidths. This paper presents a study of copper plated heatsinks that reduce by half the best reported thermal resistances in these devices with resulting improvements in modulation bandwidth. Using the heatsinks, high bandwidth VCSELs are realized at low current densities.

II. FABRICATION

Low current density, Cu plated, top-emitting, 980 [1] and 850 nm VCSELs were fabricated from AlGaAs structures with oxide aperture diameters from 7 to 18 μm. A 100 nm of silicon nitride was used to electrically insulate the mesas sidewalls from the electroplated heatsinks, and 5 μm of cured polyimide was used for planarization and pad capacitance reduction. Annular plated heatsinks extended beyond the mesa to overlap 0, 2, or 4 μm onto the surrounding bottom mirror. Heatsinks with zero overlap did not cover the mesa sidewalls as shown for a completed device in Fig. 1(a), while ones with non-zero overlap did as shown in Fig. 1(b). The inset shows a top view of the device structure including coplanar waveguide probe pads. Fig. 2. shows a cross-section along AA' of Fig. 1 (b). Lasers with the same aperture but varying heatsink overlaps were fabricated in adjacent positions (separated by 250μm) on each sample.

III. MEASUREMENTS AND DISCUSSION

A. 980nm VCSELs

Fig. 3 compares the CW *L-I-V* characteristics of two 980nm VCSELs with heatsink overlaps of 0 and 4 μm, where both had identical mesa and oxide aperture diameters of 26 and 9 μm, respectively. The *I-V* characteristics of the two devices are essentially identical, indicating a minimal thermal impact on the 72Ω series resistance. We believe the 131% [1] increase in the maximum power output is the highest ever reported as a result of improved heatsinking.

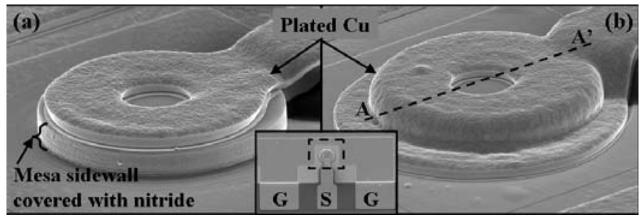

Fig. 1. SEM image of a 26-μm mesa diameter electroplated with ~2μm thick copper with (a) 0 μm and (b) 4 μm overlap.

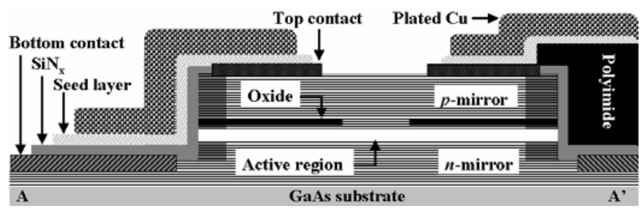

Fig. 2. A cross-section along AA' of Fig. 1 (b).

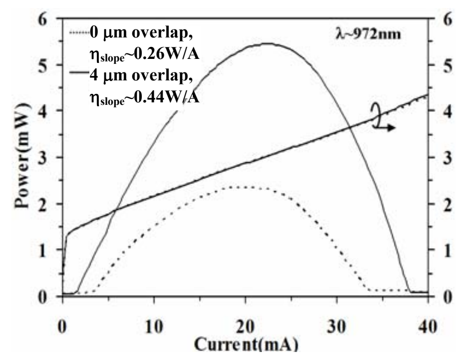

Fig.3. CW *L-I* and voltage characteristics for a 26-μm mesa diameter VCSEL with a 9-μm of oxide-aperture diameter.

The observed dependence of the thermal resistance (R_{th}) on device size with and without sidewall heatsinking further illuminates the role of lateral heat flow in VCSELs. Fig. 4 shows R_{th} as a function of the active diameter. Extension of the heatsink over the mesa sidewall reduces R_{th} by approximately 20% for a range of device sizes. The figure also shows other reported values for VCSELs fabricated with various techniques. For active diameters greater than 7 μm, the Cu plated heatsinks with 2 μm overlap gave a 50% reduction in R_{th} compared to the lowest previously published results. Fitting the data with $R_{th}=1/(2\xi d)$ where d is the active region diameter, the effective thermal conductivities, ξ, for 0 and 2μm of Cu-plated overlap were 0.41 and 0.53 W/cm.K respectively.

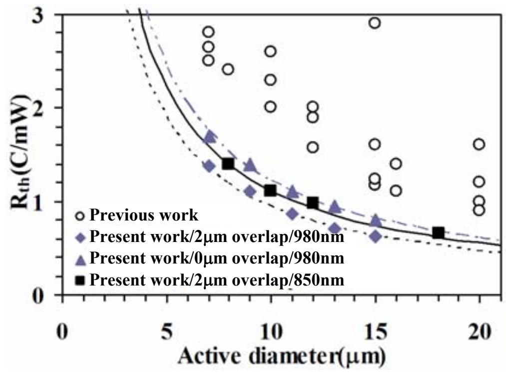

Fig. 4. VCSEL's thermal resistance as a function of the active region diameter.

The difference indicates sidewall heatsinks increase lateral heat flow since the thermal resistance of the VCSEL mirror stacks is anisotropic. Thus with sufficient heatsink overlap on the substrate and sidewall heatsinking, more heat flows laterally though the mirrors to the Cu-plated sidewalls and from there into the substrate via the heatsink overlap rather than going through the bottom mirror to the substrate.

The increased heatsink overlap also significantly improves the VCSELs' bandwidth. As shown in Fig. 5, 9-μm lasers with 4μm heatsink overlaps exhibit 9.8-GHz maximum 3-dB bandwidths when biased at I_b=6.7 mA. The 4μm overlap increased the 3-dB bandwidths by 40% in comparison to zero overlap heatsinks. The major mechanism behind the increased MCEF for the 980 nm devices is the higher slope efficiency with lower R_{th}.

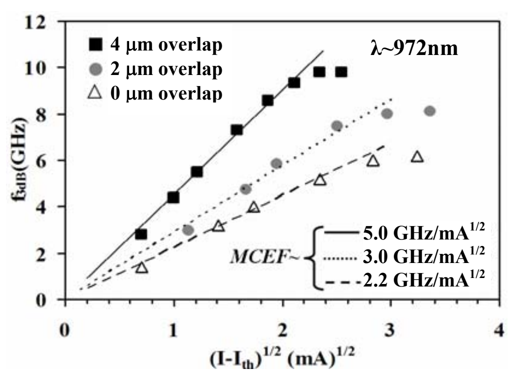

Fig.5. VCSEL 3-dB modulation frequency as a function of the square root of the current above threshold.

B. 850nm VCSELs

Due to the limited bandwidth of 980 nm VCSELs, similar experiments were performed on higher speed 850 nm wafers. Fig. 4 shows R_{th} of the higher Al content 850 nm lasers were only slightly higher than the 980 nm ones and had an effective thermal conductivity of ξ =0.45 W/cm.K. Fig. 6, shows the VCSEL 3-dB modulation frequency as a function of the square root of the current above threshold for different device sizes at different bias currents.

Higher heatsink overlap improved MCEF without changing slope efficiency in the operating range. VCSELs with 8 μm diameter oxide aperture exhibited a MCEF of 15GHz/mA$^{1/2}$

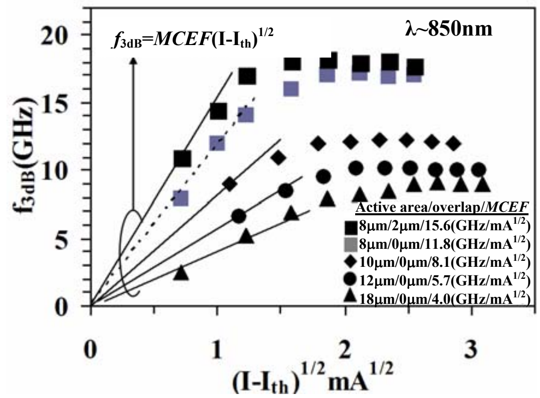

Fig.6. VCSEL 3-dB modulation frequency as a function of the square root of the current above threshold.

which is slightly lower than the highest previously reported MCEF of 16.8GHz/mA$^{1/2}$ [2].

The high MCEF gave high bandwidths at low current densities. An 8μm active diameter VCSELs with 2μm of plated Cu exhibited an 18-GHz bandwidth at only 8kA/cm^2 which is a ~14% improvement compared to unplated devices with 16GHz bandwidth at 8kA/cm^2. Lifetime acceleration studies lead to a common commercial benchmark for VCSEL current density of 10kA/cm^2 or less for reliable operation. Fig. 7 summarizes reported VCSELs bandwidths as a function of current density including the work presented here for 850 and 980 nm VCSELs.

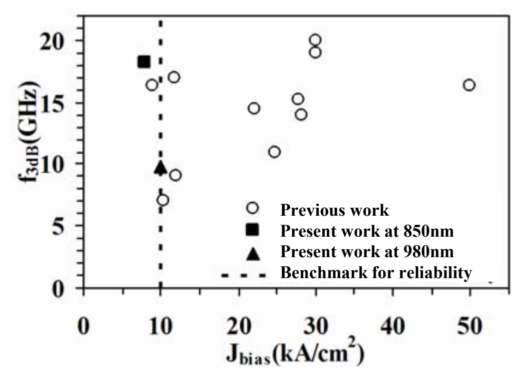

Fig.7. VCSEL bandwidths vs. current densities

IV. SUMMARY

Cu-plated heatsinks on 980 and 850nm VCSELs have reduced thermal resistance to record low levels and improved laser modulation bandwidth. The 850nm VCSELs exhibited a maximum modulation bandwidth of 18GHz at a current density of only 8kA/cm^2. This work was supported in part by Defense Advanced Research Projects Agency under contract DAAD19-03-1-0059.

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