High Efficiency Wide Temperature Range GaAs VCSELs

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Using solid source MBE and Carbon as p-type dopant we have fabricated 840 nm wavelength GaAs vertical cavity lasers (VCSELs) with maximum conversion efficiencies of 57 % [P-39]. Investigations on the temperature behavior exhibit a maximum cw operation range from −80° C up to +185° C. Threshold current in a reduced temperature range from −40° C to +80° C stays below 500 µA while the laser current required for 1 mW of optical output power ranges between 1.5 mA and 1.85 mA.

1. Introduction

Due to intensive research the device characteristics of VCSELs have been strongly improved during the last few years. Using selective oxidation power conversion efficiencies exceeding 50 % were obtained for the first time in 980 nm wavelength InGaAs devices [1]. Agreements on the 820 nm to 860 nm wavelength regime for short distance optical data links have focused the interest on VCSELs with active GaAs [2] or InAlGaAs [3] quantum wells.

2. Device Structure

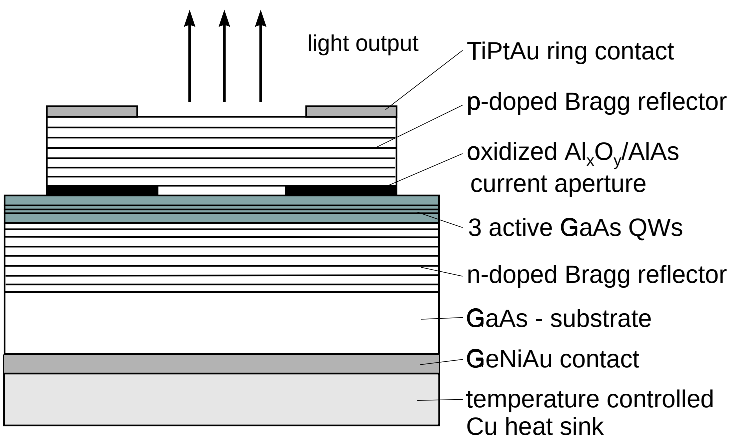

Fig. 1. Cross-sectional view of an oxidized GaAs VCSEL.

Fig. 1 shows a cross-sectional view of the optimized layer structure of the oxide confined GaAs VCSELs under investigation. The active region contains three 8 nm thick GaAs quantum wells in $Al_{0.2}Ga_{0.8}As$ barriers. The bottom Bragg reflector consists of 30.5 n-type Si doped $AlAs/Al_{0.2}Ga_{0.8}As$ pairs. The p-type output coupler has 26 modulation doped $Al_{0.2}Ga_{0.8}As$ /

$Al_{0.9}Ga_{0.1}As$ pairs. In comparison to our previous Beryllium doped devices, Carbon allows the realization of sharper doping profiles and with the high acceptor activation rate the total doping concentration and therefore absorption in the mirror can be reduced by a factor of two with even improved current-voltage characteristics. The 30 nm AlAs layer to be used for subsequent selective oxidation is shifted out of the antinode of the longitudinal standing wave pattern in order to weaken optical waveguiding.

3. Device Characteristics

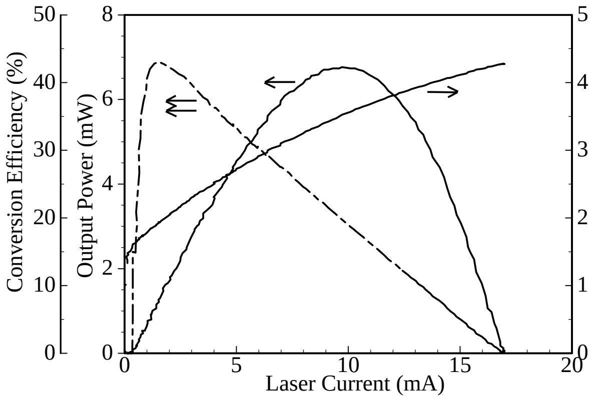

Fig. 2. Output characteristics of an extremely efficient $4\,\mu$m GaAs VCSEL.

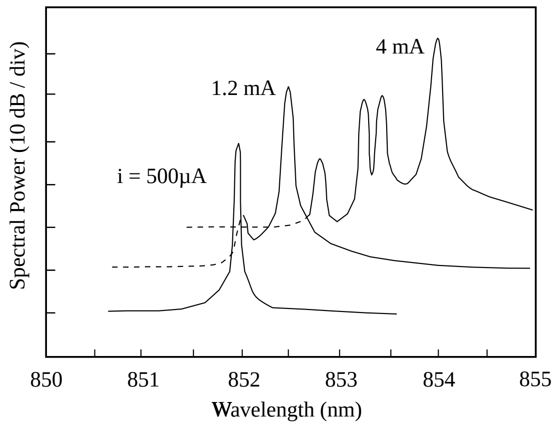

Fig. 3. Output spectra of the VCSEL in Fig. 2 for different driving currents.

In contrast to the record efficiency lasers of $5\,\mu$m diameter, investigations on the thermal behavior are performed using devices with a reduced active diameter of $4\,\mu$m. Output characteristics at room temperature are given in Fig. 2. Threshold current and voltage are $390\,\mu$A and 1.60 V, respectively. Maximum conversion efficiency of 43 % is obtained at 1.6 mA current for an output power of 1.3 mW. Maximum output power of 6.4 mW achieved at 9.5 mA is limited by thermal roll over. Threshold voltage is about 120 mV above the bandgap energy. The differential resistance of about $260\,\Omega$ is caused by the small current aperture. The emission spectra for different currents are given in Fig. 3, offset by 10 dB for clarity. Up to 1.2 mA laser emission is single-mode at about 852 nm wavelength. The mode spacing of the lateral higher order modes, appearing at slightly shorter wavelength, is related to a calculated diameter of $3.7\,\mu$m that is in good agreement with the nominal diameter of $4\,\mu$m. In the multimode regime the superposition of several higher order modes results in an improved overlap of gain and intensity profiles.

4. Temperature Range

Highly efficient lasers exhibit high optical gain as well as low internal heating and therefore are well suited for operation over a wide temperature range. In Fig. 4 optical output characteristics for cw operation from $-80\,^\circ$C up to $+185\,^\circ$C are depicted. The light output versus current curves are recorded from threshold up to thermally induced turn off of the lasers. For example, at a heat sink temperature of $-80\,^\circ$C laser operation is observed from $400\,\mu$A up to 24 mA, the latter corresponding to a current density of $180\,\mathrm{kA/cm^2}$.

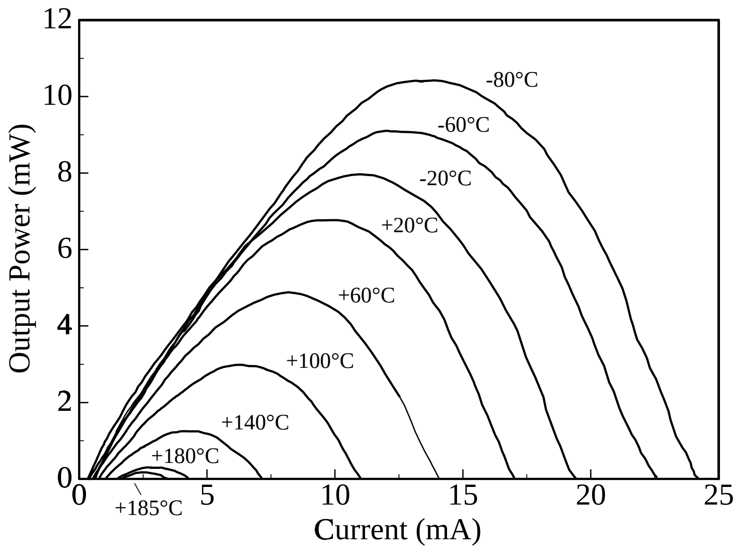

Fig. 4. Light output power versus current for various temperatures from −80 °C up to +185 °C.

Threshold currents and maximum output powers extracted from the light current characteristics are depicted in Fig. 5 over the whole temperature range. Threshold current is determined by the temperature dependent gain as well as the alignment of lasing mode and spectral gain maximum resulting in a minimum threshold of 300 μA at an ambient temperature of −20 °C for the particular devices under study. Maximum output power, limited by thermal roll over, steadily decreases with increasing heat sink temperature. Fig. 6 shows laser characteristics in a temperature range from −40 °C to +80 °C which is of primary technical interest. Within this temperature range threshold current varies between 300 μA and 500 μA, while laser current required for 1 mW of optical output power ranges between 1.5 mA and 1.85 mA. These homogeneous characteristics should allow applications without requiring any temperature stabilization. The spectral shift of the emission wavelength with temperature is evaluated to 0.065 nm/K.

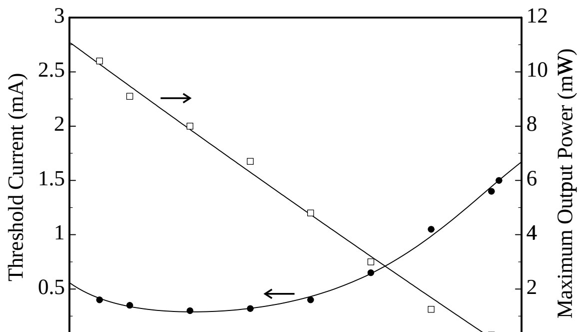

Fig. 5. Temperature dependent threshold current and maximum output power.

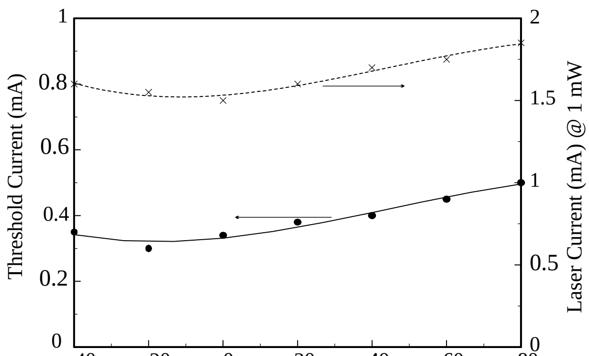

Fig. 6. Homogeneous temperature behavior of threshold current and laser current required for 1 mW output power in an industrially relevant temperature range from −40 °C to + 80 °C.

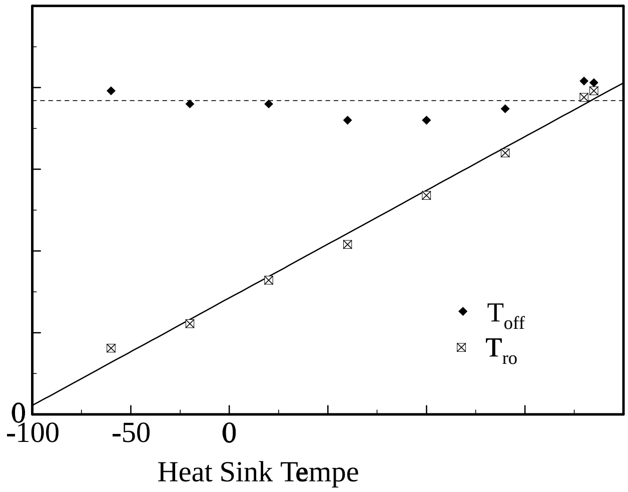

Fig. 7. Thermal roll over and laser turn off temperatures for various heat sink temperatures.

Dissipated power causes a red shift of 0.155 nm/mW, giving a thermal resistance of 2.38 K/mW for the 4 μm devices. With these spectral measurements and the evaluated thermal resistance, intrinsic temperatures for the roll over in the light current curves and the turn off of the laser are determined and plotted in Fig. 7. The intrinsic temperature for thermal roll over increases linearly with heat sink temperature while the turn off temperature of about 195 °C is found to be constant.

5. Conclusion

We have fabricated highly efficient oxide confined GaAs VCSELs emitting around 850 nm wavelength. Investigations of the operating temperature range show cw operation from −80 °C to +185 °C, where the minimum temperature is limited by the measurement setup. In an industrially relevant temperature range from −40 °C to 80 °C threshold current remains below 500 μA and the laser current required for 1 mW optical output power ranges between 1.5 mA and 1.85 mA. Other than the roll over temperature, the intrinsic turn off temperature of the VCSEL is shown to have a constant value of about 195 °C independent of the heat sink temperature.

References

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