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30nm Wavelength Tunable Vertical Cavity Lasers

F. Sugihwo, *M. C. Larson, and J. S. Harris, Jr.
Solid State Electronics Laboratory, CIS-X 328, Stanford University
Stanford, CA 94305. Phone: (415) 725-6911, Fax: (415) 723-4659
email: fred@snowmass.stanford.edu
*Currently with Hitachi Central Research Laboratory, Kokubunji, Japan

1. Introduction

Micromachined wavelength Tunable Vertical-Cavity Surface-Emitting Lasers (Mi-T-VCSELs) have generated much interest for applications such as wavelength division multiplexing (WDM) and spectroscopic remote sensing. Our approach to MiTVCSELs uses a micromachined suspended deformable membrane that functions as the top mirror above the semiconductor cavity [1]. Electrostatic modulation of the airgap thickness between the membrane and the semiconductor cavity produces a phase shift that modulates the resonant frequency of the VCSEL. With this simple yet powerful approach, we have demonstrated a continuously tunable MiTVCSEL with a 19.1 nm wavelength tuning range and a submilliamp threshold current [2]. However, threshold current density is high and we attribute it to a low reflectance top mirror. With an improved membrane design, we have lowered the threshold current density and increased the continuous tuning range to 30 nm.

2. Device Structure

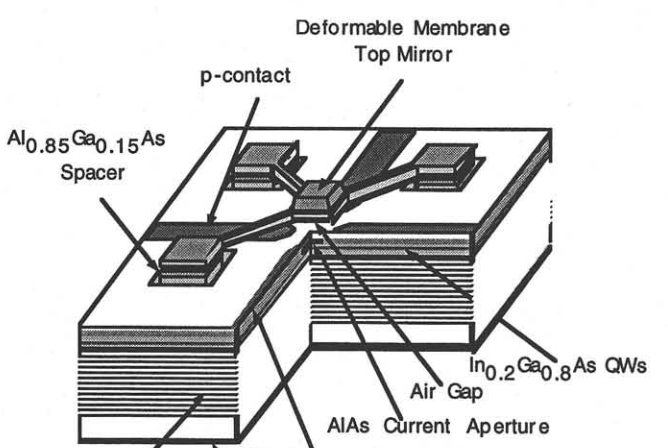

Fig. 1 Schematic diagram of Mi-T-VCSEL.

Figure 1 shows a schematic diagram of a MiTVCSEL. The central reflector/top mirror is fabricated on top of a membrane which is attached to four flexible legs anchored on four rigid membrane posts. The central reflector is made of a hybrid mirror consisting of 1/4 λ GaAs, optically inert 1/2 λ Si_3N_4, 2.5 pair SiO_2/Si_3N_4 dielectric DBR phase-matched to gold, and 1500 Å gold layer. The design wavelength is centered at 970 nm. We intentionally remove the 2.5 pair dielectric DBR from the membrane legs to reduce the stiffness of the membrane legs. This approach enables us to obtain arbitrarily high reflective top mirror by incorporating more dielectric mirror pairs while keeping reasonable tuning voltages. We also match the total tensile stress of Si_3N_4 with the total compressive stress of SiO_2 in the 2.5 pair dielectric DBR to prevent the central reflector region from warping. The membrane is held up primarily by tensile stress generated by the 1/2 λ Si_3N_4. A semi-isotropic dry etching process is used to create the tapered sidewall central reflector ensuring electrical continuity between the membrane contact pads and the central reflector. The complete processing sequence is published elsewhere [3].

3. Testing Results

The device was characterized at room temperature without heat sinking. The lasing spectra is taken with an optical spectrum analyzer and the output power is measured with a calibrated power meter. The lowest threshold current and threshold current density of fabricated devices at zero membrane bias is 0.323 mA and 258 A/cm^2 respectively. The largest measured output power is 0.39 mW for a 20 μm current aperture and the largest measured quantum efficiency is 0.088 W/A at zero membrane bias.

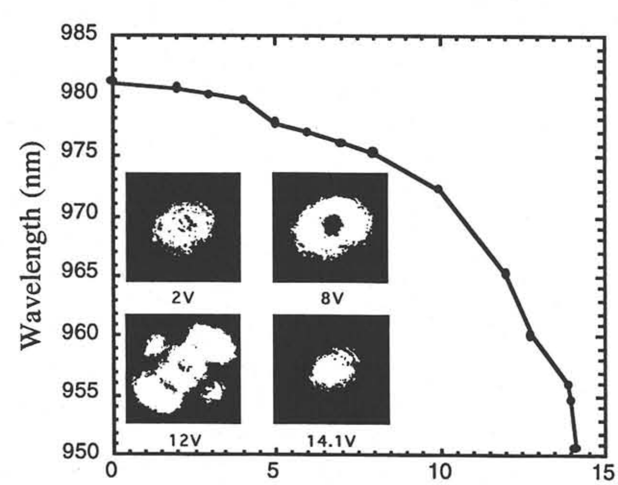

Fig. 2 Wavelength vs. membrane bias for multi transverse mode device. Inset is the near field image of the lasing mode under different membrane bias.

Fig. 2 shows the lasing wavelength versus tuning voltage for a device with a 20 μm diameter central reflector region and 15 μm current aperture formed by oxidizing an

AlAs layer [4,5]. The device is driven continuous wave at room temperature with 4.5 mA current. The multiple transverse mode laser starts lasing at 981 nm (center wavelength) at zero membrane bias and the device stops lasing near 951 nm (center wavelength) with 14.1 V membrane bias. Since the membrane size is 22% smaller than that of Ref. 2 and the membrane legs in this design have rather high tensile stress compared to the low stress membrane legs of Ref. 2, we attribute the lower tuning voltage of the current design to thinner membrane legs (260 nm of 400 MPa tensile stress Si_3N_4 compared to 424 nm of 260 MPa tensile stress SiO_2/Si_3N_4 of Ref. 2). Wavelength tuning is continuous throughout the entire tuning range although the transverse mode changes as the device detunes, as can be seen from the inset in Fig. 2.

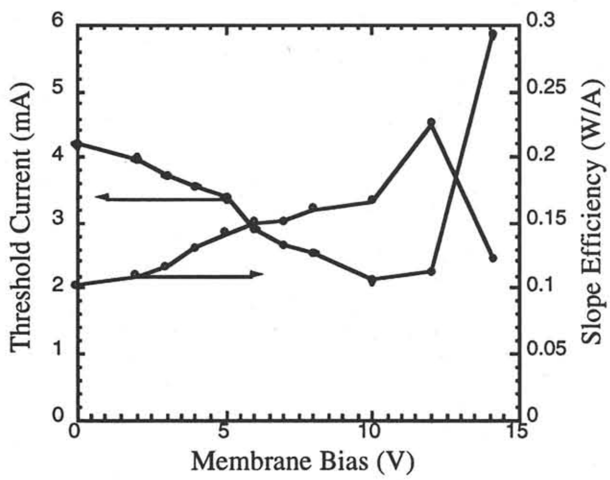

Fig. 3 Plot of threshold current and slope efficiency of multiple transverse mode laser at different membrane bias.

Fig. 3 shows the differential quantum efficiency and threshold current extracted from the L-I curve (not shown) at different membrane bias. Since the device is designed to have 0.89 λ_0 nominal airgap thickness at zero membrane bias, threshold current decreases and quantum efficiency increases as the airgap thickness is reduced to 0.75 λ_0,where the impedance of the whole structure corresponds to π phase shift. Threshold current increases and quantum efficiency decreases as we detune beyond this optimal resonance condition. The lowest threshold current is obtained at 965 nm, corresponding to 10 V membrane bias. The variation in threshold current tracks that of quantum efficiency, deviating only at 12 V membrane bias where threshold current and quantum efficiency both increase. We suspect the anomaly was caused by the hysterisis in the membrane response due to photoresist "stringers" underneath the membrane legs.

4. Conclusions

With an improved top mirror design, we have fabricated wavelength tunable VCSELs with 30 nm wavelength tuning range for multiple transverse mode devices. We have lowered the threshold current density to 258 A/cm^2 while keeping the tuning voltage low.

References

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