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Continuous-Wave Electrically-Pumped GaSb-based VCSELs at ~ 2.6 µm Operating up to 50°C

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Abstract: **The first electrically-pumped single-mode GaSb-based vertical-cavity surface-emitting lasers emitting at ~ 2.6 µm are presented. The devices operate in continuous-wave with low threshold currents (I_{th} = 3.8 mA at RT) up to 50°C.**

Keywords: TDLAS, electrically-pumped, VCSEL, GaSb.

1. INTRODUCTION

Trace gas sensing in the mid-infrared wavelength regime by the so-called tunable diode laser absorption spectroscopy (TDLAS) is currently attracting a great interest [1,2]. As a matter of fact, there are strong absorption lines of a number of pollutant gases, such as CO, CO_2, H_2S and NH_3 at this spectral region, especially above 2 µm. This absorption spectroscopy method requires electrically-pumped (EP), tunable and single-mode lasers at a particular wavelength that operates in continuous wave (CW) at room temperature (RT) [3]. Compared to distributed feedback (DFB) lasers, vertical-cavity surface-emitting lasers (VCSELs) have some nicer features, for instance, low power consumption, higher current tuning coefficient, circular beam profile for better coupling and a cost-effective production which make them ideally suited laser sources for this application. Recently, Ducanchez et al. [4] reported monolithic EP GaSb-based VCSELs in quasi-continuous wave emitting at 2.63 µm. These broad-aperture devices, however, suffer from multimode operation which essentially limits their usability as laser sources in the targeted applications.

In this work, we present the first GaSb-based CW, single mode, EP VCSELs at ~ 2.6 µm operating up to 50°C. Using buried tunnel junctions (BTJ) as current apertures, the threshold currents at RT are as low as 3.8 mA for circular devices with 6 µm BTJ apertures.

1. DEVICE CONCEPT

The VCSEL structure was grown in two growth steps by Varian Gen-II solid-source molecular beam epitaxy (MBE) system. In the first run, a half VCSEL structure was grown which consists of a bottom Bragg mirror, a quantum well (QW) gain section and highly doped tunnel junction layers made of n^+-InAsSb/p^+-GaSb. The Bragg mirror is composed of 24 pairs of Te-doped quarterwave thick AlAsSb / GaSb layers with a refractive index contrast of $\Delta n \approx 0.64$, to achieve a reflectivity of approximately 99.8% at 2.6 µm. The active region comprises seven 10 nm thick $Ga_{0.57}In_{0.43}As_{0.15}Sb_{0.85}$ QWs with a compressive strain of 1.7% separated by 8 nm thick GaSb barriers. The presented VCSELs use structured tunnel junctions as current apertures, comparable to the oxide apertures in standard GaAs-based VCSELs. In addition, the tunnel junction is placed at the node of the standing wave pattern in order to avoid strong absorption by its high carrier density.

In the second run, *n*-doped material with high electrical mobility and good thermal conductivity was grown to spread out the current and heat from the active region. The epitaxial growth was ended by growing a highly doped InAsSb contact layer where a low resistive unannealed ohmic contact was formed by evaporating Ti/Pt/Au sequentially. Finally, a dielectric DBR, consisting of 4 pairs of alternating amorphous Si / SiO_2 ($\Delta n \approx 2$) was evaporated on top of the structure, yielding a reflectivity of 99.8%, at 2.6 µm. The final device structure is displayed in Fig. 1 schematically. The diameter of the current aperture defined by the BTJ is denoted by D_{BTJ}.

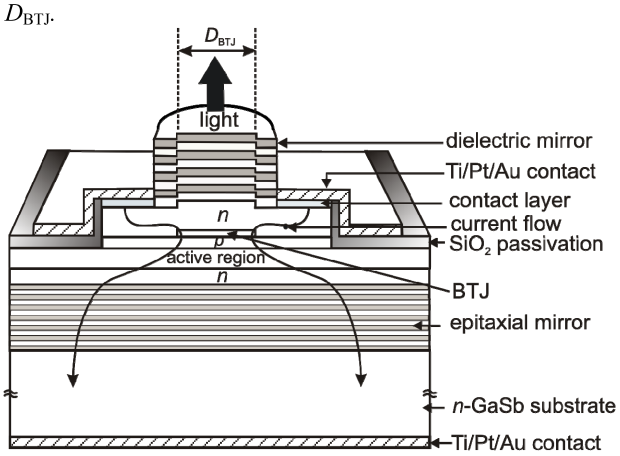

Fig. 1. Schematic cross-sectional view of the 2.6 µm GaSb-based VCSEL structure

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2. DEVICE RESULTS

Devices were tested on-wafer under CW operation on a temperature controlled heat sink. Fig. 2 illustrates the temperature dependent *L-I* (light output-current) character--istics of a VCSEL with 6 µm BTJ diameter. CW operation has been achieved up to 50°C. At RT, the threshold current of the device is 3.8 mA, corresponding to an effective threshold current density of 7.5 kA/cm^2, where lateral carrier diffusion of 2 µm has been taken into account. The maximum output power at 20°C is 176 µW @ 13.5 mA and the threshold voltage, V_{th} is 0.7 V.

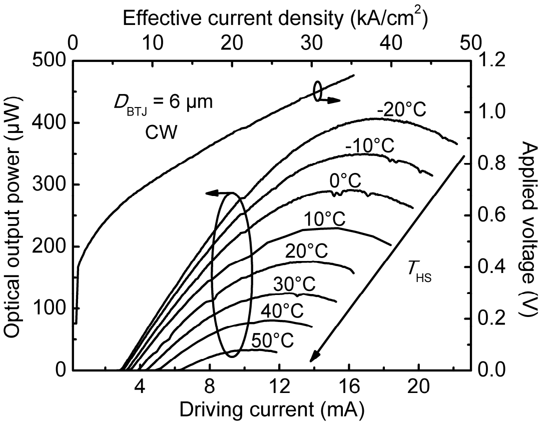

Fig. 2. Temperature dependent *L-I* characteristics of 2.6 µm wavelength BTJ-VCSEL. The *I-V* curve is shown for 20°C.

Fig. 3 shows the threshold current and maximum output power as a function of the heat sink temperature where it is clear that the minimum threshold current is located at a temperature below -20°C, hinting that the spectral alignment of the cavity mode and gain spectrum is not optimum even at this low temperature. Therefore, a further blue-shift of the emission of the active region or red-shift of the cavity resonance by larger cavity length could further improve threshold current and output power.

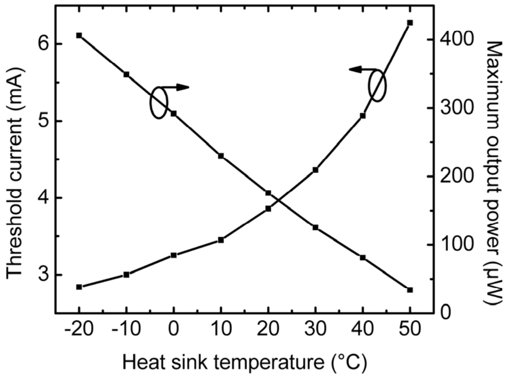

Fig. 3. Threshold current and maximum output power against heat sink temperature, T_{HS}

The emission spectra at various laser driving currents are displayed in Fig. 4, yielding distinct single-mode emission. They show a side-mode suppression ratio (SMSR) of over 25 dB. The wavelength shifts at a rate of 0.5 nm/mA.

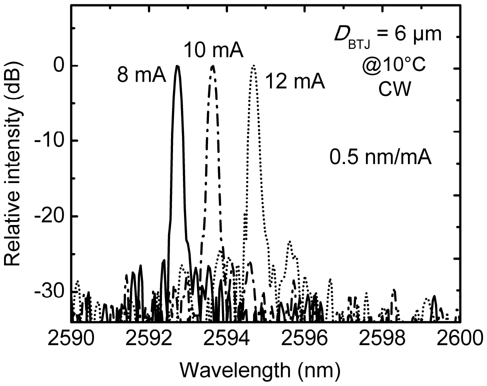

Fig. 4. Emission spectra for driving currents of 8, 10 and 12 mA at constant T_{HS} = 10° C.

While being sufficient for many gas sensing systems, the optical output power is still rather low because of the temperature dependent loss mechanisms present in this low bandgap material system and misalignment of the cavity mode with respect to the gain peak. The latter is due to the thickness inaccuracies in the epitaxial growth.

3. CONCLUSION

We demonstrated the extension of the wavelength range of VCSELs to 2.6 µm and presented the first single-mode (SMSR > 25 dB), CW, EP devices using BTJ technology being well-suited for trace gas sensing applications.

4. ACKNOWLEDGMENTS

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