Large-aperture single-mode GaSb-based BTJ-VCSELs at 2.62 µm

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Abstract: *We report on large aperture (D_{BTJ} = 9 µm) GaSb-based BTJ VCSELs at 2.62 µm which show single-mode operation (SMSR > 30 dB) over the entire operating range. Devices are electrically-pumped and operate in continuous-wave mode.*

SUMMARY

Mid-infrared semiconductor lasers are key components for Tunable Diode Laser Absorption Spectroscopy (TDLAS) based trace gas sensing applications. Among different semiconductor lasers, Vertical-Cavity Surface-Emitting Lasers (VCSELs) are very attractive choices for these applications because VCSELs exhibit excellent lasing characteristics such as a true single-mode operation, a high current tuning coefficient and a cost-effective production. Since most of the trace gases have strong absorption lines above 2 µm, the GaSb-based material system is used for covering this wavelength regime. Electrically-pumped (EP) VCSELs at 2.3 µm operating in pulse or continuous wave (CW) mode have already been reported [1,2].

In this work, GaSb-based CW-operated EP VCSELs incorporating a Buried Tunnel Junction (BTJ) with emission wavelengths of 2.62 µm have been demonstrated. The devices with 9 µm current aperture exhibit true single-mode operation with a side mode suppression ratio of over 30 dB over the entire operating current range. This is advantageous for any type of spectroscopic applications since a reasonable amount of output power can be obtained from the large-aperture device maintaining single-mode operation.

A schematic illustration of the GaSb-based BTJ VCSEL is shown in Fig. 1 where D_{BTJ} denotes the aperture diameter of the device. The electric current injected around the dielectric mirror is effectively confined to the tunnel junction. In this way, the active region defined by the BTJ diameter plus an extension caused by carrier diffusion is effectively pumped. In addition, this tunnel junction also enables self-adjusted lateral optical waveguiding, which is of paramount importance for VCSELs. The waveguiding in BTJ VCSELs mainly arises from a longer cavity (optical wavelength) in the central region with a tunnel junction aperture rather than in the perimeter. Consequently, a radical index step, Δn_{eff} is formed in the tunnel junction region. Evaluations of the resonance conditions in the cavity with tunnel junction and the cavity without tunnel junction of the VCSEL by means of the transfer matrix method lead to the relative refractive index step $\Delta n_{eff} / n_{eff} \approx 1.7\%$ [3]; showing that VCSELs utilizing this tunnel junction are strongly index guided. But nevertheless, single mode operations can be obtained even at large apertures in long wavelength VCSELs as long as the value of Δn_{eff} formed by the tunnel junction remains within reasonable limits.

Fig. 2 shows the light output-current-voltage (*LIV*) characteristics of a CW-operating device with a large BTJ aperture, D_{BTJ} = 9 µm for heat sink temperatures between -20°C and 5°C. The device did not work at higher temperatures due to non-optimized cavity mode-gain offset and temperature dependent several loss mechanisms at longer wavelengths. At -20°C, the maximum output power obtained is 0.77 mW @ 25 mA and the threshold current is 11 mA, corresponding to an effective threshold current density of 8.3 kA/cm^2 where lateral carrier diffusion of 2 µm on each side of the BTJ has been assumed. *I-V* characteristics show a low threshold voltage of 0.74 V at 5°C.

The spectra of the devices were measured with a Vertex 70 FTIR (Bruker Optics GmbH). As can be seen in Fig. 3 (a), the devices show single-mode emission with a side-mode suppression ratio (SMSR) of 30 dB even at thermal rollover current. The devices can be (electro-)thermally tuned over 4 nm at a constant heatsink temperature of -5°C, yielding a wavelength tunability of 0.34 nm/mW as illustrated in Fig. 3 (b) . In addition, the devices can be tuned over 6 nm by changing the heat-sink temperature between -20°C to 5°C at a constant driving current of 18 mA as shown in Fig. 4 (a). The wavelength shifts at a rate of 0.27 nm/K.

In conclusion, EP, CW operated GaSb-based BTJ VCSELs with an emission wavelength of 2.62 µm are reported. Devices with aperture diameters of 9 µm show transverse single-mode operation over the entire operational range. Due to their single-mode behavior even at large BTJ diameters and their current tunability, they are ideal light sources for gas-sensing applications using TDLAS.

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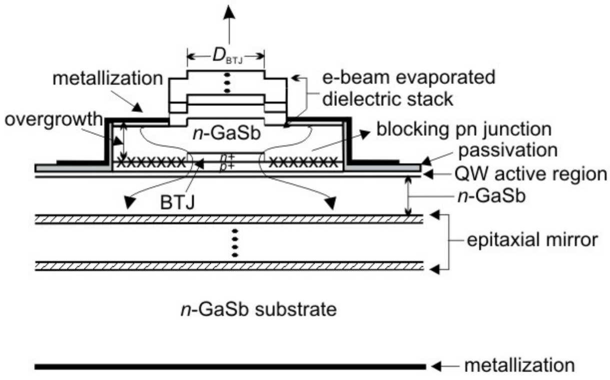

Fig. 1: Schematic structure of GaSb-based VCSEL

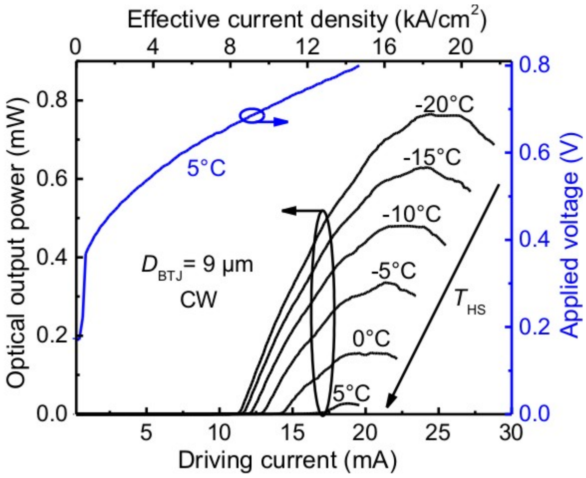

Fig. 2: Temperature dependent *L-I* characteristics of a GaSb-based VCSEL with a circular aperture of 9 µm.

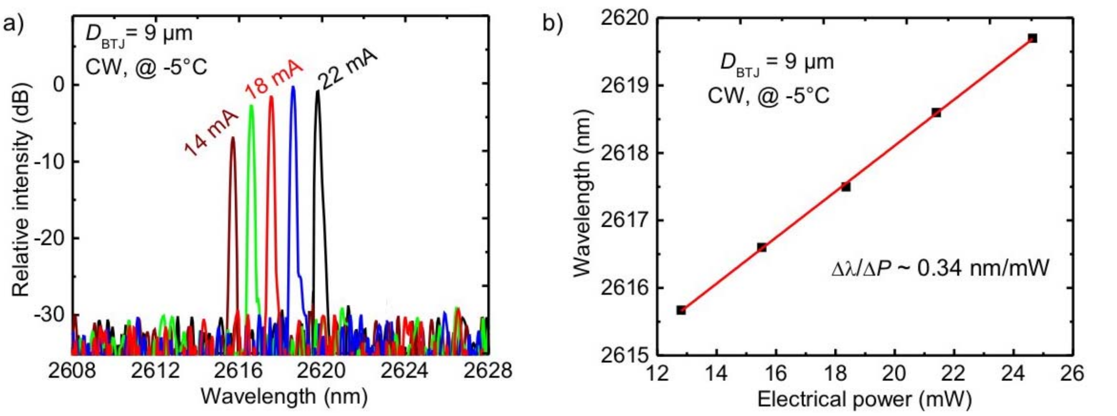

Fig. 3: (a) Spectra of VCSEL at different driving currents and constant heatsink temperature of -5°C, yielding single-mode operation with a SMSR > 30 dB. (b) Wavelength tuning by changing the applied electrical power, yielding a tuning rate of 0.34 nm/mW.

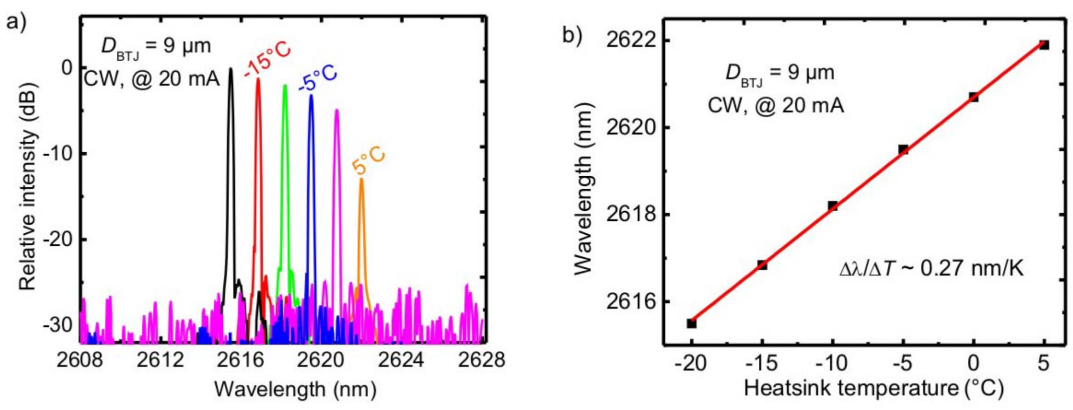

Fig. 4: (a) Spectra of VCSEL by varying heatsink temperature at constant driving current of 20 mA. (b) Wavelength tunability by changing the heatsink temperature, yielding a tuning rate of 0.27 nm/K.