

Sub-kHz linewidth GaSb semiconductor diode lasers operating near 2 μm

Mahmood Bagheri^{1*}, Ryan M. Briggs¹, Clifford Frez¹, Alexander Ksendzov¹ and Siamak Forouhar¹

¹Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

*mahmood.bagheri@jpl.nasa.gov

Abstract: We report on the phase noise properties of DFB lasers operating near 2.0 μm . Measured noise spectra indicate intrinsic laser linewidths below 1 kHz. An effective linewidth of less than 200 kHz for 5 ms measurement times is estimated.

OCIS codes: (140.3490) Lasers, distributed-feedback; (290.3700) Linewidth.

A variety of eye-safe diode-pumped solid-state and external-cavity semiconductor lasers operating near 2 μm wavelength have been developed for applications in remote sensing, high-resolution spectroscopy and optical metrology [1,2]. These lasers have extremely narrow emission linewidth, which makes them suitable for spectroscopy and lidar applications. However, these lasers are bulky and are susceptible to environmental fluctuations, which makes them unfit for airborne applications. Monolithic semiconductor diode lasers have the advantages of low mass, small size, and long operating lifetime, which are important metrics for airborne and satellite applications. To date, there has been little work reported on the development of semiconductor diode laser in the spectral region from 2.0 to 2.1 μm , where several vibrational absorption features of water vapor and carbon dioxide are available [3-5].

We have previously reported on high-power single mode emission from Fabry-Perot and distributed-feedback (DFB) semiconductor lasers [4,5] emitting at 2.0 μm . Yet, for these lasers to be suitable in lidar and other spectroscopic applications, they need to have narrow emission linewidth as well. Here, we report on the linewidth properties of semiconductor laterally coupled DFB lasers operating near 2.0 μm wavelength. The lasers were fabricated from a wafer with two $\text{In}_{0.23}\text{Ga}_{0.77}\text{As}_{0.1}\text{Sb}_{0.9}$ quantum wells (QWs) centered within an $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}_{0.02}\text{Sb}_{0.98}$ waveguide layer and surrounded by $\text{Al}_{0.85}\text{Ga}_{0.15}\text{As}_{0.07}\text{Sb}_{0.93}$ cladding, grown on a GaSb substrate by molecular-beam epitaxy. 4- μm -wide waveguide ridges were etched into the top cladding layer, and second-order gratings were etched alongside the ridges. Device fabrication has been detailed elsewhere [5]. The output facets were coated with an anti-reflection (AR) coating and the back facets were passivated. Individual lasers were soldered epitaxy-side up onto gold-coated copper mounts for testing.

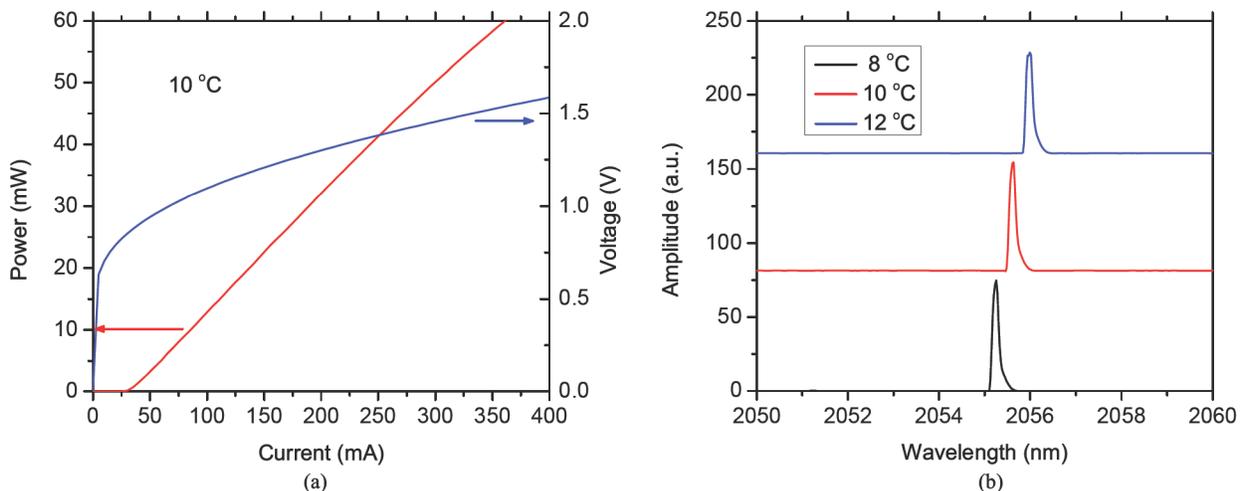


Figure 1. (a) Semiconductor diode laser output power (left axis) and voltage (right axis) versus input current. (b) Measured spectra at different temperatures at 200 mA input current.

The laser mounts were fixed on a temperature-controlled stage. Light was collected using a high-NA (0.56) aspheric lens AR-coated for 2.0 μm spectral region. Collected light passes through an optical isolator and is then collected into a single-mode optical fiber for further analysis. Figure 1(a) shows CW light-current-voltage curves for

a DFB laser measured at 10 °C on a broad-area detector. Figure 2(b) shows the emission spectra of the DFB laser under 200 mA input current at different temperatures. Measured spectra show single mode operation of laser up to 250 mA input current, above which the spectra show multimode operation with contributions from the nearby Fabry-Perot cavity modes.

To analyze the phase noise properties of the lasers, a Fabry-Perot interferometer was used to convert frequency fluctuations into amplitude fluctuations. The amplitude fluctuations were recorded and converted into phase information using the phase-amplitude transfer function. A digital Fourier transform of phase fluctuation is then used to obtain the laser's frequency noise power spectral density. The measured frequency noise spectra reveal two dominant contributions from different mechanisms: White-noise contribution is due to spontaneous emission coupled to the cavity optical mode and gives rise to an emission spectrum with Lorentzian lineshape. This contribution is expected to decrease with increasing laser power before other nonlinearities in the active region rebroaden the emission linewidth. The second contribution that can be approximated by a $1/f$ -noise model is due to temperature and other environmental fluctuations as well as laser drive and detection electronic circuitry.

Figure 2(a) shows measured frequency noise spectra of a DFB laser at different injection currents above threshold. The white noise region of the spectra reveals a Lorentzian linewidth of less than 1 kHz at 25 mW output power. The spurious peaks at 15 kHz and below are due to mechanical resonances from the Fabry-Perot interferometer. Figure 2(b) shows the behavior of the laser linewidth due to white-noise contribution versus the injection current above threshold at two different temperatures. The increase in laser linewidth at higher temperature is mainly due to gain peak offset from the lasing wavelength that is defined by the DFB grating pitch. The laser lineshape with contributions from both $1/f$ -noise and white noise contributions is a Voigt profile, with a total linewidth of 160 kHz at 25 mW over 5 ms period of observation.

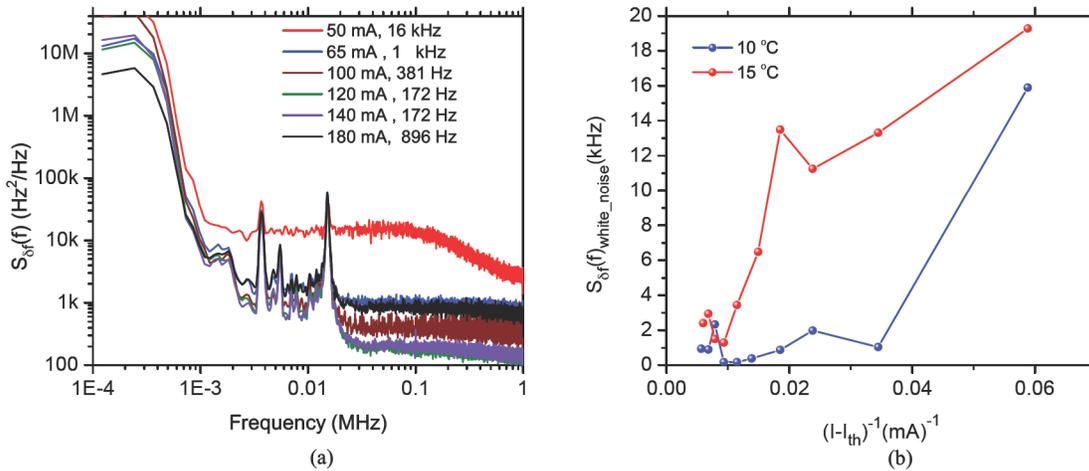


Figure 2. (a) frequency noise power spectral density of a DFB laser after passing through a Fabry-Perot interferometer. (b) Behavior of laser linewidth versus the inverse of the input current above threshold.

In summary, we have performed frequency noise measurements on single-longitudinal-mode DFB lasers at 2.05 μm . Our measurements show extremely narrow linewidth emission spectra for DFB lasers operating at more than 20 mW output power. Lasers with high output power and narrow linewidth at 2.05 μm are important building blocks for lidar systems for CO₂ and other atmospheric constituents monitoring.

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

References

- [1] S. Kaspar, *et al.*, "Semiconductor disk laser at 2.05 μm wavelength with <100 KHz linewidth at 1 W output power," *Appl. Phys. Lett.*, 100, 031109 (2012).
- [2] U. N. Singh, "Progress on high-energy 2-micron solid state laser for NASA space-based wind and carbon dioxide measurements," *Photon. Soc. Summer Topical Meeting Series*, pp.64-65 (2011).
- [3] J. A. Gupta, P. J. Barrios, J. Lapointe, G. C. Aers, and C. Storey, "Single-mode 2.4 μm InGaAsSb/AlGaAsSb distributed feedback lasers for gas sensing," *Appl. Phys. Lett.* 95, 041104 (2009).
- [4] K. Franz, *et al.*, "GaSb-based high-power single-spatial-mode lasers at 2.0 μm ," *Conference on Laser and Electro-optics, CTuC6*, Baltimore, MD (2011).
- [5] S. Forouhar, *et al.*, "High-power laterally coupled distributedfeedback GaSb-based diode lasers at 2mm wavelength," *Appl. Phys. Lett.* 100, 031107 (2012).