Widely Tunable 2.6 µm GaSb Diode Lasers Utilizing Diffraction Gratings or Silicon Photonics Reflectors

(Student Paper)

Samu-Pekka Ojanen[1], Jukka Viheriälä[1], Matteo Cherchi[2], Nouman Zia[1], Eero Koivusalo[1], Pentti Karioja[3] and Mircea Guina[1]
[1] Optoelectronics Research Centre, Physics Unit, Tampere University, FI-33720 Tampere, Finland
[2] VTT Technical Research Centre of Finland, FI-02044 Espoo, Finland
[3] VTT Technical Research Centre of Finland, FI-90570 Oulu, Finland
e-mail: samu-pekka.ojanen@tuni.fi

ABSTRACT

We present two tunable extended cavity laser configurations emitting around 2.6 µm. The gain is provided by a type-I GaSb-based quantum well heterostructure. To demonstrate the high power and broad tuning capabilities of the gain material, an extended cavity laser based on feedback via a diffraction grating is demonstrated. Tuning range of 154 nm, with an average output power of ~10 mW at 2.63 µm, corresponding to a peak power of ~100 mW, is demonstrated. For a more compact and integrable configuration, we demonstrate an extended cavity laser utilizing silicon photonics resonators, where the feedback and tuning is obtained via Vernier effect between two microring resonators. Here, a tuning range of ~70 nm, with an average output power of ~1 mW at 2.55 µm, corresponding to a peak power of ~10 mW, are demonstrated.

Keywords: tunable lasers, mid-IR laser, silicon photonics, photonic integration, extended cavity diode lasers

1. INTRODUCTION

The development of a light source for gas sensing in the wavelength region of 2-3.5 µm has captured increasing attention, because many important environmental gases, like H_2S, C_2H_4, CH_4, CO, CO_2, N_2O, and H_2O, have strong absorption in this wavelength region [1]. Tunable extended cavity lasers, which combine a semiconductor gain chip and an external tuning mechanism, are attractive for gas sensing and spectroscopy applications, since they are able to achieve wide tunability and narrow linewidth simultaneously. In contrast, monolithic diode lasers often have to make a compromise between these two characteristics.

Hybrid integrated III-V/SOI lasers are able to achieve continuous tuning and narrow linewidth in a compact and cost-effective architecture, making them optimal for gas sensing and spectroscopy applications. However, so far such integrated lasers have been limited to around 2.35 µm wavelength, exhibiting mW-level peak powers near room temperature (RT) operation [2]. To address a wider range of environmental gases there is a need to extend the wavelength range towards 3 µm, ideally using gain elements based on GaSb-based type-I quantum well (QW) heterostructures. However, non-radiative recombination processes limit the output power of such sources, especially at wavelengths beyond 2.3 µm. For example, state-of-the-art superluminescent diodes (SLDs) at 2 µm exhibit continuous wave (CW) output powers as high as 150 mW at RT [3], while SLDs at 2.55 µm require pulsed operation, and exhibit only mW-level average output power [4].

Here, we demonstrate two extended cavity laser configurations, one utilizing a diffraction grating for feedback and tuning (Littrow laser), and one utilizing a thermally tunable silicon reflector chip, exploiting the Vernier effect between two microring resonators (MRRs) (Vernier laser). In both lasers, the gain is provided by a GaSb-based single-transverse-mode reflective semiconductor amplifier (RSOA) chip with a wide gain peak around 2.6 µm.

2. GAIN CHIP AND CAVITY CONFIGURATIONS

The epitaxial structure of the RSOA chip was similar to the SLDs we have reported earlier [4]. The RSOA employed a “J-shape” ridge waveguide (RWG), where the front facet is tilted at 7° to reduce back reflections, and the rear facet is kept straight to provide maximum reflection. The bending radius of the waveguide was large enough to lead to negligible bending losses. The RSOA chip was mounted p-side up in the Littrow laser, and p-side down in the Vernier laser. The front facet had an anti-reflection coating (ARC) to maximize output coupling, while the rear facet was either as-cleaved (p-side up chip) or had an Al_2O_3 protective layer (p-side down chip), providing ~30% reflection in both cases. In order to minimize the heating effects, the chips were driven in pulsed operation with a pulse width of 1 µs, and a duty cycle of 10% at 20°C. The average output power of the chips as a function of injection current amplitude is shown in Fig. 1 (a), and the amplified spontaneous emission (ASE) spectrum is shown in Fig. 1 (b).

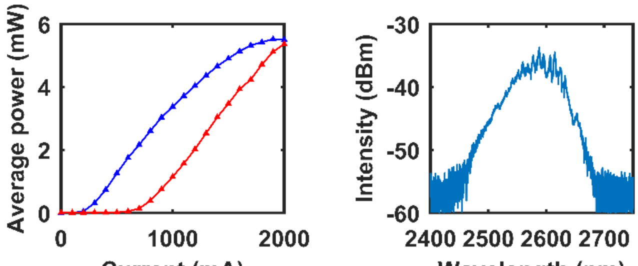

Figure 1. (a) Average power as a function of injection current pulse amplitude for the p-up chip (red), and the p-down chip (blue), and (b) the ASE spectrum of the RSOA chips.

Fig. 2 shows a schematic of the Littrow laser. The front facet of the RSOA is coupled with a lens to an external diffraction grating, which provides feedback at the first diffraction wavelength. Tunability was achieved by rotating the grating with a linear motor. The output signal was gathered from the rear facet of the RSOA with a multimode fiber.

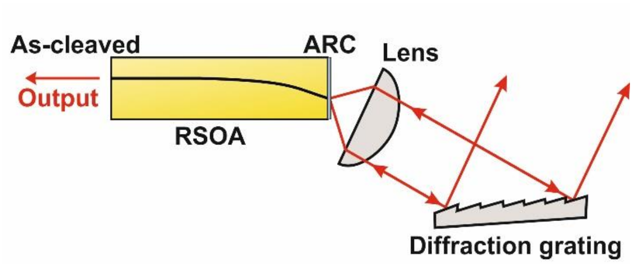

Figure 2. Schematic of the Littrow laser cavity.

Fig. 3 shows a schematic of the Vernier laser. The RSOA was edge-coupled to the SiPh chip, which had an ARC on both facets to minimize parasitic reflections. The SiPh chip consisted of two MRRs (MRR1 and MRR2) with slightly different free spectral ranges (FSRs), which leads to Vernier effect, where only certain wavelengths are transmitted strongly, while other wavelengths are suppressed (spaced by a FSR of ~42 nm). Wavelength tuning is achieved with two resistive heaters (heater 1 and heater 2) that were integrated next to the MRRs. By applying voltage to the heaters, the temperature change inflicts a change of the effective refractive index of the MRRs, which moves the location of the reflected peaks. Because the SiPh chip was originally designed to be used as the out-coupler, it has a 72:28 multimode interference (MMI) coupler at the output waveguide, which transmits 28% of the Vernier signal, and reflects 72% back to the RSOA.

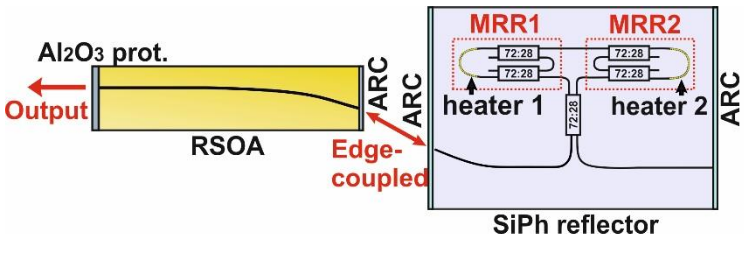

Figure 3. Schematic of the Vernier laser cavity.

3. MEASUREMENT RESULTS

The Littrow laser was driven with 700 mA pulses, and the emission wavelength was measured with a Fourier transform infrared (FTIR) spectrometer, while the grating was scanned with the linear motor. The emission wavelength as a function of linear motor position is shown in Fig. 4. The laser was tunable from 2513 nm to 2667 nm, corresponding to a tuning range of 154 nm. The full width at half maximum of the spectra were <0.2 nm, and the side-mode suppression ratio was >20 dB (both limited by the FTIR) over the whole scanning range. By driving the laser up to 1500 mA injection current, an average output power of ~10 mW was measured at 2628 nm. This corresponds to a peak power of ~100 mW.

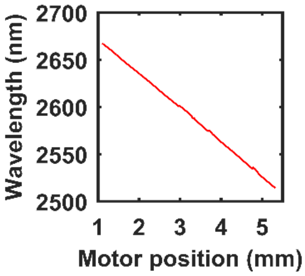

Figure 4. Emission wavelength of the Littrow laser as a function of the position of the linear motor.

The average output power of the Vernier laser at 2.55 µm as a function of injection current pulse amplitude is shown in Fig. 5 (a). The laser reaches an average power of ~1 mW, corresponding to ~10 mW of peak power. This is the highest power reported for hybrid lasers in the 2.5-2.7 µm wavelength range. The Vernier laser was then driven with 2000 mA pulses, and the emission wavelength was measured as a function of power driven to heaters 1 and 2. The result is shown in Fig. 5 (b). The laser is able to attain almost all wavelengths between 2550 nm and 2620 nm, corresponding to a tuning range of ~70 nm. This is limited by the FSR of the Vernier reflector, which is much smaller than the gain bandwidth of the RSOA. In addition, the laser exhibits fairly strong side maxima, which is evident in the emission spectrum shown in Fig. 5 (c). This is related to the fact that the reflectance peaks adjacent to the maximum reflectance have too high reflectivity.

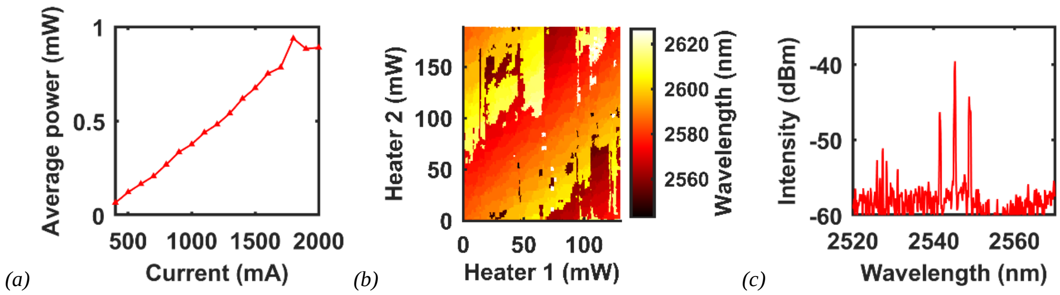

Figure 4. (a) Average power at 2.55 µm as a function of injection current pulse amplitude, (b) the emission wavelength as a function of power applied to the heaters, and (c) the emission spectrum of the Vernier laser at 2.55 µm.

4. CONCLUSIONS

We have demonstrated two tunable GaSb-based extended cavity lasers in the 2.5-2.7 µm wavelength region. The Littrow laser showed a wide tuning range of 154 nm, and a high average output power of ~10 mW (100 mW peak power), while the Vernier laser showed a tuning range of ~70 nm, and an average power of 1 mW (10 mW peak power). In future, we will test SiPh chips with 100% reflectance, lower losses, wider FSR, and higher spectral purity, in an effort to suppress the side modes, as well as increase the tuning range and the output power of the Vernier laser.

ACKNOWLEDGEMENTS

Authors wish to thank M.Sc. Jarno Reuna for preparation of AR/HR coatings, and Ms. Mariia Bister for fabrication of the devices. S.-P. Ojanen would like to thank Vaisala Oyj for funding of the Ph. D. program. The research was funded by EU H2020 project MIREGAS (Grant Agreement 644192), and Business Finland project RAPSI (decision 1613/31/2018). The work is part of Academy of Finland flagship program PREIN (decision 320168).

REFERENCES

[1] I. E. Gordon, *et al.*: The HITRAN2016 molecular spectroscopic database, *J. Quant. Spectrosc. Radiat. Transfer*, vol. 203(Supplement C), pp. 3-69, Dec. 2017.

[2] R. Wang, *et al.*: Widely tunable 2.3 µm III-V-on-silicon Vernier lasers for broadband spectroscopic sensing, *Photon. Res.*, vol. 6, pp. 858-866, Aug. 2018.

[3] N. Zia, *et al.*: High-power single mode GaSb-based 2 µm superluminescent diode with double-pass gain, *Appl. Phys. Lett.*, vol. 115, pp. 231106, Dec. 2019.

[4] N. Zia, *et al.*: GaSb superluminescent diodes with broadband emission at 2.55 µm, *Appl. Phys. Lett.*, vol. 112, pp. 051106, Jan. 2018.