Widely tunable III-V-on-silicon Vernier lasers operating in the 2.3 μm wavelength range

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Abstract: We report widely tunable III-V-on-silicon lasers with more than 40 nm tuning range near 2.35 μm wavelength. By combining two lasers with different distributed Bragg reflectors, a tuning range of more than 70 nm is achieved.

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1. Introduction

Tunable diode laser absorption spectroscopy (TDLAS) has been shown to be a powerful analytical method to detect gases down to the ppb or sub-ppb level [1]. Tunable semiconductor lasers operating in the 2-2.5 μm spectral range are of great interest for TDLAS applications due to the fact that many important gases have strong absorption lines in this wavelength range [2]. For example, the wavelength range near 2.35 μm offers a window for highly sensitive detection of CH_4, NH_3 and CO. The development of widely tunable semiconductor lasers in the 2-2.5 μm range enables to simultaneously detect several gases. Besides, this type of laser source is also useful for non-invasive blood glucose measurements [3]. Conventional 2-2.5 μm range widely tunable semiconductor lasers require a bulky diffraction grating for wavelength selection that needs to be mechanically controlled [4], which makes them quite expensive and difficult to use for portable sensing systems. Silicon photonics provides a platform to realize compact and low-cost photonic components and systems. High-performance optical filters, beam combiners and laser feedback circuits can be fabricated on a silicon photonics platform. Integrating III-V materials with silicon photonic integrated circuits (ICs) is a promising solution to realize miniature widely tunable laser diodes [5]. Here we demonstrate 2.3 μm wavelength range widely tunable III-V-on-silicon lasers by heterogeneously integrating an InP-based type-II heterostructure with a silicon photonic IC.

2. Design and fabrication

The tunable III-V-on-silicon laser consists of a III-V gain section, a Vernier filter and two distributed Bragg reflectors (DBRs) as schematically shown in Fig. 1(a). An InP-based type-II epitaxial layer stack with six pairs of "W"-shaped InGaAs/GaAsSb quantum wells is heterogeneously integrated on the silicon photonic IC to serve as the gain section [6]. The light coupling between the III-V waveguide and silicon waveguide is realized using a III-V/silicon spot size converter (SSC). A Fabry-Perot laser cavity is formed between a high reflectivity silicon DBR (DBR1, 30 periods, duty cycle 50%) and a lower reflectivity silicon DBR (DBR2, 8 periods, duty cycle 50%). Simulation results indicate DBR1 has a peak reflectivity around 95% and a 3 dB bandwidth of ~200 nm. This broadband reflectivity is due to the high refractive index contrast between silicon and silicon dioxide. The Vernier filter consists of two silicon microring resonators (MRRs). The lasing wavelength can be selected by thermally tuning the resonances of the two MRRs.

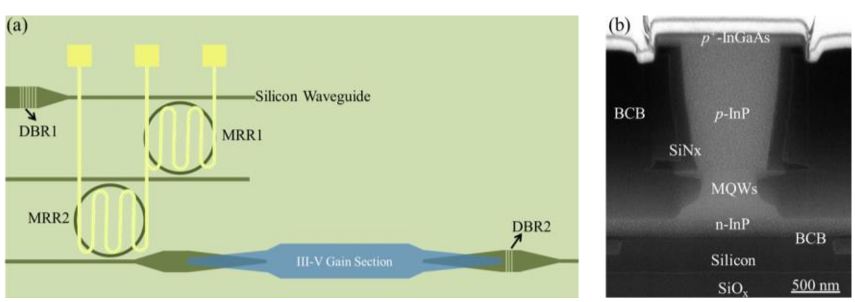

Fig. 1. (a) Schematic of the tunable III-V-on-silicon Vernier lasers; (b) SEM image of the cross section of the III–V gain section of the device near the tip of the III-V taper structure.

The fabrication of silicon photonic ICs is carried out in imec's CMOS pilot line on 200 mm silicon-on-insulator (SOI) wafers, comprising a 400 nm thick silicon device layer and a 2 µm buried oxide layer. The InP-based type-II epitaxial layer stack is adhesively bonded to the silicon photonic IC using a 50 nm thick benzocyclobutene (DVS-BCB) bonding layer. After bonding, the InP substrate is removed using HCl wet etching. Then the III-V-on-silicon lasers are processed on the III-V membrane. A scanning electron microscope (SEM) image of the cross-section of a fabricated III-V-on-silicon device is shown in Fig. 1(b). Ti/Au micro-heaters are deposited on the MRRs to thermally tune the lasing wavelength.

3. Measurement results

The fabricated sample is mounted on a temperature-controlled stage during measurements. Figure 2(a) shows the power-current (P-I) curve of a III-V-on-silicon laser (comprising a 900 µm long and 5 µm wide gain section) with DBR pitch of 420 nm in continuous-wave (CW) and pulsed operation (pulse duration 1 µs, period of 100 µs) at 5 ˚C. The laser outputs a maximum peak power of 3 mW in pulsed regime and 0.2 mW in CW regime, both at 2340 nm wavelength. The threshold current is 80 mA and 130 mA in pulsed and CW regime, respectively. Wavelength tuning is achieved by adjusting the thermal power dissipated in the micro-heaters on top of the two MRRs. The two MRRs have a free spectral range (FSR) of 5 nm and 5.5 nm, thus the FSR of the Vernier filter is 55 nm, which limits the maximum tuning range of the Vernier laser. The InP-based type-II epitaxial material used in the III-V-on-silicon Vernier laser has a broadband gain spectrum. A III-V-on-silicon distributed feedback laser array with 150 nm wavelength coverage (2.28-2.43 µm) was demonstrated based on the same III-V gain material [7]. In order to efficiently utilize this broadband gain property, we designed two Vernier lasers with DBRs with a different grating period to address a broader wavelength range. Figure 2(b) and 2(c) shows the emission spectra of the two Vernier lasers with different DBRs in pulsed regime at 5˚C, by tuning one of the MRRs. For the DBR with grating pitch of 420 nm, its reflectivity quickly reduces around 2.35 µm, therefore the laser with DBR grating pitch of 420 nm has a tuning range from 2.305-2.345 µm, as seen in Fig. 2(b). The DBR with grating pitch of 460 nm starts to strongly reflect from 2.31 µm wavelength, so this laser exhibits tuning from 2.325 µm to 2.375 µm as shown in Fig. 2(c). A tuning range more than 70 nm can be achieved by combing these two lasers on the silicon photonic IC.

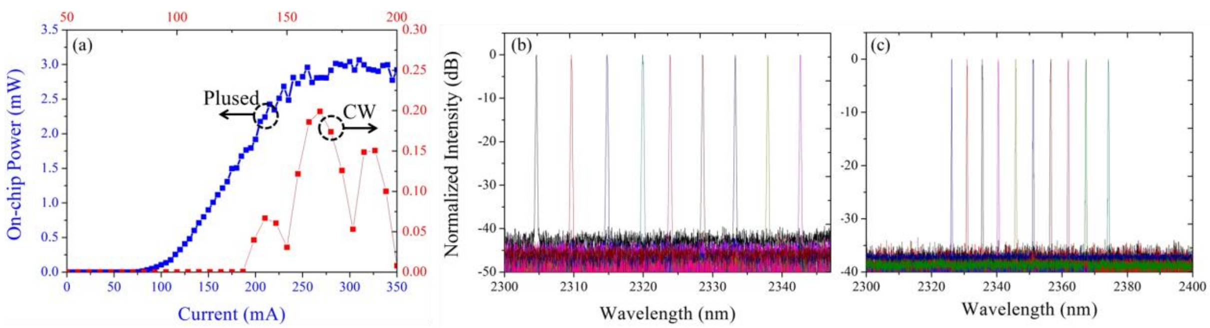

Fig. 2. (a) CW output power and peak pulsed output power as a function of the bias current at 5 ℃; lasing spectra of the III-V-on-silicon Vernier laser with a DBR grating pitch of 420 nm (b) and 460 nm (c).

4. Conclusion

We report for the first time widely tunable III-V-on-silicon lasers in the 2.3 µm wavelength range. The laser cavity consists of an InP-based type-II heterostructure gain section, two silicon DBRs and a Vernier filter. A single III-V-on-silicon laser can provide more than 40 nm tuning range. By adjusting the DBR grating pitch, a different wavelength region within the gain spectrum can be selected to lase. More than 70 nm tuning range in the 2.3 µm wavelength range can be achieved by combing two lasers with different DBRs.

References

[1] J. Hodgkinson and R. P. Tatam, "Optical gas sensing: a review," Meas. Sci. Technol. **24**, 012004 (2013).
[2] L. S. Rothman, *et al.*, "The HITRAN2012 molecular spectroscopic database," J. Quant. Spectrosc. Radiat. Transf. **130**, 4-50 (2013).
[3] N. V. Alexeeva, and M. A. Arnold, "Near-Infrared Microspectroscopic Analysis of Rat Skin Tissue Heterogeneity in Relation to Noninvasive Glucose Sensing," J. Diabetes Sci. Technol. **3**, 219-232 (2009).
[4] K. Vizbaras, *et al.*, "High power continuous-wave GaSb-based superluminescent diodes as gain chips for widely tunable laser spectroscopy in the 1.95–2.45 µm wavelength range," Appl. Phys. Lett. **107**, 011103 (2015).
[5] R. Wang, *et al.*, "Compact GaSb/silicon-on-insulator 2.0x µm widely tunable external cavity lasers," Opt. Express **24**, 28977-28986 (2016).
[6] S. Sprengel, *et al.*, "InP-based type-II quantum-well lasers and LEDs," IEEE J. Sel. Topics Quantum Electron. **19**, 1900909 (2013).
[7] R. Wang, *et al.*, "Broad wavelength coverage 2.3 µm III-V-on-silicon DFB laser array," Optica, **4**, 972-975 (2017).