GaSb/SOI flip-chip integrated DBR laser at 2 µm wavelength region

(Student paper)

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Integrated photonics is rapidly progressing towards addressing the needs of a wider range of applications, owing to its potential for mass manufacturability and miniaturization. This development trend requires novel laser sources compatible with silicon photonics technology and operating at wavelengths beyond the traditional telecom window. In particular, novel applications in gas sensing or medical diagnosis require operation at 2–3 µm range. To this end, the first flip-chip integrated hybrid laser comprising a cavity formed by a GaSb gain element and a distributed Bragg reflector (DBR) grating realized in a silicon photonics platform is demonstrated. The laser emitted slightly more than 6 mW at room temperature with a narrow spectral linewidth.
Keywords: *SOI, GaSb, flip-chip, DBR*

INTRODUCTION

Photonics Integrated Circuits (PICs) technology has seen prodigious growth since its advent, powered by penetration to an increasing number of volume applications, such as datacom, sensing, or lab-on-chip bio-photonics. In this context, silicon photonics (SiPhs) and InP-based PICs have become already mature technology with major commercial deployment in datacom applications, operating around 1.3 µm and 1.55 µm wavelength regions [1,2]. However, many other emerging applications, for example, sensing of atmospheric pollutants [3] or real-time monitoring of biomarkers [4], such as glucose, lactates, or ethanol would require wavelength extension of PIC platforms beyond 2 µm. While the heterogeneous integration of InP light-emitting material and SiPhs have enabled the wavelength extension slightly beyond 2µm [5], the further wavelength increase is limited by the inherent bandgap engineering of InP. To this end, GaInAlAsSb/GaSb-based laser diodes can reach an emission wavelength up to 3.5 µm [6], which then can be leveraged to SiPhs applications.

Hybrid extended cavity lasers based on GaSb reflective semiconductor optical amplifiers (RSOA) and SiPhs PICs have been already demonstrated near 2µm [7] and more recently at 2.6 – 2.7 µm window [8]. However, these demonstrations are based on butt-coupling GaSb and SiPhs chips on different carriers hence lacking essential integration features of PICs, like compactness and the ability to combine different types of chips on the same PIC. Here we demonstrate for the first an on-chip hybrid distributed Bragg reflector (DBR) laser comprising GaSb RSOA and a 3µm thick silicon-on-insulator (SOI) circuit waveguide for wavelength locking. The integration method is based on "flip-chip" bonding. Specifically, we are deploying the µm-scale SOI waveguide technology, which we have shown to exhibit low loss at 2.65 µm [9]. In general, the µm-scale SOI waveguides exhibit lower loss at mid-IR compared to more conventional submicron waveguides. This is because of the strong mode confinement in the Si waveguide, which minimizes the cladding loss and scattering loss. Moreover, the optical mode size for propagation in µm-scale SOI waveguides matches the mode size of III-V waveguides enabling high coupling efficiency between the two platforms. This demonstration opens an attractive perspective towards wavelength versatility by integrating broadband GaSb-based gain chips for the detection of multiple gas or biophotonics.

DESIGN AND FABRICATION

The detailed hybrid DBR laser cavity architecture used in this work is shown in Figure. 1. It comprises a J-shaped ridge waveguide RSOA [10] end-fire coupled to a tilt-facet DBR on SOI. The tilt angle of the RSOA, θ, was 7° and was optimized for the minimum back reflection. The RSOA ridge waveguide (RWG) width and epitaxially grown waveguide thickness were optimized to maximize simultaneously the coupling efficiency between the two waveguides (mode overlap) and RSOA modal gain. The simulation results for the mode mismatch

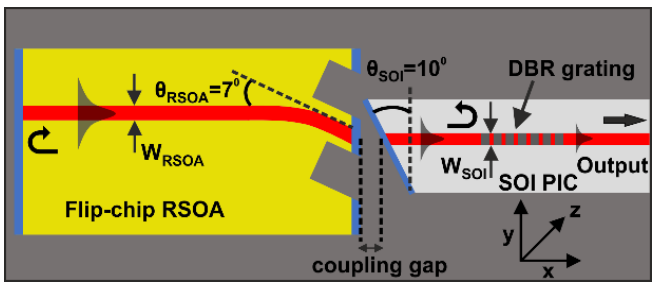

Fig. 1. Schematic of the hybrid integrated DBR laser based on flip-chip integration of RSOA and SOI waveguides.

loss and quantum well confinement (QWC) factor are shown in Figure 2. The ridge width and waveguide thickness were chosen to be 3µm or 5µm, and 130nm respectively. These values ensured a mode mismatch loss of ~0.6dB and quantum well confinement (QWC) factor of ~ 2.4%.

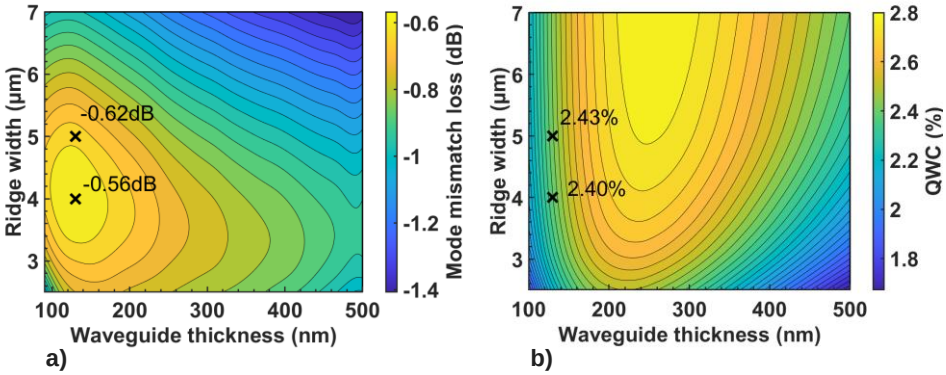

Fig. 2. Simulated mode mismatch loss (dB) between the RSOA and SOI waveguides, assuming perfect alignment, and b) quantum well confinement factor (%) in RSOA, for varying RSOA epitaxial waveguide thicknesses and ridge widths. The markers indicate the parameters used in the fabrication.

The epitaxial structure was grown by molecular beam epitaxy (MBE) using similar parameters as previously reported for the state-of-the-art superluminescent diodes [10]. The RWG width and the etch depth were optimized to ensure operation with the transverse electric single-mode profile. The RWG was defined by UV photolithography and dry-etched with an inductively coupled plasma reactive ion etch system(ICP-RIE). Additional ICP steps etch were done to etch a trench, which was used to fine-tune the optical axis vertical alignment, as well as grooves along the RSOA front facet. This last step was essential in minimizing the gap between RSOA and SOI waveguide, as shown in Figure.1. For current confinement, SiN_x was deposited and a contact window was etched at the center of the RWG employing photolithography and RIE-etching. The p-side contact consisted of Ti/Pt/Au-layers that were deposited with an e-beam evaporator. The sample was thinned to allow the subsequent cleaving of high-quality facets and on the n-side of the sample, a Ni/Au/Ge/Au stack was evaporated to form the n-contact. The wafer was cleaved into bars and the rear and front facets were coated with high-reflection (HR) and anti-reflection (AR) coatings, respectively. Individual devices were tested under continuous wave (CW) current injection before the flip-chip bonding.

RESULTS AND DISCUSSION

The hybrid integrated DBR lasers were tested under controlled temperature and continuous wave (CW) operation. The output power as a function of the injection current at 23˚C is shown in Figure. 3. The maximum output power of 6.12 mW was achieved for an injection current of 352 mA where the laser emits around 1984nm. Thermal tuning was also measured to be 0.14 nm/ ˚C. The oscillations in the power-current curve are caused by the laser locking to the DBR mirror, i.e. at the peaks the cavity mode overlaps with the resonance peak of the DBR, and in the dips, there is minimal overlap between the cavity mode and DBR resonance. In addition, the output power is saturated at larger currents due to increased thermal and carrier-induced losses in the RSOA.

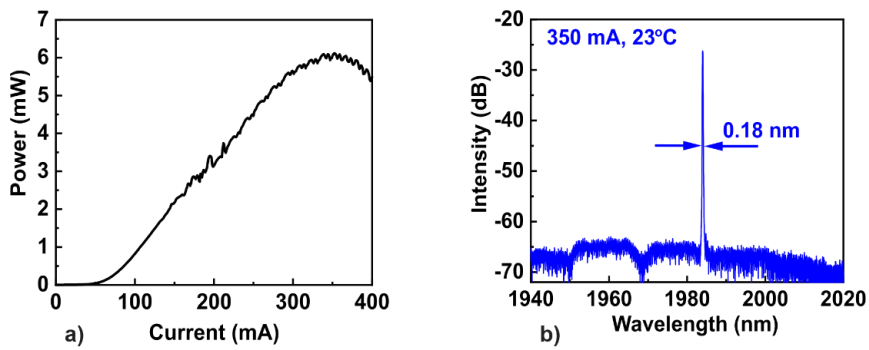

Fig. 3: a) The light-current characteristic curve of the hybrid laser at 23˚C, and b) the spectrum of same laser at 23˚C for an injection current of 350 mA. The maximum wavelength was 1984 nm with a full-width at half-maximum of 0.18nm.

CONCLUSION

A GaSb/SOI hybrid DBR laser based on the flip-chip integration technique was demonstrated. A GaSb RSOA was - based on a double quantum well with a J-shaped waveguide provided gain at around 2 µm. The use of µm-scale SOI enables a mode mismatch loss as low as 0.6 dB assuming perfect alignment. The hybrid DBR laser generated a CW output power up to 6.12 mW at 23˚C. Further work is aimed at the wavelength extension beyond 3 µm wavelength, and demonstrating advanced tuning capability, so far realized only using but-coupling between GaSb and SOI chips mounted on different carriers.

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