Discretely Tunable GaSb/Si_3N_4 Hybrid Laser Emitting at 2594, 2629, and 2670 nm

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Abstract. Details on the development and characterization of a discretely tunable GaSb/Si_3N_4 hybrid multiwavelength laser are presented. The integrated laser combines a GaSb-based reflective semiconductor amplifier with a novel Si_3N_4 circuit. The Si_3N_4 is comprised of two Mach-Zehnder interferometers interconnected with three thermally tunable distributed Bragg reflectors to form a discretely tunable hybrid laser. It showcases discrete emission at 2670.42 nm, 2629.12 nm, and 2594.27 nm wavelengths, with maximum average output powers of 2.8 mA at 480 mA, 5 mW at 410 mA, and 3.3 mW at 495 mA, respectively. The unique characteristics of the hybrid laser are appealing for multiwavelength absorption spectroscopy of H_2S, CO_2 and H_2O.

Keywords: hybrid lasers, GaSb, silicon nitride photonics

1 Introduction

Many important gases like H_2S, C_2H_4, CH_4, CO, CO_2, and N_2O [1], as well as biomarkers such as lactate, glucose, and urea [2,3], exhibit absorption in the 2–4 µm wavelength region. This makes this range particularly attractive for designing compact and efficient multiwavelength sensors. Mid-infrared hybrid integrated lasers, which combine GaSb-based semiconductor optical amplifiers (SOAs) with photonic integrated circuits (PICs), offer a promising avenue for achieving this goal.

Sensing applications typically require access to multiple absorption features to allow the detection of different analytes, and to increase the selectivity and accuracy of the measurement. In general, this can be achieved either with a tunable laser, such as a double ring resonator Vernier laser [4,5], that covers the whole gain bandwidth of the SOA, or with a multiwavelength laser (MWL), which emits and can be tuned around specific wavelengths [6,7].

Here, we present design and fabrication details of a tunable GaSb/Si_3N_4 hybrid MWL platform [9], employing a novel silicon nitride-on-insulator (SNOI) circuit. Using two thermally tunable Mach-Zehnder interferometers (MZIs) coupled to three thermally tunable narrow-band distributed Bragg reflectors (DBRs), we target lasing corresponding to absorption lines of H_2O, H_2S, and CO_2 of 2605.6, 2639.6, and 2682.0 nm,

respectively. By tuning the MZI arms, the emission wavelength of the laser can be switched between the DBRs, while the DBRs themselves have integrated heaters, allowing to fine-tune the emission wavelength. A schematic illustration of the laser circuit is provided in Fig. 1.

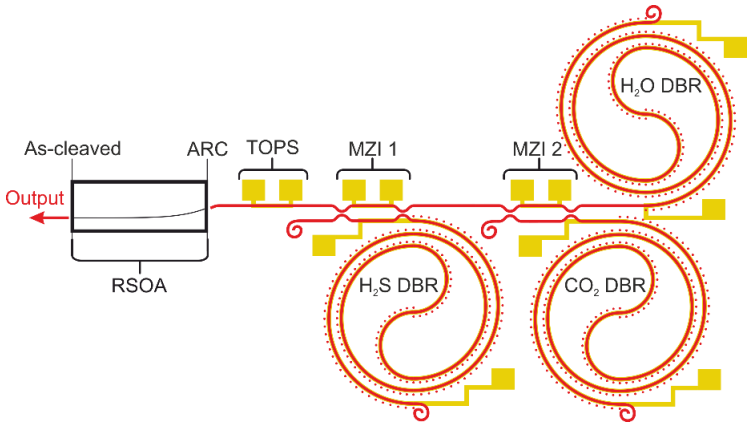

Fig. 1. Schematic of the GaSb/Si_3N_4 tunable hybrid MWL circuit.

The advantage of such a hybrid MWL design is that tuning the wavelength requires the simultaneous operation of only two heaters, the DBR and the TOPS. This is in contrasts with a Vernier hybrid laser, where wavelength tuning requires the simultaneous tuning of three heaters, the two ring resonators and the TOPS [5]. Moreover, compared to previous demonstrations of MWLs [6,7], our design has the advantage of achieving multiwavelength emission with a single SOA component, decreasing the footprint, assembly effort, yield, and complexity of the laser compared to an assembly combining multiple SOAs. The hybrid MWL emits at wavelengths of 2670.42 nm, 2629.12 nm, and 2594.27 nm, showcasing its multiwavelength operation capability.

2 Measurements

The SNOI chip was manufactured utilizing an open-access foundry service (LIGENTEC). The laser includes a GaSb-based reflective SOA (RSOA) with a ridge waveguide (RWG) architecture. The RWG utilizes a J-shaped geometry with a tilted (7˚) front facet with an anti-reflectance coating (ARC) to minimize back reflections and maximize transmission, and a straight as-cleaved rear facet to provide ~30% reflection. The light from the RSOA is coupled to an 800-nm-thick SNOI waveguide. An inverse taper tapering from 1.65 µm to 0.4 µm towards the facet was utilized to maximize coupling; the coupling loss was measured to be ~3 dB at 2.55 µm. The 1.65 µm SNOI waveguide width was chosen to prevent the excitation of higher order lateral modes. The waveguide propagation loss of 0.67 dB/cm was measured at 2.68 µm utilizing a Norcada distributed feedback (DFB) laser. A 700-µm-long thermo-optic phase shifter (TOPS), consisting of a resistive heater layer placed above the waveguide was utilized

in both lasers to allow phase-matching the RSOA with the SNOI circuit to maximize power and spectral purity. The MZIs were formed with two 50/50 broadband phase-controlled directional couplers (PC-DC), exhibiting a low measured insertion loss of ~0.2 dB at 2.68 µm. A 700-µm-long TOPS was placed in both MZI arms to allow switching between the two output channels.

The DBRs were formed by placing periodic circular posts next to a spiral waveguide to achieve high-reflectance and narrow-bandwidth DBRs [8]. To take into account variation in the DBR resonances caused by geometric and index variations in the multi-project wafer (MPW) process, the resonances were designed 2.5 nm shorter than the target absorption lines, while also implementing resistive heaters above the DBRs to allow the laser to be tuned to the absorption lines. Thus, the target resonances for the DBRs were 2603.1 nm, 2637.1, and 2679.5 nm for the H_2O, H_2S, and CO_2, respectively.

The RSOA was placed on a heatsink that was stabilized to room temperature (23˚C), and the SNOI PIC was placed on a closed-loop piezo stage. The output signal was coupled to a multimode fiber connected to a photodiode, and the waveguides were actively aligned by maximizing the signal. The hybrid MWL was then switched to each of the three DBRs by applying current to the MZIs, and the IL characteristic of each DBR was measured by applying pulsed current (100 kHz frequency, 50% duty cycle) to the RSOA and measuring the average output power from 0 mA to 500 mA. The IL curves are shown in Fig. 2. When operating with the H_2O DBR, the laser has a threshold of 210 mA, and reaches a maximum average output power of 2.8 mW at 480 mA. Operation with the H_2S DBR led to a threshold of 185 mA with a maximum average output power of 5 mW at 410 mA. Finally, when operating at the CO_2 DBR, the laser had a threshold of 200 mA, and a maximum output power of 3.3 mW at 495 mA.

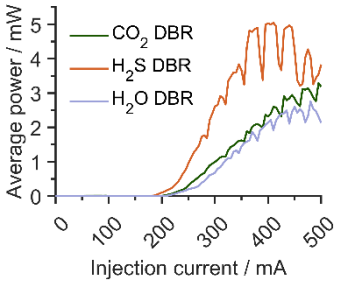

Fig. 2. IL curves of the hybrid MWL when operating at the different DBRs.

The spectrum of the hybrid MWL was measured for each DBR at 400 mA injection current is shown in Fig. 3 (left). These measurements reveal that the hybrid MWL achieves emission at 2670.42 nm, 2629.12 nm, and 2594.27 nm, showing successful switching between the DBR wavelengths. The wavelengths show on average ~8.6 nm blue shift comparted to the design wavelengths. By measuring the emission wavelength using several PICs from the same manufacturing process, we observed a ~1.0 nm standard variation in the wavelength, which is much smaller than the blue shift observed in the measurements. This implies that the shift can be attributed to inaccuracies in the Si_3N_4 refractive index data that was used in the simulations.

To measure the tunability of the hybrid MWL, the laser was switched to the CO_2 DBR, and the spectrum was measured without tuning, and with 140 mW power applied to the heater on top of the DBR. The results are shown in Fig. 3 (right), which shows that ~0.30 nm tuning is achieved at these power levels. The tuning was limited by the high 10-kΩ-level resistance of the DBR heater due to its long length. With an optimized heater design, multi-nm tuning is expected to be achievable with the hybrid MWL.

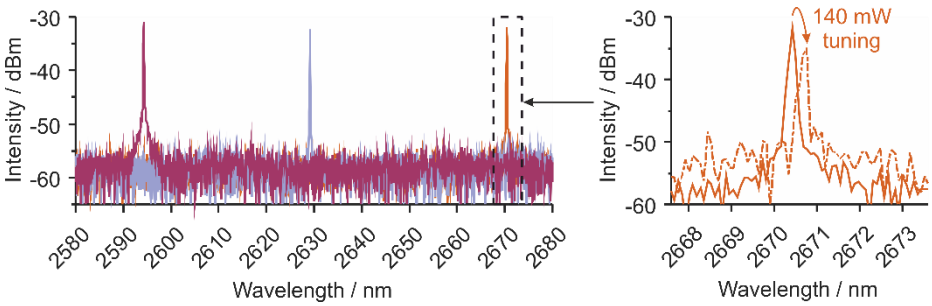

Fig. 3. Spectrum of the laser when the laser is switched to the different DBRs (left), and the CO_2 DBR emission spectrum without tuning, and with 140 mW applied to the heater on top of the DBR (right).

In conclusion, we have demonstrated a novel GaSb/Si_3N_4 hybrid MWL, which can be switched and tuned at 2670.42, 2629.12, and 2594.27 nm wavelengths. An output power of mW-level was achieved at each wavelength. The 2670.42 nm emission wavelength represents the longest wavelength emission achieved with a GaSb-based hybrid laser. Future research will focus on optimizing the DBR heater design, as well as integrating the RSOA on the PIC, and extending the wavelength towards and beyond 3 µm.

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