A hybrid-integrated external cavity laser with ultra-wide wavelength tuning range and high side-mode suppression

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Abstract: We present a III-V/Si_3N_4 hybrid-integrated tunable laser. The laser shows a record of ~170-nm tuning range with a side mode suppression ratio above 64 dB and an intrinsic linewidth below 2.8 kHz.

1. Introduction

High-performance semiconductor lasers are widely used in the fields of telecommunications, optical sensing, RF photonics, and atomic clocks, etc. Recently, integrated chip-scale lasers have been developed rapidly, showing a narrow intrinsic linewidth, high output power, a large side-mode suppression ratio, and a large tuning range [1-4]. Ultra-wideband (UWB) wavelength division multiplexed (WDM) systems [5] and light detection and ranging (LiDAR) systems (using the wavelength for beam scanning) [6, 7] require lasers operating over a wide wavelength range. There are a variety of solutions for chip-scale broadband wavelength-tunable lasers, such as distributed feedback (DFB) lasers, sampled-grating distributed Bragg reflector (SG-DBR) lasers, interferometric structure lasers, and external cavity lasers (ECLs). The wavelength tuning of the DFB lasers is mainly achieved by changing the grating refractive index. Due to the limitation of the thermo-optic coefficient, a 40-nm wavelength tuning range requires 12 channels of DFB lasers [8]. Although the Vernier grating design in SG-DBR lasers can effectively expand the wavelength tuning range, as far as we know, it does not exceed 72 nm while still maintaining a high side mode suppression ratio (SMSR) [9]. The tuning range of a typical interference laser is 52.5 nm [10]. An ECL can offer a wider tuning range than the others because the high-performance mode selection filter is separated from the gain section and it is easy to expand the free spectral range (FSR). In addition, an ECL is capable of a narrow linewidth and a high SMSR, because the external cavity significantly improves the quality factor. Here we present an ECL consisting of a broadband reflective semiconductor optical amplifier (RSOA) and a low-loss Si_3N_4 cavity extension chip. We use a three-microring-resonators (MRRs)-based Vernier filter to expand the FSR and enhance the side mode suppression. Therefore, the ECL shows a wide tuning range while keeping a high SMSR.

2. Device description

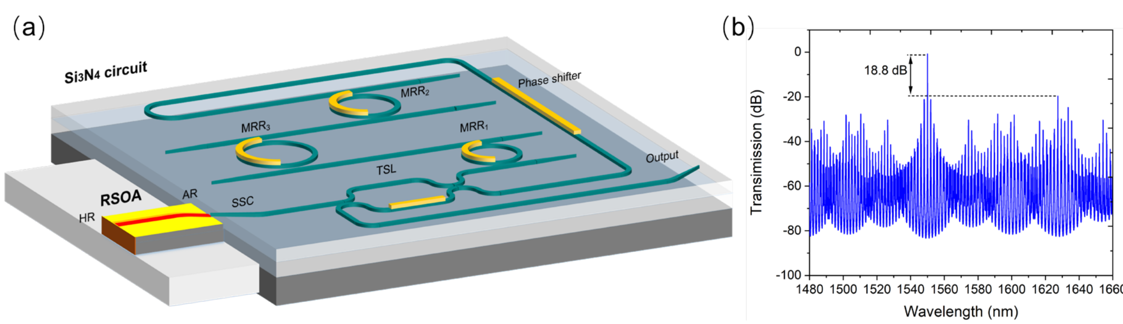

Fig. 1. (a) Schematic structure of the hybrid-integrated external cavity laser. HR, high-reflection coating; AR, anti-reflection coating; SSC, spot-size converter; MRR, microring resonator; TSL, tunable Sagnac loop. (b) Simulated transmission spectrum of the Vernier filter. The passive side mode suppression ratio is 18.8 dB.

Fig. 1(a) shows the structure of the hybrid laser, which consists of a 1-mm-long commercially available III-V RSOA and a low-loss Si_3N_4 cavity extension chip. The back facet of the RSOA is high-reflection (HR) coated serving as the back mirror of the laser. To suppress back reflection at the coupling interface, the coupling facet of the gain chip is anti-reflection (AR) coated and the waveguide is slanted so that the laser beam emits at an angle of 20°. The Si_3N_4 cavity extension chip was fabricated by LIGENTEC in the standard multi-project wafer (MPW) process. The waveguide propagation loss is <0.2 dB/cm at the wavelength of 1550 nm. The thickness of the waveguide is 800 nm and the width is 1 µm. An inverse taper with a tip width of 200 nm is tilted at 17.7° to match the beam emitting angle of the RSOA. A tunable Sagnac loop (TSL) reflector using a Mach-Zehnder interferometer (MZI) coupler serves as the output mirror of the laser cavity. Three cascaded add-drop MRRs with slightly different circumference (565 µm, 583 µm, and 611 µm) are inserted in the TSL to act as the longitudinal mode filter. Compared to a two-MRRs-based Vernier filter, the three-MRRs-based filter allows only one aligned resonance peak over the wide gain spectrum and the misaligned resonances are highly suppressed, leading to a higher SMSR of the lasing mode. The power coupling coefficient (PCC) between the three MRRs and the bus waveguides is 0.1 (MRR_1), 0.1 (MRR_2), and 0.05 (MRR_3). We simulated the transmission spectrum of the filter with the MRRs aligned at the 1550 nm resonance wavelength, as shown in Fig. 1(b). The wavelength dependence of the TSL is not considered. The desired Vernier resonance peak is 18.8 dB higher than the side peaks over the wavelength range of 1480-1660 nm. The 3-dB passband width is about 2.9 GHz. An additional phase shifter is also integrated in the Sagnac loop to tune the laser longitudinal mode.

3. Experimental results

We first measured the amplified simultaneous emission (ASE) spectra of the RSOA using an optical spectrum analyzer (OSA, YOKOGAWA, AQ6370D-12) with the resolution set at 0.1 nm. As shown in Fig. 2(a), the 3-dB bandwidth increases from 75 nm to 100 nm with the injection current increasing from 100 mA to 300 mA. The spectral ripple is less than 0.5 dB, indicating that no self-lasing occurs.

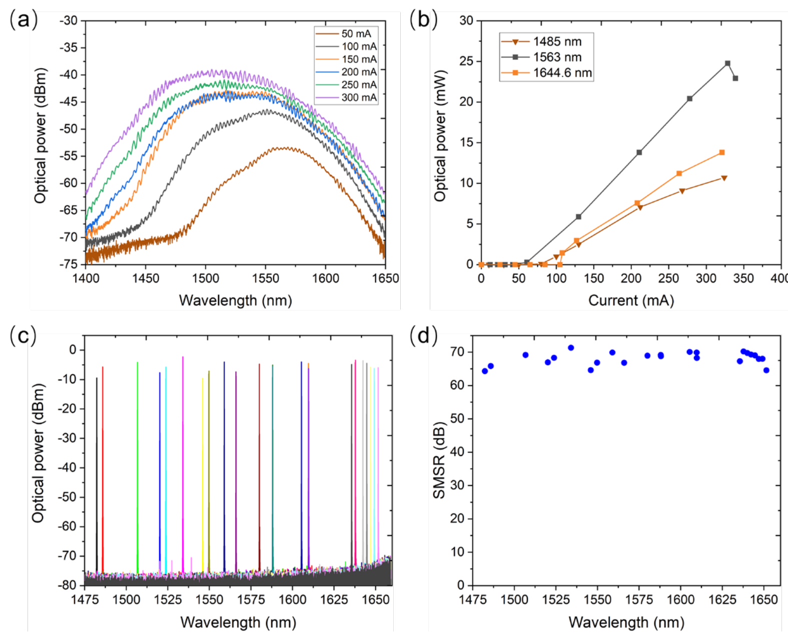

Fig. 2. (a) Measured ASE spectra of the RSOA. The ripple is below 0.5 dB. (b) Measured L-I curves at several typical wavelengths. The maximum power is 24.8 mW under a 329 mA pump current. (c) Superimposed lasing spectra of the hybrid-integrated laser. The wavelength tuning range is about 170 nm. (d) Extracted SMSR as a function of lasing wavelength. The SMSR exceeds 64 dB in the entire wavelength tuning range.

Laser wavelength tuning can be achieved by adjusting the MRRs and the phase shifter. First, the heating power of the MRRs is changed to align the resonances to a new wavelength. Then, the phase shifter is adjusted to align the laser mode to the filter peak to maximize the output power. We measured the light-current (L-I) curves of the laser at wavelengths of 1485 nm, 1563 nm, and 1644.6 nm. As shown in Fig. 2(b), the maximum on-chip optical power is 24.8 mW at the 1563 nm wavelength, limited by the increased temperature of the RSOA. The output power can be further increased by improving the coupling efficiency through a box-type spot-size converter (SSC) on the Si_3N_4 chip [11]. Fig. 2(c) shows the superimposed lasing spectra measured by the OSA with a wavelength resolution of 0.02 nm. The lasing wavelength is tuned from 1482.3 nm to 1651.6 nm, covering half of the S-band, the full C- and

L-band, and half of the U-band. To the best of our knowledge, this tuning range is a record for the chip-scale ECLs. Fig. 2(d) shows the associated SMSRs of the laser spectra. The SMSR exceeds 64 dB over the entire wavelength tuning range. The increased noise floor on the long-wavelength side beyond 1610 nm is attributed to the measurement range of the apparatus. Compared to our previous work [4], the improved SMSR benefits from the high passive side mode suppression of the three-MRRs based Verner filter.

We also measured the optical frequency noise (OFN) using a commercial phase noise measurement system (SYCATUS, A0040A). Fig. 3(a) shows the OFN power spectral density at the wavelength of 1506 nm. In the measurement, the reflectivity of the TSL was set so that the output power reached 7.8 dBm at an injection current of 300 mA. The intrinsic linewidth is 0.61 kHz, calculated by multiplying the white frequency noise level by π in the high-frequency range. We also measured the OFN at several other wavelengths with the injection current set at a similar level. As shown in Fig. 3(b), the intrinsic linewidth is below 1.55 kHz for most of the wavelengths. The slightly increased linewidth at both short and long wavelength ends may be caused by the decrease in gain or the misalignment of the laser wavelength from the optimal position of the filter.

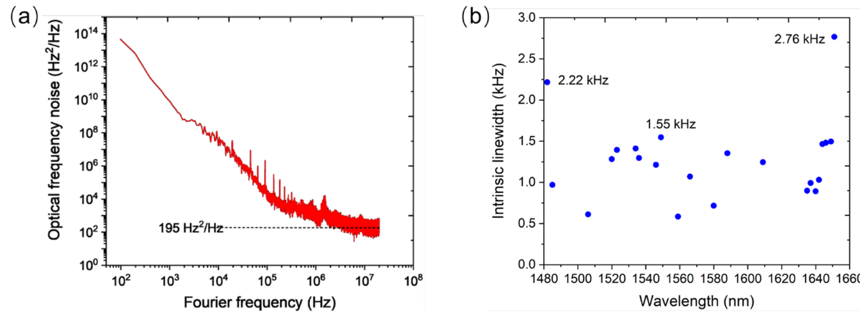

Fig. 3. (a) OFN power spectral density at the lasing wavelength of 1506 nm. The output power is 7.8 dBm at an injection current of 300 mA. (b) Intrinsic linewidth measured at various wavelengths.

4. Conclusions

We have demonstrated a hybrid-integrated ECL composed of a broadband RSOA and a low-loss Si_3N_4 chip. Benefiting from the three-MRRs-based filter, the laser establishes a record of ~170-nm tuning range while keeping a high SMSR above 64 dB over the entire tuning range. The maximum power reaches 24.8 mW and the intrinsic linewidth is below 2.8 kHz. The performance can be further improved by optimizing the coupling between two chips and increasing the effective length of the Si_3N_4 MRRs. The device shows that the performance of the chip-level hybrid laser is expected to reach that of an ECL based on free-space optics.

5. References

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