CMOS-Compatible Tunable Vernier Ring Laser using Erbium Doped Waveguide on a Silicon Photonics Platform

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Abstract: We demonstrate the first silicon photonic tunable laser with integrated erbium-doped Al_2O_3 waveguides. The laser is designed to have Vernier ring structure for wide tuning operation. It has a 0.23cm^2 footprint and 1.6mW output power. © 2018 The Author(s)

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Silicon photonics is a promising technology for integrated optical circuits [1, 2]. The high refractive index contrast between silicon and a silicon dioxide cladding enables compact devices. The compatibility with mature CMOS fabrication technology can lead to low-cost and high-volume production of silicon photonics devices. In an integrated photonic circuit, a tunable laser source is a key component for a variety of applications. Wide tunability is commonly obtained by utilizing the Vernier effect based on two cavities with slightly different free spectral ranges (FSR) [3-4]. Compared to lasers using III-V semiconductor gain medium, lasers based on erbium-doped gain medium have a wide gain bandwidth across the C- and L-bands. Additionally, erbium-doped lasers can achieve narrow linewidths with large side mode suppression ratios (SMSR) due to homogeneously-broadened gain. Since erbium can be co-sputtered with its hosts (e.g. silica, alumina, or phosphate glass), integration into a CMOS-compatible silicon photonics platform is straightforward as a back-end step. Monolithically integrated erbium-doped waveguide lasers have been demonstrated using erbium co-sputtered with Al_2O_3 as a host [5-6]. However, previously demonstrated lasers could not be actively tuned. Lasers using erbium-doped fiber as gain medium instead of an integrated gain medium with integrated silicon microdisk cavities have been demonstrated with passive [7] and active [8] wavelength tuning. However, these demonstrations were not compact since they are mostly fiber based and not fully integrated on-chip.

In this paper, we present a fully integrated erbium-doped laser on a CMOS-compatible silicon photonics platform. Wavelength tunability is achieved by utilizing a Vernier structure formed by two Si_3N_4 micro-ring resonators. Erbium-doped Al_2O_3 is used as the gain medium, and metal layers are deposited as heaters and contacts. Wavelength tuning over 46 nm (from 1527 to 1573 nm) with more than 40 dB SMSR is achieved. With 100 mW 980nm pump power on chip, up to 1.6 mW output lasing power is obtained, with a 2.2% slope efficiency. The fine-tuning capability of the lasing wavelength is demonstrated by tuning the gain cavity longitudinal mode phase shifter. In addition, the laser linewidth is measured to be 340 kHz by using the self-delay heterodyne method.

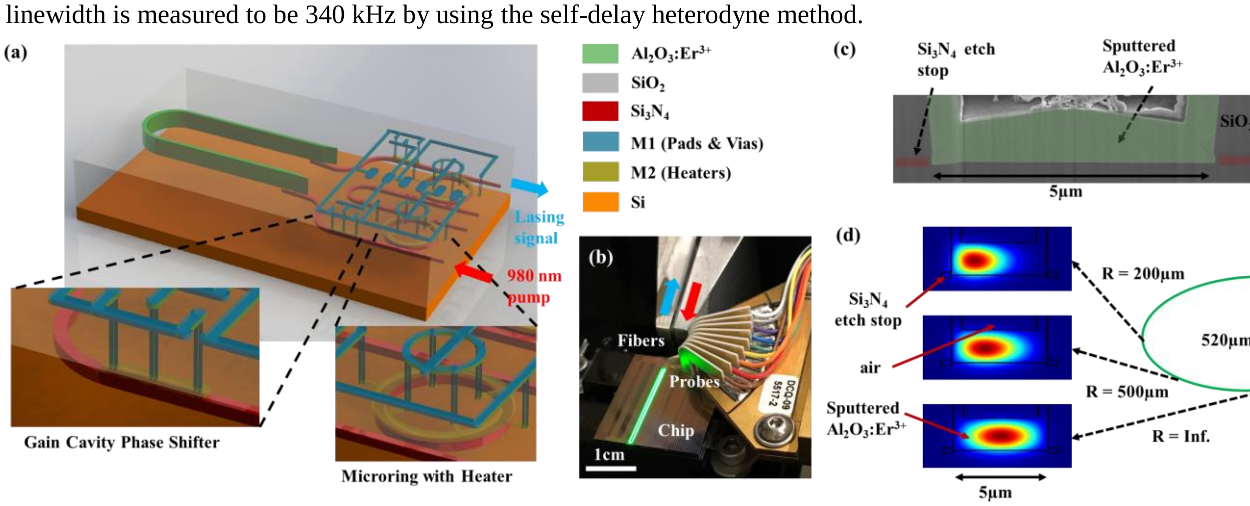

Fig. 1(a) 3D illustration of integrated tunable laser, showing different material layers, heaters for microring and gain cavity phase shifters (not to scale); (b) Fabricated device on the test setup, showing Erbium green color fluorescence under 980 nm pump; (c) SEM image of the tunable laser gain waveguide cross section; (d) The transverse electric (TE) field intensity of the fundamental mode for different bend radii along the Euler bend.

A schematic perspective view of the tunable laser design is shown in Fig. 1(a). The rings are made of 200 nm thick and 1.6 µm wide Si_3N_4 with a bending radius of 100 µm and 104.6 µm, thereby giving a FSR of 2.23 nm and 2.13 nm, respectively. The length of each gain cavity phase shifter is 500 µm and 2π phase shift can be readily achieved. The gain waveguide is formed by a 1.1 µm thick $Al_2O_3:Er^{3+}$ film deposited in a 4 µm deep and 5 µm wide trench. The green color fluorescence due to the upconversion in Er^{3+} under pump is shown in Fig. 1(b). Fig. 1(c) shows an SEM image of the gain waveguide cross-section. The gain waveguide is bent to allow for a >4 cm long waveguide to provide sufficient gain. Fig. 1(d) shows the mode profile for several bending radii. The large bend mode mismatch between these modes is resolved by using an adiabatic Euler bend [9].

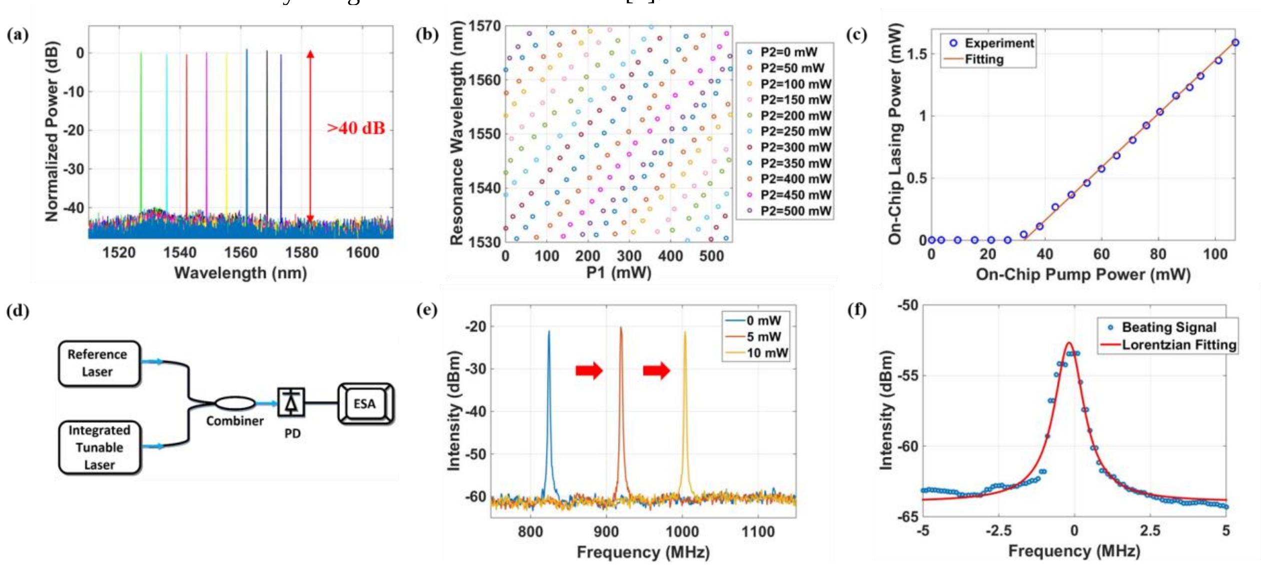

Fig. 2(a) Laser output spectrum showing 46 nm tuning range; (b) Laser cavity resonance wavelength tuning for difference heating powers applied on the heaters for both ring 1 and 2; (c) On-chip output power with respect to launched pump power, showing 2.2% slope efficiency; (d) Fine tuning measurement setup: the tunable laser signal and a signal at fixed wavelength are beat through a combiner; (e) The beat signal recorded by the electrical signal analyzer (ESA), showing continuous tuning. (f) Self-heterodyne spectrum with Lorentzian fitting showing a linewidth of 340 kHz.

Both ring heaters are tuned for Vernier operation. The lasing wavelength tuning over the C-band from 1527 nm to 1573 nm is shown in Fig. 2(a). Wavelength tuning up to 46 nm with more than 40 dB SMSR is achieved. Fig. 2(b) shows the laser cavity resonance wavelength tuning by heating two microrings simultaneously. The laser output power at 1561 nm as a function of pump power is shown in Fig. 2(c). Lasing power up to 1.6 mW is collected from the output port when 107 mW is used for the 980nm pump. A slope efficiency of 2.2% with respect to on-chip pump power at 980 nm is obtained. To characterize the fine-tuning capability of the Er integrated tunable laser, a reference laser at a fixed wavelength is used to beat with the tunable laser through an optical combiner, as shown in Fig. 2(d). The gain cavity phase shifter is used for the fine tuning. The beat signals under different electrical powers supplied to the gain cavity phase shifter are shown in Fig. 2(e). As we increase the heater power, the beat signal shifts continuously to higher frequencies, without mode hopping. In order to measure the linewidth of the Er integrated tunable laser, a delayed self-heterodyne detection method [10] is used. A stable and narrow linewidth of 340 kHz is observed.

In conclusion, we have demonstrated a fully-integrated erbium-doped tunable laser on a silicon photonics platform. Two Si_3N_4 microring resonators are used to form a Vernier cavity. The tuning range is from 1527 nm to 1573 nm with >40 dB SMSR. A slope efficiency of 2.2% is reported, with 1.6 mW maximum output power. Fine tuning of the signal is demonstrated by tuning the gain cavity phase shifter. The laser linewidth is measured to be 340 kHz.

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