

Integrated tunable ring resonator for the InP membrane on silicon platform

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Abstract – In this paper we present a thermally tunable ring resonator for use in a laser cavity on the InP Membrane On Si (IMOS) platform. A resonance shift of 210 pm is found for 1mW power dissipation in a heater on top of the ring.

Introduction

InP Membrane On Si (IMOS) is a highly promising platform for photonic integration, as it enables realization of small devices and combines both active and passive components in one optic layer [1]. One of the most important components for this platform is an efficient laser [2]. In this work we present the tunable ring resonators for the laser, which give an opportunity for tuning a single laser mode over a wide range using the Vernier principle [3].

Design

To design the ring resonator the FDTD method was used. The cross-section of the waveguide with heaters is shown in Fig. 1 (a)

The standard dimensions of IMOS waveguides are 400 nm width and 300 nm height. We need to obtain an FSR of around 3 nm to match the channel spacing of a WDM system. For a Vernier laser it is enough two resonators each by only 1/8 of the FSR. For the thermal tuning we take into account wavelength and temperature dependence of the refractive indexes [3]. Based on previous measurements the group index used in simulation is 3.8 and the propagation loss is 15 dB/cm. The ring radius in this case is around 30 μm . The simulated spectra and Q factor dependence on the gap between a bus waveguide and the ring are presented in Fig. 1 (b) and (c), respectively.

Also we solved the heat equation using FEM to find the amount of dissipated power needed to shift the spectrum of the ring resonator by 1 FSR. The heater a metal stripe above the resonator through which a current is flowing. To avoid optical losses due to the metal there is a 1 μm SiO₂ buffer layer between the waveguides and the heater.

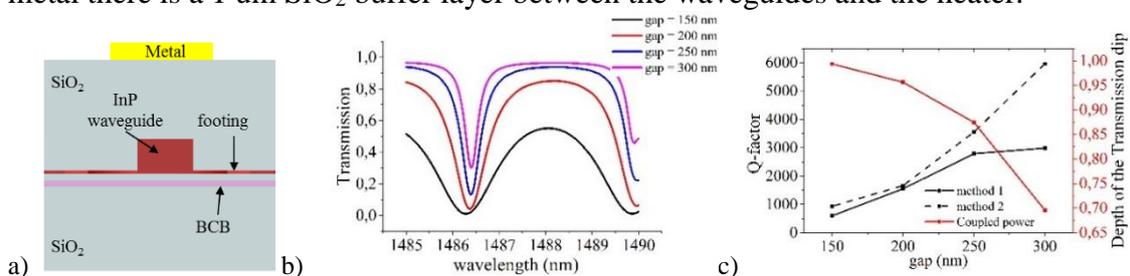


Fig. 1. (a) Cross-section of the waveguide and the metallization; (b) Spectra of the ring resonator for different gaps between the ring and the bus waveguide; (c) dependence on the gap of the depth of the transmission dip, the Q-factor calculated from the FWHM (method 1) and the Q-factor calculated from the decay over time of the output pulses (method 2).

Calculated temperature change for tuning of the resonance spectrum over 1 FSR is 41 °C (see Fig. 2 (a)). From the FEM calculations we obtain the waveguide temperature dependence on the dissipated power in the heater (see Fig.2 (b)).

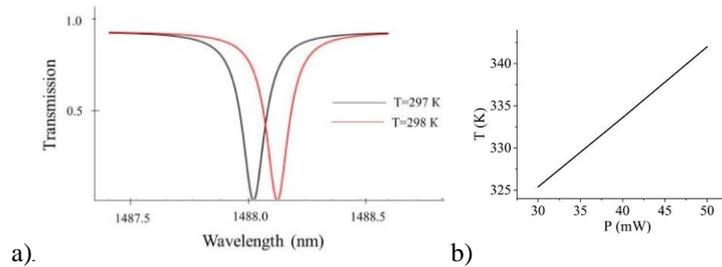


Fig. 2. (a) Calculated wavelength shift with temperature change; (b) Waveguide temperature dependence on dissipated power.

It was found that for heating the by 41°C it is necessary to dissipate 45 mW of power. This means a current injected in our heater of 40 mA.

Fabrication

The fabricated rings have two bus waveguides which forms half of the Vernier cavity. The distance between the ring and the bus waveguides varies from 100 nm to 500 nm with 50 nm steps.

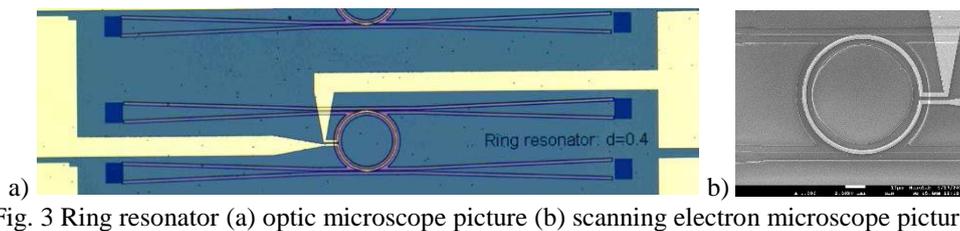


Fig. 3 Ring resonator (a) optic microscope picture (b) scanning electron microscope picture

The fabrication process starts with InP and Si substrates. On the InP substrate InGaAs and InP layers are grown. InGaAs is a sacrificial layer, which is necessary for saving InP-membrane during InP substrate etching. First of all, 1800 nm of SiO₂ and 50 nm of SiO₂ are deposited on the Si and InP samples, respectively, for better adhesion. Then, a layer of BCB is spun. In total, the combined thickness of the SiO₂ and BCB layers is 1900 nm, which gives constructive interference in grating couplers for input and output. After spinning of BCB the two samples are bonded and the InP substrate and the sacrificial InGaAs layer are etched away. At the next step, two lithographies are conducted; for grating couplers and for the waveguides. After etching these structures, 1 μm layer of SiO₂ is deposited and then the metal layer is evaporated and patterned using lift-off lithography.

Measurement

First measurements without heating were conducted for choosing the ring resonator with optimal parameters. In Fig. 4(a) spectra of ring resonators with different gaps between the bus waveguide and the ring are represented. Fig. 4 (b) shows the dependence of Q-factor and depth of the transmission dip on the gap width.

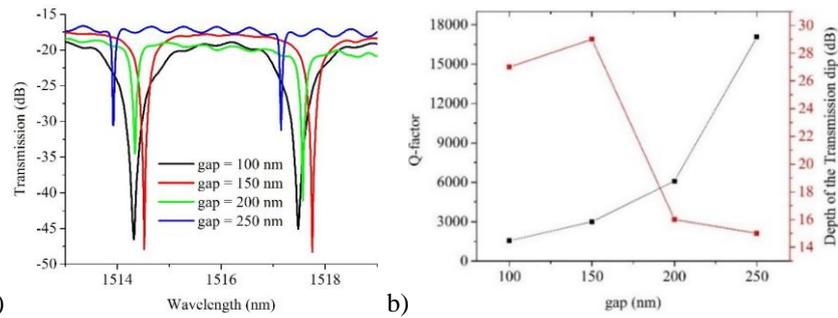


Fig. 4. (a) Spectra of the ring resonator with different gaps; (b) Q-factor and the depth of the transmission dip dependence on the gap

Fig. 4 (b) shows, that a trade-off between the Q-factor and the transmission dip can be chosen. In this case the resonator is used in a Vernier cavity and a high value of Q-factor is required to obtain single mode lasing. However, as there are two ring resonators, and thus four coupling regions, in the Vernier cavity, the amount of light coupled through the rings should be high, i.e., the rings should be close to the critical coupling condition. Therefore, it is more suitable to choose the ring resonator with a gap in the range of 150 nm (with critical coupling) to 250 nm where around 90 % of the power is still coupled. After 4 coupling regions the feedback for the laser is > 65% which is sufficient.

In the next measurements the water controller temperature was increased in steps of 2°C, affecting the whole chip through heating of the chip holder. Results of the spectral tuning are represented in Fig. 5.

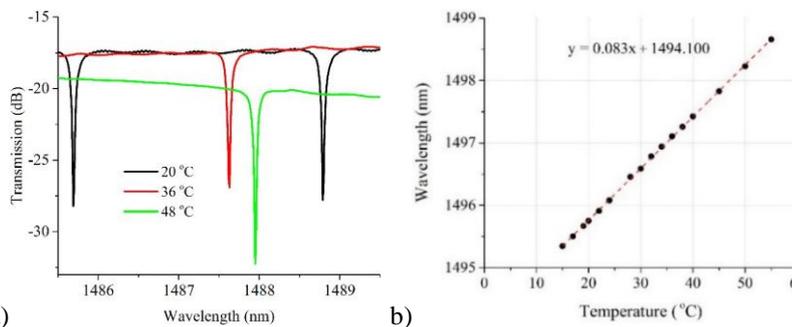


Fig. 5. (a) Spectra of the ring resonator at different water cooler temperatures; (b) Wavelength shift dependence on the temperature

In Fig. 5 (b) it is shown that an approximation of the experimental data was made (red line) using the linear equation $y = a \cdot x + b$, where $a = (0.083 \pm 0.003) \text{ nm/C}^\circ$. This means that by changing the temperature of the chip with 1°C the wavelength is shifted by 83 pm. Further measurement was done with injecting current in the metal stripe and thus heating the ring resonators. The results of this measurement are represented in Fig. 6.

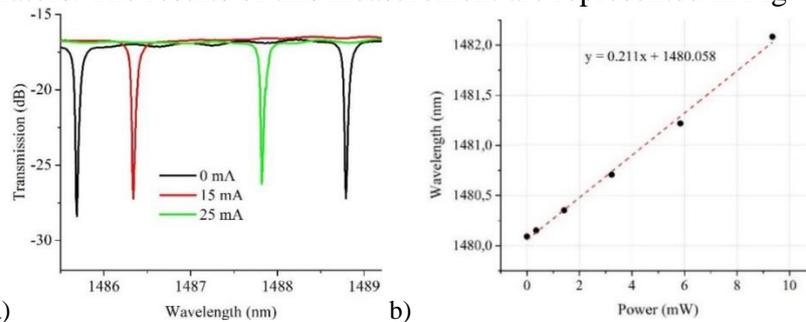


Fig. 6. (a) Spectra of the ring resonator at different currents; (b) Wavelength shift dependence on applied power

From Fig. 6 (a) it can be seen that with the current injection there is almost no change in Q-factor and transmission dip. Also, an approximation of the experimental data was made (red line) using the linear equation $y = a \cdot x + b$, where $a = (0.211 \pm 0.006)$ nm/mW. The equation which shows the dependence of the temperature shift of the ring on the power change is:

$$\frac{\Delta T}{\Delta P} \approx (2.542 \pm 0.159) \frac{^{\circ}\text{C}}{\text{mW}}. \quad (\text{Eq. 1})$$

Eq. 1 can be used for control of the temperature of the ring resonators with applied power change and thus for control of the spectral shift.

Conclusion

In this work we performed the design, fabrication and characterization of ring resonators for a Vernier laser cavity. Fabricated devices' spectra are measured in different conditions: with heating and injecting current into the metal stripe. From measurements it was found that for the use of the resonator in Vernier cavity resonators with the gaps ranging from 150 to 250 nm between the ring and the bus waveguide are most suitable. The relations for controlling spectral shift were. Tuning of the spectrum of each channel by 1/8 FSR can be realized with heating of the ring by 5°C, which corresponds to a power dissipated in the heater of 2 mW. Furthermore, calculations on the ring resonator were made where optical, thermal and electrical parameters were found: temperature change for the spectrum shift by 1 FSR is $T = 41^{\circ}\text{C}$, related power $P = 45$ mW. This is a factor of 2.5 smaller than what was found experimentally, which is most probably due to stronger heatsinking in the simulations, where a thinner BCB-layer was assumed.

References

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