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Silicon reflectors for external cavity lasers based on ring resonators

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ABSTRACT

We propose and experimentally investigate types of silicon ring reflectors on Silicon-On-Insulator (SOI) platform. These reflectors are used for realizing the silicon hybrid external cavity lasers. A suspended edge coupler is used to connect the reflective semiconductor optical amplifier (RSOA) chip and the reflectors. The properties of the reflectors and the hybrid external cavity lasers with these reflectors are illustrated. The experimental results show that all of those reflectors have a high reflectivity and the highest reflectivity can up to be 95%. The lowest insertion loss can be as low as 0.4 dB. The output power of the hybrid external cavity lasers with these reflectors can reach mW magnitude and the highest output power is 6.1 mW. Over 30 dB side mode suppression ratio is obtained.

1. Introduction

In recent years, optical interconnects has developed rapidly due to the large integration of devices on silicon [1]. The urgent need of high quality light source with narrow linewidth, high power and compact size promotes the progress of optical interconnects [2–5]. Silicon photonics has emerged as a promising and commercially-viable solution for high speed optical interconnection with low energy consumption, low latency [6,7]. Taking the good advantage of CMOS-technology, silicon material become the optimal choice for photonic products. However, the silicon is an indirect band material so the light source on a silicon photonics platform cannot be realized monolithically in a CMOS process. Many approaches have been researched for low energy consumption laser sources that can be also integrated with silicon photonics circuits [8–12]. So far, the most practical approach has been the hybrid integration of III–V with SOI. As for the hybrid integration laser, the external cavity plays a very important role because the parameters of the output in laser such as peak power, threshold current and repetition rate rely on the reflector cavity. Therefore, a good quality reflector is required.

Silicon based micro-ring resonators (MRRs) possess a wide variety of functionalities as for they have very high refractive index contrast, which allows realizing ultra-compact devices. In previous works, many structures of MRRs have been applied for the wavelength filters [13,14]. However, it is also possible to create reflectors using MRRs [15–17]. Besides, the small size as well as the tunability of MRRs make it suitable to replace the grating structures on silicon. A metallic heater is implemented on top of the ring resonator to allow thermal tuning of the resonant wavelength. Unlike the distributed bragg reflector which have a long cavity [18], ring-resonator external cavity is a good way to achieve the compact size and narrow linewidth.

In this paper, we demonstrate types of silicon ring reflectors with different characteristics. Four designs are implemented: the first one shows the structure of the coupled ring reflector. The second one is made up of ring resonator and a waveguide loop mirror which is used to play a role as a comb-like reflector. The third one is the combination of micro-ring resonator and grating reflector. The last one is composed of a micro-ring resonator and a Mach–Zehnder interferometer (MZI). The experimental results show that they all have a high reflectivity and the highest reflectivity can reach 95%. The insertion loss can be as low as 0.4 dB. So these micro-ring reflectors can be used for resonance cavity. The main application of the reflectors is applied as external cavity in hybrid external cavity lasers. The laser consists of the RSOA, a spot size converter and the wavelength tunable filter. The large mismatch between the silicon ring reflector and RSOA is solved by a suspended edge coupler. We measure that all the output power of the hybrid external cavity lasers with these reflectors can reach mW magnitude and the highest laser output power is 6.1 mW. The side mode suppression ratio (SMSR) can be over 30 dB.

2. Device structure and characterization

The hybrid external-cavity laser is formed by optical coupling between a silicon ring reflector and an III–V chip providing the optical gain. Wavelength selectivity is provided by the silicon ring reflector on SOI chip, while the optical gain is generated by RSOA.

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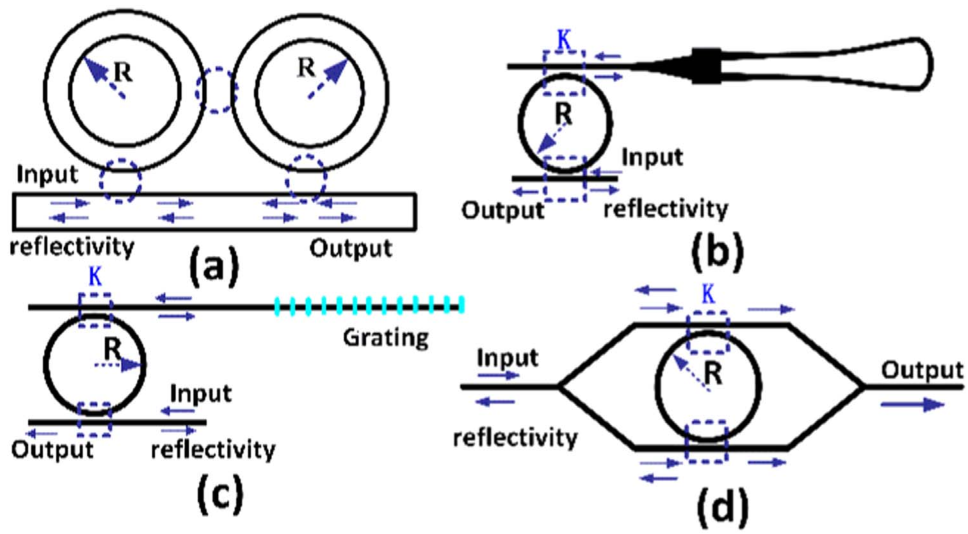

Fig. 1. Schematic structures of (a) reflector 1 (b) reflector 2 (c) reflector 3 (d) reflector 4.

The property of the ring reflector has a great influence on the property of the external-cavity laser.

Fig. 1(a) shows the schematic diagram of the coupled ring reflector. An incident optical wave is coupled into the clockwise wave of ring 1. The clockwise wave of ring 1 is coupled into the counterclockwise wave of ring 2. Finally, the wave is coupled into the backward wave of the bus waveguide. The diameters of the two ring resonators are the same. There are two factors which effect the reflectivity of the reflector. One is the coupling ratios containing ring-ring coupling ratio and ring-bus coupling ratio. The other is the loss coefficient. Fig. 2(a) shows the relationship between the single peak reflectivity and the coupling ratios when the loss coefficient is 2 dB/cm. From Fig. 2(a) it shows that single peak can only be obtained with an appropriate pair of ring-ring and ring-bus coupling ratios. Fig. 2(b) shows the impact of the loss coefficient to the reflectivity.

The other three reflectors are the reflectors based on the single ring resonator. Fig. 1(b) shows the schematic diagram of the reflector 2. It consists of a ring resonator and a waveguide loop mirror. By tuning the voltage applied on ring resonator, the

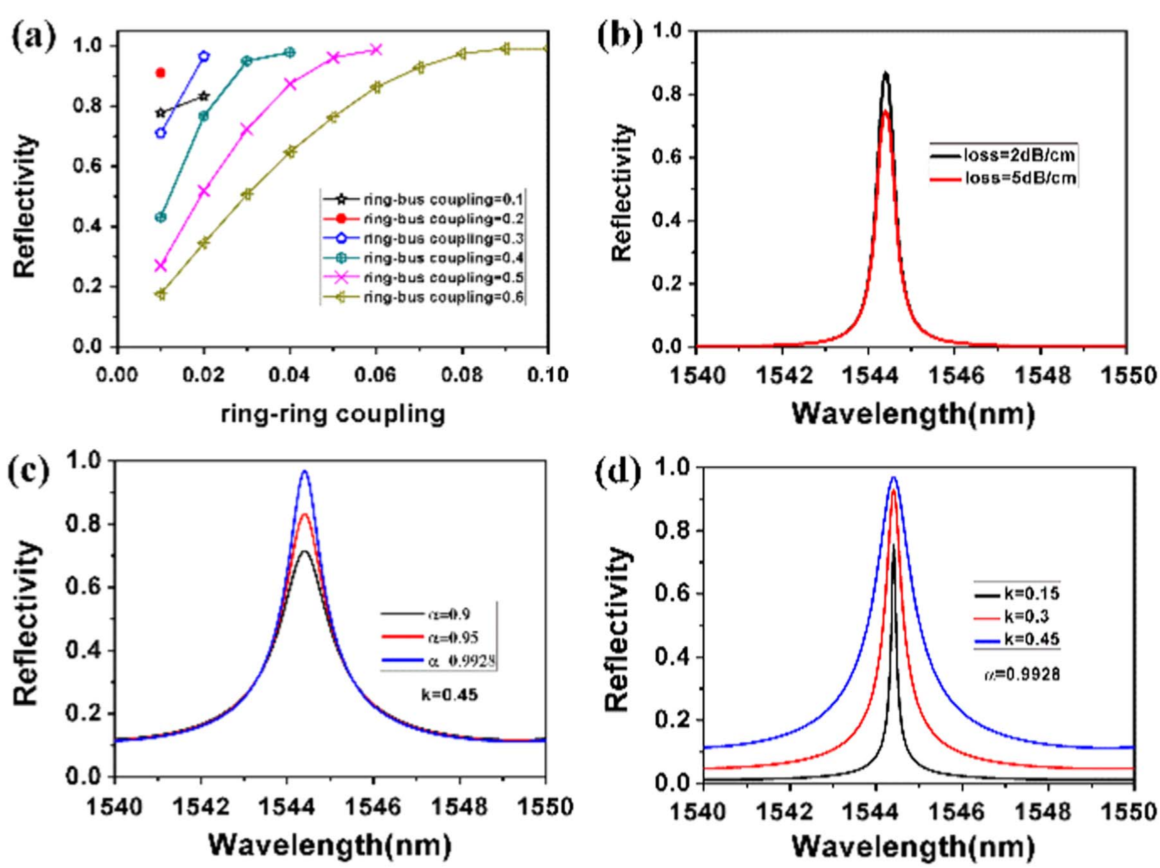

Fig. 2. (a) the relationship between the single peak reflectivity and the coupling ratios when the loss coefficient is 2 dB/cm (b) the impact of the loss coefficient to the reflectivity (c) reflectivity response as functions of amplitude attenuation factor (d) reflectivity response as functions of coupling coefficient.