Silicon Micro-ring Resonator Integrated in an Optoelectronic Oscillator System

(Student paper)

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ABSTRACT

In this paper, we present our recent results on the integration of an add-drop silicon micro-ring resonator in an optoelectronic oscillator (OEO) system for the generation of low phase noise RF signal at around 16 GHz. The add-drop ring serves as a selective band pass microwave filter in the OEO, being the frequency operation of the loop defined by the resonator free spectral range (FSR). The investigated micro-ring resonators have been fabricated using a standard silicon-on-insulator (SOI) substrate with 450-nm-wide Si waveguides and an unfolded physical length of 4.7 mm. To reduce the footprint of the device, a spiral arrangement was chosen with a total footprint of 500 µm by 500 µm. After fabrication, samples were tested using input and output grating couplers. The measured micro-ring resonators exhibited typical loaded qualities factors of around 120 000 at 1.55 µm wavelength. Optimized resonators were then introduced in the OEO system, to generate a RF signal around 16.2 GHz matching well the designed resonator FSR. These results constitute the first demonstration of an OEO RF oscillator integrating such a long SOI add-drop silicon ring resonator, paving the way for the future integration of an OEO system on a single chip.

Keywords: Function integration, silicon micro-ring resonator, microwave photonic filter, optoelectronic oscillator.

1. INTRODUCTION

Since the first introduced by X.S Yao and L.Maleke in 1994 [1], the optoelectronic oscillator (OEO) system is known for its ability to generate spectrally pure microwave signals. By using a long length optical fiber with extremely low losses to introduce a large delay to propagate microwave by an optical wave, this system has also potentials for providing tunability and the possibility of microwave comb-type generated RF frequency bands [2]. Because of these advantages, OEO has widespread applications in many fields of science and technology ranging from metrology to communications, radar and even sensing [3]-[5]. However, an OEO has some problems related to the optical fiber delay line that are difficult to solve. First of all, the use of long length optical fiber leads to a large number of RF frequencies satisfying the 2π phase oscillation condition of the loop. This may result in detrimental mode hoping from one of these frequencies to another. Moreover because of the dependence of the refractive index on temperature, the optical fiber delay line has to be placed into a temperature controlled box, which makes the system become bulky. An alternative approach to solve these problems of optical delay line in OEO has been proposed as early as 1999 [6] and consists in replacing the optical fiber by an optical resonator. Nowadays, many types of optical resonators have been proposed for use in OEO such as a whispering gallery mode (WGM) micro or mini-disk resonator [7, 8], optical fiber ring resonator [9]. However, these approaches are realized with a lack of integration, which makes them hardly transferrable to real applications. Here we present experiment results dedicated to an OEO loop in which a silicon micro-ring resonator is employed in order to replace the optical fiber delay line and that also acts as a selective microwave photonic band pass filter. This resonator has been fabricated based on silicon fabrication processes including electron beam (e-beam) lithography and inductively coupled plasma (ICP) etching.

2. OPTICAL RESONATOR FABRICATION AND CHARACTERIZATION

An overall view of the fabricated ring resonator is given in figure 1(a). The ring fabrication started by using silicon on insulator (SOI) wafer with 220 nm of silicon and a 2 µm buried oxide. The patterns were lithographically defined in a 100 nm of photoresist ZEP-520A by using e-beam lithography. After lithography, the patterns were transferred using ICP etching with Sulfur hexafluoride SF_6 and Octafluorocyclobutane C_4F_8 gas. After patterning, a top cladding of Poly methyl methacrylate (PMMA) was deposited. No additional post processing was done. The spirals consisted entirely of photonic wires with a width of 450 nm. Light was coupled in and out of the chip using vertical grating couplers, as shown in figure 1(d), that were optimized for transverse magnetic-polarized (TM) mode at 1550 nm wavelength. Several spirals with different combinations of coupling gaps/coupling lengths were fabricated with 500 µm x 500 µm footprints.

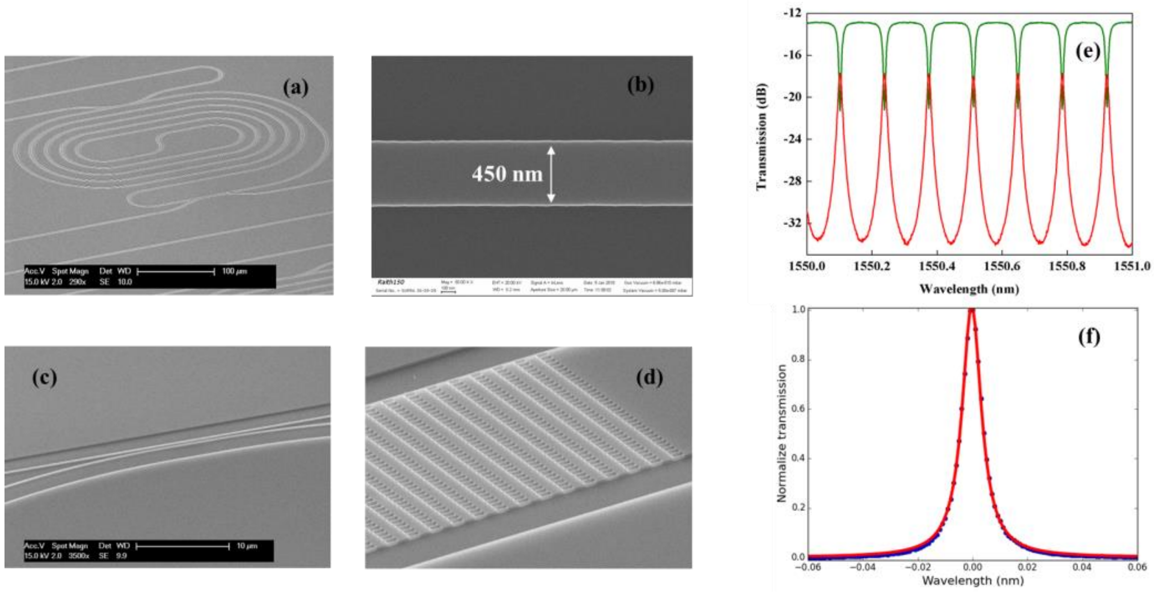

Figure 1. SEM pictures (a,b,c,d) and transmission spectrum (e,f) of an add-drop ring resonator

Figure 1(e) shows the transmission spectrum measured at the through and the drop ports of the add-drop ring resonator having a coupling gap of 400 nm and a linear coupling length of 17.5 µm. Figure 1(e) shows a Lorentzian curve fit of a single resonance peak, from which the loaded quality factor, Q_L, was determined to be 120 000. The *FSR* estimated from the transmission spectrum was 0.137 nm, which corresponds with 16.2 GHz. Moreover, from the transmission spectrum at both through and drop port, we estimated the intrinsic losses of 2.3 dB/cm based on the theory introduced by by Shijun Xiao [10].

3. DEDICATED OF MICRO-RING RESONATOR IN OEO LOOP

The schematic of the integration of the micro-ring resonator that we have performed into an OEO loop is shown in Figure 2(a). A CW laser beam at around 1.55 µm wavelength was modulated by the intensity modulator, with a frequency matching the FSR of the ring, and injected into the micro-ring resonator. The output signal at the drop port of the resonator was applied to the photo-detector, performing optical to electrical conversion. Due to the periodical spectrum of the resonator, a microwave signal of frequency corresponding with the optical ring FSR was generated. This RF signal is then amplified by a RF amplifier and split by an RF coupler (see Fig 2(a)). One part of the signal is sent to the electrical signal analyzer (ESA) while another is sent back to the modulator to form a closed loop OEO.

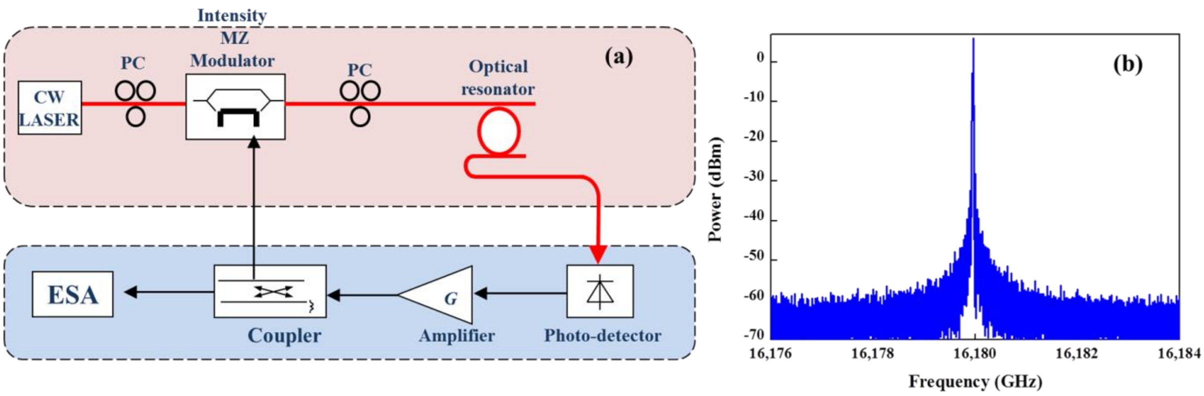

Figure 2. Experiment setup (a) and oscillation spectrum of OEO with integration of silicon ring resonator (b).

A typical generated microwave oscillation spectrum characterized is shown in Figure 2(b). The oscillation frequency observed of around 16.2 GHz, which corresponds to the FSR of the SOI photonics resonator. This result constitutes first observation of an OEO RF oscillator integrating such a long SOI add-drop silicon ring resonator.

4. CONCLUSIONS

We have successfully integrated a 16 GHz-FSR silicon add-drop ring as a microwave photonic band pass filter in an OEO system. As many optoelectronic elements in an OEO loop such as the modulator and the photodetector are now classical parts of the silicon photonics-tools and as other elements such as the RF amplifier and filter can be straightforwardly fabricated in CMOS lines, this work contributes to show the potential of fully integrated OEO systems in a single chip. Cost efficiency and scalability of such systems are envisioned to broaden their application in many fields.

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