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# Tunable optoelectronic oscillator based on silicon micro-ring resonator (INVITED)

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## ABSTRACT

A new silicon optoelectronic oscillator (OEO) system is proposed and experimentally demonstrated. The proposed OEO, generates the microwave signal by beating the un-modulated and amplitude-modulated versions of the same laser source. The drop port of a silicon micro-resonator is used to select one of the side band lobes generated by the amplitude modulation, thus serving as frequency selective element in the OEO. In this scheme, the microwave frequency generated is determined by the wavelength separation between the laser and the ring resonance. Thus, seamless microwave frequency tuning can be achieved just by sweeping the wavelength of the laser source. A proof-of-concept demonstration is implemented, experimentally showing microwave frequency generation in the range from 5.9 GHz to 18.2 GHz.

**Keywords:** Silicon photonic, function integration, silicon microring resonator, optoelectronic oscillator.

## 1. INTRODUCTION

The generation of broadband and low noise microwave and millimetre wave signals is important for a plethora of applications, including among other, radar, wireless communications, optical signal processing, warfare systems, etc [1]. Among various types of microwave and millimetre wave generation approaches, the optoelectronic oscillator (OEO) is a particularly interesting solution due to its capability to provide spectrally pure and wideband tunable signals [1]. However, the tunability of the conventional OEO is limited by the tunability of the microwave filter inside the loop, especially for high operation frequency. Microwave photonic filters (MPF) are a promising alternative to overcome this limitation, allowing reconfigurable microwave signal generation in OEO with a wide tuning range [2,3]. Moreover, the progress of integrated microwave photonics (IMWP) [4] provides now a solid framework for the possible full integration of OEOs.

Here, we propose a new approach for the implementation of Si OEO that allows for wideband tunability in the microwave signal generation. The oscillation signal is created by the beating between the optical source and one of the sideband lobes generated by amplitude modulation. This sideband lobe is selected by a silicon add-drop ring resonator (RR) working as an optical bandpass filter. We experimentally show that by tuning the wavelength of the source, the microwave frequency generated by the OEO can be tuned within the range from 5.9 to 18.2 GHz, which is limited by the elements available in the experimental setup.

## 2. PRINCIPLE OF OPERATION

The basic schematic and principle of operation of the proposed OEO are depicted in Fig. 1. In the proposed tunable OEO, the optical signal coming from laser source is separated in two branches, one is sent directly to photo-detector (PD) while the other is sent to an intensity modulator (IM). Initially, the modulator signal gets just seeded by white noise existing inside the loop. This signal is then passing through an add-drop RR before being sent to the PD. If the laser wavelength and one of the resonances of RR have the same phase and the distance between them is in close proximity in working range of the loop, then a beating of frequency will be generated. This beating signal is converted as an RF frequency ( $f_i$ ) through PD (point (2)).

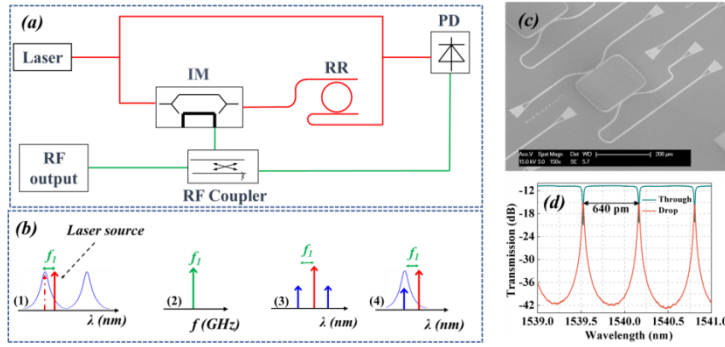


Figure 1. Basic schematic (a) and principle of operation (b) of the proposed tunable OEO, SEM of the fabricated ring resonator (c) and the optical transmission of the device (d) (coupling gap: 300nm, coupling length: 4.5  $\mu$ m). IM: Intensity modulator, RR: Ring resonator, PD: Photo-detector.

### 3. EXPERIMENTAL RESULTS.

For the proof-of-concept demonstration of the proposed OEO, we integrate only the micro-ring resonator in the silicon chip. The RR is an add-drop silicon ring resonator, implemented with 450-nm-wide strip waveguide, fabricated from SOI wafer with 220 nm thick Si thin film on top of a 3  $\mu$ m buried oxide layer. The fabrication result shows in Fig.1c. Fig.1d illustrates for optical transmission of the device. We obtained optical transmission with free spectral range FSR at  $FSR_\lambda = 640$  pm, corresponding with  $FSR_{f_{\text{res}}} \approx 77$  GHz. Optical quality factor  $Q_{\text{opt}}$  of the RR has been investigated by fitting the resonance peak through the Lorentzian function, by doing so, the  $Q_{\text{opt}}$  at  $8.1 \times 10^4$  has been obtained.

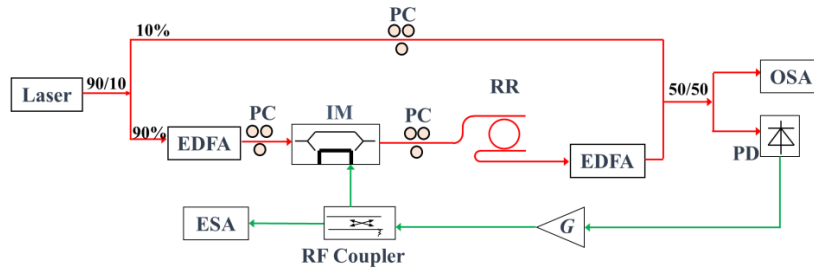


Figure 2. Experiment setup for tunable OEO. EDFA: Erbium doped amplifier, PC: Polarization controller, OSA: Optical spectrum analyser, G: RF amplifier and ESA: Electric spectrum analyser.

Figure 2 shows the experimental setup used to characterize the OEO. A 90/10 optical splitter is used to separate the light source from tuneable laser. 90 % of the optical power is sent to the Erbium doped amplifier (EDFA) followed by the IM, RR and a second EDFA. Signal at the output of second EDFA is combined with the other 10 % of the optical source (see Fig. 2) using 50/50 optical combiner. In the experiment setup, the polarization controller (PC) has been used in order to proper control the polarization matching between the laser source and the signal at the output of the second EDFA. At the output of the optical combiner, one arm is connected with the optical spectrum analyser (OSA) in order to read the laser or resonance wavelength while the other is connected with the PD. The final setup includes RF amplifier, RF coupler and electrical spectrum analyser (ESA). Fig.3a illustrates the electrical spectrum of the generated microwave signal at 5.9 GHz with resolution bandwidth of 2.2 kHz and span of 6 MHz.

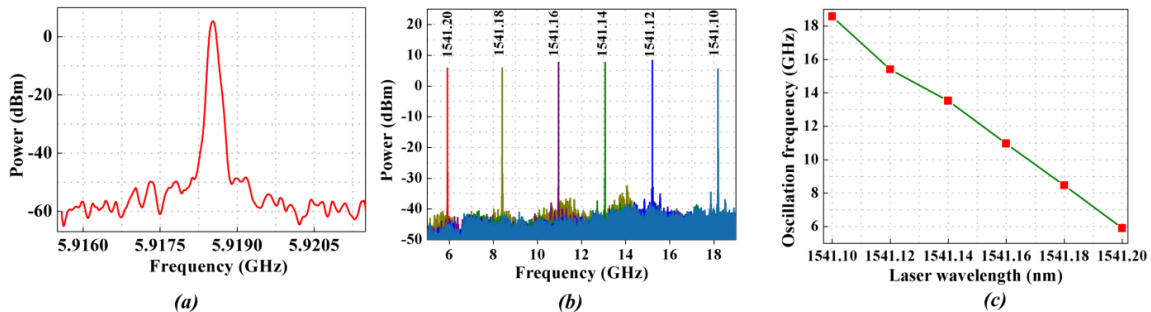


Figure 3. Spectrum of signal (a) and oscillation signal change with different laser wavelength (b) oscillation frequency / laser wavelength.

In order to quantify the tunability capability of the OEO, we sweep the wavelength of the laser and collect the microwave signal in the ESA. Fig.3b shows the measured oscillation spectrum with different laser wavelength, with a tuning range of 12.3 GHz, between 5.9 GHz and 18.2 GHz. Fig.3c illustrates the linear variation of the oscillation signal as a function of the laser wavelength.

#### 4. CONCLUSION.

As a conclusion, a novel OEO, based on add-drop Si micro-ring resonator, providing wideband tunability in the frequency of the microwave signal generated. The oscillation signal is created via the beating between a laser source and a sideband lobe produced by the intensity modulation of the same laser. We show experimentally that by changing the wavelength spacing between the optical source and the resonance wavelength, a microwave signal is generated with a tuneable frequency range from 5.9 GHz to 18.2 GHz. These results are an important step towards the implementation of tuneable OEO based on silicon photonics.

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An optoelectronic oscillator including a Si micro-ring is proposed to generate a frequency tunable microwave signal by beating the un-modulated and amplitude-modulated versions of the same laser source.