Microwave Frequency Mixer in integrated Photonic circuits for Signal Processing

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Abstract: We demonstrated the all-optical microwave frequency mixer in the integrated photonic circuits. A microwave light is mixed with the mechanical frequency by nonlinear optomechanical coupling, which is explained by stokes and anti-stokes process.

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1. Introduction

Frequency mixing refers to a nonlinear electrical circuit that creates new frequencies from two signals applied to it. It plays an important part in the modern signal processing of communication systems [1]. With the development of the optical communication system, it is desired to realize the all-optical frequency mixing without resorting to the electrical circuits [2]. More importantly, realizing the frequency mixing in the silicon photonics chips is of great interest for it is compatible with traditional CMOS process flow and are promising for integrated photonic systems. Most of the study of frequency mixing rely on the nonlinear characters of the materials [3]. However, it is hard to achieve the strong nonlinear optical effect in the silicon for the silicon is a relative low nonlinearity optical material. Rapid development of optomechanics provides an ideal platform to study the photon-photon interactions without resorting to the nonlinear material characters [4]. In this paper, we demonstrate the frequency mixing in the silicon ring resonator based on the nonlinear coupling between the mechanical resonator and input optical light. The frequency mixing not only has a wide working range but also can be well extend to microwave range, making it quite suitable for microwave photonic signal processing.

2. Results and Discussions

Figure 1(a) shows the three dimensional schematic of the silicon ring resonator with double-clamped beam separated by 200 nm with the ring. The modulated input driving light at frequency ω_d is pumped into the control waveguide and then couples into the ring resonator. The thermal mechanical noise of the beam at ω_m modifies the effective index of the ring and the changes the resonance wavelength, which is detected by the signal light. The nonlinear coupling between the mechanical frequency and modulated pump frequency generates the frequency mixing.

Fig. 1. (a) Schematic illustration of proposed optical ring resonator. The beam supported by the anchor is 200 nm separated with the ring. (b) Nonlinear coupling between the input driving light and mechanical resonance. (c) SEM image of the ring resonator with a scale bar of 5 µm.

Figure 1(b) shows the working principle of the frequency mixing, which can be analyzed by stokes and anti-stokes processes. The driving frequency has two side band frequencies labelled as ω_m and ω_d,m, which is due to stokes conversion. The frequency ω_d,m is generated by anti-stokes process. Figure 1(c) is the SEM image of the fabricated device. The ring resonator is fabricated with the standard CMOS compatible nano photonics processes on a 220 nm SOI wafer. The waveguide, ring resonator, grating coupler is patterned by deep UV lithography and etched by plasma dry etching. A 70 nm silicon dioxide hard mask is adopted to make the waveguide have a good profile and reduce the optical loss, in turn improving the mechanical and optical performance. Then the silicon structure is covered by a layer
of SiO$_2$ cladding (2 μm thick) which is deposited by using plasma enhanced chemical vapor deposition (PECVD). The ring resonator has a radius of 10 μm and the coupling gap between the ring and the waveguide is 200 nm. The cross section of the beam is 200 × 220 nm.

Figure 2(a) shows the transmission spectrum of the ring resonator with sensing and driving mode labeled. The ring resonator has a quality factor of $4.5 \times 10^4$ at 1583.3 nm. In order to avoid the influence of the driving signals, the two lights are pumped in counter directions. Frequency domain of the thermal mechanical noise with four fundamental modes is shown in Fig. 2(b). It should be noted that the four fundamental modes are not in the same plane. The in plane and out of plane mode have different mechanical quality factor, which are easy to be identified in the figure. Figure 2(c) shows the frequency domain of the fundamental frequency is shifted by the pump light due to the optical spring effect.

Figure 3 shows the experimental results of the frequency mixing. We first pump the signal light into the waveguide to measure the thermal mechanical noise then the modulated light is pumped to generate the frequency mixing. When the driving light is modulated at 11 MHz, the side band frequency is 14.2 MHz and 7.8 MHz separately, while the first mechanical frequency is 3.2 MHz, which is shown in Fig. 3(b). It should be noted that only the first mechanical frequency is mixed in our experiment. The frequency mixing is not only observed in pumping modulated light, but also demonstrate itself in the self-oscillation as shown in Fig. 3(c). The mixing can be extended to several hundred megahertz.

### 3. Summary

In this paper, we demonstrate the frequency mixing in the silicon ring resonator based on the nonlinear coupling between the mechanical resonator and input optical light. The working principle of the frequency mixing is analyzed by stokes and anti-stokes processes. The nonlinear coupling between the mechanical frequency and modulated optical frequency results in the sideband generation, which can be understood by anti-stokes and stokes process. The frequency mixing not only has a wide working range but also can be well extend to microwave range, making it quite suitable for microwave photonic signal processing.

### 4. References