Impact of Laser Detuning on Four-Wave Mixing in Microring Resonators

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***Abstract*—Dual-pumped four-wave mixing of microring resonators fabricated on a dispersive silicon on insulator material platform is experimentally explored. The conversion efficiency is obtained as a function of the pump laser detuning.**

***Index Terms*—four-wave mixing, microring, silicon nitride**

I. Introduction

Microring resonators used in the nonlinear regime have proven to be an essential building block for integrated photonics, with valuable use in a large variety of applications, including all-optical logic, neural networks, optical communications and quantum photonics. The effect of laser detuning on stimulated four-wave mixing (FWM) in such devices is not thoroughly studied: in this work, we explore the effect of laser detuning on double-pump stimulated FWM in highly dispersive silicon nitride (SiN), without the use of laser locking.

II. Device design and fabrication

The microring resonators (MRRs) are based on a 300 nm thick SiN platform; the SiN has been deposited with a low-pressure chemical vapour deposition (LPCVD) process. Strip waveguides are obtained. The ring geometry adopted is circular with single-bus coupling in a notch filter configuration.

The gap between the bus waveguide and the microring resonator has been optimized to achieve critical coupling. The design provided to the foundry includes a variation of the gap between the bus waveguide and the microring resonator to account for fabrication variabilities and to accommodate for the wavelength dependency of the direction coupler and the waveguide optical properties. The waveguide width is chosen to be 1.2 μm for single-mode operation, as well as for the achievement of low-loss. The optimal directional coupler gap, according to simulations, is 1 μm, but values from 0.6 to 1.2 μm have been investigated. CORNERSTONE has carried out the fabrication [1] on a 200 mm CMOS foundry. Fig.1 shows microscope image of microring resonators.

III. Device charcaterization

The measurement setup consists of two tuneable lasers (Keysight N7778C and EXFO T100s-HP) with < 10 kHZ and < 400 kHz linewidths, respectively, and of a high-sensitivity powermeter (-110 dBm), and an optical spectrum analyzer (OSA).

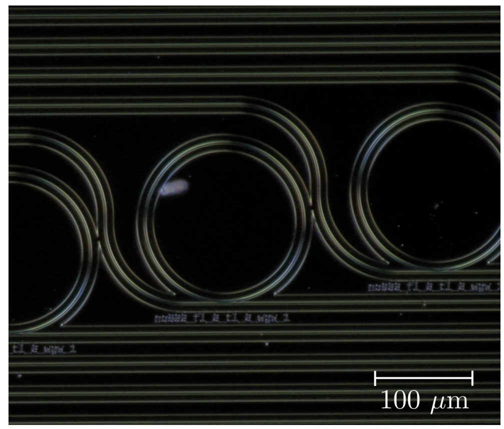

Fig. 1. A microscope picture of the characterized microring resonators. The different microring resonators shown have different directional coupler gaps.

A. Transmission and Q-factor Charcaterizaiton

In this section, we characterize the extinction ratios and quality factors (Q-factors) of the microring resonators by analyzing their transmission spectra. This characterization will determine the ideal device with the optimal gap to perform the FWM experiment. The Q-factor is obtained via Eq.1 where λres is the resonance wavelength, and $FWMH$ is the full-width half maximum, both evaluated at the specific resonance mode under study [2].

$$Q_{factor} = \frac{\lambda_{res}}{FWHM} \tag{1}$$

This measurement requires the use of one continuous tunable laser and a power meter in order to obtain the transmission spectra of the microring resonators. Tab. I summarizes and correlates the indices of the microring resonators with their directional coupler spacing, expressed as the gap between the bus waveguide and the microring resonator waveguide.

Ring index	Spacing d (μm)	Ring index	Spacing d (μm)
1	0.2	6	0.7
2	0.3	7	0.8
3	0.4	8	0.9
4	0.5	9	1.0
5	0.6	10	1.2

TABLE I

Microring resonatros-bus waveguide spacings d for the MRRs considered.

Fig. 2 summarizes the Q-factors measured for the microrings under test. The FWM efficiency of several microrings on this chip has been evaluated. However, the ring with index 8 has the highest FWM efficiency as well as the design specifications closer to the desired critical coupling condition; hence, this will be the subject of a further in-depth study.

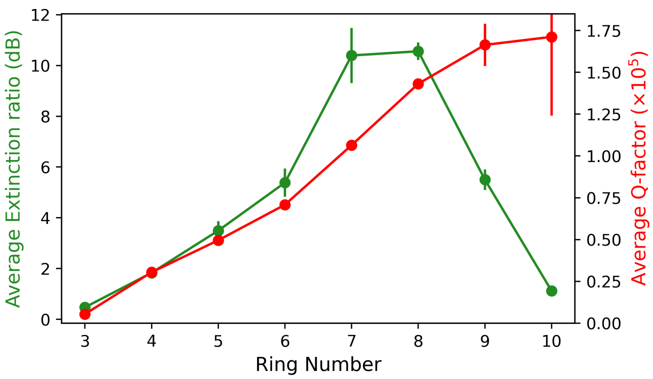

Fig. 2. Change in average extinction ratios (in green) and Q-factors (in red) of resonances in the microring resonators, with the errors given by the standard error on the parameters.

B. Nonlinear and FWM Characterization

For this part of the experiment, two input lasers are needed. We pump the cavity with laser power levels below the optical parametric oscillator (OPO) threshold [3]. The resulting FWM will require the setup and fibre-to-chip coupling losses to be minimized in order to measure the FWM intensity. The dual-pump scheme consists of two distinct lasers being pumped on two different neighbouring resonances. This allows for both degenerate and non-degenerate FWM, such that the FWM signal measured is maximal.

The output is then measured by an OSA. The initial FWM experiment is performed by aligning the two lasers to the approximate optimal resonances of the microring resonator, using a pump power of 15 mW for each laser, which corresponds to their maximum output power. Scans are then performed on the OSA at these pump wavelengths. The laser wavelengths are then fine-adjusted to ensure they are sitting at the bottom of the resonance dip, as indicated by a minimum in the measured peak power on the OSA. Once optimized, a high-sensitivity scan is performed at the neighbouring resonances to search for FWM.

IV. FWM Detuning Characterization

After demonstrating the FWM signal on the specific microring, an in-depth detuning characterization is performed. The measurement process is fully scripted and automated to ensure consistency and stability over a long measurement (2 hours).

In a step, the two laser wavelengths, λ_1 and λ_2, are set and the OSA performs the scans. A high-sensitivity scan is performed at the expected FWM wavelengths, with a lower sensitivity scan applied at the two laser wavelengths. The splitting of the scanning process allows the experiment to be performed faster. We carried out a double laser high-resolution scanning. In the analysis of these plots, it is important to remember that laser 2 is only stepped in wavelength once laser 1 has finished a full sweep across its wavelengths. Therefore, we can consider laser 2 to be pumped at a stationary wavelength while laser 1 is scanned.

Fig. 3 presents the results of a finer scan across the wavelengths.

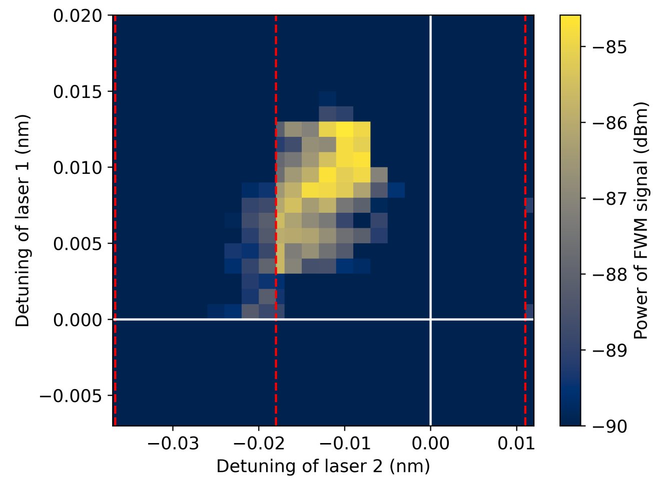

Fig. 3. Plot showing the variation in FWM signal power as the pump lasers are finely scanned from red to blue wavelengths. Optimal FWM occurs when laser 2 is blue-detuned. The red dotted lines show the wavelengths at which the setup was re-aligned, while the white lines show the centres of the resonances.

V. Conclusion

In conclusion, we explore the nonlinear dynamics of microring resonators implemented in a dispersive silicon nitride material platform. We show a strong dependence of the FWM signal observed on the detuning. We found optimal FWM where one laser was red-shifted from its resonance. We found the other laser to be optimal while blue-shifted.

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