Supporting Information

On-Chip Fabry-Perot Bragg Grating Cavity Enhanced Four-Wave Mixing

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Description of the supplementary material: We discuss the four-wave mixing efficiency, the spontaneous four-wave mixing efficiency, and the tunability and stability of the microheater control.

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FWM and SFWM Efficiency Calculation

In this section, we discuss the FWM and SFWM efficiency at higher pump power and lower losses. For the FWM efficiency of a FPBG cavity at high pump power, it is expected that, under undepleted condition, the stimulated FWM efficiency will be governed by equation (7),

$$\eta = \left|\gamma P_p L'\right|^2 (IE_p)^2 (IE_s)(IE_c)$$

Hence, the conversion efficiency would be quadratically proportional to the pump power.

SFWM is also possible in this platform at high pump power. The FWM process in ring resonator and Fabry-Perot resonator are essentially the same since they are both third order nonlinear processes and the enhancement are both from the resonance. According to Azzini *et al.* [S1], we may estimate the power generated by SFWM signal by,

$$\mathrm{P}_{sp} = (\gamma 2\pi R)^2 \left(\frac{Q v_g}{\omega_p \pi R}\right)^3 \frac{\hbar \omega_p v_g}{4\pi R} P_p^2$$

It is obvious that the SFWM is also related to P_p^2. Under current condition, the SFWM power is around -107 dBm, corresponding to a photon generation rate of 185 kHz. Unfortunately, the noise level of our current OSA is higher than the SFWM level and we cannot directly observe the SFWM at this moment. In addition, we may roughly estimate the parametric oscillation threshold power by [S2],

$$P_{th} \approx 1.54 \times \frac{\pi\, Q_c \quad n^2 V}{22\mathrm{Q_L} n_2 \lambda Q_L^2}$$

where P_{th} is the threshold power of parametric oscillation, Q_c is the coupling Q, Q_L is the loaded Q, Q_i is the intrinsic Q, V is the mode volume and n_2 is the nonlinear refractive index. The Q_c can be calculated by,

$$\mathrm{Q}_i = \frac{2\pi n_g}{\alpha \lambda_0}$$

$$\frac{1}{Q_c} = \frac{1}{Q_L} - \frac{1}{Q_i}$$

and is calculated to be 920k. Thus, the parametric oscillation threshold power is estimated to be 59mW (17.7 dBm) in our current device, which is available from a commercial high power EDFA. By minimizing both the grating loss and the cavity loss to 0.1 dB/cm, the parametric oscillation threshold power can be further reduced to 4.8 mW (6.8 dBm), which is comparable to our current pump power.

Tunability and Stability of the microheater control

The microheater must be tiny otherwise not only the phase of the cavity, but also the phase of the grating will be affected such that the relative positions of the resonances will not be tuned. Here, as shown in Figure S1, the heater is designed to be a $70\mu m \times 20\mu m$ zigzag like structure, right on top of the FPBG cavity. We used double alignment photolithography to define the pattern of the microheater and deposit a total of $10\mu m$ chromium and $120\mu m$ nickel. The measured resistance of the microheater is measured to be around 50Ω. We use a DC power source to implement the thermal tuning. The maximum sustainable power of our microheater is 102 mW, beyond which the microheater will burn. Here we designed three FPBG cavities each of which has a 1/3Λ cavity length difference such that the resonances position will have a 1/3 FSR difference, as shown in Figure S1(b). Our experimental result shows that the tuning range of one microheater already exceed 1/3 FSR, which guarantees that the resonances can be tuned to anywhere within the stopband. Thus, the phase matching condition is controllably achievable. Theoretically, the FSR detuning should reach 0 if a perfectly controlled thermal tuning is implemented. However, the best FSR detuning we observed experimentally is -5.6 MHz, which is already much smaller than the linewidth of the stopband. With a more advanced power source and a temperature controlling technique, the thermal tuning can be more accurate and zero FSR detuning is achievable.

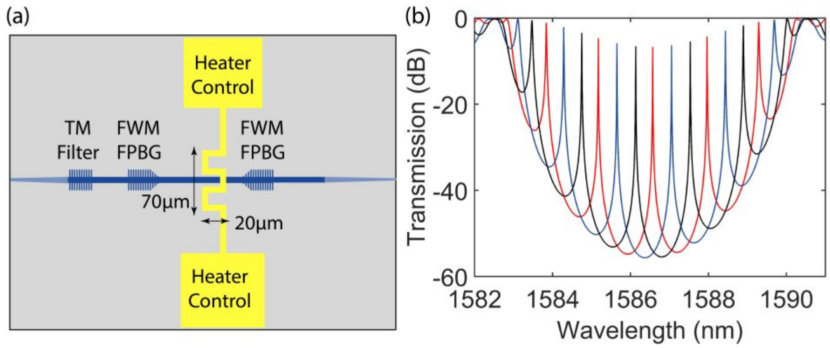

Figure S1. (a) Schematic of the microheater (b)Simulation of transmission of three FPBG cavities whose cavity lengths have 1/3Λ difference between each other. The red line shows the transmission of a FPBG cavity whose cavity length L ensure that the resonances to be exactly symmetrical within the stopband, while the blue line and the black line show the transmission of the FPBG cavity with a cavity length of L+1/3Λ and L+2/3Λ, respectively.

Reference

[S1] Azzani. S. et al, "From classical four-wave mixing to parametric fluorescence in silicon microring resonators," Opt. Lett. 2012, 37, 3807-3809

[S2] Ji, X.; Barbosa, F. A. S.; Roberts, S. P.; Dutt, A.; Cardenas, J.; Okawachi, Y.; Bryant, A.; Gaeta, A. L.; Lipson, M. Ultra-Low-Loss on-Chip Resonators with Sub-Milliwatt Parametric Oscillation Threshold. Optica 2017, 4, 619-624.