

Ultra-low Power Wavelength Conversion in a Hydrogenated Amorphous Silicon Microring Resonator

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Abstract: We demonstrate ultra-low power wavelength conversion via four-wave mixing in a hydrogenated amorphous silicon microring resonator with 10- μm radius. The results show 22.8-dB conversion efficiency enhancement in the ring compared to a 3.8-mm long waveguide. © 2018 The Author(s)
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All-optical processing devices are a key technology for the future ultrahigh bandwidth classical and quantum communication systems and a promising way to realize all-optical processing is utilizing ultrafast parametric nonlinear processes. Four-wave mixing (FWM), a third-order nonlinear effect, has been employed for a wide range of applications such as OTDM demultiplexing [1], all-optical logic gate [2], phase sensitive amplification [3] and photon pair generation [4][5]. However, efficient FWM generally requires significant optical power even in guided wave geometries. To reduce power requirements, resonant enhancement in devices such as microring resonators can be employed, however this resonant approach results in a trade-off between the power requirements and operation bandwidth due the linewidth of the employed resonances. Since resonant enhancement scales with the cavity finesse, realizing efficient high-speed operation in a resonant geometry requires a small cavity size. Additionally, a resonator material with high nonlinear coefficient is desired to reduce the required level of resonant enhancement. To this end, hydrogenated amorphous silicon (a-Si:H) is a promising material due to its large nonlinearity [1][3][5][6][7]. Specifically, recent works show that the Kerr coefficient of a-Si:H is one order of magnitude large than that of c-Si. In this paper, we investigate FWM interactions in a 10- μm radius a-Si:H microring resonator with 18.7-GHz resonant linewidth. In this device, we achieve a conversion efficiency of -29.5 dB with only a 4.3-mW peak pump power and a 22.8-dB efficiency enhancement compared to a 3.8-mm long a-Si:H waveguide.

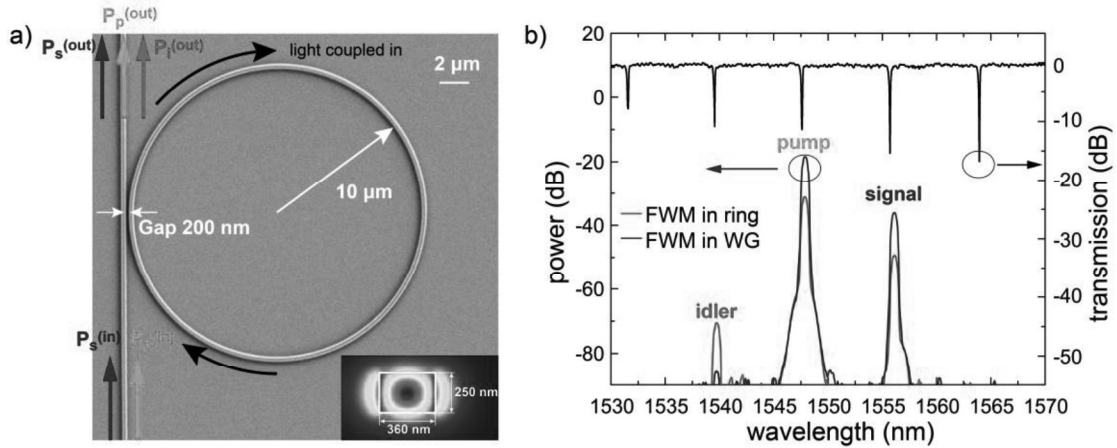


Fig. 1 a) SEM image of the microring resonator; inset: simulated electric field distribution of the waveguide TE-like mode; b) transmission spectrum and FWM spectra in the ring and waveguide; black line: normalized transmission spectrum of the microring; red line: spectrum of FWM in the ring resonator; blue line: spectrum of FWM in the waveguide.

Figure 1a illustrates the structure of our device. The ring has a radius of 10 μm , and the gap between the ring and the bus waveguide (total length ~ 3.8 mm) is 200 nm; both the bus waveguide and the ring are 250 nm in thickness and 360 nm in width, which is designed to have a zero group velocity dispersion (zGVD) wavelength around 1550 nm for the TE-like mode. The device is fabricated using the technique described in [6]. Inverse adiabatic tapers on both ends of the waveguide are designed to couple light into and out of the device. The nonlinear refractive index of the material is determined to be around $5 \times 10^{-13} \text{ cm}^2/\text{W}$ by FWM [6].

The black line in Fig. 1b shows the transmission spectrum of the microring. In the FWM experiments, we use a quasi-CW laser source modulated at 10 GHz with a duty cycle of 1 to 6, the pump is tuned into the resonance at 1548 nm with an extinction ratio of 11.3 dB and a 3-dB linewidth of 0.15 nm (18.7 GHz), corresponding to a Q

factor of 10,300. The red line shows the spectrum with both the pump and the signal in the ring resonances, while the blue line is the spectrum when both pump and signal are out of resonances (in this condition the FWM takes place in the 3.8-mm long bus waveguide). In both cases, the peak pump power input to the waveguide is 1.58 mW, and the input signal power is 37 μ W. The FWM conversion efficiency in the ring is defined as the ratio of the output idler power $P_i^{(out)}$ to the input signal power $P_s^{(in)}$ (see Fig. 1a). Based on the spectra, the FWM conversion efficiency in the ring is -34.6 dB, while in the waveguide is -57.4 dB, providing a resonant enhancement of 22.8 dB due to the ring.

We measure the FWM conversion efficiency as a function of the input peak pump powers while maintaining the signal power at 37 μ W, and these results are shown in Fig. 2a. As depicted with the red dots, the conversion efficiency increases at low pump powers, and starts to saturate around 2 mW, and we observe an efficiency of -29.5 dB with only 4.3-mW pump powers. This process is simulated following the analysis described in [8]. As shown in Fig. 2a, the simulation agrees well with the experimental results where the discrepancy at higher powers is likely due to inaccurate estimation of the nonlinear loss. Finally, we compare the FWM efficiency after tuning the signal to other resonances, and the spectra are depicted in Fig. 2b. As can be seen, the efficiencies are similar when the signal is in adjacent resonances at 1539 nm and 1564 nm as expected from the low GVD design.

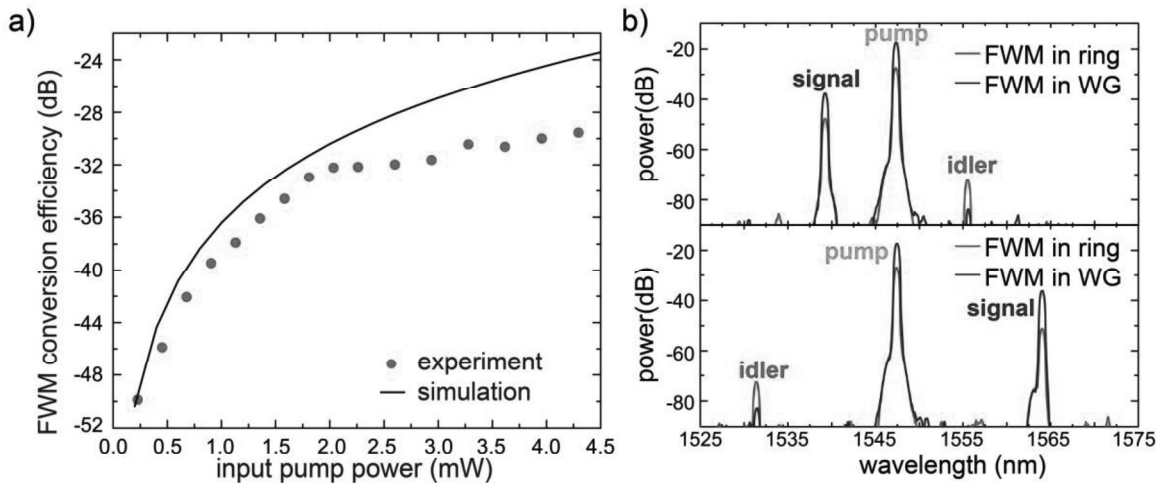


Fig. 2 a) FWM conversion efficiency in the microring resonator as a function of input pump power; red dots: experimental data; black line: simulation result; b) spectra of FWM with signal in different resonances; top: signal ~ 1539 nm; bottom: signal ~ 1564 nm.

To summarize, in this paper we demonstrate ultra-low power parametric wavelength conversion via four-wave mixing in a 10- μ m radius a-Si:H microring resonator with 18.7-GHz resonant linewidth. Conversion efficiency as high as -29.5 dB is realized with only 4.3-mW pump power, and a 22.8-dB conversion efficiency enhancement is demonstrated in the ring compared to the FWM process in the 3.8-mm long waveguide. Compared to c-Si microrings with similar size [8], our device can achieve higher efficiency with lower Q factor and hence broader resonant linewidth, allowing for higher operation speed.

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