Ultrahigh-Q Packaged Microrod Resonator for Efficient FWM Wavelength Conversion

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***Abstract*—We fabricate a packaged microrod resonator with ultrahigh quality factor of 9.0×10^8. Based on the packaged microrod resonator, we demonstrate the four-wave mixing wavelength conversion with -4.81 dB conversion efficiency (CE) at 21 mW pump power and 3.43 µW signal power. To the best of our knowledge, a CE enhancement of about 8 dB is obtained compared with previous works realized in the WGM resonators.**

***Index Terms*—WGM resonators, packaged microrod, wavelength conversion, four-wave mixing, conversion efficiency**

I. Introduction

In optical signal processing (OSP), wavelength conversion based on four-wave mixing (FWM) process plays a vital role in enhancing the flexibility of optical routing [1]. Microresonators, especially whispering-gallery-mode (WGM) resonators, have been utilized for improving the FWM-based conversion efficiency (CE), owing to the high optical confinement. Enhanced FWM-based wavelength conversion in WGM ring resonators has been demonstrated before [2]–[4]. However, due to the limited quality factor (Q) in which causes the low power intensity inside these resonators, the FWM-CE is low and hard to improve.

In this work, we fabricate a packaged microrod resonator with ultrahigh-Q of 9.0×10^8 to achieve efficient FWM-based wavelength conversion. The FWM-CE is -4.81 dB at 21 mW pump power and 3.43 µW signal power, which is enhanced about 8 dB compared with previous works based on WGM resonators [5]–[8]. In addition, we characterize the long-term stability of the packaged microrod resonator and measure the intrinsic noise based on Allan variance. This work presents the packaged microrod resonator as a potentially ideal platform for applications in OSP.

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II. Results and discussion

The experimental setup for wavelength conversion through FWM process in the packaged microrod resonator is depicted in Fig. 1(a). The pump light beam and the signal light beam are generated from two individual continuous-wave tunable lasers. The two lights are combined with 50:50 coupler and coupled into the packaged microrod resonator by the fiber taper. Both pump and signal waves pass through fiber polarization controllers, and each optical power is controlled by the erbium doped fiber. The output light is detected by a low-noise photodetector and an optical spectrum analyzer. A power meter is utilized to measure the power of the input light.

The packaged microrod resonator consists of a silica microrod resonator with diameter of 3.0 mm, a coupling fiber taper, a thermoelectric cooler (TEC) and a thermistor. Using the automatic technique with the laser-machine reflow process, the fabrication of the silica microrod resonator is fast, reliable and cost-effective. Fig. 1(b) depicts the transmission spectra of the packaged microrod resonator. The ultrahigh-$Q \sim 9.0 \times 10^8$ is obtained via Lorentz fitting near 1560 nm. To demonstrate the performance of the packaged microrod resonator showing in the stability of resonant wavelength, we monitor the real-time wavelength shift of the packaged microrod resonator as illustrated in Fig. 1(c). The resonant wavelength shift is up to about 0.452 pm, which shows the high stability of resonant mode in the packaged microrod resonator. The inset in Fig. 1(c) depicts the intrinsic noise in the system measured by Allan variance. The fluctuations at $\sim$ 100 s may be due to the laser self-shifting and environmental temperature fluctuations. The long-term stability leads to the packaged microrod resonator a reliable platform for optical processes. The FWM experiments in the packaged microrod resonator are demonstrated in Fig. 2. With the input signal wavelength of 1555.56 nm and the pump wavelength of 1557.60 nm, an idler wave can be observed

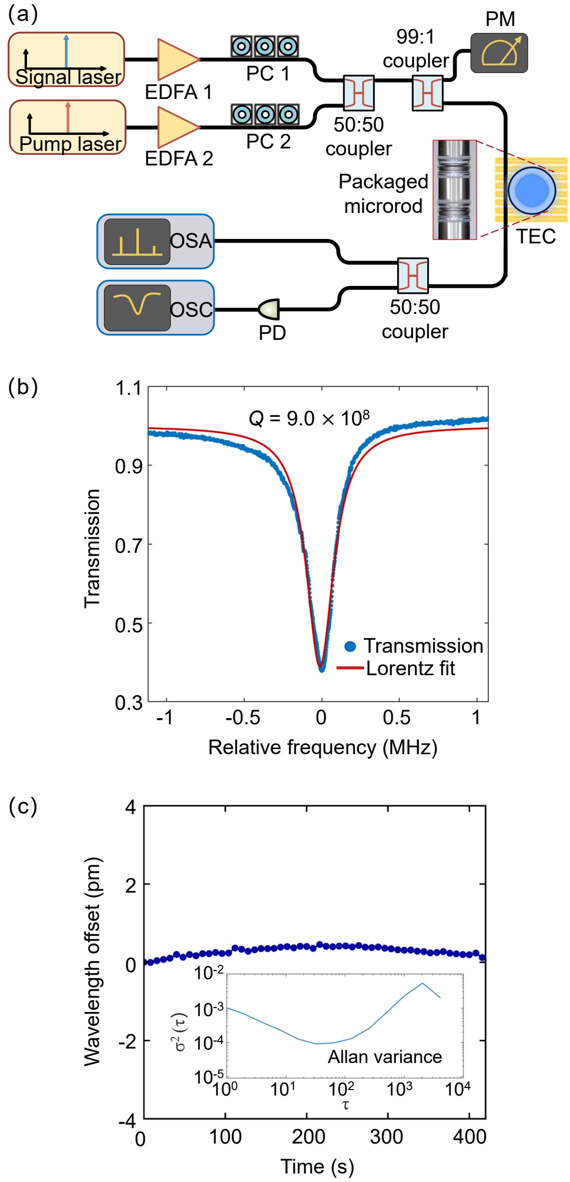

Fig. 1. (a) FWM-based wavelength conversion experimental setup. EDFA, Erbium-doped fiber amplifier; PC, fiber polarization controller; PD, photodetector; OSA, optical spectrum analyzer; OSC, oscilloscope; PM, power meter. (b) Transmission spectrum of the packaged microrod resonator. (c) Real time stability of the packaged microrod resonator. Inset: Allan variance of the system intrinsic noise.

at the wavelength of 1559.66 nm, as depicted in Fig. 2(a). For the packaged microrod resonator, the FWM-CE is defined by the power ratio between converted idler to output signal. We measure the power-dependent FWM-CE in the packaged microrod resonator, as shown in Fig. 2(b). It can be observed that the CE via FWM process rises linearly as the increment of the pump power, which demonstrates that nonlinear loss is negligible in the packaged microrod resonator. We obtain the FWM-CE of -4.81 dB when the pump power is up to 21.0 mW (13.2 dBm).

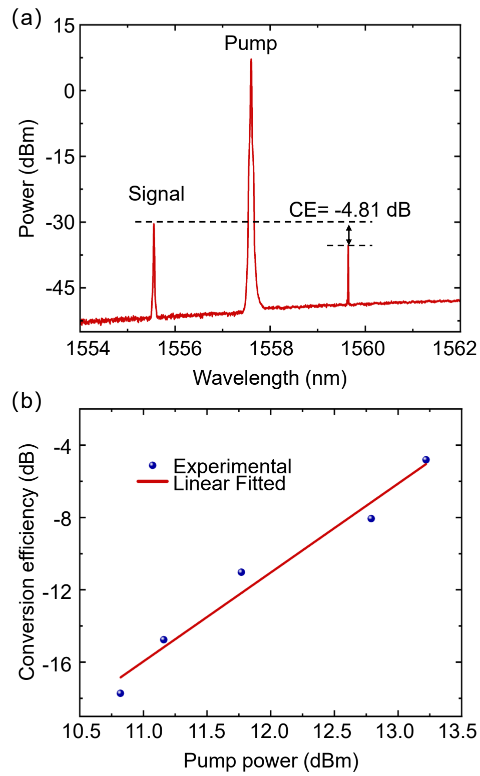

Fig. 2. (a) The measured FWM spectra in the packaged microrod resonator. (b) FWM-CE of the packaged microrod resonator. Horizontal axis is pump power while vertical axis is the CE.

III. Conclusion

In conclusion, we achieve the highly efficient FWM-based wavelength conversion in the ultrahigh-Q packaged microrod resonator. The CE of -4.81 dB is obtained when the pump power is 21 mW. Compared with the previous FWM-CE achieved in WGM resonators, we obtain 8 dB enhancement in CE with a pump of 21 mW, owing to the ultrahigh-Q of the packaged microrod resonator for tight light confinement. It is expected that the ultrahigh-Q packaged microrod resonator has broad application prospects in optical signal processing functions and quantum photonics.

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