Ultrahigh-Q packaged silica microrod cavity for microcomb generation

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Abstract: A packaged silica microrod cavity with greater than one billion Q factor is demonstrated. Based on this packaged device, a single soliton microcomb with repetition rate of 24 GHz is generated.

1. Introduction

Optical frequency comb (OFC) has become of great interest in high-precision time and frequency measurement [1], massively parallel optical communications [2] and so on. The Kerr soliton comb manifests itself by virtue of the ultra-wideband and low phase noise [3]. Especially, the single soliton Kerr comb is considered as the ideal state of the Kerr comb due to the extremely lower phase noise and smooth spectral envelope. Recently, Kerr optical combs generated in whispering gallery mode (WGM) resonators are gradually emerging from many OFC generation schemes [4-6]. However, the soliton state of Kerr comb is susceptive to the coupling state and the power threshold of the soliton comb is limited by the Q factor. Hence, it is urgent to achieve the packaged ultrahigh-Q microcavity.

In this work, the single soliton Kerr comb is generated by using the packaged silica microrod resonator (SMR) with ultrahigh-Q ~1.15×10^9. Herein, the packaged SMR protects the coupling system from environmental perturbations to keep ultrahigh Q and improve the coupling stability. Moreover, due to the enhanced stability and robustness the proposed packaged SMR, a single soliton comb with repetition rate of 24 GHz ranging from 1550 nm to 1570 nm is experimentally demonstrated when the pump power is ~20 dBm. This work provides a promising platform for massively parallel optical communications. Thus, this is potentially an ideal plat-form for massively parallel optical communications and ultra-stable microwave oscillator, etc.

2. Ultrahigh-Q Packaged Silica Microrod Resonator

The ultrahigh-Q microrod cavity (diameter ~ 3.0 mm) is fabricated by a laser-machine reflow process [7,8]. A microrod cavity with intrinsic Q factor exceeding 1.2 billion is used in this study. As shown in Fig. 1(a), the loaded Q (Q_L) factor before package is ~ 0.79 billion fitted by Lorentzian fit. Fig. 1(b) depicts the transmission spectrum of a packaged microrod cavity with Q_L ~ 0.93 billion at the pump wavelength of 1560 nm. It is shown that Q_L raises after packaging due to the increase of coupling Q factor. Q_L is affected by the intrinsic loss and the coupling loss, which can be expressed as [9]:

$$Q_L^{-1} = Q_{in}^{-1} + Q_{co}^{-1} \tag{1}$$

where Q_{in} and Q_{co} denote the intrinsic and coupling Q factor, respectively. During the packaging process, Q_{in} decreases from 1.2 billion to 1.15 billion, which results from the scattering and absorption loss caused by environmental contaminants. The microrod-taper coupling system changes from over-coupling into under-coupling state, which can be explained by the tiny displacement of the taper fiber due to the solidification of ultraviolet glue. Therefore, as the coincidence degree of the evanescent field between the microcavity and the tapered fiber decreases after packaging, the coupling loss decreases and Q_{co} increases from 2.3 billion to 5 billion. It is noted that intrinsic losses dominate the coupling losses in the under-coupling state and the measured Q (Q_L) is approximately equal to the Q_{in} [10]. Therefore, the Q_L increases after packaging.

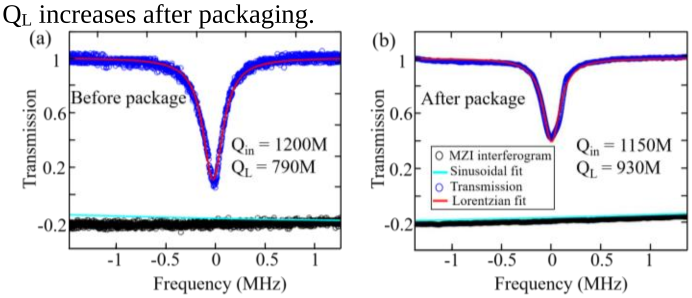

Fig. 1(a) and (b) are the transmission spectra for a microrod (diameter ~3mm) before and after packaging, respectively. The blue dotted line is transmission spectra with Lorentzian fit (red line) and the black dotted line represents a frequency calibration with sinusoidal fit (cyan line) from a Mach-Zehnder interferometer (free-spectral-range around 40 MHz).

3. Single Soliton Kerr Comb Generation

To verify the practicability of the ultrahigh-Q packaged microrod cavity, soliton optical comb experiment is carried out, as shown in Fig. 2(a). In this work, the "power-kicking" technique [11] is used to generate soliton optical combs. The laser frequency is controlled by arbitrary function generator (AFG) to start scanning from blue detuning and the laser power is amplified by erbium-doped fiber amplifier (EDFA). Then, the microcavity power suffers a sudden drop controlled by acousto-optic modulator (AOM) so that the pump light transmits into the red-detuned regime. Experimentally, a soliton step is observed. Finally, the soliton can be reliably captured and maintained indefinitely by the control of servo. Fig. 2(a) shows the optical spectrum of a single soliton comb with the pump power of ~ 20 dBm. The frequency comb is proven to be a single-soliton state fitted with a smooth sech^2-shaped spectral envelope. The bandwidth of the soliton comb ranges from 190.5THz to 193.5THz (1550 nm ~ 1570 nm). Fig. 2(c) is zoom-in of the optical spectrum over a 1 THz span showing the repetition frequency of approximately 24 GHz. Moreover, by preparing microcavities of different diameters (0.5mm-6mm), packaged soliton combs with different repetition frequency in the range of 10-100 GHz can be obtained, which can meet the needs of various applications, such as precision spectroscopy, astronomical spectrometer calibration, ultra-stable microwave oscillator and other fields.

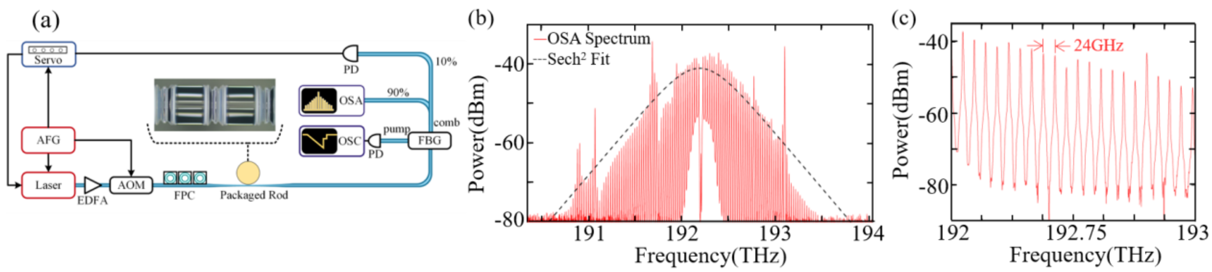

Fig. 2. (a) Experimental setup. AFG, arbitrary function generator; EDFA, Erbium-doped fiber amplifier; AOM, acousto-optic modulator; FPC, fiber polarization controller; FBG, fiber Bragg grating filter; PD, photodetector; OSA, optical spectrum analyzer; OSC, oscilloscope. (b) The single soliton optical spectrum with sech^2 fit (black dotted line). (c) Zoom-in of the optical spectrum over a 1 THz span.

4. Conclusion

In summary, we have realized a soliton microcomb based on ultrahigh-Q (over one billion) packaged silica microrod cavity. The bandwidth of the soliton comb is ~ 20 nm and the repetition rate is ~ 24 GHz. The ultrahigh-Q packaged soliton microcomb we have achieved contributes to the development of integrated comb frequency source and has broad application prospects in high-speed communications, arbitrary waveform generation and so on.

5. Acknowledgements

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