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Nonlinear properties of high-Q optical microresonators in normal dispersion range

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Abstract. We demonstrate the generation of Kerr frequency combs and platicons in whispering gallery mode crystalline microresonators in normal group velocity regime at 780 nm and 1064 nm wavelengths.

Whispering gallery mode (WGM) microresonators can have extremely high values of quality-factor (exceeding 10^9) in the optical range, that allows low threshold of many interesting nonlinear effects, in particular, the generation of Kerr frequency combs [1]. Kerr combs in optical microresonators may become a basis for a new class of compact devices for spectroscopy, precision measurements, and generation of femtosecond pulses.

Coherent low-noise frequency combs are of particular interest. These combs may be generated in the form of dissipative Kerr solitons in the region of anomalous group velocity dispersion (GVD) [2] and to date have been already demonstrated on different platforms. However, most materials suitable for the manufacturing of WGM microresonators (for example, widely used fluorides MgF_2 and CaF_2) have a normal GVD in the visible and near IR ranges, which prevents soft generation of coherent frequency combs and bright dissipative Kerr solitons. Therefore, the development of new methods for coherent frequency comb excitation in microresonators with normal GVD and studying the properties of such combs is an actual and practically significant task. It was shown recently that in the normal GVD regime coherent frequency combs could be achieved in the form of soliton-like pulses of a particular form, so-called platicons [3]. It was also demonstrated that the efficiency of the transformation of pump power into the power of the frequency comb lines is significantly better for platicons compared to the generation of bright solitons in anomalous GVD regime. This properties of platicons are important for many practical applications.

In the recent years, several methods for the generation of platicons were proposed: the use of a local dispersion perturbations caused by mode interactions [3,4], pump modulation at a frequency equal to the free spectral range (FSR) of a microresonator and biharmonic pump [5], self-injection locking of a laser source to a mode of the WGM microresonator [6].

In our work MgF_2 microresonators and prism coupling were used. For 3 mm in diameter MgF_2 microresonators the GVD is mostly determined by material dispersion which is normal at given wavelengths. The microresonator's loaded quality-factor exceeded $5x10^8$.

For the pump at 1064 nm, the experimental setup was adapted both for biharmonic and for the amplitude-modulated pump (see Fig. 1). For the pump at 780 nm, a setup with an

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external cavity diode laser self-injection-locked to a mode of the same high-Q WGM microcavity was used (Fig. 1, on right). The experimental results showed that, due to the effect of self-injection locking, the generated linewidth may become less than 1 kHz.

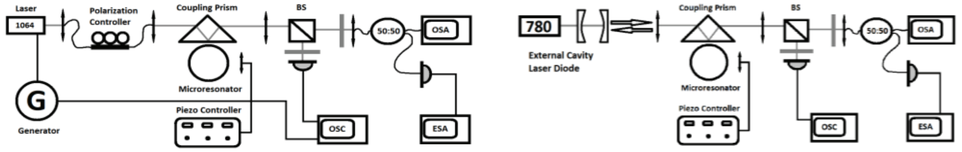

Fig. 1. Experimental setup for the pump at 1064 nm; self-injection locked pump at 780 nm (right).

For the pump at 1064 nm, combs were observed for all modes with a quality-factor exceeding $5x10^8$ and coupling efficiency better than 10%. Frequency combs with asymmetric spectral envelope caused by mode interaction were observed. High-efficiency power conversion into comb lines (more than 30%) was also observed.

For the pump at 780 nm, in addition to the combs similar to the combs obtained at 1064 nm, platicon-like spectra with a width of 1-3 nm were also regularly detected. The characteristic plateau of the spectrum was 20 dBm below the pump line. The width of the microwave beatnote signal between the comb lines was less than 1 kHz and was detected on an electrical spectrum analyzer at a frequency corresponding to the FSR of microresonator.

The results of the experiments are shown in Fig. 2.

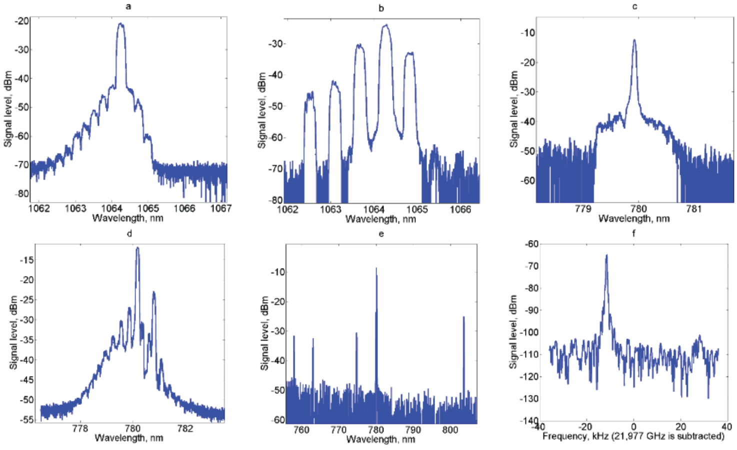

Fig. 2. a, b – frequency combs, formed as a result of mode interaction with pump at 1064 nm: a – the distance between the lines corresponds to 3 FSR; b – the first lines are below the pump by 6 dB, the generation efficiency is more than 30%. c, d, e – combs generated by the self-injection-locked diode laser pumping at 780 nm. c – is a platicon-like spectrum with a width of 1.5 nm. d – platicon-like spectrum with pronounced comb lines. e – hyperparametric generation in the range of 50 nm. f – the beatnote between the comb lines, the line width is less than 1 kHz.

Experimental setups for the of optical frequency combs generation in WGM microresonators with normal GVD were designed and tested. It is planned to investigate the combs properties and to compare different methods of its excitation.

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