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Low Threshold Frequency Comb Generation in AlGaAs-on-Insulator Microresonator in the Normal Dispersion Regime

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Abstract: We present milli-Watt threshold frequency comb generation in AlGaAs-on-insulator integrated microresonators exhibiting normal GVD by employing the effects of mode interaction.

OCIS codes: (190.4390) Nonlinear optics, integrated optics; (190.4970) Parametric oscillators and amplifiers.

1. Introduction

Optical frequency combs have advanced metrology and spectroscopy. The generation of frequency combs from integrated Kerr microresonators is very attractive for many applications, including optical communications [1]. The generation of frequency combs in such microresonators is based on parametric frequency conversion in four-wave mixing processes. Efficient generation of frequency combs in those systems requires a high Kerr nonlinearity and tight confinement of light, as well as phase matching. In most demonstrations of Kerr frequency comb generation, microresonators are designed to achieve anomalous group velocity dispersion (GVD) at the pump wavelength to satisfy the phase matching condition and generate coherent combs via soliton generation [2]. However, there is a growing interest in generating frequency combs in the normal dispersion regime. This is beneficial when it is difficult to achieve anomalous dispersion or when the requirements to achieve anomalous dispersion conflict with other important merits such as the quality factor. In addition, coherent frequency comb generation has been theoretically predicted and experimentally observed in the normal dispersion regime when the dispersion is locally disturbed by mode interaction [3, 4]. The AlGaAs-on-insulator platform offers a very high Kerr nonlinearity. In addition, due to its high index contrast between the core and the cladding materials, it also offers tight confinement of light. Those two features have allowed the generation of frequency combs with very low threshold powers [5]. However, the high index contrast also results in bigger scattering loss due to the sidewall roughness. To mitigate this effect, we design microresonators with a wider cross-section so that the overlap of the fundamental mode profile with the sidewalls is decreased. The wider microresonators exhibit normal GVD. The microresonator supports a higher-order mode that interacts with the fundamental mode, shifting the modes frequencies, which makes phase matching possible. Since the two mode families have different FSRs, they interact periodically giving rise to a periodic shift in the dispersion and resonances for which the phase matching condition is satisfied.

2. Dispersion disturbance by mode interaction

The microresonator, made from $\mathrm{Al_{0.17}Ga_{0.83}As}$, has a thickness of 270nm, a width of 900nm and a perimeter of 810µm. The bus waveguide is integrated on-chip and, together with the microresonator, are embedded in $\mathrm{SiO_2}$ [6]. The fundamental mode FSR is 102GHz and the higher-order mode FSR is 89GHz at 1550nm, which results in an interaction period of around 6nm. The dispersion of the fundamental mode is characterized by measuring its FSR in a wide wavelength range. The dispersion measurment setup is shown in Fig.1.(a). An external-cavity diode laser (ECDL) is coupled to the waveguide by a lensed fiber and the ouput light is collected by another lensed fiber. The laser frequency is swept and the transmitted light is detected by a photodiode (PD). Simultaneously, a part of the laser light passes through a free-space Mach-Zehnder interferometer (MZI) which has a FSR of 2490MHz and its output is detected by another PD. The PD signals are recorded by an oscilloscope. The MZI is used to accurately calibrate the laser frequency shift while the scan is running. Fig.1(b) shows the measured FSR of the fundamental mode. The FSR increases with wavelength giving normal GVD and exhibits disturbances of up to a few GHz.

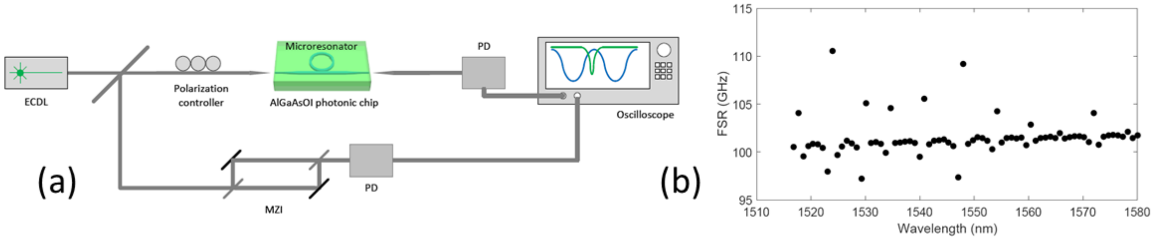

Fig.1 (a): Dispersion measurement setup, (b) measurement of the FSR of the fundamental mode

3. Comb generation

Mode interaction results in blue (red) shifted modes, which appears as a decrease (increase) in the FSR. Because of this disturbance of the dispersion, there are sets of modes for which the FSR is effectively decreasing with wavelength, satisfying the phase matching condition. To demonstrate comb generation in our device, we use the setup shown in Fig.2 (a). Light from an ECDL is amplified by an Erbium-doped fiber amplifier (EDFA) and is coupled to the chip by a lensed fiber. The output light is collected by another lensed fiber and is detected by an optical spectrum analyzer (OSA). The input laser is tuned on resonance from the blue side of a resonance with a loaded Q of 190,000 and 9dB extinction around 1548nm. Fig.2 (b) shows the output spectrum at the threshold power of 7mW. When the input power is increased to 30mW, the spectrum shown in Fig.2 (c) results. This spectrum has dominant peaks separated by around 6nm, which is equal to the interaction period of the mode families. This suggests that phase matching results because of mode interaction.

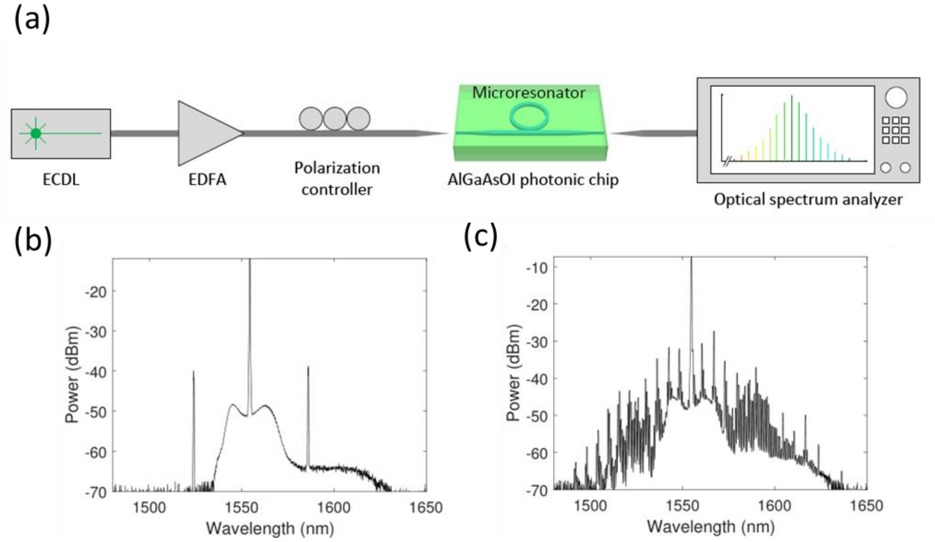

Fig.2 (a): The setup employed for frequency comb generation, (b) the obtained spectrum at the threshold power of 7mW, (c) the obtained spectrum at a power of 30mW

4. Conclusion

We have demonstrated frequency comb generation in an AlGaAs-on-insulator microresonator with normal dispersion through mode interaction. This regime of comb generation allows the use of wide microresonators that exhibit higher quality factors, resulting in lower threshold power.

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