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Ultra-Low Threshold Power On-Chip Optical Parametric Oscillation in AlGaAs-On-Insulator Microresonator

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Abstract: We present a record-low threshold power of 7 mW at ~1.55 µm for on-chip optical parametric oscillation using a high quality factor micro-ring-resonator in a new nonlinear photonics platform: AlGaAs-on-insulator.
OCIS codes: (190.4390) Nonlinear optics, integrated optics; (190.4970) Parametric oscillators and amplifiers.

1. Introduction

Frequency combs generated through optical parametric oscillation (OPO) in microresonators are appealing, as this approach allows high repetition rates, which extends comb applications into astronomy, microwave photonics and telecommunication [1]. Pioneers made great efforts to attain ultra-high quality factor (Q) micro toroid [2] and micro spheres which enables efficient OPO with ultra-low threshold power. However, the pump power is coupled using free-standing specially tapered fibers which is not a robust solution. Alternatively, coupled waveguides can be integrated with microresonators to realize on-chip OPOs which have been demonstrated in various material platforms including SiN [3], Hydex [4], AlN [5] and Diamond [6]. Although ultra-high Q factors up to a million are achieved with state of the art fabrication technologies, the material nonlinearities of those materials are relatively low. To further increase the effective nonlinearity of a nonlinear platform, a high index contrast is preferred to get strong light confinement in a submicron waveguide. The silicon-on-insulator (SOI) platform offering a large index contrast is believed to be a promising nonlinear platform and has been used for frequency comb generation in the mid-infrared wavelength range [7]. However, the small bandgap of silicon (1.1 eV) results in strong two-photon absorption (TPA) in the telecom wavelength range which limits its applications for e.g. integrated multi-line light sources [8]. Therefore, a nonlinear platform offering as high a nonlinearity as the SOI platform but does not suffer from TPA in the telecom wavelength range is highly desired. Our recent proposed AlGaAs-on-insulator (AlGaAsOI) platform [9] fulfills this requirement, as the material nonlinear coefficient (n_2) of AlGaAs (~1.43×10^{-17} W/m^2) [10] is larger than that of all the aforementioned nonlinear platforms and the bandgap of $Al_xGa_{1-x}As$ can be tailored by adjusting the Al concentration during epitaxial growth to avoid TPA in the telecom wavelength range (~1.55 µm). Moreover, its strong light confinement induced by the high index contrast layout not only enable an efficient dispersion engineering for waveguide-based devices but also maximizes the achievable effective nonlinearities. Thus, in such a highly efficient nonlinear platform, an ultra-low threshold power on-chip OPO is expected even in a modest Q microresonator. In this paper, we demonstrate an AlGaAsOI microresonator with a Q of ~109,000. We also achieve an on-chip OPO with a record-low threshold power of 7 mW in the telecom wavelength range.

2. AlGaAsOI microresonator for on-chip OPO

Fig. 1(a) shows the scanning electron microscopy (SEM) picture of a 35-µm diameter AlGaAsOI microresonator. A 320-nm thick $Al_{0.17}Ga_{0.83}As$ layer is fabricated on a SiO_2 layer through wafer bonding and substrate removal. The device is defined using electron-beam (E-beam) lithography and dry etching. Hydrogen silsesquioxane (HSQ) is used as E-beam resist and etching mask. Since the HSQ has a similar refractive index as SiO_2, it is kept on top of the

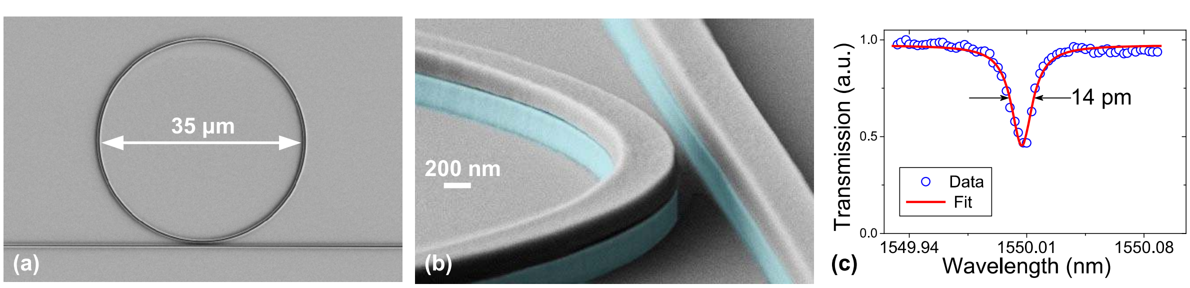

Fig.1 SEM pictures: (a) Top-view of the AlGaAsOI microresonator showing ring and bus waveguide. (b) Bird's-eye view of the coupling region of the AlGaAsOI microresonator. The AlGaAs material is indicated by the blue color. (c) Measured transmission spectrum around the resonance of the AlGaAsOI microresonator at 1550 nm.

device. Fig. 1(b) shows the coupling region for the microresonator before it is cladded with SiO_2. The device works in a slightly under-coupling condition (coupling gap: 230 nm). The ring waveguide width is 630 nm in order to obtain anomalous dispersion in the C-band, which is critical to achieve parametric gain. The bus waveguide is tapered to 120 nm at both chip facets for an efficient fiber-to-chip coupling. The total insertion loss and fiber-to-chip coupling loss of the device are 7.2 dB and 3.3 dB, respectively. The waveguide linear loss is ~1.5 dB/cm. Fig. 1(c) shows the measured transmission spectrum for the resonator resonance at 1550 nm. The measured loaded *Q* is ~109,000, which, to our knowledge, is the highest demonstrated *Q* for III-V microresonators.

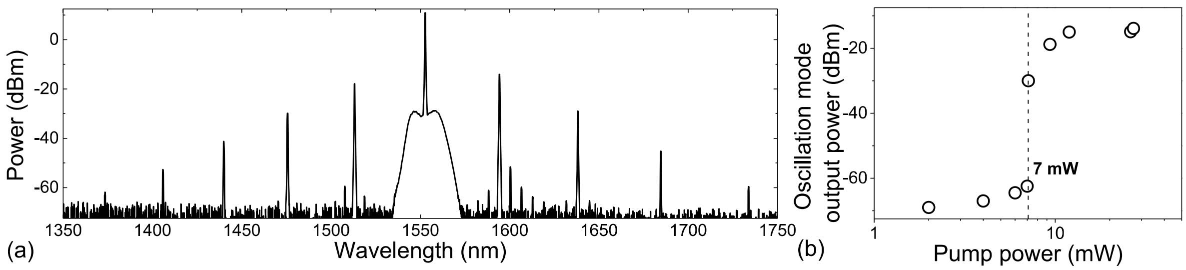

Fig.2 (a) Measured optical spectrum for on-chip OPO at 25-mW pump power, clearly showing the OPO frequency peaks. (b) Measured output power of the first oscillation mode as a function of pump power coupled in the bus waveguide.

The OPO mechanism relies on a combination of parametric amplification and oscillation as a result of the nonlinear four-wave mixing (FWM) processes within the microresonator. OPO occurs when the roundtrip parametric gain exceeds the roundtrip loss of the resonator. In our OPO demonstration, the light from a continuous wave (CW) tunable laser at ~1.55 μm is amplified by an erbium-doped fiber amplifier and then coupled into the AlGaAsOI chip through tapered fibers. The wavelength of the pump is carefully tuned into the resonator resonance. Fig. 2(a) shows the measured output optical spectrum when a pump power of 25 mW is coupled into the bus waveguide. Equispaced oscillation modes are observed over a 410 nm wavelength range clearly demonstrating OPO operation. Fig. 2(b) shows the measured output power of the first oscillation mode as a function of the pump power. The on-chip OPO threshold power for our device is ~7 mW. Compared with other integrated microresonator-based on-chip OPO demonstrations operating in the telecom wavelength range [3]-[6], the threshold power is much lower for the AlGaAsOI, even though the *Q* of our device is relatively low. The ultra-low threshold performance is ascribed to the high material nonlinear coefficient and strong light confinement. With further improving the resonator design [11] and fabrication processes, especially the dry etching process [12], a higher *Q* AlGaAsOI microresonator, and thus an even lower threshold power, can be expected.

3. Conclusion

We have demonstrated an on-chip OPO spanning 410 nm using an AlGaAsOI microresonator with a high *Q* of ~109,000. As the AlGaAsOI nonlinear platform offers a highly efficient parametric process, a record-low threshold power of 7 mW is obtained with the pump wavelength at ~1.55 μm. The reduction of threshold power for integrated microresonator-based on-chip OPO will potentially speed up development of a fully integrated parametric oscillator chip where both the CW light source and the microresonator are monolithically integrated.

Acknowledgements

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