On-chip erbium-doped lithium-niobate microring lasers

Qiang Luo¹, Chen Yang¹, Ru Zhang¹, Zhenzhong Hao¹, Dahuai Zheng¹, Hongde Liu¹, Shiguo Liu¹, Fang Bo¹*, Yongfa Kong¹*, Guoquan Zhang¹*, and Jingjun Xu¹,∗
¹MOE Key Laboratory of Weak-Light Nonlinear Photonics, TEDA Institute of Applied Physics and School of Physics, Nankai University, Tianjin 300457, China; ¶bofang@nankai.edu.cn; kongyf@nankai.edu.cn; zhanggq@nankai.edu.cn; jjxu@nankai.edu.cn

Abstract: 1550-nm continuous lasers with ∼20 μW threshold and stable performance were realized in erbium-doped integrated lithium niobate microrings with loaded quality factors higher than one million. © 2021 The Author(s)

Lithium niobate is widely used in microwave and photonic fields by virtue of its excellent second-order nonlinear, electro-optic and acousto-optic properties. With the development and maturity of the preparation of lithium niobate on insulator (LNOI), the researches on LNOI photonics have increased dramatically. Lasers, as an indispensable part of integrated optical system, were reported very recently based on erbium-doped LNOI microdisk resonators [1–3]. In these works, disk resonators were coupled with tapered fibers in experiments thus lacking of coupling stability and potential of scalability. Here, we report the fabrication of waveguide-coupled erbium-doped LNOI microring resonators with quality (Q) factors up to 10⁶, based on which 1550-nm lasers with a threshold of ∼20 μW were realized.

Microring resonators were fabricated on a z-cut erbium-doped LNOI wafer with a 600 nm thick lithium niobate film on a 2 μm thick silicon dioxide layer on a silicon substrate by using electron beam lithography and inductively coupled plasma reactive ion etching. Figure 1(a) shows the scanning electron microscope image of a microring resonator with a 100 μm radius and a 1.8 μm width. The etching depth and wedge angle of the waveguide (microring) were measured to be 0.3 μm and 60°, respectively. Magnified views of the coupling region (Fig. 1(b)) and the cross section (Fig. 1(c)) of the waveguide reveal a smooth surface indicating a high Q factor. The Q factors of the fabricated microring resonators can be derived from the transmission spectra obtained by using the wavelength scanning method. From the transmission spectrum shown in Fig. 1(d), the loaded Q factor near 971 nm of the fabricated erbium-doped LNOI microring was measured up to 1.39 × 10⁶.

The photoluminescence characteristics of erbium-doped LNOI microring resonators were investigated under the pump of a 980-nm tunable laser. The output of the laser was coupled into the waveguide coupled with the microring resonator through a pair of fiber lens. In experiments, the coupling depth of the pump mode and thus the signal power were first optimized by adjusting the pump polarization. Subsequently, we collected the photoluminescence spectra under different pump power, from which the power and the linewidth of the signals in 1550-nm band can be obtained. Figure 2(a) shows the emission spectrum in the range of 1531.50-1532.65 nm at 46.4 μW pump power. Figure 2(b) depicts the dependence of the power of the strongest signal (marked in Fig. 2(a)) on the pump...
Figure 2(c) shows the linewidth drops rapidly with increasing pump power, eventually approaching the resolution of our spectrometer (∼10 pm). From Fig. 2, we can see a laser threshold of ∼20 µW, at which the signal power and linewidth changed significantly with respect to the pump power. The threshold is more than an order of magnitude lower than the reported values of LNOI microdisk lasers [1–3]. Such a low threshold is attributed to the enhancement of the pump light intensity and the space overlap between the pump and the signal modes due to the tight confinement of microring resonators. At the same time, we got a differential conversion efficiency of $6.61 \times 10^{-5}\%$ by linearly fitting the data in Fig. 2(b). Compared with the tapered-fiber-coupled microdisk lasers, microring lasers were provided with much more robust and repeatable performance benefiting from the integration of the waveguide and the microring resonator.

In summary, we demonstrate an on-chip erbium-doped LN microring laser with a threshold of ∼20 µW and a differential conversion efficiency of $6.61 \times 10^{-5}\%$. Benefiting from the integration of the microring and the waveguide, the performance of LNOI laser was effectively improved, which will promote the development of integrated optics on LNOI platform.

References

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