Vernier effect facilitates integrated lithium niobate single-mode lasers

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A research group from Nankai University in China has demonstrated an integrated whispering gallery mode (WGM) microcavity laser on erbium-doped thin-film lithium niobate with a pump threshold of about 200 μW and a side-mode suppression ratio exceeding 26 dB [1]. The Vernier effect is applied to realize the single-mode lasing in a photonic molecule. The work provides a feasible scheme for on-chip single-mode laser for integrated lithium niobate on insulator (LNOI) photonic circuits, and more active devices in LNOI will be developed inspired by this work.

As a mature material, lithium niobate (LN) shows favorable properties in piezoelectric, electro-optic, acousto-optic, and nonlinearity optics effects [2]. Benefiting from the high-quality LNOI material and advanced nano-fabrication process, ultra-low loss passive LN waveguide has been realized by many groups in the world, and consequently, various high-performance passive devices are enabled [3]. Besides, high-speed modulators beyond 100 GHz [4] and single-photon detectors [5] have also been developed on this platform. These achievements are so exciting, and the dream combining all functional photonic devices on a single chip seems possible by LNOI. In addition to the above devices, the integrated optical source is another kind of indispensable active device to make this dream true.

To realize the on-chip laser in LNOI, the erbium-doped LN WGM microcavity is a promising candidate [6]. The advantages of a small mode volume and high-quality factor of the integrated microcavity promises strong interaction between light and matter [7,8] and can significantly reduce the laser threshold. Erbium ions as gain materials are widely used in erbium-doped fiber amplifiers. Recently, by doping the erbium ions into the integrated microcavities, on-chip erbium-doped lithium niobate WGM microcavity lasers have been realized in a single microdisk [9–11] and a single microring [12]. However, due to the multimode nature of these traveling-wave microcavities, the laser is always multi-mode either. To realize the single-mode laser, the net gain coefficient except the target wavelength should be suppressed in the gain spectral bandwidth. One of the solutions is to reduce the dimension of the microcavity to increase the free spectral range (FSR); however, it will decrease the quality factor and thus require a higher pump power. Recently, an ultra-narrow-linewidth single-mode laser was realized in a coupling microdisks structure with the Vernier effect to increase the FSR [13]. The result is appealing and encouraging, but it remains elusive to realize monolithic integrated photonic components via standard dry etching or other nanofabrication processing, and thus its potential for scalable information processing is unrevealed.

Now, the researchers from Nankai University propose a

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Figure 1 (Color online) (a) Schematic diagram of the LNOI photonic molecule. (b) Numerical simulation results of resonant wavelengths of ring resonators. The black dotted box indicates that the two ring resonators have the same resonance wavelength, i.e., 1531.8 nm. (c) Single-mode lasing signals in the range of 1500–1600 nm from an erbium-doped LNOI photonic molecule under different pump powers. (d) Power (blue hollow box) and linewidth (red hollow circle) of the signal light at different pump powers. (e) A high side-mode suppression ratio lasing signal was observed at a pump power of about 900 μW . Reprinted with permission from Zhang et al. [1].

fully integrated LN single-mode lasers scheme by the Vernier effect in coupling microring optical molecule as shown in Figure 1(a) [1]. The device is fabricated by standard dry etching. Because two microcavities have slightly different radii, once two modes of two cavities have the same resonant wavelength, the adjacent modes of these two cavities will not collide in the spectrum as Figure 1(b) shows. The interval between adjacent dual-resonant wavelengths is $\lambda_0^2 / (2\pi n_g |\Delta R|)$, where λ_0 is the dual-resonant wavelength, n_g is the mode group index, and ΔR is the difference of the radii of two cavities. By carefully designing the radii of two cavities, the FSR of the coupling cavities can be tailored and

this is the so-called Vernier effect.

In the experiment, the researchers used an erbium-doped X-cut LNOI wafer with a doping concentration of 0.1 mol% to fabricate the photonic molecule. The lasing spectra as well as the power and the bandwidth of the main signal peak with various pump powers were measured as shown in Figure 1(c) and (d). The laser threshold was estimated to be 200 μW . Besides, a side-mode suppression ratio of about 26.3 dB is observed in Figure 1(e).

The achievement by Zhang et al. [1] demonstrates a fully integrated single-mode laser on the LNOI platform, which is a highly desired device for integrated LN photonics. In the future, electrodes can be integrated into devices to further realize a tunable single-mode laser.

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