Compact multi-mode silicon-nitride micro-ring resonator with low loss

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Silicon nitride (Si_3N_4) waveguides, recognized for their large transparency window and low propagation loss, have been widely applied in microwave photonics, integrated lasers, and optical computing. Pushing towards even lower loss in the Si_3N_4 platform would enable large-scale photonic integrated circuits and reduce the overall size, weight, power, and cost (SWaP-C). Current strategies to reduce the loss of silicon nitride waveguides include thermal annealing,[1] multipass lithography,[2] or using deuterated silane as the precursor.[3] While effective, these approaches are either incompatible with the CMOS process or currently not available from the foundry.

Propagation loss in the high-confinement Si_3N_4 waveguides mainly arises from the interaction between the mode field and the rough sidewalls. Recently, Yuan Yu and co-workers leveraged the multi-mode structure to minimize the scattering loss from the sidewall of the waveguide (see Fig. 1). They optimized the waveguide width, adopted adiabatic multi-mode directional couplers, and employed modified Euler bends, consequently, the propagation loss is significantly reduced from 20 dB/m down to 3.3 dB/m.[4] Notably, all designs are realized in a multi-project wafer run and no additional process is required, distinguishing it from other complicated fabrication techniques.

The authors verified the results by measuring the resonance linewidth of multiple microring resonators (MRRs) across one wafer. They reported intrinsic linewidth of MRRs in the range of 18 to 20 MHz, corresponding to an intrinsic quality factor of approximately 10.8 million (see Fig. 2). This improvement over previous values demonstrates the effectiveness of the multi-mode waveguide approach in minimizing propagation loss, which also has the potential for broader applications across different material platforms.

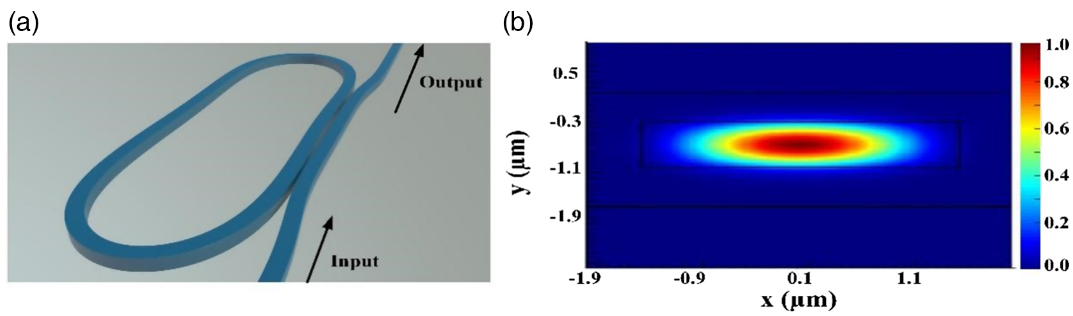

Fig. 1 (a) Schematic illustration of the proposed compact ultrahigh-Q MRR; (b) the simulated mode profiles when the waveguide width of the MRR is 3 μm (reproduced from Ref. 4).

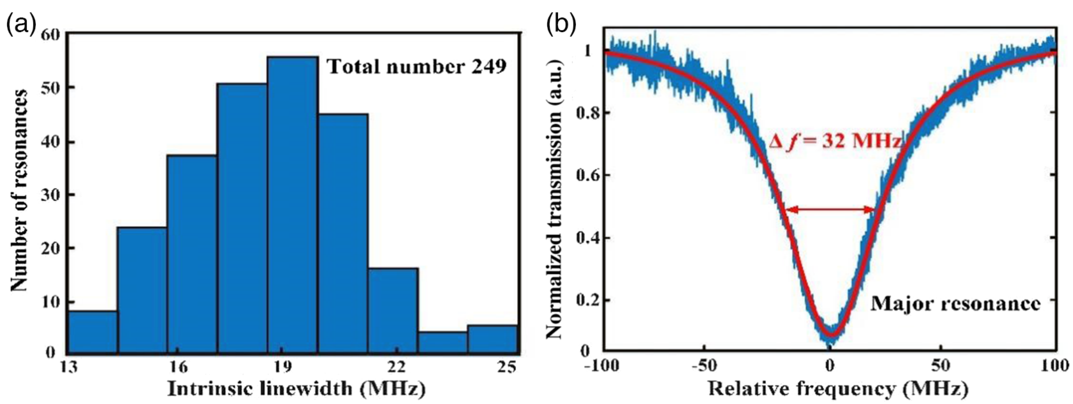

Fig. 2 (a) The histogram of the intrinsic linewidth of the MRRs; (b) a representative resonance with critical coupling (reproduced from Ref. 4).

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Benefiting from the high optical confinement of the Si_3N_4 waveguide, the bending radii of the waveguide can be small. Based on their optimized waveguide structure, the authors demonstrate an MRR with a free spectral range (FSR) of 65 GHz. The large FSR makes the device attractive for microwave photonics applications that require large bandwidth.

While the introduction of multi-mode waveguides is innovative, it may introduce complexities in terms of mode control and design optimization. The suppression of higher-order modes excitation and coupling in multi-mode structures is quite challenging, thus requiring additional research and design efforts. Certain components, such as modified Euler bends and multi-mode directional couplers, may require high-precision fabrication techniques. Ensuring consistent and precise fabrication can be challenging, impacting yield and reproducibility.

In summary, the new publication from Yu and co-workers offers a new way to design MRR with a large FSR and high intrinsic Q-factor within the standard manufacturing process. With further exploration and refinement, the proposed multi-mode waveguide approach has the potential to benefit a wide range of applications across industries.

References

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