High-Quality-Factor SiN Ring Resonator of 12 GHz Repetition Rate

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Primary CNF Tools Used: JEOL 9500, ASML PAS 5500/300C DUV Stepper, Oxford PECVD, PT Takachi HDP-CVD, LPCVD Furnace, Oxford 100 ICP Dielectric Etcher, Unaxis 770 Deep Silicon Etcher, PT Deep Silicon Etcher, YES EcoClean Asher, Xactix Xenon Difluoride Etcher

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Abstract:

We demonstrate a high-quality-factor silicon nitride ring resonator of 12 GHz repetition rate. Special fabrication techniques are applied to acquire an intrinsic quality factor of 10 million as well as anomalous dispersion (for fundamental modes) in the resonator.

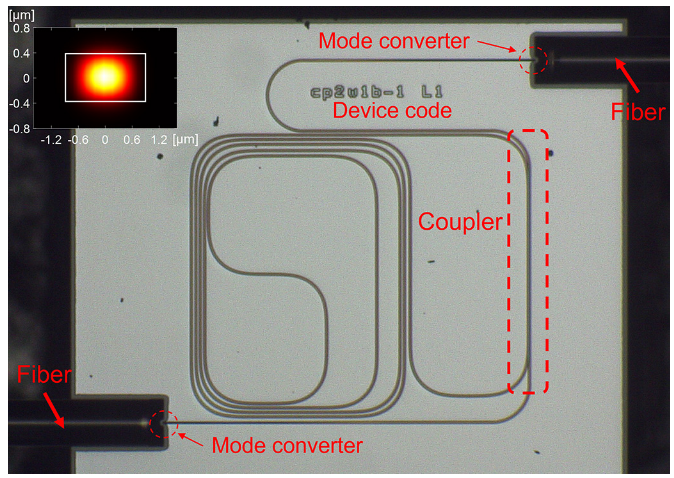


Figure 1: Camera picture of a fabricated device. Inset: TE_0 mode of the device.

Summary of Research:

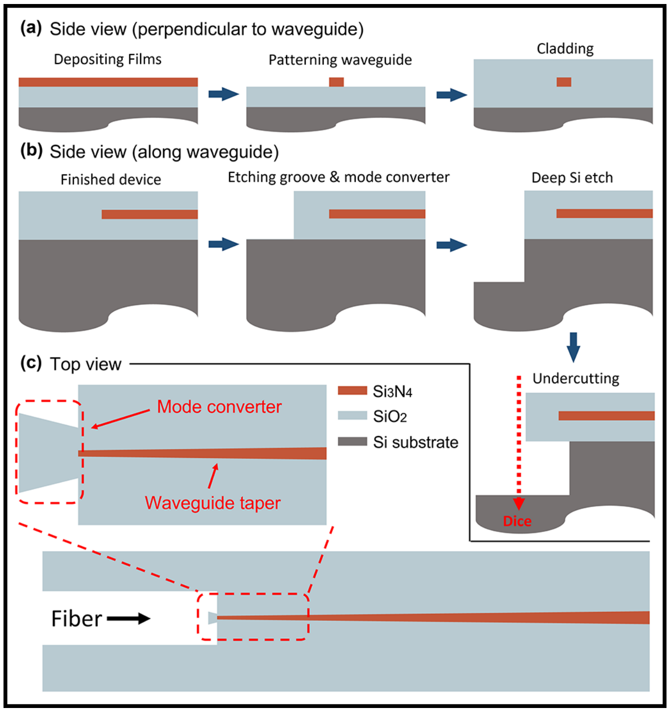
Silicon nitride (Si_3N_4) [1] is a high-performance material platform for chip-scale photonic devices. Benefiting from its ultra-low loss and good CMOS-compatibility, Si_3N_4 is a preferable choice for making waveguides, resonators, and other passive components for photonic integrated circuits (PICs). In addition, Si_3N_4 supports not only applications in the optical communications band but also in the visible [2] and the mid-infrared band, such as (bio)medical and (bio)chemical sensing, due to its broad transparency window (400-6700 nm [3]).

Ring resonator is one of the fundamental components in integrated photonics. It can work for versatile purposes, including laser cavity, modulator, filter, etc. In this work, we design and fabricate a Si_3N_4 ring resonator with anomalous dispersion (for fundamental modes) for generating dissipative Kerr solitons (DSK) [4]. The resonator has a cross-section of 1.6 μm × 0.76 μm. Such a structure supports a very confined fundamental transverse electric (TE0) mode (inset in Figure 1) and, therefore, leads to an anomalous dispersion [5].

We design the cavity length of the resonator to be 11.6 mm and have a repetition rate (the inverse of its round-trip time) of 12.3 GHz according to $T_R = L/c_0 n_g$ where T_R is the round-trip time, L is the cavity length, c_0 is the light speed in vacuum, and n_g is the group index of the guide mode (2.11 for TE_0 mode in our case). This repetition rate allows the incorporation of the generated solitons with radio frequency (RF) applications. Figure 1 shows a fabricated device.

We use adiabatic turnings in our spiral-like ring resonator to minimize the bending loss. The radius of curvature of the waveguide smoothly changes from 3 mm to 0.1 mm through a tanh function [6] instead of a conventional abrupt turning of fixed radius. We use SiO_2 mode converters [7] and tapered Si_3N_4 waveguides (Figure 2(c)) to optimize the power coupling efficiency from the fiber to the device.

The fabrication steps are shown in Figure 2(a-b). We deposit 0.76 μm stoichiometric Si_3N_4 using low pressure vapor chemical deposition (LPCVD) over 4 μm of thermally-grown silicon oxide (SiO_2) on silicon wafer. We rotate the wafer by 45° after every 300 nm deposition to alleviate the total strain accumulated in the film and prevent it from cracking [8]. We pattern the device using 100 kV electron-beam lithography. The pattern is exposed twice with half of the required dose each time ('double pass') for better lithography accuracy and better sidewall roughness. We etch the structure



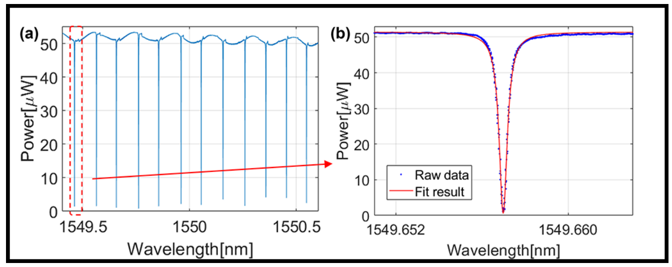


Figure 2, left: (a-b) Fabrication procedures of the device. (c) A zoom-in view of the waveguide taper and the mode converter.

Figure 3, above: (a) Measured typical transmission spectrum of the device. (b) Typical fitting result of a resonance.

with inductively coupled plasma reactive-ion etching (ICP-RIE). The etched structures are then clad with 4 μm SiO_2 through plasma-enhanced chemical vapor deposition (PECVD). Afterward, we pattern the mode converters and the grooves, which are used to ensure stable fiber-to-chip power coupling, with deep ultraviolet (DUV) lithography. The SiO_2 outside the chip boundary is etched using ICP-RIE. We continue to etch down the exposed Si substrate by approximately 100 μm using a Bosch process so that fibers can be pushed all the way to the mode converter (vertically aligned) after dicing without being blocked by the substrate. We anneal the device at 1200°C to improve the material quality and mitigate the material loss. Finally, we use the isotropic XeF_2 etch to remove the Si beneath the mode converter and make it suspended after dicing the wafer into chips.

We then measure the transmission spectrum (Figure 3(a)) of the fabricated device and characterize its performance. Figure 3(a) shows a typical spectrum. We numerically fit (Figure 3(b)) the resonances in the spectrum using a Lorentzian equation [9]

$$T = T_0 \frac{(a-t)^2 + \frac{4at\pi^2}{FSR^2}(\lambda-\lambda_0)^2}{(1-at)^2 + \frac{4at\pi^2}{FSR^2}(\lambda-\lambda_0)^2}$$

where T stands for power transmission, T_0 is a constant, t is the field transmission of the coupler, a is the round-trip field transmission of the ring, FSR is the free spectral range, λ is the testing laser wavelength, and λ_0 is the central wavelength of the resonance. The round-trip is approximately 1% across the 1480-1640 nm bandwidth, which corresponds to a propagation loss of 0.04 dB/cm and an intrinsic quality factor of 10 million in our 11.6 mm ring.

We further extract the group index and the group velocity dispersion of the device (TE_0) to be 2.11 (corresponding to 12.3 GHz repetition rate) and -1.84 × 10^5 fs^2/m, respectively.

Conclusions and Future Steps:

In conclusion, we demonstrate a silicon nitride ring resonator with anomalous dispersion, 12.3 GHz repetition rate, and 10 million intrinsic quality factor. This work will help to enable RF-frequency applications directly based on high-performance Si_3N_4 ring resonators.

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