Dispersion engineered high-Q resonators on a chip

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Abstract: We demonstrate dispersion control in optical resonators over an octave of optical bandwidth. Dispersion is engineered lithographically and Q factor is maintained above 100 million, which is critical for efficient nonlinear devices such as microcombs.

OCIS codes: (190.4380) Nonlinear optics, four-wave mixing; (230.5750) Resonators; (260.2030) Dispersion.

1. Introduction

High-Q microresonators enable various nonlinear optical processes, and the control of dispersion is an essential ingredient in many systems. This is particularly important in parametric oscillators where the group velocity dispersion must be anomalous at the pump wavelength and in frequency microcombs where both the sign of the dispersion as well as its magnitude and shape are important for comb operation [1–3]. There have been several dispersion engineering approaches demonstrated in optical resonators. The waveguide cross-sectional dimension in Si_3N_4, diamond, AlN, MgF_2, and CaF_2 resonators has been used to control geometric dispersion [4–7] . HfO_2-coated Si_3N_4 and SiO_2-cladded Si resonators also provide dispersion control [8, 9]. Our work demonstrates dispersion control over an octave of bandwidth in ultra-high-Q (UHQ) silica disks [10]. This is possible by creating multiple wedge angles at the exterior of the resonator through a multi-step lithography and etch process. Measurements of dispersion over an octave agree with modeling.

2. Device design and characterization

The resonator structure uses a fabrication technique that extends earlier work on ultra-high-Q wedge resonators [10, 11]. The resonator is shown in Fig. 1a and allows for control of the zero crossing of dispersion through control of the wedge angle [11, 12]. Measurements of free-spectral-range (FSR) and D_2 (change in FSR per mode) are presented in the lower half of the panel. These measurements were performed by comparing the resonator FSR with the line spacing

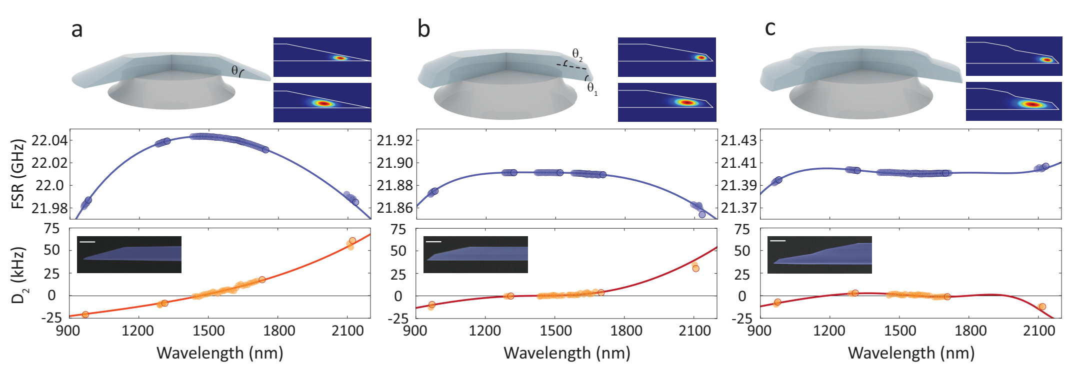

Fig. 1. Three dispersion control geometries are presented. The panels show the engineered resonator structure (upper left), optical mode finite-element-simulations (upper right) at wavelengths of 1000 nm (upper) and 2000 nm (lower), measured free-spectral-range (FSR) and D_2 (=ΔFSR per mode) of (a) single-, (b) double-, (c) quadruple-wedge disks. Inset within the D_2 plots shows the scanning electron microscope images of resonator cross sections (bar: 10 μm).

of an electro-optical frequency comb. Panels b and c present double- and quadruple-wedge resonator structures. The addition of these extra wedge features at the exterior of the resonator introduces new control over the geometrical component of dispersion in the resonator waveguide. Intuitively, this happens because the centroid of motion of the optical mode is shifted inwards toward the center of the resonator as wavelength increases. By varying the wedge angle, the variation of this centroid motion with wavelength can be controlled and, in turn, the geometrical component of dispersion. The overall progression in dispersion control that is possible can be seen by inspection of the dispersion measurements in panels a, b and c. A flattening of dispersion over an octave is possible as can be seen in the dispersion measurement in panel c.

To illustrate the fabrication control that is possible, Fig. 2a presents a plot of measured D_2 versus outer wedge height (t, see inset) at 1550 nm in a double-wedge resonator. The measured D_2 shows that good control of dispersion is possible through microfabrication. Because of the added complexity of the process used to fabricate the multi-wedge disk resonators, the Q factors are lower than for the single wedge devices. Nonetheless, average Q factors of 1.1 and 1.6 $\times$ 10^8 for double- and quadruple-wedge resonators, respectively, were achieved. In conclusion, we have demonstrated octave-span dispersion control in optical resonators. Dispersion can be lithographically controlled with the maintenance of high Q factor above 100 million, which is important for efficient operation of nonlinear optical oscillators [13].

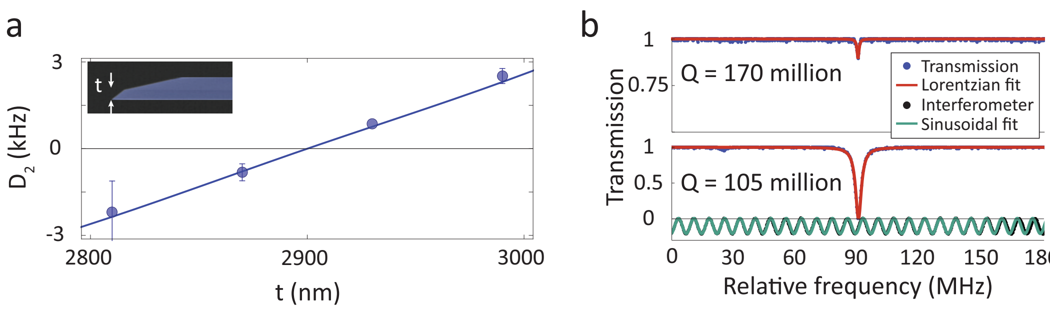

Fig. 2. (a) D_2 (=ΔFSR per mode at 1550 nm) as a function of outer wedge height (t) in a double-wedge disk. The dashed line is the measured D_2 of a single-wedge disk (θ=10°). (b) Spectral scan for the case of 170 (undercoupled), and 105 (critical coupled) million Q-factors (quadruple-wedge disks). The sinusoidal curve is a calibration scan performed using a fiber interferometer.

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