Imaging Nanophotonic Modes of Microresonators using a Focused Lithium Ion Beam

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On-chip dielectric photonic microresonators with high quality factors can enable a host of important applications where exquisite sensitivity or enhanced light-matter interaction is required, such as single molecule sensing and quantum optics. The nanophotonic mode shape is critical to the device performance, but is difficult to measure directly and non-invasively. Near-field scanning optical microscopy has been the best option for nanoscale field mapping, but the perturbation introduced by the physical probe is often too large to accurately probe sensitive high-Q resonances. Here, we present a new approach to probing nanophotonic modes in microresonators by introducing a controllably small and local optomechanical perturbation using a focused ion beam (FIB).

We fabricate fiber-pigtailed silicon microdisk optical cavities (diameter 10 μm, Q > 20,000) that we have previously developed for the optomechanical motion detection of nanoscale cantilevers.[1] We optically monitor a resonance of the microdisk (Figure 1) while probing it using a lithium FIB, a custom system with probe sizes of a few tens of nanometers at beam energies of 500 eV to 5 keV and beam currents of a few picoamperes.[2] The FIB creates defects in the silicon lattice, and induces a picometer scale dynamic deformation of the surface, which we detect through a shift in the resonant wavelength. We map the spatial mode profiles by measuring this wavelength shift as a function of the spatial position of the FIB probe, as shown in Figure 2. The technique achieves good spatial and spectral resolution in a minimally perturbative measurement, and can be applied to a variety of nanophotonic systems.

Additionally, the ability to detect FIB-induced perturbations in situ also allows us to reverse the experiment and utilize the microresonator as a sensor to study the real-time interaction of an ion beam with a solid. We present measurements of the system's response to millisecond-long ion pulses, showing that the FIB-induced damage relaxes logarithmically on time scales up to seconds. This provides a new way to study, with unprecedented sensitivity, the relaxation of ion beam induced defects in silicon, a problem of long-standing interest in silicon microelectronics and nuclear materials engineering.

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[1] K. Srinivasan, H. Miao, M. T. Rakher, M. Davanço, and V. Aksyuk, Nano Lett. **11**, 791 (2011)

[2] K. A. Twedt, L. Chen, and J. J. McClelland, Ultramicroscopy **142**, 24 (2014)

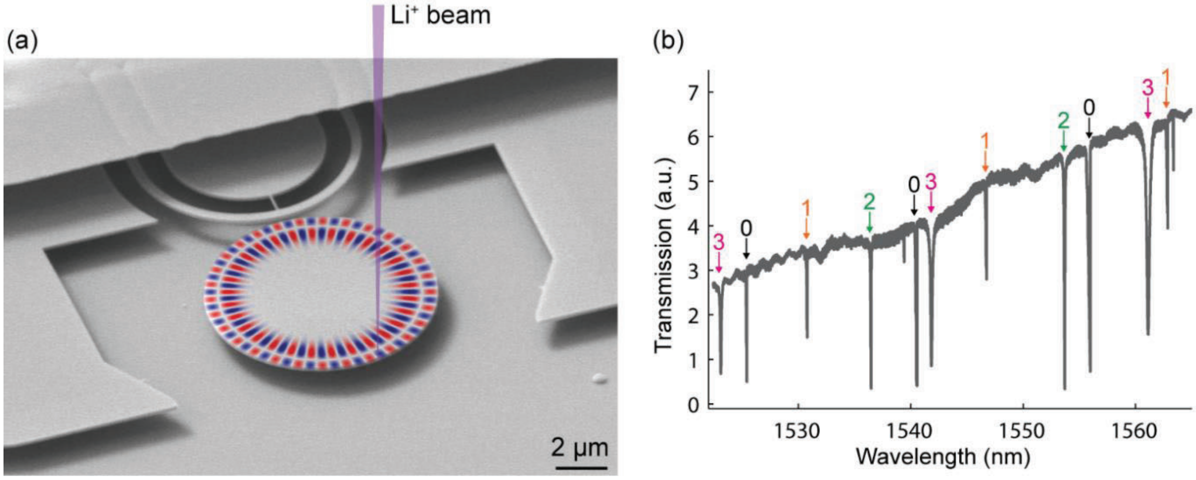

Figure 1: (a) Scanning electron micrograph of the microdisk cavity. The calculated mode profile of a $TM_{1,29}$ mode is superimposed. A lithium ion beam is focused and scanned across the surface. (b) Optical mode spectrum of the microdisk cavity. The radial order of each mode is labeled.

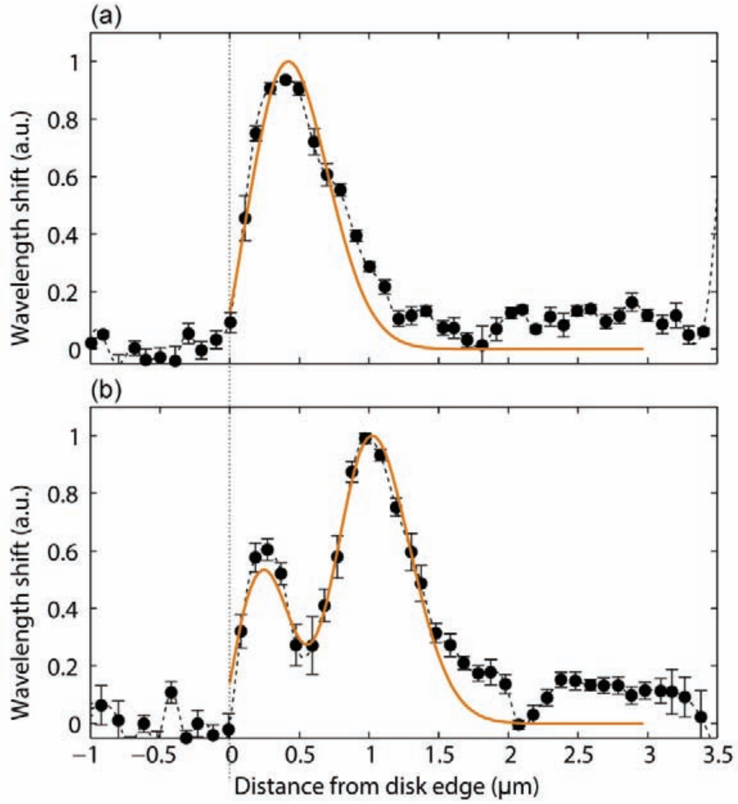

Figure 2: Measured shifts of the resonant wavelength of the (a) $TM_{0,33}$ and (b) $TM_{1,29}$ modes as a function of the radial position of the FIB probe relative to the disk edge. Orange lines are the expected wavelength shifts from a perturbation theory calculation, which are closely related to the electric field energy density at the surface.