**Abstract:**

We demonstrate a specially designed resonant structure for enabling efficient static control of the optical response with relatively weak optical forces. Using this resonator, we show extreme tuning of its optical resonances (31.4 nm) using optical gradient forces. We estimate the static mechanical displacements to be as large as 60 nm using 13 mW of optical power.

**Summary of Research:**

Large gradient optical forces can be achieved by exploring the fast decaying optical near field in micro photonic structures. Several groups have shown theoretically and experimentally that such forces can modify both the static and dynamic behavior of optical waveguides and cavities [1-3]. However, the optical force-induced resonance tuning is just few nanometers, limiting the potential of optomechanical tuning of these devices [4]. This limited displacement may translate into poor performance when compared to other tuning techniques such as thermo-optic, carrier injection and electrostatic-force actuation. Hence, it is of great interest to pursue optomechanical devices, which allow large tuning of their optical properties.

Here, we show evidence of optomechanical tuning of a microcavity resonance by 31.4 nm (1581-1612.4 nm) extending the tuning range to cover the entire L-band, using a laser power of 13 mW. By exploring resonant optical structures, we have recently demonstrated tuning range of 2.5 nm with displacements of about 20 nm [4]. Painter, et al. have also demonstrated similar displacement (17 nm); in either case however, the spectral shift of the optical resonances was limited to a few nm (~ 0.5 THz). In this work, we extend this tuning range to 3.7 THz.

We design a structure that enables giant static displacement and broadband tuning of optical resonances. The fabricated structure, shown in the Figure 1(a,b) is based on two coupled ring resonators similar to the one studied in [4], but brought close together down to 170 nm. The mechanical stability of the cavity is ensured by using relatively low optical quality factors (~ 18,000) that, together with the large damping of the mechanical modes caused by squeeze-film damping due to air trapped between the rings. We also use thin spokes (300 × 200 nm cross-section) to create a very compliant structure with stiffness of 1.2 N/m. This combination of properties minimizes optomechanical oscillations in the system which, otherwise, can be extremely large on such cavities [4]. With a diameter of 30 µm, the optical finesse is F~125, leading to resonant enhancement of the optomechanical forces while allowing quasi-static reconfiguration.

We measured the optical transmission of the 30 mm diameter cavity using a tapered optical fiber that is coupled to the microcavity as shown in Figure 1(d). The transmission spectra are recorded at different laser power levels. As the laser sweeps over the cavity resonances, the optical power couples to the cavity, inducing an optical gradient force between the two rings [4]. At low optical powers (11 µW),
two sets of modes can be observed in the 40 nm scanning range. As the laser power is increased, a strong gradient optical force builds up in the cavity, leading to a change in the air-gap between the rings. Such change in the gap between the rings shifts the optical resonances, resulting a bistable transmission.

The transmission spectra for the cavity for 11 µW to 13 mW are shown in Figure 1(c). Although the transmission spectrum at high powers is severely distorted, the bistability curve extends over 31 nm. Figure 1(d,e) shows the top view microscope image of the cavity. The large change in the gap between the rings can be readily observed as a change in the cavity color. We highlight on Figure 1(e) some cavity images recorded at the points indicated in the 13 mW spectrum.

The optomechanical force generated is estimated to be $F = 35$ nN, and a corresponding mechanical displacement of 59 nm for an optical power of 13 mW. These estimates are obtained from the usual expression for the optical gradient force \[ F = \frac{U}{\lambda k_{\text{om}}} \] where $U$ is the intra-cavity energy and $k_{\text{om}}$ is the optomechanical tuning efficiency. Since the optical transmission is $T \approx 0.5$ and the loaded $Q = 18,000$, the maximum intra-cavity energy is $U = 123$ fJ. We assumed an optomechanical tuning of $k_{\text{om}} = 0.49$, obtained from numerical simulations of such a cavity [4]. The change in the gap obtained with such a force is $\Delta g = 2 \left( \frac{U}{\lambda} k_{\text{om}} / k \right) \approx 59$ nm. The estimated shift from this gap change would be $\Delta \lambda = k_{\text{om}} \Delta g = 28$ nm, in reasonable agreement with the shift based on the bistability shift.

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