Multi-modal optical microcavities for loss avoidance

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Abstract: We demonstrate optical microcavities wherein multiple guided modes interfere to avoid scattering loss at sidewall contacts. Cavities with 62 direct silicon contacts show resonances with intrinsic quality factors near 40,000 across an 80nm spectral range.

OCIS codes: (130.3120) Integrated optics devices; (230.5750) Resonators; (230.7370) Waveguides.

To gain access to dynamical degrees of freedom of an optical microcavity (such as electrical, mechanical or thermal), it is often necessary to place physical contacts on the cavity. Several approaches have been utilized to make contact to silicon microphotonic devices [1-5], and here we present work that builds upon the approach presented in Ref. 1. The device is part of a class of silicon photonic microstructures which superpose multiple guided modes to form interference patterns with nulls where contacts can be placed. We demonstrate racetrack-type resonators with contacts made directly to the waveguide sidewalls. Cavities with numbers of contacts between 10 and 62 are measured to have intrinsic Q factors across the C-band averaging higher than 33,000 with peak values near 40,000. Devices with FSRs between 500GHz and 1.12THz were investigated.

To achieve such contacted microcavites, two guided modes are excited with a particular ratio of amplitudes which gives rise to a field pattern with interference nodes where contacts can be placed without incurring substantial loss. For a given waveguide width, the TE_1 and TE_2 modes have a beat period given by $\Lambda = 2\pi / (\beta_1 - \beta_2)$. If loss centers are placed along the waveguide with this periodicity, light entering the structure in the fundamental mode will be converted into the superposition of modes TE_1 and TE_2 which incurs the least loss. An FDTD simulation of this scenario is shown in Fig. 1(a); the fundamental mode enters from the left, and the contact array acts as a mode converter to leave an interfering combination of modes TE_1 and TE_2 which avoids the sidewall contacts.

By observing the amplitudes of the two modes leaving the simulation space after the contact array, we can determine the appropriate ratio of amplitudes to minimize loss. We can then excite precisely that ratio of modes in the structure by utilizing a non-adiabatic taper. As shown in Fig. 1(b), the light entering the contact array from the taper avoids loss even at the first contact, and the intensity after the array is very nearly that at the input.

This principle of multi-mode interference for loss avoidance has applications from waveguide crossings [1] to optomechanics. In this work we developed racetrack resonators wherein two contacted waveguides like that shown in Fig. 1(b) are connected by 180° bends with the eventual intention of creating optical modulators for CMOS to DRAM optical interconnects [6-7]. Fabrication of these devices was carried out by Micron Technology in a bulk CMOS memory flow. At 1550nm the poly-silicon propagation loss is near 10dB/cm. Quality factors near the intrinsic value were measured with the loss ring method: several cavities of identical design were laid out along a common through port bus, and each cavity was coupled to an independent drop port of increasing ring/bus gap.

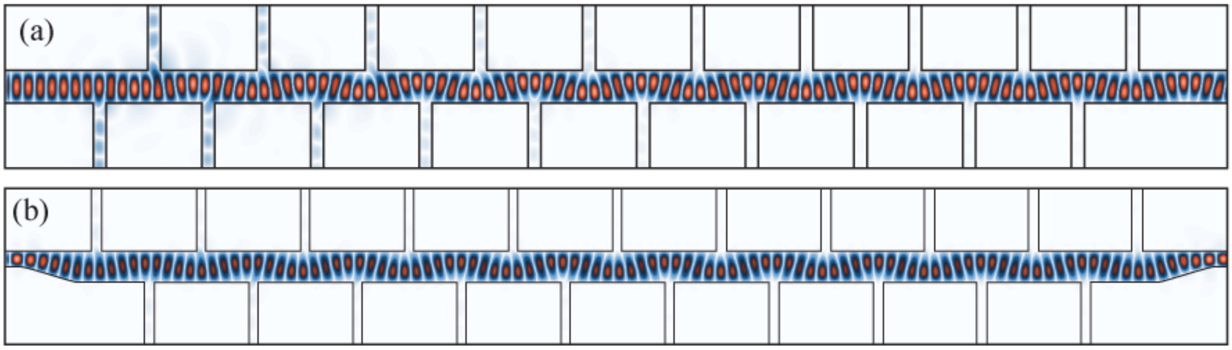

Fig. 1. (a) Light in the fundamental TE_1 mode enters a contact array with periodicity equal to that of the beat pattern of modes TE_1 and TE_2. The light is filtered until only the low-loss superposition of modes TE_1 and TE_2 remains. (b) Tapers are implemented to convert from a single-mode waveguide to a dual mode waveguide with the optimal ratio of mode excitation.

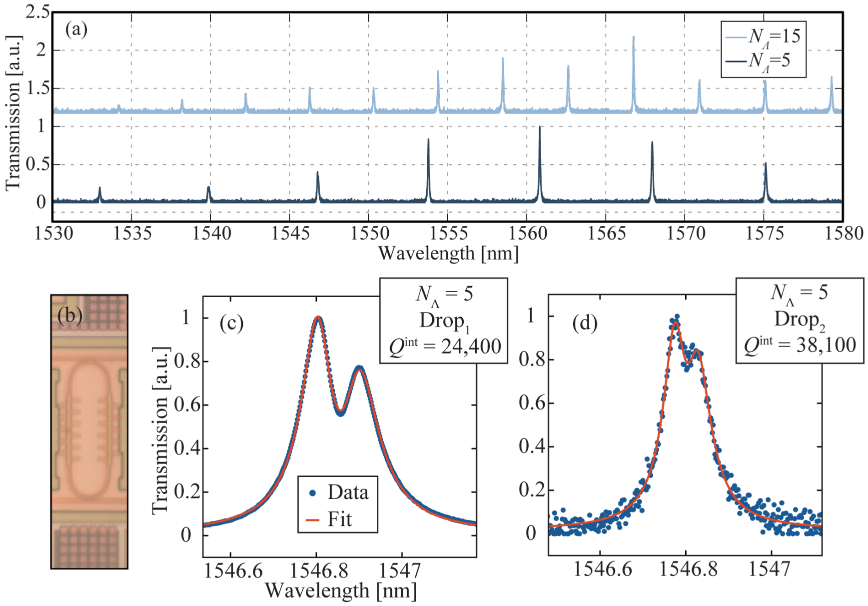

Fig. 2. Experimental measurements: (a) Spectra from cavities with five and 15 periods of contacts (22 and 62 total contacts). (b) An optical micrograph of a racetrack resonator fabricated in a DRAM poly-silicon process by Micron Technologies. (c) High-resolution spectrum of a resonance in a cavity with 22 total contacts. This data was taken from the drop port of a cavity with coupling sufficient to broaden the linewidth beyond that of the intrinsic cavity. (d) Spectrum of a resonance analogous to that in (c) but from a device with weaker through and drop couplings giving rise to a higher measured Q of 24,600. After accounting for the 10dB/cm propagation loss of the poly-silicon, this resonance is revealed to have an intrinsic Q of 38,100.

We identify cavities by the number of periods of contacts, N_{Λ}. The total number of contacts on each resonator is $N_{\mathrm{tot}} = 2(2\ N_{\Lambda}+1)$. Figure 2(a) shows spectra from a weakly coupled drop port of structures with N_{Λ} = 5 and 15. Both devices have high-Q resonances, and the FSR is determined by the number of periods as well as the length of the racetrack bends. A microscope image of a cavity with N_{Λ} = 5 is shown in Fig. 2(b). This device is observed to give rise to doublet resonances, as one would expect from the breaking of degeneracy between counter-propagating modes. A resonance observed in a relatively strongly coupled drop port is shown in Fig. 2(c). The doublet nature is evident, and the Q factor is measured to be 18,100. After accounting for poly-silicon propagation loss, the intrinsic cavity Q is 24,400. The corresponding resonance in a device with a more weakly coupled drop port is shown in Fig. 2(d). A fit to this spectrum gives a Q factor of 24,600 which corresponds to a value of 38,100 after accounting for the 10dB/cm loss of the poly-silicon. The observed resonances were quite consistent across 80nm of wavelength range, thereby demonstrating that such multimodal loss-avoidance structures are robust and have broad operating bandwidths.

Quality factors as high as those measured here are sufficient for many cavity applications including modulators, detectors, optomechanical structures, and nonlinear light-matter interactions. For such applications it is often necessary to access electrical, mechanical, or thermal degrees of freedom. An exceptional aspect of a cavity with 62 independently addressable contacts is that some can function to manipulate certain degrees of freedom leaving plenty for other uses, thus enabling highly multi-physical optical cavity systems.

This work was supported by NSF award no. ECCS-1128709 and by DARPA POEM program awards HR0011-11-C-0100 and HR0011-11-9-0009. The views expressed are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government (Approved for Public Release, Distribution Unlimited).

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