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Suppression of Higher-Order Radial Whispering Gallery Modes in Waveguide-Coupled Microcavity Disk Resonators

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Nanofabrication techniques now allow the realization of high-Q semiconductor microcavity ring and disk resonators with evanescent wave coupling to sub-micron-width waveguides across sub-micron-width air gaps, as demonstrated recently [1]. These devices may function as micron-size narrowband tunable filters, frequency-domain switches, or intensity/phase modulators. Additionally, these resonators can be integrated with low-threshold photonic-wire microcavity lasers [2].

In comparison to single-mode microring resonators, microcavity disk resonators supporting whispering gallery modes (WGM's) have the advantage of less side-wall scattering loss and higher Q. However, the microdisk resonator has multiple sets of resonances corresponding to fundamental and higher-order radial WGM's of the disk. Suppression of the higher-order modes is necessary in order to use microdisks as single-mode laser sources or as WDM devices with low crosstalk across a wide spectrum. We have investigated methods for suppressing the higher-order modes using FDTD simulations. As the radial order of the WGM increases, the mode width increases and the peak of the mode shifts toward the center of disk. Therefore, we can manipulate the resonances by taking advantage of the spatial characteristics of the WGM's.

First, the width of the adjacent waveguide can be chosen to minimize coupling between the waveguide mode and the higher-order WGM's of the microdisk. Fig. 1 shows FDTD-computed normalized power transmission spectra for a 5.0-μm-diameter microdisk coupled to two straight adjacent waveguides with an air gap width of 0.2 μm. In all of these simulations, the disk and the waveguides have a refractive index of 3.2. Each resonance in Fig. 1 is labeled with a WGM radial number, q. In Fig. 1(a), where the width, w, of the adjacent waveguides is 0.2 μm, the four sets of resonances correspond to the first four radial modes of the disk. For $w = 0.3$ μm, as shown in Fig. 1(b), the fourth-order radial mode resonances no longer exist; furthermore, the presence of the third-order radial modes is weak. Increasing the width to $w = 0.35$ μm, as shown in Fig. 1(c), eliminates the third-order resonances. Finally, in Fig. 1(d), where $w = 0.38$ μm, the second-order resonances are strongly suppressed; thus, for this example of a 5.0-μm-microdisk, a waveguide width of 0.38 μm suppresses all of the higher-order radial mode resonances in the output spectrum. As w approaches 0.38 μm, the Q of the fundamental radial mode resonances increases. However, without changing the gap size, the minimum on-resonance transmission increases. Once the optimum waveguide width is determined, the gap size can be readjusted to give the best fundamental mode transmission characteristics (i.e. low on-resonance transmission and high Q).

Second, the center of the disk can be etched out to create larger losses for the higher-order modes which propagate in that region. Here, we study three intermediate geometries that bridge the gap between the extremes of the solid disk and a thin ring. Starting with the solid 5.0-μm-diameter microdisk (similar to Fig 1(b)), we etch out the center, creating an inner rim diameter, d_i, of 3.0 μm. As seen in the FDTD-computed transmittance curve of Fig. 2(a), this suppresses the q=3 mode which has fields concentrated toward the center of the disk. In the next structure, d_i is increased to 3.5 μm. Fig. 2(b) shows that the third-order mode resonances have been eliminated. Furthermore, the second-order resonances have been shifted; only the first-order resonances remain unaffected. The transmittance curve (Fig. 2(c)) for the third structure, where $d_i = 4.0$ μm, shows further suppression and shifting of the q=2 resonances. In this case, the fundamental mode resonances are also shifted and the Q's are slightly lowered. The resonance behavior is approaching that of single-mode narrow-waveguide microring, shown in Fig. 2(d), for which the Q's of the fundamental mode resonances are at a minimum. In contrast to changing w, this method alters the resonance wavelengths, as seen by tracking the q=1 resonances in Fig. 2(a)-(d).

REFERENCES

[1] D. Rafizadeh, J. P. Zhang, S. C. Hagness, A. Taflove, R. C. Tiberio, K. A. Stair, and S. T. Ho, "Nanofabricated waveguide-coupled 1.5-μm microcavity ring and disk resonators with high Q and 21.6-nm free spectral range," *Conference on Lasers and Electro-Optics*, Baltimore, MD, May 1997, postdeadline paper CPD23.

[2] J. P. Zhang, D. Y. Chu, S. L. Wu, W. G. Bi, R. C. Tiberio, C. W. Tu, and S. T. Ho, "Directional light output from photonic-wire microcavity semiconductor lasers," *IEEE Photon. Technol. Lett.*, vol. 8, no. 8, pp. 968–970, Aug. 1996.

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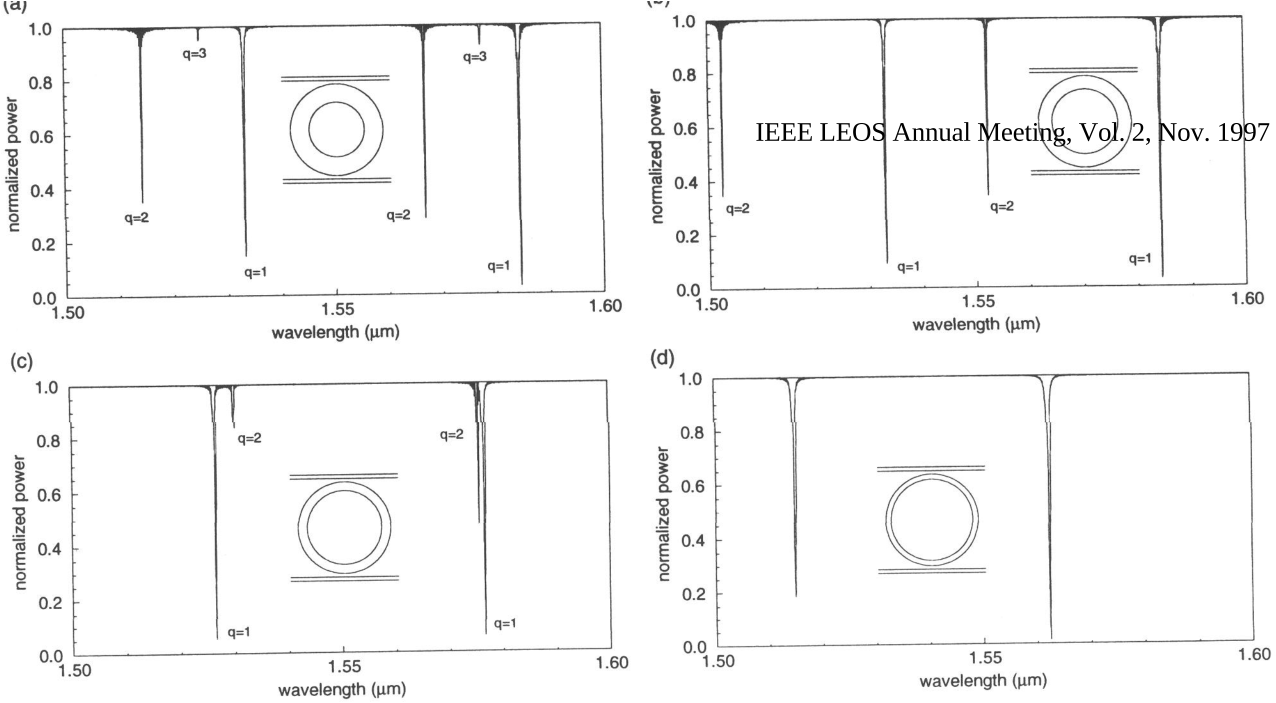

Fig. 2. FDTD-computed transmittance of a 5.0-μm-diameter microcavity resonator coupled to 0.3-μm-wide waveguides. The inner rim diameter is increased from zero for the case of the solid disk, shown in the inset of Fig. 1(b), to (a) 3.0 μm, (b) 3.5 μm, (c) 4.0 μm, (d) 4.4 μm.

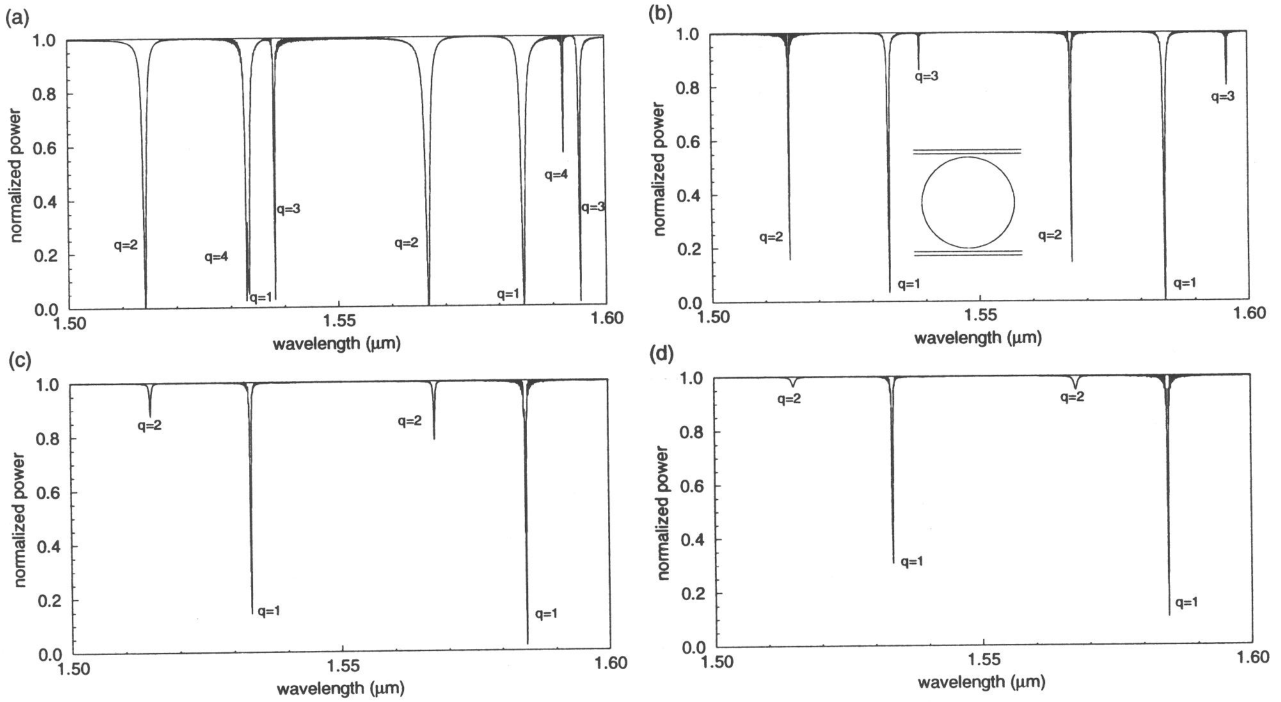

Fig. 1. FDTD-computed transmittance of a solid 5.0-μm-diameter microdisk coupled to straight waveguides of width w: (a) 0.2 μm, (b) 0.3 μm, (c) 0.35 μm, (d) 0.38 μm. The disk and adjacent waveguides have a refractive index of 3.2. The width of the air gap between the disk and waveguides is 0.2 μm.