Asymmetric Resonant Optical Cavities

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A new and useful type of optical resonator has been proposed based on the principles of chaos [1]. The asymmetric resonant cavity (ARC) is an extension of the concept of spherical or cylindrical dielectric resonators which have high-Q "whispering gallery" (WG) modes trapped by total internal reflection [2]. In the ARC such a cylinder or sphere is deformed substantially but in a smooth and convex manner, leading to an oval cross-section, as shown in the figure. The deformation allows control of the Q value of the WG modes and also induces highly directional emission from these modes, making this an attractive design for microlasers. This overcomes a major drawback of symmetric resonators which have intrinsically isotropic emission patterns and require additional optical elements to guide the emission of the light. Recent experiments measuring the lasing emission from deformed micro-droplets [1,3] and deformed cylindrical dye jets [4] have confirmed the basic predictions of the theory with respect to directional emission.

The essential novelty of the ARC concept from the theoretical point of view lies in its connection to the theory of quantum or wave chaos [1]. Since the dielectric is strongly deformed, the wave equation is not separable, so the modes cannot be described in terms of standard special functions; nor can they be described by perturbation theory. Instead, its properties are inferred from the geometric optics limit, using semiclassical methods and taking into account the fact that an increasing deformation makes the ray dynamics more and more chaotic. The ray-optics model for ARCs makes the striking prediction that their WG resonances fall into subsets, all of which have the same lifetime for large deformation [1]. This is because the resonance lifetime is controlled by chaotic motion which is independent of wavelength and lasts until the total internal reflection condition is violated and the light escapes by refraction. The same model predicts the directions of high emission for the ARC resonances (see figure), which for a glass resonator - surprisingly - are not perpendicular to the points of highest surface curvature. The ray predictions (histogram, bottom right) are in excellent agreement with actual wave solutions (left, and top right).

The ARC design is of significant interest for passive and active optical device applications such as add-drop filters and microlasers. Initial exper-

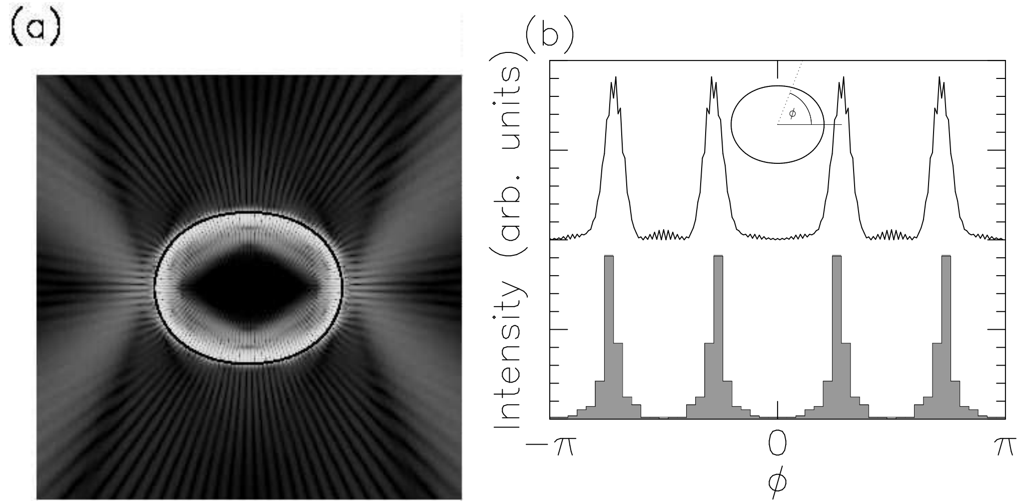

Figure 1. (a) Grayscale plot of the electric field intensity profile of a TM whispering gallery mode for a deformed cylindrical dielectric cavity of refractive index $N = 1.54$. Lighter regions indicate high intensity, so the four lighter lobes emanating from the points of high cavity curvature indicate the high emission directions for a microlaser. (b-top) Same data as in Fig. 1 plotted in the far field as a function of azimuthal angle (see inset) and compared (bottom) with the far-field intensity predicted by the ray-optics model of reference 1.

imental work to develop these applications at Yale [5] and Bell Labs [6] is showing promise.

References

[1] "Ray and wave chaos in asymmetric resonant cavities", J. U. Nöckel and A. D. Stone, Nature **385**, 45 (1997)

[2] "Optical processes in microcavities" Y. Yamamoto and R. E. Slusher, Physics Today **46**, 66 (1993)

[3] "Q-spoiling and directionality in lasing droplets", A. Mekis, J. U. Nöckel, G. Chen, A. D. Stone and R. K. Chang, Phys. Rev. Lett. **75**, 2682 (1995)

[4] "Directional emission from asymmetric resonant cavities", J. U. Nöckel, A. D. Stone, G. Chen, H. Grossman and R. K. Chang, Opt. Lett. **21**, 1609 (1996)

[5] R. K. Chang *et al.*, (unpublished)

[6] C. Gmachl *et al.*, (unpublished)