Wave-Chaotic Optical Micro-resonators and Microlasers for Integrated Optics

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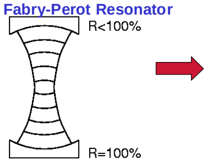
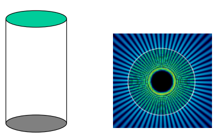
Optical Micro-resonators

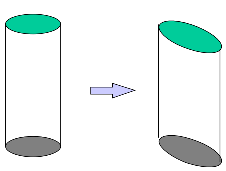


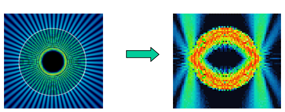
Dielectric resonators



Optical Resonators are crucial components in all lasers and in other telecommunications technology. In the push for miniaturized integrated optical circuits there has been much interest in micron-scale optical components. At this size scale it is difficult to fabricate good mirrors for conventional Fabry-Perot type resonators and research has focused on dielectric resonators exploiting the principle of total-internal reflection. These resonators also are of interest for fundamental optical and atomic science.

New Concept: Asymmetric Resonant Cavity

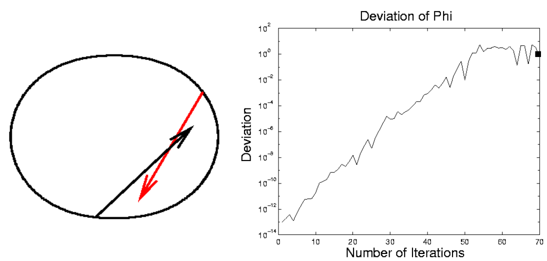




Breaking the cylindrical symmetry of the dielectric micro-cavity leads to highly directional emission, an important property for applications. However the reduced symmetry greatly increases the difficulty of the electromagnetic theory of these resonators; one symptom of this is that the motion of a light ray now becomes chaotic and unpredictable except in a statistical sense.

Chaotic Ray Dynamics

Ray motion in an elliptical resonator (left) is regular; in the oval (quadrupole) resonator (right) it is chaotic. Chaotic motion is exponentially unstable and hence unpredictable.



Two light rays initially moving in the same direction in the oval resonator, but starting from points separated by 10^{-14} radians after 70 reflections are moving in opposite directions. An initial uncertainty of 10^{-14} has been amplified to order unity, the essence of chaos.

The electromagnetic field generated by such ray dynamics is not however unpredictable because it averages over many such motions. Using techniques from chaos theory we are able to predict in which directions most of the light will escape for a given shape. This has been tested experimentally by research at Yale and Bell Labs.

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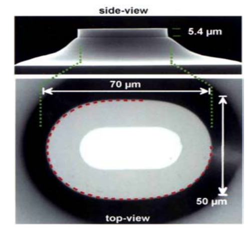
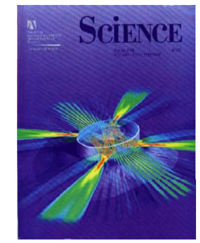
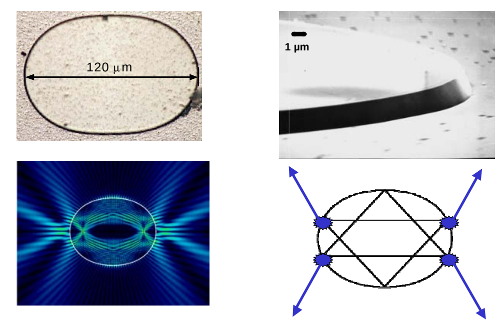
Wave-chaotic Bow-tie Lasers





A Yale - Bell Labs collaboration designed novel semiconducting micro-lasers emitting in the far infra-red ("quantum cascade lasers"). Peak output power for optimal shape was 1000 times higher than for conventional cylindrical dielectric micro-lasers. Electromagnetic field pattern corresponded to periodic ray orbit with shape of bow-tie. [Gmachl et al., Science, **280**, 1186 (1998)]

Yale True Blue GaN Micro-lasers



Very recently lasers and LEDs based on the semiconductor Gallium Nitride (GaN) have been developed which are of great importance since they are the first to emit in the blue region of the optical spectrum. GaN micro-lasers have been fabricated here at Yale and have been shown to emit in the "Star of David" pattern (see above) and other directional patterns. The ability to switch between different output patterns can be very useful for integrated optical circuits and is being currently studied at Yale.