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A NEW ERA FOR SPONTANEOUS EMISSION: THE SINGLE-MODE LIGHT-EMITTING-DIODE

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As we learn to engineer spontaneous emission, it begins to assume many of the roles previously reserved for stimulated emission. While interest in low-threshold semiconductor laser diodes has grown, e.g. for optical interconnects, its spontaneously luminescent half-brother, the light-emitting-diode (LED) has begun to re-emerge in a new form. In this new form the LED is surrounded by an optical cavity. The idea is for the optical cavity to make available only a single electromagnetic mode for the output spontaneous emission from the semiconductor diode.

With all the spontaneous emission funneled into a single optical mode, the LED can begin to have many of the coherence and statistical properties normally associated with above-threshold lasing. The essential point is that the spontaneous emission factor, which measures the proportion of spontaneous emission going into the preferred electromagnetic mode, should approach unity. (A closely related concept is that of the "zero-threshold laser", in which the high spontaneous emission factor produces a very soft and indistinct threshold characteristic in the light output-versus-current input curve of laser diodes.)

The idea is to combine the advantages of the LED which is thresholdless and highly reliable, with those of the semiconductor laser which is coherent and very efficient.

The essential ingredient for these concepts is a single mode electromagnetic micro-resonator which captures all the spontaneous emission from the LED active region. There has been great progress, recently, in designing and making dielectric resonators employing the concepts of photonic band structure. A photonic bandgap can occur in a 3-dimensionally periodic structure (a photonic crystal), which does to photon waves what a semiconductor crystal does to electron waves; it creates a forbidden band of energies irrespective of propagation direction in space. By introducing a defect into the otherwise perfect photonic crystal, a local electromagnetic mode forms in the forbidden gap region. In keeping with the electronic analogy, the defect mode can be either acceptor-type or donor-type.

Figure 1 shows a cross-sectional view of an acceptor defect in a practical photonic crystal. We have been fabricating a 3-dimensional photonic band structure in GaAs and will review our progress. In addition, we will consider some other types of dielectric resonator structures which are derived from millimeter wave technology[1]. These include various types of microscopic dielectric buttons, disks, and cylinders. The behaviour of these dielectric resonator structures in LED's are being tested by observing their spontaneous emission behaviour under optical pumping.

We will present our experimental results on the spontaneous emission from various types of microscopic dielectric structures, which have been designed for the goal of being useful for making a single-mode LED.

1. "Dielectric Resonators", ed. by D. Kajfez and P. Guillon (Artech House, Norwood, Mass., 1986)

2. E. Yablonovitch, T. J. Gmitter and K. M. Leung, Phys. Rev. Lett. 67, 2295 (1991).

FIGURE CAPTION

Figure 1: A $\langle 1,\bar{1},0 \rangle$ cross-sectional view of our face-centered-cubic photonic crystal[2] consisting of non-spherical "air-atoms" centered on the large dots. Dielectric material is represented by the shaded area. The rectangular dashed line is a face-diagonal cross-section of the unit cube. We selected an acceptor defect as shown, centered in the unit cube. It consists of a missing horizontal slice in a single vertical rib.