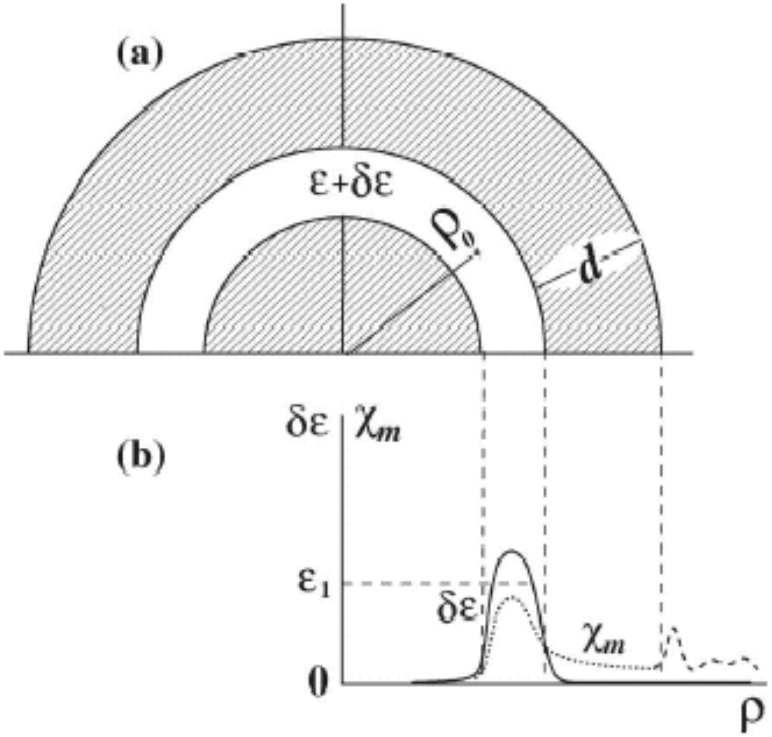
Lasing in π-Conjugated Systems

Z. V. Vardeny, M. E. Raikh and M. DeLong

DMR 02-02790; The University of Utah

The properties of coherent random lasers in π-conjugated films and infiltrated into opal photonic crystals have been studied both experimentally and theoretically. It has been demonstrated that random cavities are formed in these media, which are responsible for the coherent feedback necessary for lasing.



Top panel: Schematic illustration of a disorder-induced resonator in a dielectric film. *Bottom panel*: Radial dependence of the dielectric constant (solid line) and the corresponding field distribution (dotted line) for the whispering-gallery mode. The dashed line outside the shaded region illustrates the evanescent leakage.

THE UNIVERSITY OF UTAH Physics

Our FRG program deals with laser action of pi-conjugated organic systems, including films, solutions, infiltrated opal photonic crystals, single crystals and self assembled monolayers. There are basically four types of laser action phenomena known in the literature. These are: amplified spontaneous emission, super-radiance, super-fluorescence, and cavity lasing (or true lasers). During the last two years we have focused our studies, however on a new laser action type called "random lasing".

A random collection of scatterers in a gain medium can produce coherent laser emission lines dubbed "coherent random lasing". This type of lasing gives sharp laser modes within the gain spectrum, with photon statistics typical of coherent laser modes (Polson et al., Adv. Mater. 13, 760 (2001)). We have studied random lasing in various media including films of pi-conjugated conducting polymers, pi-conjugated polymers and oligomers infiltrated into opals, and single crystals. We have also extended our studies of random lasing to other media including biological tissues, as well as human tissues (Polson and Vardeny, Appl. Phys. Lett. 85, 1289 (2004)). The theoretical team has elucidated the underlying mechanism for random lasing.

Our studies have conclusively demonstrated that random lasing is coherent. This discovery poses a conceptual question as to what is the mechanism of coherent feedback in a generic random medium? Conventional coherent lasing requires a resonator with a high quality factor, Q. On the other hand the random media that we have studied do not contain any built-in resonators. Moreover, these media are considered to be in the weakly scattering regime in which the light mean free path, l^* (extracted from coherent backscattering measurements) is much larger than the laser wavelength, or $kl^* >> 1$, where k is the laser wave-vector (Polson et al., IEEE Quantum Electronics 9, 120 (2003)). This means that 'on average' the light propagation process in these media is diffusive.

A crucial step towards understanding the origin of the coherent feedback in a weakly scattering random media was reported in our paper V. M. Apalkov, M.E. Raikh, and B. Shapiro, Phys. Rev. Lett. 89, 016802 (2002), which is considered to be a milestone. In this paper we have identified the disorder configurations that can trap light for a long time, and,

thus, assume the role of a resonator. An example of such a configuration is shown in the attached figure (see above). It represents a ring-shape region within which the medium dielectric constant slightly exceeds (by $\delta\varepsilon$) the average value ε (top panel). Then such a region (blank area in the bottom panel) can be viewed as a waveguide that supports a specific type of laser mode, namely the whispering-gallery mode. The laser mode lifetime is limited only by evanescent leakage, and consequently can be quite long even if $\delta\varepsilon << 1$.

We have calculated analytically the likelihood, exp[-S(Q)] of formation of such ring-shape cavities. For *point-like scatterers* we found $S(Q) \sim kl^* \ln(Q)$; meaning that the likelihood of finding such resonators for $kl^* > 1$ is very small. Our main finding is that with increasing the disorder correlation radius, R_c, the exponent S(Q) falls off dramatically for a given value of kl^*. Our calculation shows that when kR_c exceeds the value of 2, the ring-shaped cavities become quite abundant (see Fig. 2, below). Overall, our studies provide ample justification for the concept of random resonators in weakly scattering disordered media (Raikh et al., SPIE Conference Proceedings 5472, 74 (2004)).

Fig. 2: The value of the normalized exponent S_m in the probability of finding a random resonator, as a function of the disorder correlation length, R_c. Note that smaller S_m corresponds to larger probability.

Lasing in pi-Conjugated Systems

Z. V. Vardeny, M. E. Raikh and M. DeLong

DMR 02-02790; The University of Utah

Education:

This work involves three graduate students (C. X. Sheng, M. Tong and A. Tulek), an undergraduate student (B. Burns), and a postdoc (Dr. V. M. Apalkov).We have also collaborated with a visiting professor, Dr. Boris Shapiro from the Technion, and Dr. R. Polson from the Utah Laser Institute.

We also have an effort in SAM growth of pi-conjugated molecules, directed by a postdoc, Dr V. Burtman and a grad student, A. Ndobe.

A new graduate course on the optical properties of pi-conjugated systems has been developed and taught for a class of about 12 students.

Outreach:

The electronic and optical characteristics of pi-conjugated systems have been discussed in various G- and UG classes, and HS students that visit the department, for demonstrating the unique properties of molecular electronics and organic semiconductors .

The PI, Z. V. Vardeny demonstrates the unique properties of pi-conjugated crystals to students at the University of Utah in Salt Lake City.