RANDOM LASERS

Resonance control

Random lasers do not have mirrors or optical elements. They often lack a well-defined shape or size, and their emission wavelength is difficult to tune. Now it is shown that the optical resonances in an ensemble of microspheres can provide the crucial element of control.

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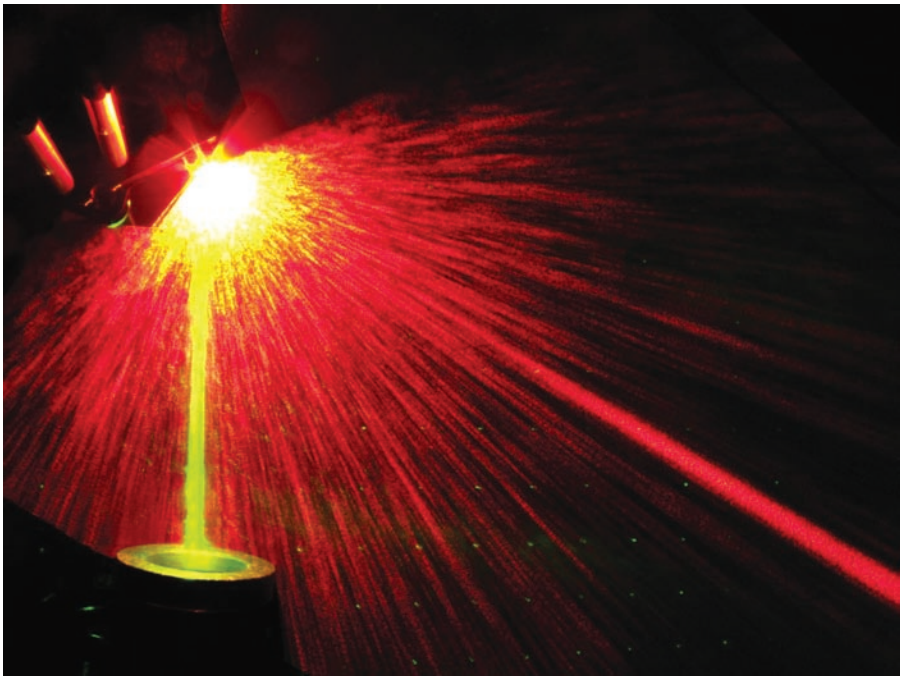
Random lasers are unique sources of stimulated emission in which the feedback is provided by light scattering in a gain medium[1] rather than a cavity, as in conventional lasers. Random lasers have been demonstrated in a variety of materials, including liquid dyes, polymers, semiconductors and dielectric crystals, and their potential applications range from medicine to laser fusion[1]. In all previously reported structures, the scattering spectrum was nearly flat within the gain band of the active medium, and lasing occurred at a wavelength coinciding with the maximum of the gain band. On page 429 of this issue[2], Gottardo *et al.* report a random laser in a system with a spectrally varying scattering coefficient determined by Mie resonances in monodisperse polystyrene microspheres — a solid random system dubbed by the researchers as 'photonic glass'. The wavelength in such a random laser can be tuned by changing the index of refraction or the diameter of the microspheres. This pioneering work paves the way to a new generation of random photonic devices with custom-tailored scattering cross-section spectra.

The two major elements of conventional lasers are the gain medium, which provides light amplification, and the optical resonator (cavity), which provides feedback and, in its simplest form, can consist of just two parallel mirrors. In many cases, a variety of other optical elements, which control the emission wavelength, the temporal profile of the laser pulse and the mode structure, are incorporated into the cavity. In contrast, random lasers do not require any cavity or optics besides possibly the optics used in the pumping channel. This makes them inexpensive, simple and robust in operation. On the other hand, this ultimate simplicity limits the means to control the random laser emission.



The multidirectional emission from random lasers could be useful fo future displays technology.

In the first random laser[3,4] proposed by Letokhov in 1967, the non-resonant feedback was governed by photon diffusion in an ensemble of scatterers. Such random lasers, which include many dye random lasers and neodymium random lasers[1], are highly multimode, and the modes spectrally overlap to form a continuum. In ensembles of randomly shaped and oriented scatterers, the diffusion coefficients are, as a rule, nearly constant within the gain spectral bands. Correspondingly, the wavelength of the random laser emission is determined by the maximum of the gain spectrum rather than the feedback. This increases the stability of the random laser operation but, at the same time, makes the emission wavelength difficult to control.

In random lasers with resonant feedback[5,6], the mode density is much lower, and the emission peaks corresponding to different lasing modes are well resolved. However, these spectral lines are randomly positioned, and statistically the spectrum of stimulated emission is again determined by the gain band.

Gottardo *et al.* now show that in ensembles of identical randomly oriented polystyrene microspheres, the spectra of the diffusion coefficient and thus the feedback can have distinct maxima determined by size-dependent Mie resonances. This provides a mechanism for controlling the random laser emission spectrum. Note that alternative techniques to control the random laser emission with external mirrors, external seeding light, or dichroic absorption have been reported in the literature, see ref. 1, for example.

Spectral inhomogeneity of the scattering efficiency and, in particular, intense morphology-dependent peaks in the scattering spectrum are very interesting, both from the point of view of fundamental physics and for applications that extend far beyond random lasers. In particular, they can be used for realization of Anderson localization of light[7,8] in random media consisting of inclusions with custom-tailored shapes and sizes.

Relevant to this work are the studies of collective states in ensembles of coupled relatively large microspheres that support whispering-gallery modes. This includes coupled resonator optical waveguides[9] and a variety of other transport phenomena[10]. In particular, it has been shown[10] that collective resonances in ensembles of 5-μm-diameter spheres can be an order of magnitude stronger than those in the approximately 1-μm-diameter spheres used by Gottardo and colleagues. Also, the types of granules used to create random media for photonic applications should not be limited to dielectric spheres. As an example, resonant polarization responses in elongated SiC particles have been proposed[11] to achieve a negative index of refraction. By using hybrid metal–dielectric particles with tailored shapes and sizes a rich variety of polarization and surface-plasmon responses can be realized, potentially enabling very strong scattering cross-sections and local field enhancements within certain spectral bands.

To summarize, the work of Gottardo *et al.* is a very important step in the development of the emerging field of photonics, combining collective responses of resonant structures, scattering phenomena in random media, localization, transport, random lasers and broadly defined active metamaterials.

References

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