optics & photonics focus

Random Lasers under Control

Random lasers are generally difficult to control: they emit in every direction at once and in many different colors. Now, exploiting a fundamental physical phenomenon, it is possible to choose their color.

When we think of a laser, we usually imagine a device that can emit a monochromatic light beam in a specific direction. However, neither of these characteristics forms part of the definition of laser: light amplification by stimulated emission of radiation. In fact there are lasers, known as random lasers, that emit in every direction and in many different colors. Now the groups led by Cefe López at the Institute of Material Sciences of Madrid (ICMM-CSIC, Madrid, Spain) and Diederik S. Wiersma at the European Laboratory for Nonlinear Spectroscopy (LENS, Florence, Italy) have designed a new generation of random lasers that still emit in every direction, but at the desired wavelength.

In the simplest picture, a standard laser comes about by placing an amplifying material between a pair of mirrors, which form a cavity. The light gets amplified while it bounces back and forth across the material. An implicit assumption is that the material must not scatter the light, as this would cause the light to get lost in many different directions, instead of continuing to go back and forth through the cavity.

Random lasers, in contrast, do not need cavity mirrors to retain the light. The amplifying material itself repeatedly scatters the light, which, like in a photonic labyrinth, gets retained long enough for lasing to occur even without mirrors. Therefore, far from being a problem, scattering is of fundamental importance. In a simple picture the conventional mirrors are replaced by scattering particles. “Typically, in materials of this kind the light does not travel in a straight line,” explains Riccardo Sapienza from ICMM-CSIC, “but follows a random walk. To cross a few micrometers in the material it has to travel several centimeters!”

When the shape and size of the scattering particles are heterogeneous, the amplifying material chooses the wavelength at which the random laser emits: that which is most amplified by the material. The main practical difference with ordinary lasers is that “in a conventional laser system the emission is directional and in a random laser it is not: light is emitted from a volume in all directions and in a broader range of frequencies,” comments Sapienza, “random lasing is evident as a narrowing of the emitted light spectrum.”

The breakthrough made by the groups at LENS and ICMM-CSIC was to use a new material. In 2007 the ICMM-CSIC group was able to fabricate a new three-dimensional

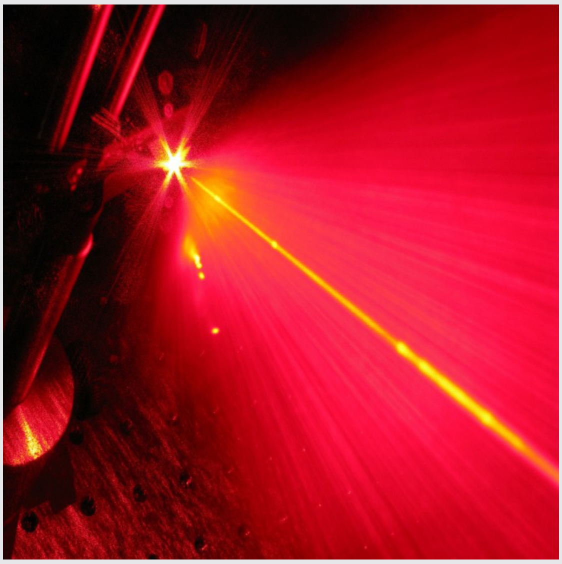

Figure 1: A random laser flash of light. A random laser (red) shines light in all direction while it is pumped by a standard unidirectional laser (yellow).

material composed by microscopic polymer spheres all of the same size arranged completely randomly, which they dubbed photonic glass [1]. “Actually,” notes Sapienza, “when you have a solution of particles all of the same size, they tend to organize in a crystalline fashion, and it was quite a challenge to get them to be randomly placed.”

For a spherical particle of a given diameter, certain wavelengths are more scattered. In particular, this happens when the wavelength of the light is close to the size of the spheres, because there is a resonance between them, known as Mie resonance. Therefore this wavelength travels in the amplifying material for a distance longer than the other wavelengths. As a consequence, lasing can start at this wavelength, and not at the one that the amplifying material would have chosen.

Sapienza and his colleagues observed this effect using the right photonic glass corresponding to the desired wavelength. They were able to experimentally show that the lasing wavelength becomes very sensitive to the diameter of the spheres and follows the Mie resonance of the system. Cefe López comments that “in a usual laser the cavity selects the lasing wavelength. In a random laser the cavity is absent, and the lasing wavelength can be selected by the accumulative effect of the spheres. You can choose the lasing wavelength by changing the size of the spheres.” It is like a competition among different wavelengths, where the one related to the Mie resonance beats all the others.

“It is now possible to have control over the position of this broad spectral peak by capitalizing on the sharp Mie resonances,” says Hakan E. Türeci, research associate at the Zürich based Institute of Quantum Electronics of the Swiss Federal Institute of Technology (ETH). “Of course, this requires precise control over the diameter of the microspheres, a challenge that was finally overcome in this particular work. One may generate precisely-tuned colors by using several amplifying materials along with several sets of spheres with well-defined diameters.” Looking to the future, he says that “an important milestone that is still eluding the community is electrical pumping of these devices and stable continuum wave operation. This achievement, I expect, has the potential to unveil important aspects of the physics of lasing in complex media, and also to lead to new devices.”

[1] P. D. García *et al.*, *Photonic Glass: A Novel Random Material for Light*, Adv Mat **19**, 2597-2602 (2007).

[2] H. E. Türeci *et al.*, *Strong Interactions in Multimode Random Lasers*, Science **320**, 643-646 (2008).

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