Trapping light with disorder

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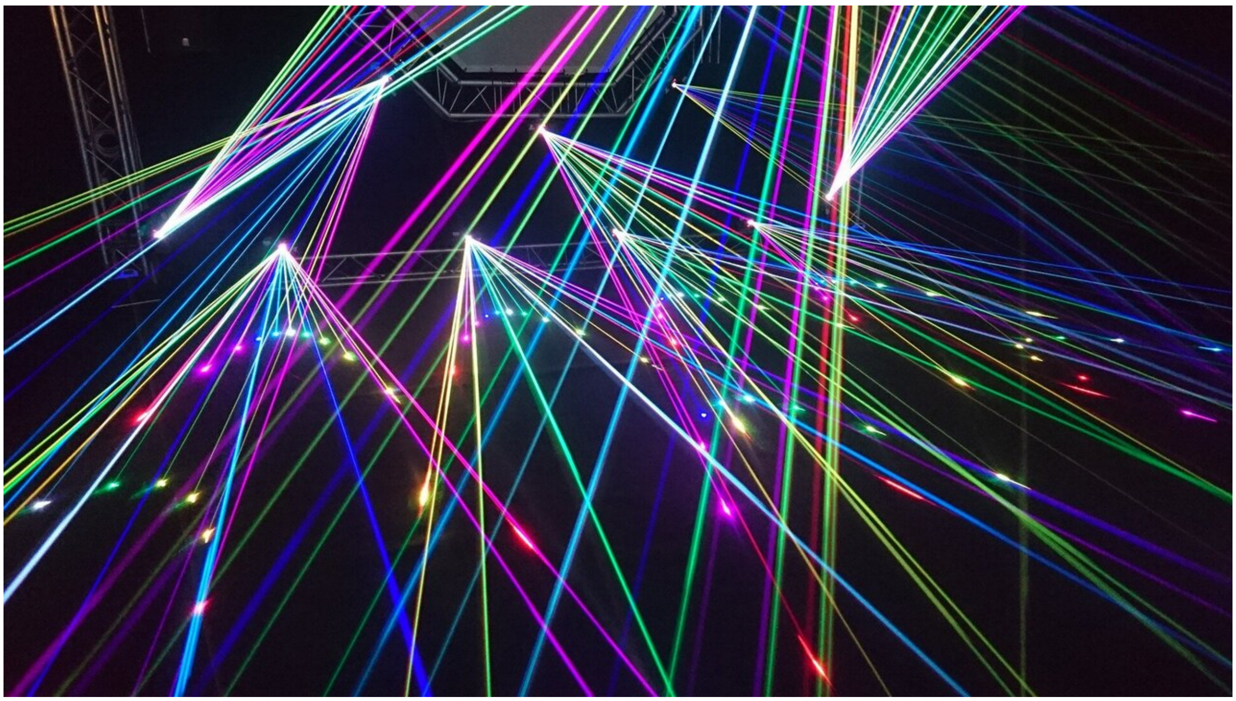

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Like a pinball game in the hands of a good player, a collection of obstacles randomly positioned can be sufficient to trap light without the need for an optical cavity. By adding amplification, at no cost, a mirrorless laser—often dubbed "random laser"—can be obtained.

Using this concept researchers at Bar-Ilan University in Israel have demonstrated disorder-induced localization, a rather difficult wave phenomenon to observe, but also one of the most striking and puzzling manifestations of wave interference predicted by Nobel Prize laureate P.W. Anderson for electrons and, later, generalized to light waves. This phenomenon was recently elucidated in the journal *Optica*.

"We realized that a random laser has many degrees of freedom that are not available in conventional cavity lasers. Based on this discovery, we showed that laser emission can be simply controlled by shaping the pump profile that provides the gain inside the scattering medium," says Prof. Patrick Sebbah, of the Department of Physics and Institute of Nanotechnology and Advanced Materials at Bar-Ilan University, who led the research. "This is done optically with total flexibility. It contrasts with the technical challenge of realigning a mirror cavity in a conventional laser," adds Sebbah, whose research collaborators included Prof. Mélanie Lebental, from France, and students from his Mesoscopic Optics group at Bar-Ilan.

Because this faint phenomenon is amplified in a "plastic microlaser", it is possible to directly observe laser light built up in a confined scattering region, each confined mode corresponding to a different color/wavelength emission. All of these colors/modes lase together and localized modes interact, each one trying to seize to gain for itself at the expense of the others.

In order to observe these localized lasing modes individually, Sebbah and colleagues proposed a method, based on a 2014 article in *Nature Physics*, to disentangle interacting modes and suppress mutual competition for gain. To do so, a non-uniform gain distribution is created that optimally selects one mode and extinguishes the other.

They were surprised to find that once mode competition was suppressed and a laser mode optimized, they were able to boost laser power-efficiency, and unleash the "optimally-outcoupled lasing modes" i.e., the laser modes with the strongest emission for the smallest energy cost. "This is the magic of modal confinement by multiple scattering of light," says Bhupesh Kumar, the postdoc who led the experiments.

These findings open a unique route to investigate Anderson localization, one of the most challenging tasks in optics, to explore the role of nonlinearities on localization and test experimentally theoretical predictions. The method developed here can be applied to the design of highly efficient and stable random microlasers, where the random and non-Hermitian nature of these lasers offers unprecedented degrees of freedom.

More information: Patrick Sebbah et al, Localized modes revealed in random lasers, *Optica* (2021). DOI: 10.1364/OPTICA.428217

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