ORDER FROM DISORDER

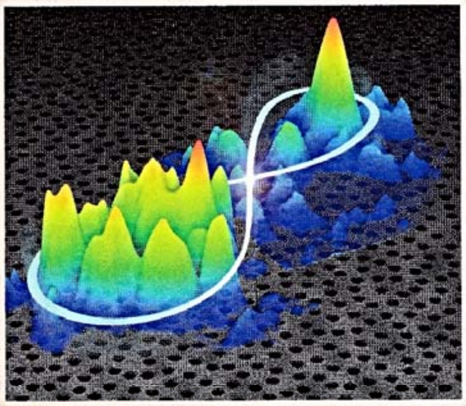
The white lotus features a disordered internal structure that strongly scatters light, accounting for much of the flower's glowing beauty. Light scattered through disordered, random media retains its wave characteristics and the optical information it carries. As with nonlinear effects, the effort to understand, control and harness scattered light is spurring some interesting research and applications.

The light in strongly scattering, disordered media is characterized by photonic modes with resonances of finite spectral width and spatial extent. Francesco Riboli, a researcher at the University of Trento (Italy) in collaboration with Diederik Wiersma and Massimo Gurioli at the European Laboratory for Non-linear Spectroscopy (University of Florence, Italy) found a way to confine and control the interaction of these modes in a two-dimensional disordered photonic structure of gallium arsenide (GaAs).

The group built GaAs waveguides 320 nm thick with layers of indium arsenide (InAs) quantum dots etched with random patterns of circular holes ranging in size from 180 to 250 nm in diameter. A 780-nm diode laser directed across the samples excited the quantum dots and caused them to emit photoluminescence at wavelengths ranging from 1,150 to 1,380 nm. A near-field probe tip introduced perturbation of the modes that enabled the team to observe and map the resulting near-field intensity, which revealed that localized modes were interacting in a way similar to that of covalent chemical bonds. The team has effectively engineered a disordered structure featuring strongly isolated modes, the coupling of which can be controlled. This could lead to open transmission channels in strongly scattering media.

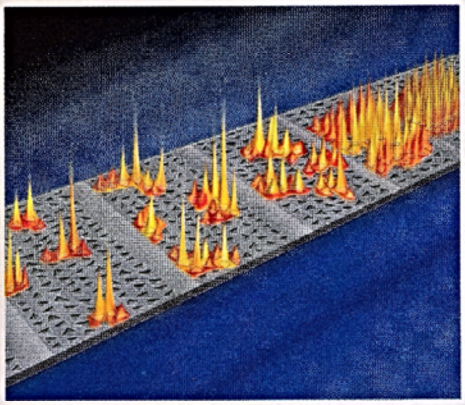
"By changing the degree of spatial correlation between the holes," said Riboli, "it is possible to engineer the photonic properties of the disordered material. This may be an important step toward the control of photonic resonators and traps, among other things." Riboli and colleagues have also proposed thin-film photovoltaics using disordered materials to improve absorption efficiency.

A white lotus. iStock



SEM image of a disordered photonic sample, superimposed with experimental near-field maps of two disordered modes. Figure-eight shape illustrates covalent-bond-like form of the individual and overlapping random modes that can be tuned into resonance, leading to mode hybridization.

F. Riboli and M. Montoya



Pin-Chun Hsieh, Chee Wei Wong and colleagues fashioned photonic crystal superlattice nanostructures, with different hole shapes and levels of disorder. Light travels in localized, narrower beams through this superlattice, with increased beam collimation as the level of structural disorder introduced by the holes increases. Nicoletta Barolini

"Depending on the application," says Riboli, "disordered materials with a certain degree of spatial correlation are preferred in some cases, like in thin-film photovoltaics. Alternately, in optoelectronics where a perfect and deterministic control of the signal is needed, the disorder is unwanted."

Another study, from the University of California, Los Angeles (UCLA; USA), used disordered photonic crystal superlattices, transparent lattice structures made of crystals, to control light across a broad region of the infrared. Chee Wei Wong, associate professor of electrical engineering at the UCLA Henry Samueli School of Engineering and Applied Science, led an international collaboration that fabricated anisotropic superlattices with tiny patterned holes of different shapes to induce photon transport and beam collimation via transverse Anderson localization.

In the study, published in *Nature Physics* in February 2015, the researchers were able to achieve nanoscale control of light—at essentially the distance between the holes in the lattice (center to center) of only 500 nm, which is smaller than the wavelength range of the input beam from 1,500 to 1,600 nm. Most surprising is that the superlattices with the most disordered patterns (for example, those where the hole shape deviated most from circular, and where the orientation of the shapes had the highest structural randomness) were better at trapping and collimating the incoming beam.

"The findings are completely counterintuitive," says Pin-Chun Hsieh, who was a doctoral student at Columbia University (New York, N.Y., USA) advised by Wong during the research. Hsieh, now chairman and majority owner of Quantumstone Research (Taipei, Taiwan), adds, "controlling disorder can arrest transverse transport and really reduce the spreading of light."

The ability to control light propagation at subwavelength scales could help advance research in negative or zero index of refraction, transformation optics, cloaking, metamaterials and slow light. "Pin-Chun has observed a step toward controlling light through engineered randomness in an otherwise periodic structure," said Wong. "That is, delivering structure from randomness."