

# Localization of Light in Disordered Lattices

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In basic solid-state physics, it is often assumed that solid materials, such as metals and semiconductors, are periodic arrays of atoms, where electrons are described by Bloch functions extended all over the lattice. In reality, however, the picture is more complex: Disorder always exists, and no material is perfectly periodic. In 1958, Philip Anderson predicted that interference effects may alter the eigenmodes of a disordered lattice from extended states into localized ones.<sup>1</sup> Consequently, when an electron is initially placed on one atom, it cannot diffuse to cover the whole crystal, but will rather remain localized around its initial position, and therefore the material will not conduct electric current (at zero temperature). Anderson's prediction had rewarded him with the Nobel Prize in 1977. Today, the phenomenon of Anderson localization is a basic concept in solid-state physics. However, phonons, which are always present at non-vanishing temperatures, and interactions among the electrons themselves, have prohibited the observation of Anderson localiza-

tion in atomic crystals. Consequently, Anderson localization (strong localization)—namely, exponential suppression of transport—has never been observed in atomic lattices.

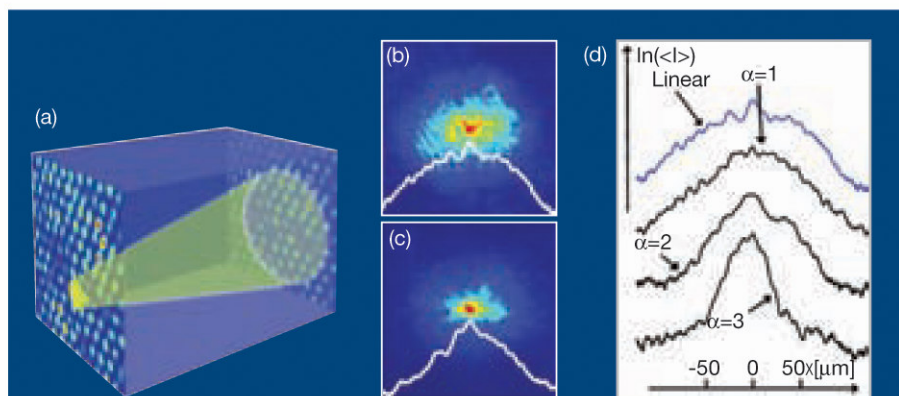
In recent years, several experiments demonstrated strong localization effects in highly scattering media—powders or suspensions of dielectric material.<sup>2,3,4</sup> Nevertheless, the medium in these experiments was completely random, lacking the underlying periodic structure of Anderson's model describing localization in disordered lattices.

Earlier this year, we reported the experimental observation of Anderson localization in a disordered photonic lattice—the localization of light in a periodic structure with disorder superimposed upon it. The experiment used the transverse localization scheme, which can be mapped directly to the original Anderson model.<sup>6</sup> We imprinted a two-dimensional periodic pattern with a controlled degree of disorder in a dielectric medium, and propagated a probe beam in the induced structure.

The evolution of the beam along its propagation direction has a complete equivalence to the time-evolution of a wave packet in a two-dimensional lattice, and we recorded the intensity cross-section of the outgoing beam. We repeated the measurements with hundreds of different realizations of disorder, obtaining the statistical (ensemble-average) transport properties of the perturbed photonic lattice. The experiments demonstrated a clear crossover from diffusive transport to Anderson localization (see figure).

We then proceeded to study nonlinear propagation in disordered lattices and its effect on the localization process. Theoretically, there are many open questions regarding the combined action of nonlinearity and disorder, and our system can serve as a well-controlled tool to answer such questions. We find that, under self-focusing, nonlinearity localization is enhanced, as the beam narrows down when we increase the strength of nonlinearity, and the characteristic exponentially decaying intensity profile appears at a lower level of disorder, where the transport was still diffusive in the linear case.

In conclusion, we have presented the first experimental observation of Anderson localization in periodic structures containing disorder and a study of the effects of nonlinearity on localization. We foresee that our system would become a standard tool in future study of the Anderson localization of light, and that it will provide the experimental avenue for gaining deeper understanding of localization, in optics as well as in other physical systems. ▲



(a) A probe beam propagates in a photonic lattice of hexagonal symmetry, periodicity of  $11 \mu\text{m}$ , and a controlled level of disorder, where the index of refraction is invariant along the propagation direction. The beam width at the input face is about  $9 \mu\text{m}$ , and the transport properties of the disordered lattice are studied by monitoring the intensity profile at the output face of the lattice. (b) Intensity cross-section of the probe beam, ensemble-averaged at the lattice output, under moderate disorder, exhibiting diffusive broadening. The white curve corresponds to the logarithm of the intensity profile, and shows the Gaussian profile characteristic to diffusion. (c) Same as (b), but with stronger disorder. Here the intensity profile is exponentially decaying, revealing Anderson localization. (d) Averaged intensity profiles (in log scale) at the lattice output, showing the transition from diffusion in linear propagation (blue curve) to localization with an exponential decay in nonlinear propagation (black curve).

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## References

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