LOCALIZATION

Photon Localization in Resonant Media

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In analogy with electron localization in insulators,[1] it has been anticipated that photons may be trapped by the constructive interference of waves returning to a point within a strongly scattering medium.[2] Since the closeness to the transition between diffusive and localized waves determines the statistics of multiply scattered waves, charting this transition is of fundamental interest for both statistical optics and electronic mesoscopic physics.[3] However, the very possibility of observing photon localization in random systems has been called into question by the difficulties of achieving strong scattering and of unambiguously detecting electromagnetic localization.

Measurements of the exponential scaling of transmission have not definitively established photon localization since such scaling may also be due to the presence of absorption. Recently, however, we have shown that the variance of the relative fluctuations of intensity or total transmission provide a decisive test for localization, even in the presence of absorption. These measurements provide a sure guide in the search for photon localization, which can be used to sort out the precise material and structural characteristics that may edge samples towards and potentially across the localization threshold.

We have carried out measurements of microwave transmission in an ensemble of random collections of alumina spheres randomly positioned in a copper tube at low density. Scattering from high-index dielectric spheres is strongest when the wavelength is comparable to or smaller than the diameter of the spheres. Strong scattering near the first five Mie resonances is evident from the observation of precipitous drops in transmission and sharp peaks in the photon transit time, seen in Figs. 1(a) and 1(b), respectively.[4] However, waves are localized only in a narrow frequency window above the first resonance, as indicated by the rise of relative fluctuations above the critical value of 7/3 at the threshold of the localization transition [Fig. 1(c)].[4] Within this window, the probability distribution for intensity becomes extraordinarily broad.[3] At the same time, in contrast to the behavior for diffusing waves, the photon transit time becomes correlated with the transmitted intensity [Fig. 1(d)].[5] This is consistent with the expectation that, for localized waves, the transmitted intensity and photon dwell time are each high when the wave is at resonance with a localized state. Localization occurs when this correlator is greater than 1.1.

When the sample is thinner than the absorption length, we find that the ratio of the field correlation frequency and the mode spacing in a thin sample gives a reliable measure of the extent of localization and is in accord with measurements of conductance and of relative intensity fluctuations.[4] The minimum of this ratio, known as the Thouless number, occurs above the first Mie resonance as a result of a sharp drop in the density of states due to collective scattering. These results make it possible to track the changing character of static and dynamic wave statistics through the Anderson localization transition.

References

1. P.W. Anderson, Phys. Rev. **109**, 1492 (1958).
2. S. John, Localization of Light, Physics Today, 32, May 1991.
3. A.A. Chabanov, M. Stoytchev and A. Z. Genack, Nature **404**, 850 (2000).
4. A.A. Chabanov and A. Z. Genack, Phys. Rev. Lett. **87**, 153901 (2001).
5. A.A. Chabanov and A. Z. Genack, Phys. Rev. Lett. **87**, 233903 (2001).

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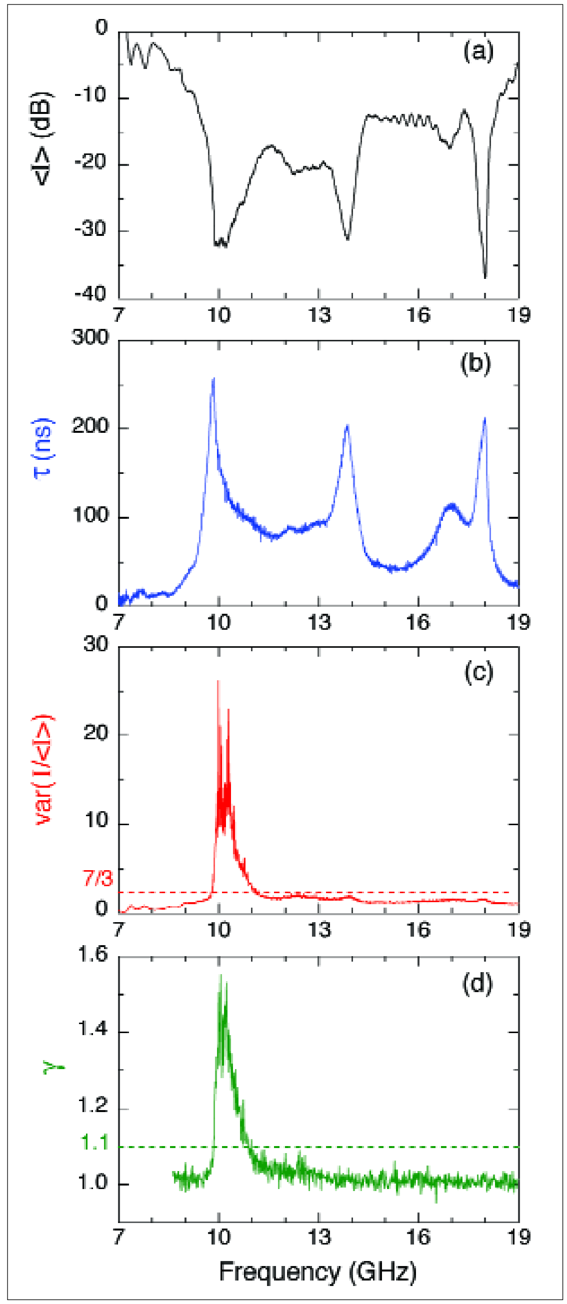

Figure 1. (a) Average transmitted intensity, $\langle I \rangle$, (b) average photon transit time, $\tau = \langle I\varphi' \rangle / \langle I \rangle$, where φ' is the spectral derivative of the phase accumulated by the field as it propagates through the sample, (c) variance of normalized transmitted intensity, $var(I/\langle I \rangle)$, and (d) dimensionless ratio, $\gamma = \langle I\varphi' \rangle / \langle I \rangle \langle \varphi' \rangle$, versus frequency in a quasi-1D alumina sample with length L=80 cm and alumina volume filling fraction f=0.068. The dashed lines indicate the localization threshold.