Mesoscopic Optics

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Mesoscopic Optics is an interdisciplinary field bridging condensed matter physics and optics. Advanced optical techniques facilitate experimental studies of mesoscopic phenomena with photons instead of electrons. One example is coherent wave transport in random scattering media. The interference of multiply scattered waves leads to remarkable phenomena in mesoscopic physics such as Anderson localization and universal conductance fluctuations. In applications, optical scattering is the main obstacle to sending information or imaging through turbid media such as fog and biological tissue.

Among many fascinating counter-intuitive effects resulting from interferences of multiply scattered waves in disordered media, one is the creation of transmission eigenchannels which can be broadly classified as open and closed. In general, the penetration depth and energy density distribution of multiply scattered waves inside a disordered medium are determined by the spatial profiles of the transmission eigenchannels that are excited by the incident light. The distinct spatial profiles of open and closed channels suggest that selective coupling of incident light to these channels enables an effective control of total transmission and energy distribution inside the random medium. Since the energy density determines the light-matter interactions inside a scattering system, manipulating its spatial distribution opens the door to tailoring optical excitations as well as linear and nonlinear optical processes such as absorption, emission, amplification, and frequency mixing inside turbid media.

We demonstrate experimentally an efficient control of light intensity distribution inside a random scattering system. The adaptive wavefront shaping technique is applied to a silicon waveguide containing scattering nanostructures, and the on-chip coupling scheme enables access to all input spatial modes. By selectively coupling the incident light to open or closed channels of the disordered system, we not only vary the total energy stored inside the system, but also change the energy density distribution from an exponential decay to a linear decay and to a profile peaked near the center. This work provides an on-chip platform for controlling light-matter interactions in turbid media.

Fig. 1: The first direct experimental evidence of the existence of open and closed eigenchannels. (a)–(c) Two-dimensional intensity distribution for (a) uncontrolled input fields, (b) input fields optimized for maximum light transmission via open eigenchannels, and (c) input fields optimized for minimum light penetration via closed eigenchannels. (d)–(f) The cross-section-averaged intensity obtained from (a)–(c). The red dashed lines are experimental data and the black solid lines are simulation results.