Light Propagation in Disordered Multimode Fibers

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Abstract: We analyze light transport in a new physical setting associated with multimode systems where reflection is completely suppressed, and interferences between modes due to disorder, non-linear mode mixing and mode-dependent losses, are dictating the propagation. An additional physical constraint is the fact that in realistic circumstances the access to the scattering (or transmission) matrix is incomplete. We have addressed some of these challenges by providing a statistical description of wave transport which fuses together tools from wave chaos, mesoscopic physics and statistical mechanics. The theory provides designed schemes that allow to control the modal energy distribution at the end of the propagation

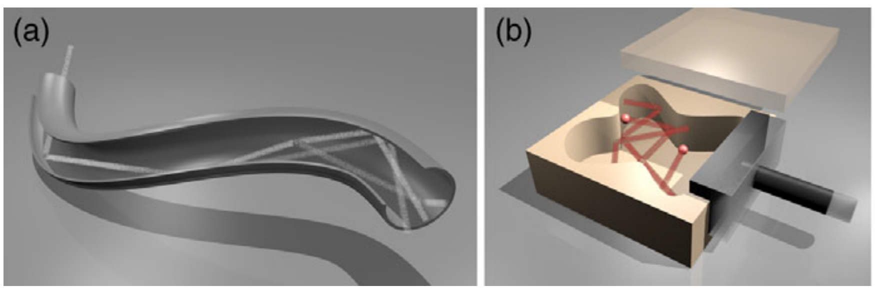

Figure 1: Schematics of various multi-mode systems with disorder/chaotic dynamics: (a) A MMF experiencing twists, bendings, and other forms of perturbations along the propagation direction z; (b) A multi-mode opto-mechanical cavity) with an incoherently moving wall.

Optical fibers have revolutionized many modern technologies ranging from medical imaging and information-transfer technologies to modern communications [1]. Along these lines, multi-mode fibers (MMFs) have recently been exploited as alternatives to single mode fibers-- the latter experiencing information capacity limitations, imposed by amplifier noise and fiber non-linearities [1]. What makes MMFs attractive is the possibility to utilize the multiple modes as extra degrees of freedom in order to carry additional information -- thus increasing the information capacity of a single fiber. On the counter-side, MMF suffer from mode coupling due to external perturbations (index fluctuations and fiber bending and twisting); from polarization scrambling effects due to fiber imperfections (core ellipticity and eccentricity, bending etc.) and from mode-mixing due to nonlinearities. All these effects cause crosstalk and interference between propagating signals in different modes/polarizations. To make things worse, the fiber imperfections vary with the propagation distance z (aka quenched disorder). It is, therefore, imperative to develop theories that take into consideration the role of disorder and non-linearities in the modal (and polarization) mixing and provide a quantitative description of light transport in MMFs.

Here, we develop a statistical theory of light transport in MMFs, using Random matrix modeling fused together with concepts from wave chaos and statistical mechanics. We show that the long-scale dynamics of an initial excitation that spread in mode space can be tailored by the coherent dynamics on a short scale [2]. Moreover, by combining together a free probability theory and a variant of a Filtered random matrix modeling we are able to analyze the effects of mode-dependent losses in the transmittances [3]. Finally, using statistical mechanics methods we are able to predict the modal distribution of the incident energy due to non-linear mixing [4].

References

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