FDTD Modeling of Correlation Functions for Scattered Light in Passive and Active Random Media Crossing from Weak to Strong Scattering Regimes

Shih-Hui Chang[1]*, Hui Cao[2], Allen Taflove[1]
[1]Department of Electrical and Computer Engineering
[2]Department of Physics and Astronomy
Northwestern University, Evanston, IL 60208

The recent discovery of lasing in random media has received considerable interest. This phenomenon has important potential practical applications, especially with regard to reducing the cost of commercial lasers. However, the physics involved is not yet well understood. Specifically, there is the question of how optical gain in random media can enhance light scattering while simultaneously leading to enhanced light confinement.

The speckle pattern of waves coherently transmitted through disordered media shows intensity fluctuation. In microwave experiments, the correlation function of this fluctuation exhibits enhanced long-range correlation in disordered media. However, in such experiments, the material absorption hinders electromagnetic wave localization, and further it is difficult to add gain media to the system.

In this paper, we apply the finite-difference time-domain (FDTD) method to study the correlation functions of scattered light in passive and active random media. The system in our calculation is a two-dimensional metal waveguide containing a random spatial distribution of material cylinders of fixed radius, fixed dielectric properties, and either zero optical gain or a fixed optical gain modeled by a macroscopic Lorentzian gain algorithm. An impulsive point source is placed in air immediately in front of one surface of the random sample, and the transmitted electric field waveform is recorded at the opposite surface. As the sample length increases, the system goes from a weak scattering regime to a strong scattering regime. We calculate the ensemble-averaged spatial and spectral field-field and intensity-intensity correlation functions of the transmitted signal along the sample surface in both scattering regimes.

For the passive random medium case, we find that the ensemble-averaged field-field correlation function is the same for all scattering regimes, but the intensity-intensity correlation shows a significant enhancement as the scattering strength increases. The spectral correlation function shows a reduced frequency correlation linewidth with an increase of the scattering strength. This indicates that the average lasing mode linewidth is reduced. When the averaged linewidth is smaller than the average mode frequency spacing, the sample enters the localization region.

For the active random medium case, we find that the spatial field-field correlation is unchanged from the passive case, but the intensity-intensity correlation is greater at long range. The spectral field-field correlation shows a reduction of the correlation linewidth due to the introduction of gain. This indicates that light confinement in an active random medium can be *enhanced* by optical gain.