Chapter 6

Concluding remarks

In this Thesis we have observed statistical fluctuations of light emission intensity from a macroscopic Random Amplifying Medium (RAM) over the ensemble of different microscopic realizations of the randomness. These show a crossover from the Gaussian (narrow, light-tailed) distribution to the Lévy (broad, fat-tailed) distribution in the limit of high gain and strong scattering. We attribute these to the “amplification of fluctuations” arising from the presence of “larger-than-rare” events which dominate the intensity statistics in the limit of high gain and strong scattering. Thus, the high gain and the strong scattering act as a “fluctuation-amplifier” much the same way as tunneling through nano/meso-scaled metal-insulator-metal junction acts for the tunneling current (which depends exponentially on the barrier height). An important point in our optical study on the RAM is the continuous tunability of the Lévy exponent through the optical-pump intensity (gain) and the scattering parameters. These studies relate to the fluctuation aspect of the random lasers.

Yet another significant finding is the R-RAM (discrete active scatterers embedded in continuous passive medium) as distinct from the D-RAM (discrete passive scatterers embedded in continuous active medium) because of the reversal of roles of the scatterers and the propagation medium. For an R-RAM, we have demonstrated the competition between the effectiveness of the individual amplifying scattering events and the frequency of these multiple scattering events. The main observation of this work is the non-monotonic dependence of the overall gain on the refractive index mismatch for a suitable range of parameter values characterizing the R-RAM.
There is a subtle point involved in treating a RAM as a dielectric with complex refractive index \( n = n' - in'' : n'' > 0 \), with the sign of imaginary part of the refractive index chosen to correspond to amplification rather than attenuation. This would, normally mean an absolute instability, e.g., for a closed laser cavity with such a medium. This would invalidate any treatment of such a medium by way of linear response theory. The important point to be noted here is that in our simulation the absolute instability (for which the gain diverges exponentially in time) is replaced by a convective instability where the wave propagates as it grows (in intensity) and thus convects away the energy. It is this which validates our treatment of a RAM. (Formally, the distinction between an absolute instability and a convective instability is that for the absolute instability, it is the frequency which is made complex while for the convective case, it is the wave vector which is made complex.)

Another interesting aspect which came out of Monte Carlo simulation of photon diffusion in a RAM is the “Lévy microscope effect”, where the sum of intensity values is dominated by the largest event (or a few very large events). Yet another case of RAM that we term F-RAM (Fiber-RAM) was experimentally studied where the disorder was structured as consisting of random aggregate of active fiber segments (with exponential length distribution) embedded in passive bulk. This also gave an optical realization of the Arrhenius cascade model. Thus, our scattering system (in particular, the D-RAM) provides example of both the Lévy microscope and the Arrhenius cascade, with Lévy exponents which are tunable optically.

Finally, we would like to point out the future possibility of translating the statistical fluctuations over the spatial realizations of disorder to random fluctuations in time (temporal fluctuations). This can be realized, for instance, in an active but turbulent fluid medium (circulated through the cavity/cell). Such a time translation of randomness through turbulence will be a directly observable fluctuation due to diffusion in the presence of a random velocity field – as in Sinai fluctuations in a random random medium.

One other idea we would like to explore in future is the experimental realization of an R-RAM. The extreme parameters (refractive index mismatch and gain) required may involve the use of partial metallic coating on the dyed active, scattering microspheres to enhance multiple scattering within these scatterers (active) due to internal reflections.