Preface

This Thesis describes the experimental, theoretical and the numerical simulation work carried out on Random Amplifying Medium (RAM). By RAM, we mean here an optically pumped lasing (active or amplifying) medium with spatial (essentially quenched) disorder. In general, disorder is understood as introduced through a dielectric medium ($\epsilon(\omega)$) with complex refractive index ($n(\omega) = \sqrt{\epsilon(\omega)} = n'(\omega) - in''(\omega)$). Here, the real part $n'(\omega)$ provides the randomness while the imaginary part $n''(\omega)$ gives the amplification. In general, both could be random. In this Thesis, we have specifically considered two distinct classes of RAMs, the direct or D-RAM and its reverse or R-RAM. A D-RAM consists of continuous active medium in which discrete, passive scatterers are randomly embedded. In contrast, in an R-RAM, it is the scatterers which are active while the continuum medium is passive.

The emphasis of the Thesis is, primarily, on studying the statistical fluctuations in the emitted intensity from RAMs. Here the statistical fluctuations are over the ensemble of different microscopic realizations of the randomness or disorder for the given macroscopic disordered sample (hence, “sample-to-sample” fluctuations). Normally, these statistical fluctuations exhibit Gaussian statistics, that is the observed intensity fluctuates about a well-defined mean with a finite variance. However, we have observed a crossover from the Gaussian to the non-Gaussian, or Lévy statistics with diverging variances for intensity fluctuations. The crossover is as a function of scattering and gain parameters characterizing the RAM; these parameters, thus, provide a means for tuning the Lévy exponent.

The Thesis comprises six chapters; their contents are stated below. References made in

1 These fluctuations are not to be confused with an intrinsic quantum/classical statistical intensity fluctuations in the emission of light.
each chapter are listed out at the end of that chapter.

Chapter 1 reviews the present state of research in RAMs and provides an elementary introduction to both the Gaussian and the Lévy statistics. The distinguishing features are described through some physical examples.

Chapter 2 discusses our theoretical and experimental studies on dye-scatterer RAMs. We analytically show that in the limit of high gain and strong scattering, Lévy statistical fluctuations in the emitted intensity should be observed. We attribute these to the "sample-to-sample" fluctuations which in turn give rise to certain rare, long paths which dominate the intensity due to high gain in the system. We experimentally demonstrate the "Gaussian-to-Lévy" statistical crossover in dye-scatterer RAMs. By altering the scattering and gain parameters, the tunability of Lévy exponent was achieved.

In order to make a parametric study of the crossover over a wide range of RAM parameters that are not easily accessible in experiments, a Monte Carlo simulation of the photon diffusion in a RAM is performed. The simulation and its results which corroborate our model calculation and physical experiments of the previous chapter, are discussed in Chapter 3. In the limit of very high gain, an interesting "Lévy microscope effect" is observed, where the mean intensity is dominated by a single largest event.

In order to establish the crucial role of rare long amplifying paths in causing Lévy statistical fluctuations, we created a specially structured RAM consisting of random aggregate of active (dye-doped) fiber segments embedded in a passive bulk. We term this an F-RAM (Fiber- Random Amplifying Medium) and showed it as an optical realization of the Arrhenius cascade model in Chapter 4. The F-RAM is shown to exhibit the crossover from the Gaussian to the Lévy statistics with tunable Lévy exponent, by means of experiments. Further, the theoretical treatment described in Chapter 2 for a dye-scatterer RAM an extended using the "effective-medium" theory to describe an F-RAM.

Chapter 5 discusses the interesting case of a reverse RAM (R-RAM) (active scatterers (discrete) embedded in passive bulk (continuum)). The Mie scattering theory was applied using negative absorption or gain to model the amplifying scatterers. Unlike conventional dye-scatterer RAMs (discussed in Chapter 2) where enhanced scattering always favours light
amplification, we find by Monte Carlo simulation of photon diffusion in an R-RAM, that this is not always true in R-RAMs. In particular, we observe a non-monotonic dependence of the overall gain on the refractive index mismatch for a suitable range of parameter values characterizing the R-RAM. We attribute this observation as arising due to the competition between the effectiveness of the individual amplifying scattering events and the frequency of these multiple scattering events in an R-RAM. This in turn is due to the reversal of roles of the scatterers and the propagation medium in an R-RAM as distinct from the D-RAM.

Finally, we conclude the Thesis by discussing in Chapter 6, some finer points of the work presented herein and some open questions that may provide directions for future studies.

As appendices, we present certain identities (appendix A), computer codes (appendices B and C) and scattering coefficients for an amplifying slab (appendix D), at the end of the Thesis.

The work presented in the Thesis has appeared in the following publications:

**Publications**

1. *Lévy statistical fluctuations from a random amplifying medium.*
   Divya Sharma, Hema Ramachandran and N. Kumar

2. *Lévy statistics of emission from a novel random amplifying medium : an optical realization of the Arrhenius cascade.*
   Divya Sharma, Hema Ramachandran and N. Kumar

3. *Gaussian-to-Lévy statistical crossover in random amplifying medium : Monte Carlo simulation.*
   Divya Sharma, Hema Ramachandran and N. Kumar
   Accepted for publication in Optics Communications.
4. Interplay of disorder and amplification in passive medium with active scatterers: Monte Carlo simulation.
Divya Sharma and N. Kumar
To be communicated.

Papers presented in Conference Proceedings

1. Enhancement of the cooling by frequency up-conversion through multiple scattering.
Divya Sharma and Hema Ramachandran

Divya Sharma, Hema Ramachandran and N. Kumar
International Conference on optoelectronics, fiber optics and photonics, Dec. 9-11, 2004, Cochin University of Science and Technology (CUSAT), Cochin, India.

3. Lévy statistical fluctuations from a random amplifying medium.
Divya Sharma, Hema Ramachandran and N. Kumar
National Laser Symposium, Dec. 7-10, 2005, Vellore Institute of Technology (VIT), Chennai, India

Divya Sharma, Hema Ramachandran and N. Kumar
International Conference on Optics and Optoelectronics, Dec. 12-15, 2005, Instruments Research and Development Establishment (IRDE), Uttaranchal, India

5. Lévy statistics in optics: Violation of the Central Limit Theorem.
Divya Sharma, Hema Ramachandran and N. Kumar
International Conference on Current Developments in Atomic, Molecular and Optical Physics with applications, March 21-23, 2006, Delhi University, Delhi.