Summary

This thesis presents an experimental study on multiple light scattering, with the necessary introductions: theoretical background and sample preparation. The emphasis is put on the effects of the multiple scattering of *waves*, *i.e.*, where interference effects exist and are significant, in the search for Anderson localization.

The principles of multiple-scattering theory are presented. Without interference, when the scattering strength of the medium increases, the propagation of light turns from ballistic via single scattering to the diffusion regime. In a stationary measurement, such as performed with a continuous-wave laser or a light bulb, diffusion is characterized by the mean free path ℓ, the average distance for light to scatter in all directions. In a dynamic measurement, such as performed with a pulsed-laser source and a time-resolved detection, the characteristic quantity is the diffusion constant (which is a length times a speed).

There are various effects of interference in multiple scattering, but we focus on the enhanced backscattering (EBS). The EBS arises from constructive interference of reciprocal (or time-reversed) paths in ensemble-averaged disordered media. The light reflected from a diffusive sample has a typical broad Lambertian shape on top of which a narrow cone at exact backscattering is present. The width of this EBS cone is characterized by the mean free path and the wavelength of the light λ. The top of the EBS cone gives information about the coherence lengths inside the material: the finite size, the absorption length, and the localization length.

The regime of multiple light scattering is studied in a porous semiconductor, gallium phosphide (GaP), known at present as the strongest scattering material for visible light (around 633 nm). A wafer of GaP, doped with sulfur, is electrochemically etched to produce a porous structure of homogeneous thickness. The understanding of the chemistry of this etching process is presented. The properties of the porous structure depend mainly on the doping concentration of the wafer and the electrical voltage applied during etching. The pores can be made with a diameter in the range 50 to 200 nm, thus smaller than the wavelength of light. The porous samples are then further photochemically etched, in order to remove a thin layer of bare GaP remaining on top of the porous structure after electrochemical etching. The removal of this top-layer simplifies the interpretation of optical measurements on the porous samples. The porous samples can also be further chemically etched, in order to homogeneously increase the average diameter of the pores, toward the wavelength of light.

The three types of samples, after electrochemical, photochemical and chemical etching, have been characterized by several optical techniques, among which the total transmission, the EBS, and the angular-resolved transmission measurements. A very important parameter of diffusive samples is the effective refractive index, which modifies both the wave vector of light inside the material and the internal reflection at the interface. A theory which carefully treats the boundary conditions of a diffusive medium is presented. This theory predicts that the angular-resolved transmission is characteristic of the refractive index contrast at the interface between the diffusive medium and the outside medium. The refractive index of strongly scattering porous samples, after photochemical etching, is determined by fitting the theory to the angular-resolved transmission data. The refractive index as a function of porosity in the domain of strong scattering is experimentally studied. The effective medium theories, rigorously derived only in the weak-scattering limit, fail to describe our measurements of the refractive index.

In the search for Anderson localization of light, very strongly scattering samples are produced by electrochemical etching. The optical absorption length is shown to exceed the thickest samples produced, namely 250 μm. The strongest scattering samples are made from GaP wafers of doping concentration $N = 2\text{–}5\times10^{17}$ cm^{-3}, electrochemically etched at the highest possible voltage. The average diameter of the pores in a sample is increased by chemical etching. The scattering strength of certain samples increases after chemical etching. A careful study of the total transmission and the width and rounding of the EBS cone shows, before and after chemical-etching, a very good agreement of the measurements with the diffusion regime. Within the scope of this thesis, no effect which can be attributed to Anderson localization has been recorded, even for very strongly scattering samples where $\ell/2\pi\lambda \simeq 3.5$.

The electrochemical etching produces a porous structure with oriented pores: pores grow in the direction normal to the surface of the GaP wafer. The geometrical anisotropy induces anisotropic diffusion. An anisotropic hopping model and subsequent diffusion theory with an anisotropic diffusion constant tensor and an isotropic mean free path is presented. The anisotropy in both stationary and dynamic measurements are predicted to depend on the components of the diffusion constant tensor. Measurements on anisotropic samples are indeed anisotropic for stationary and dynamic diffusion, and EBS. The anisotropy in the diffusion constant tensor, independently determined from these three optical measurements, is consistent. Porous GaP displays both strong scattering and strong anisotropy (the ratio of the diffusion constant components is about 4).

The last part of this thesis deals with a subject differing from multiple light scattering. The subject of the full capture of a light pulse inside a short cavity is considered, and can be seen as a macroscopic equivalent of the switching of an (Anderson) localized state. In a short cavity, the bandwidth of the incident pulse is decreased, according to the finesse of the cavity, at the expense of the incoupling efficiency. By dynamically adapting the reflectivity of the input coupler to the shape of the incident pulse, the light reflected from the cavity can be made to vanish by destructive interference. When no light is reflected off the cavity, all the incident power is coupled inside the cavity, within a single mode of narrow bandwidth. A theoretical description of the pulse capture inside a short high-finesse cavity is presented. A practical implementation of the mirror with variable reflectivity is made by using a Pockels cell and polarization optics, along with a fast high-voltage switch. The experimental results in the frequency-domain show both a higher power and a narrower bandwidth of the light pulse captured in the cavity, compared to the same setup with any constant reflectivity of the input coupler.