Ultra-short pulses propagation through a strongly scattering medium

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Optical techniques are widely applied to two phase flow characterization, in research area as well as in industry. They generally offer a precise and non intrusive way to measure particle sizes, concentration, or velocity fields. However, all the current optical techniques are limited in particle concentration. This limitation is due to multiple scattering effect. Indeed, information contained in scattered light and generally inversed assuming only single scattering processes, is progressively scrambled when the particle concentration and the multiple scattering processes increase.

The use of ultra-short optical pulses is a promising way to overpass this limitation. During 100 fs, light travel is only 30 µm in air and 20 µm in water. A femtosecond time resolved detection may then isolate the ballistic photon, from multiple scattered light. Moreover, the temporal evolution of transmitted light, which is related to photon travel paths in the medium, may contain an information on the medium itself.

1. Monte Carlo simulations

Our Monte Carlo program simulates pulses propagation in turbid media. The method allows to consider an experimental set-up without restrictive assumptions. The program is based on a semi Monte Carlo method which is as accurate than a classical Monte Carlo method and less time consuming in case of small size detector or collection angle. The transported quantities are two polarization components and not only energy, allowing to consider any detection device. In this paper only the case of small particles with respect to the pulse duration, is considered. The temporal aspects are then reduced to time delay corresponding to photon travel paths between the scattering particles. The strongly scattering media under study consists of glass cells of various lengths, full with a latex solution of 1µm diameter particles. The cell is illuminated by a 100 fs pulse and forward light scattering in a small collection angle of about 0.05° is detected, following the detection conditions of the experimental set-up.

2. Experimental set-up

The incident pulsed laser consists of Ti:Sa regenerative amplifier providing 100 fs pulses at 1 kHz repetition rate, at 800 nm carrier wavelength. Energy per pulse is 0.8 mJ. The laser pulse is separated in two parts, named as reference and probe pulses. The probe pulse travels through an adjustable delay line and illuminates the scattering medium. The scattered and reference pulses are then correlated in a BBO crystal, in a non collinear configuration and the temporal signal is recovered by

shifting the delay line. The two pulses are focused on a BBO crystal. The distance between the BBO crystal and the lens, and the distance between the sample and the lens are equal to the lens focal length, ensuring an angular selection of the light scattered from the sample. A spatial selection is then used to record only the 400 nm signal issued from the superposition of the two pulses on a Photo-Multiplier. Only the vertical polarization component of the scattered beam contributes to the frequency doubling and is then recorded.

3. Results

Experiments have been done for various particle concentrations and compared to computation results (see figure 1), where the collection angle and absorption coefficient of water have been adjusted to fit data. Other parameters are known from the set-up.
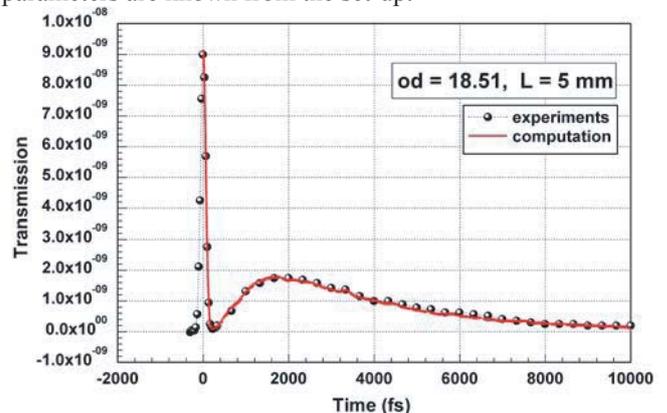

Fig. 1 Comparison between experiments and simulations

The transmitted light is composed by a ballistic contribution and a time delayed scattered contribution. Both are well separated, allowing measurement of optical depth for various concentration in the range 9 to 22 (10^{-9} of direct transmission) from direct use of Beer-Lambert law.

The scattered light contribution dependency on concentration and particle size is presented, showing that the temporal evolution of forward scattering contains information on both concentration and particle size, opening the way to metrological applications.