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Experimental investigation of bimodal temporal distributions of ultrashort laser pulses after propagation through the homogeneous layer of high scattering biological medium for three values of wavelenght

Final Report by

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Introduction

Biological tissue is a high-scattering medium (HSM). At the present time the universal model describing optical radiation propagation through HSM does not exist due to mathematical difficulties. Optical characteristics of HSM can be determined with the help of the temporal distribution (TD) of ultrashort laser pulse passed through the homogeneous layer.

The existence of distinctive groups of photons in the optical pulse passing through HSM is very interesting phenomenon. Therefore a main feature of TD is its bimodal form which is a superposition of ballistic and scattered photons (Figure 1).

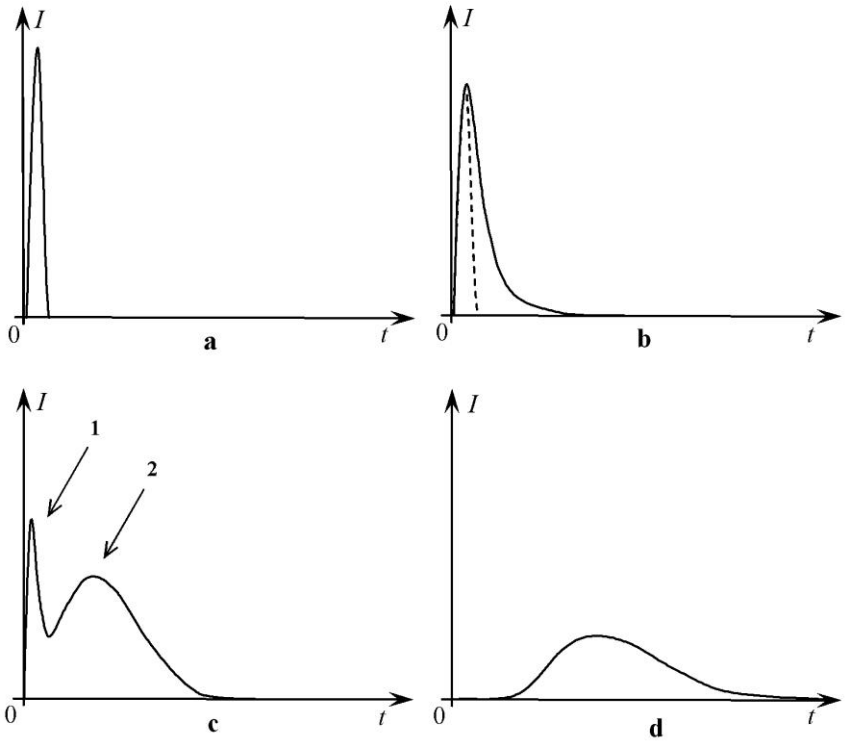

Figure 1. Typical temporal distributions of ultrashort laser pulses after passing through the homogeneous scattering layer: the ballistic component (a), the scattered component at low concentrations of the scatterer (b), the bimodal form that contains the ballistic (1) and scattered (2) photons, for intermediate concentrations of the scatterer (c), the diffused component of large concentrations of the scatterer (d)

Ballistic photons (BP) are photons which pass through a HSM layer without absorption or scattering. Moreover, BP maintain the direction as well as the initial shape, duration and polarization. It is a just part of a radiation that is applicable for using of the Radon inverse transform as in X-ray computed tomography. Other photons (off-axis and near-axis photons) are random scattered at various angles and lag in time relatively BP. The form of TD depends on parameters of the medium, namely on scattering and absorption coefficients and thickness of HSM layer.

Nevertheless the simultaneous observation of ballistic and scattered components as a bimodal temporal distribution (BTD) is a difficult experimental task [1], because we can usually observe only either a ballistic peak, or a scattered peak. The first case is typical for very thin layers or scattering media with a small scattering coefficient. The second case is observed for thick layers or in scattering media with a large scattering coefficient.

In addition, a large duration of the initial laser pulse and a poor time resolution of the detector lead to the effect of the transformation of two peaks to one peak. Therefore the simultaneous observation of two peaks is possible only in a narrow range of optical properties of HSM.

1. Material and Methods

The block-scheme of experimental setup represented in Figure 2.

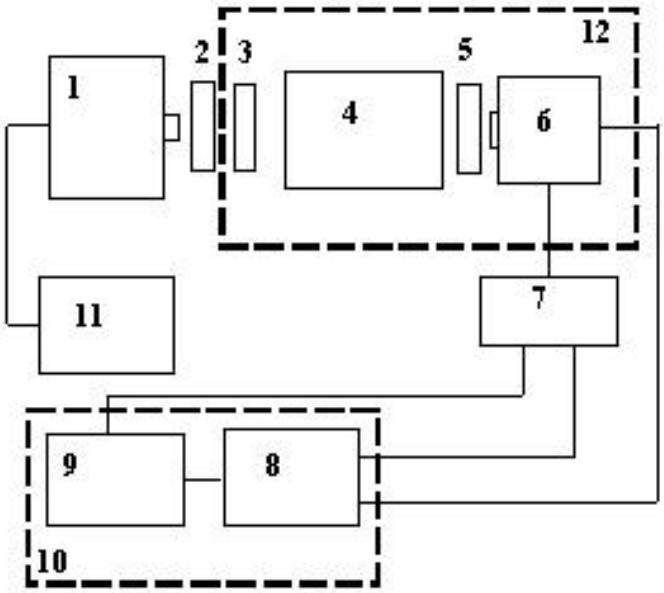

Figure 2. The experimental setup block-scheme:
1 – the femtosecond pulse Ti:Sa laser; 2 – the filter; 3 – the variable attenuator;
4 – the rectangular cuvette with the model biological high-scattering media;
5 – the filter; 6 – the microchannel photomultiplier tube; 7 – the preamplifier;
8 – the microchannel photomultiplier tube management; 9 – the registration board SPC-830; 10 – personal computer; 11 – laser power supply;
12 – light protection module

The experimental setup consists of next parts:

1) The source of optical radiation is the femtosecond pulse Ti:Sa (titanium:sapphire) laser system Chameleon Ultra (tunable wavelength 715…955 nm, pulse duration ~ 140 fs, output power ~ 1 W, frequency 90 MHz, beam diameter~ 1.5 mm) produced by «Coherent», USA.

2) The object of our investigation is the model biological HSM, namely a milk solution in a water filling the rectangular glass cuvette. We investigated

HSM layers on the three values of wavelenght (750, 825 and 900 nm). The special external light protection module (600×600×300 mm) is used in the experimental setup to minimize influence of the outside light.

3) The optical radiation detection system is realized on the basis of microchannel photomultiplier tube HAM R3809U-51 produced by «Hamamatsu», Japan, and data processing equipment SPC-830 that operates in the mode of time-correlated single-photon counting (TCSPC), produced by «Becker & Hickl GmbH», Germany. The temporal resolution of the experimental setup is about 25 ps.

The processing of measured data has been made on the base of non-stationary axial model of light propagation through the scattering medium [1].

2. Results

We represent results for the observation the bimodal TD shape for three values of wavelenght. The figures 3-5 illustrate the experimentally recorded bimodal temporal distributions for different values of milk concentration and laser wavelenght.

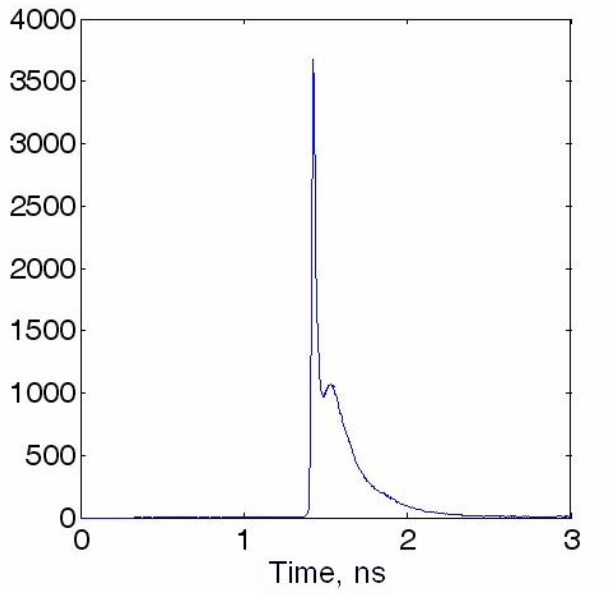

Figure 3. The bimodal temporal distribution of ultrashort laser pulse passed through the HSM for milk concentration $n = 0{,}24\%$ (λ=750 nm, layer thickness l=400 mm)

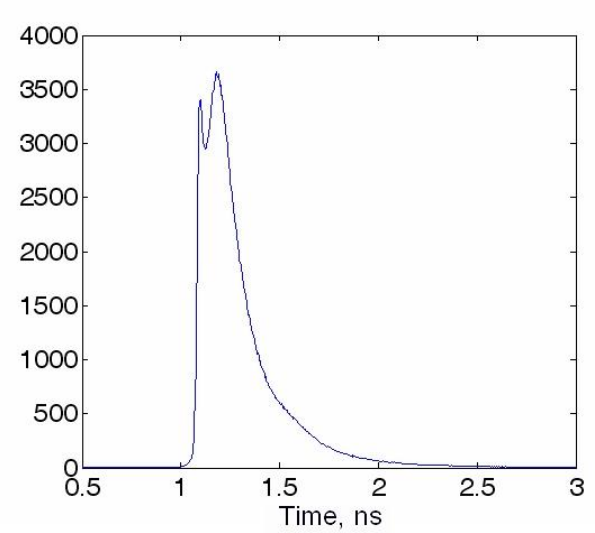

Figure 4. The bimodal temporal distribution of ultrashort laser pulse passed through the HSM for milk concentration $n = 0{,}21\%$ (λ=825 nm, layer thickness *l*=400 mm)

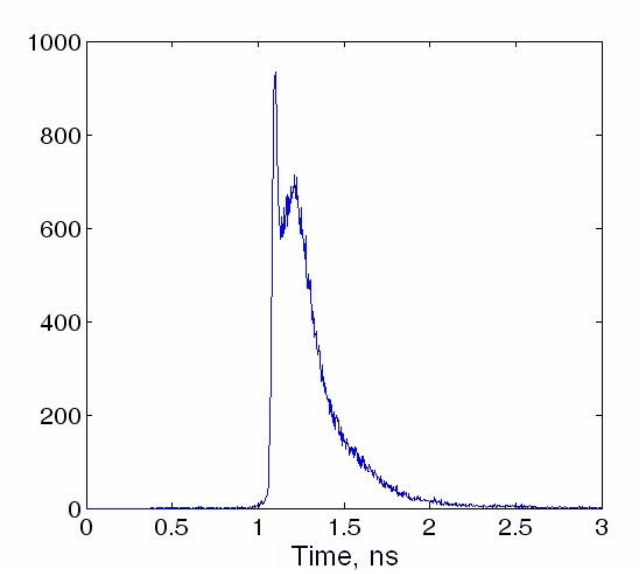

Figure 5. The bimodal temporal distribution of ultrashort laser pulse passed through the HSM for milk concentration $n = 0{,}30\%$ (λ=900 nm, layer thickness *l*=400 mm)

Properly chosen combination of parameters of the initial laser pulse, detecting apparatus and optical characteristics of the model HSM allows receive a clear separation of the ballistic and scattered components of the temporal distribution (bimodality). Nevertheless, the bimodal form of TD is formed in a narrow range of parameters of the HSM.

As a result we have found that most explicit separation of the two peaks observes when the concentration of the scatterer $n = 0{,}2 \div 0{,}33\%$ (for λ=750 nm),

$n = 0{,}17 \div 0{,}27\%$ (for λ=825nm), $n = 0{,}27 \div 0{,}39\%$ (for λ=900 nm). The results can be used to the developing of new methods of photometry and optical tomography of biological tissue.

3. Conclusion

Our work illustrates a complicated structure of a laser radiation passed through a high-scattering medium. The results obtained show that the observation of a bimodal temporal distribution for an ultrashort laser pulse passed through the HSM on various laser wavelenght may be realized only under certain experimental conditions. There is determined the narrow range of HSM characteristics allowing the observation of the bimodal temporal distribution. We can determine the optical characteristics of high-scattering medium on the base of the obtained bimodal temporal distributions.

Literature

1. Tereschenko S.A. The methods of computed tomography.– M.: Fizmatlit, 2004, 320 p. [In Russian].