Study of optical absorption and scattering of laser radiation by a biological tissue phantom using moveable integrating spheres

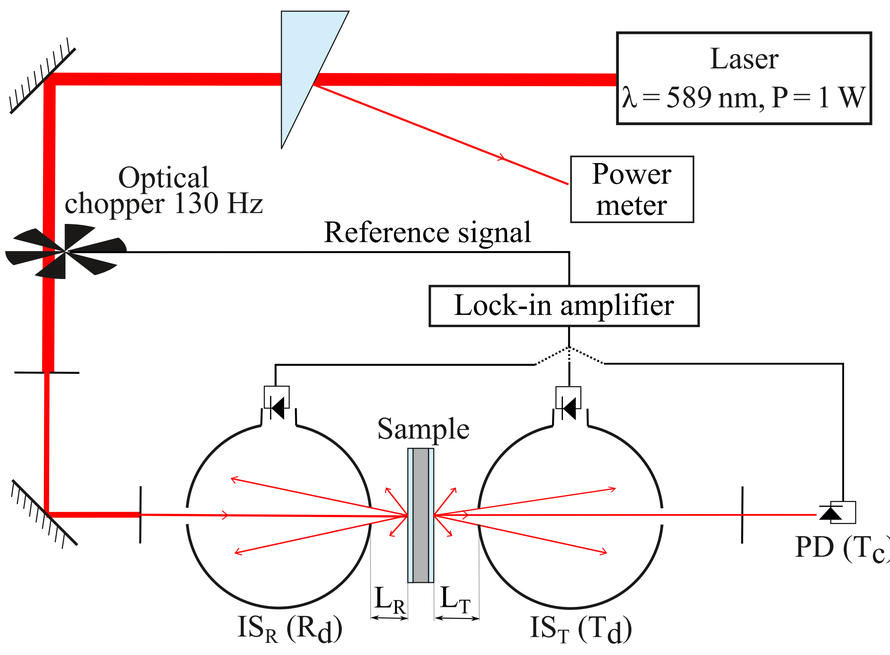
T.K. Karpova[1], N.V. Kovalenko[1,2], O.A. Ryabushkin[1,2]
[1]Moscow Institute of Physics and Technology, Dolgoprudny, Russia
[2]Fryazino branch of Kotelnikov Institute of Radio-engineering and Electronics of RAS, Fryazino, Russia

Introduction

To correctly describe the interaction of electromagnetic radiation with biological tissues, it is necessary to know their optical properties. To measure optical properties of biological tissues and other turbid media, the **moveable integrating spheres** (MIS) method has recently been proposed [1]. It was suggested that the new approach makes it possible to determine the optical properties of turbid media more accurately in comparison with the classical method, where measurements are performed only for spheres located close to the studied sample. This work presents the results of measuring the absorption and scattering coefficients and scattering anisotropy of biological tissue phantoms using the MIS method and compares the results with theoretical estimates.

Experimental setup

The MIS method measures the dependencies of the fractions of diffusely reflected and transmitted radiation R_d and T_d registered by the integrating spheres on the distances L_R and L_T between the sample surface and the ports of the corresponding spheres. The optical phantoms were made of glycerol with aluminum oxide powder (average particle diameter of 4 μm) and india ink to set the scattering and absorption coefficients of the samples.



Block-scheme of the experimental setup

Modelling

Determining of optical properties was carried out in 3 stages:
1. Calculating collimated transmission value based on PD measurements;
2. Obtaining an initial approximation for solving the inverse problem by the inverse addition-doubling method [2] using the values of T_d and R_d at the minimum distance from the ports of the spheres to the sample surface;
3. Minimizing the functional

$$F = \sum \left| T_d^{mod} - T_d^{exp} \right|^2 + \sum \left| R_d^{mod} - R_d^{exp} \right|^2$$

using Nelder-Mead method; summation was performed using the values of T_d^{exp} and R_d^{exp} obtained at different distances L_T and L_R. T_d^{mod} and R_d^{mod} values were calculated using the multilayer Monte Carlo method [3]

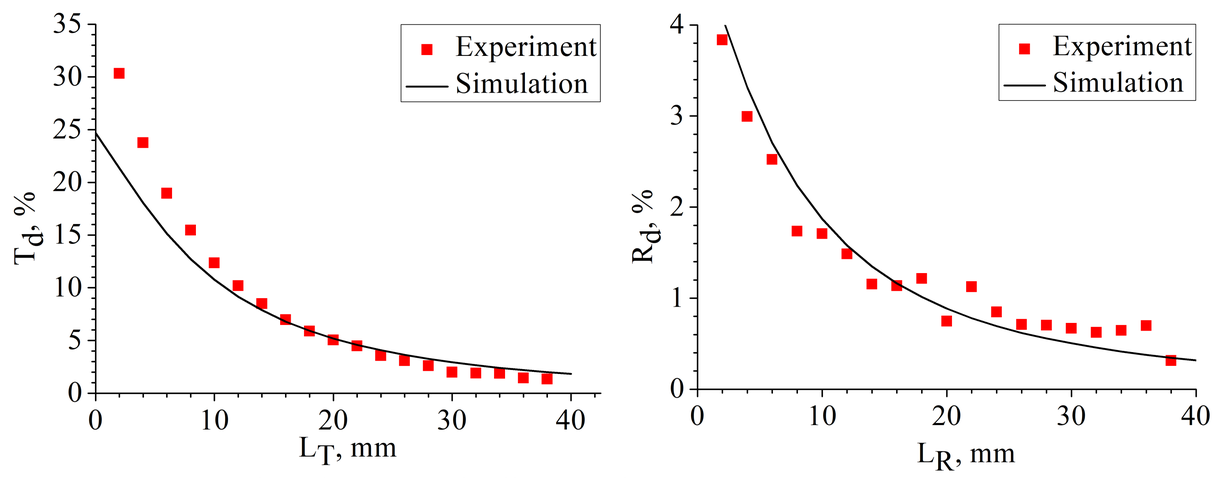
Results

The table shows the values of optical properties of 3 different phantoms obtained by using the MIS method, evaluated using the Mie scattering theory, and calculated from the values of R_d and T_d measured at the minimum distance between the ports of the spheres and the sample surface (i.e. using the classical method of fixed integrating spheres, FIS).

	Phantom 1 ω_{ink} = 0.2%, ω_{Al2O3} = 1.0%			Phantom 2 ω_{ink} = 0.4%, ω_{Al2O3} = 1.2%			Phantom 3 ω_{ink} = 0.15%, ω_{Al2O3} = 1.3%		
	Theory	MIS	FIS	Theory	MIS	FIS	Theory	MIS	FIS
μ_s, m^{-1}	5700	5900	6550	6300	6150	6300	7000	7300	7430
μ_a, m^{-1}	440	465	230	1060	860	750	350	330	195
g	0.875	0.88	0.9	0.875	0.857	0.9	0.875	0.833	0.89

Results of determining optical properties of phantoms using Mie theory, moveable integrating spheres and fixed integrating spheres methods

The discrepancies at distances smaller than 1 cm can be attributed to the change in the radiation gain by the sphere when one of its ports is closed by a scattering shutter. **The original method of movable integrating spheres makes it possible to perform measurements at a distance where this effect does not have a strong influence, and to measure the optical properties of turbid media without additional corrections to the measurements of integrating spheres.**



Dependencies of the fractions of diffusely reflected and transmitted radiation R_d and T_d registered by the spheres on the distances L_R and L_T between the sphere ports and the sample surface (phantom number 3)

Conclusion

The values of scattering and absorption coefficients and scattering anisotropy calculated for the samples using the Mie scattering theory were compared with the values obtained by measuring the scattered radiation using movable and fixed integrating spheres. It was shown that the use of the method of moveable integrating spheres allows to obtain more accurate results without additional corrections to the spheres measurements.

[1] Kovalenko N V et al 2019 Optical properties of biological tissues evaluation with a hybrid goniometer and integrating-sphere technique and Monte Carlo mathematical modelling J. Phys.: Conf. Ser. 1391 012025
[2] Prahl S A, van Gemert M J C and Welch A J 1993 Determining the Optical Properties of Turbid Media by Using the Adding-Doubling Method Appl. Opt. 32 559-568
[3] Jacques S L 2011 Monte Carlo Modeling of Light Transport in Tissue (Steady State and Time of Flight) Optical-Thermal Response of Laser-Irradiated Tissue 2nd ed ed A J Welch and M J C van Gemert (Springer Science+Business Media) chapter 5 pp 109-144