Quantum Electronics, 2006, 36 (3), 247-252.

PACS numbers: 42.30.Wb; 42.25.Fx

Effect of photons of different scattering orders on the formation of a signal in optical low-coherence tomography of highly scattering media

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Abstract. **The influence of photons of different scattering orders on the formation of a detected signal in optical low-coherence tomography (OCT) is considered. The scattering orders are estimated by analysing the spatial distribution of the probability density for the effective optical paths of detected photons calculated by the Monte Carlo method. The influence of photons with different scattering orders on the formation of a signal is estimated quantitatively depending on the optical properties of the medium under study. The results of numerical simulations are interpreted within the framework of possible applications of OCT for non-invasive diagnostics of the human skin and other highly scattering random media. It is shown by the example of calculation of OCT signals from model biological tissues that the OCT method gives reliable information on their internal structure from optical depths up to 0.3 mm.**

Keywords: *optical low-coherence tomography, Monte Carlo method, multiple scattering, low-order scattering.*

1. Introduction

The methods of optical non-invasive diagnostics being actively developed beginning from the mid-1980s [1] are widely used today in various fields of medicine and biophysics [2, 3]. One of the most promising methods, which is successfully applied for diagnostics of the human eyeground, mucosa, monitoring of morphological variations in the cutaneous covering, etc., is optical low-coherence tomography (OCT) [4, 5].* The OCT method provides the imaging of the internal structure of biological tissues with a rather high spatial resolution (2–15 μm) [5, 9]. The maximum visualisation depth is limited by the contribution from multiply scattered photons, which increases with depth, and is comparable with the transport mean free path of photons $l_{tr} = (\mu_a + \mu_s')^{-1}$. Here, $\mu_s' = \mu_s(1-g)$ is the so-called reduced scattering coefficient; μ_s is the scattering coefficient; μ_a is the absorption coefficient; and g is the anisotropy factor, which is equal to the mean cosine of the scattering angle. In this connection the most promising is the use of OCT for visualisation of near-surface layers of biological tissues. It is obvious that the maximum OCT visualisation depth can be increased, with the condition that a high spatial resolution is preserved, by increasing l_{tr} and (or) decreasing the contribution of multiply scattered photons to a signal being detected.

In practice, the value of l_{tr} can be increased by using the diffusion of osmotic substances into a biological tissue [10]. At present this is one of the most promising directions of studies in biomedical optics [3, 9–12]. In turn, the influence of multiply scattered photons can be reduced and the role of low-order scattered photons in the detected signal can be increased by using a special optical scheme, for example, by the conjugate diaphragming of an objective and the field of detector with the so-called narrow-transmission collimators [13, 14].

Hereafter, we will consider the two classes of detected photons: multiply scattered (MS) and low-order scattered (LOS) photons. For photons of the first class the difference between their optical path l in a medium and the doubled maximal optical depth $2z_{max}$ achieved in the medium exceeds the coherence length l_{coh} of a source:

$$l - 2z_{max} > l_{coh}. \quad (1)$$

In this case, it is assumed that detected photons give distorted information on the position of scatterers (structural elements of the tissue) [15]. Photons for which inequality (1) is not fulfilled belong to LOS photons carrying useful information on the distribution of optical inhomogeneities in the medium.

The aim of this paper is to study the dependence of a detected OCT signal on the contributions of photons with

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Kvantovaya Elektronika **36** (3) 247–252 (2006)
Translated by M.N. Sapozhnikov

*This method is a refined variant of optical low-coherence interferometry [6, 7] and (or) optical low-coherence reflectometry [8]. It is based on the use of a low-coherence optical radiation source in a Michelson interferometer. Nevertheless, we employ the abbreviation OCT in accordance with the accepted term Optical Coherence Tomography.

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2006-01-01T00:00:00Z

http://dx.doi.org/http://www.turpion.org/php/paper.phtml?journal_id=qe&paper_id=13130

M Yu Kirillin, I V Meglinskii, A V Priezzhev, Effect of photons of different scattering orders on the formation of a signal in optical low-coherence tomographyof highly scattering media, Quantum Electronics, 2006, 36 (3), 247-252.

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