Optical Fourier Domain Interferometry as a novel tool for biological imaging

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Purpose of this work is to introduce results of biological objects measurements with Optical Coherence Tomography system working with swept source laser (OFDI system). This specified source with spectrum centred around 1040 nm is dedicated to measure posterior segment of the eye. OCT with this wavelength is expected to be next generation for this sort of systems. Although commonly used 800 nm source enables imaging retina, deeper tissue layers are not available with this wavelength. Longer wavelengths in range of infrared spectrum (e.g. 1040 nm) are being weakly scattered which enables to go down to the choroid layer [1]. Examination this structure composed mostly from blood vessels might be very important for early diagnosis of eye diseases. In this paper system setup, swept source scheme and eye images would be introduced.

Keywords and phrases: OFDI, swept source, OCT, medical imaging, eye imaging, Michelson interferometer, interferometry.

Introduction

Optical Fourier Domain Interferometry (OFDI) known also as swept source Optical Coherence Tomography (ssOCT) is recent introduced and highly developed technique. Swept lasers finds application in high speed spectroscopy [3] but their main application is combination with OCT systems for biological imaging — especially eye [2]. Swept source lasers assure highly robustness of OFDI systems because of high sensitivity as well as simplified detection. The most developing version of this system is Fourier Domain Mode Locking [4], which ensures constantly increasing repetition rate. Commercial available version of swept sources reaches 100 kHz. This kind of source enables generation of tuneable optical frequencies in time and by knowing time step between consecutive frequencies it is sufficient to detect them by photodiode.

Swept source

Figure 1a represents scheme of swept source. This laser is based on ring cavity. Basics elements are Semiconductor Optical Amplifier and tunable filter. The most common filter type is Fabry-Perot tunable filter. SOA is gain medium and it radiate Amplified Spontaneous Emission (dotted line in Fig. 1b). Isolators constrains unidirectional light circulation. ASE is filtered by Fabry-Perot narrow bandpass filter. This filtered wavelength is amplified by SOA active medium. For sinusoidal filter driving signal, the transmission window of the filter will change in time — for shorter to longer wavelengths and backward. After several roundtrips laser action will start for all wavelength within the filter scanning range. Plot at Fig. 1b) was measured with Optical Spectrum Analyzer and it represents laser output spectra averaged in time.

Optical Coherence Tomography

Optical Coherence Tomography is a very convenient tool for imaging weakly scattering objects. It is also non-invasive and non-contact technique which provide cross-sectional images with micrometer resolution [5]. OCT system is versatile tool dedicated for biological imaging but it also might be useful in conservational examination [6]. Nowadays it is approved method for eye disease diagnostic but future major purpose of OCT is non-invasive tool for tissue biopsies.

OCT is an interferometric method analogical to ultrasound technique. It is based on Michelson interferometer. Light reflected or backscattered from

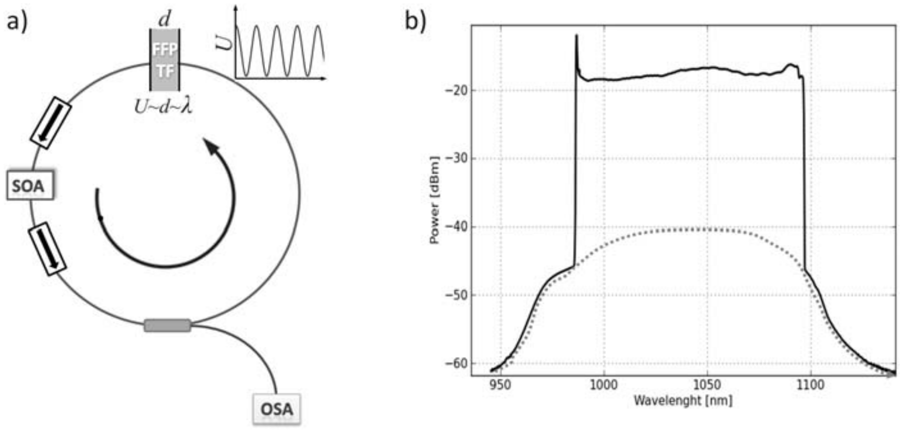

Fig. 1. a) Swept source scheme, b) swept source spectrum (continuous line), ASE — dotted line.

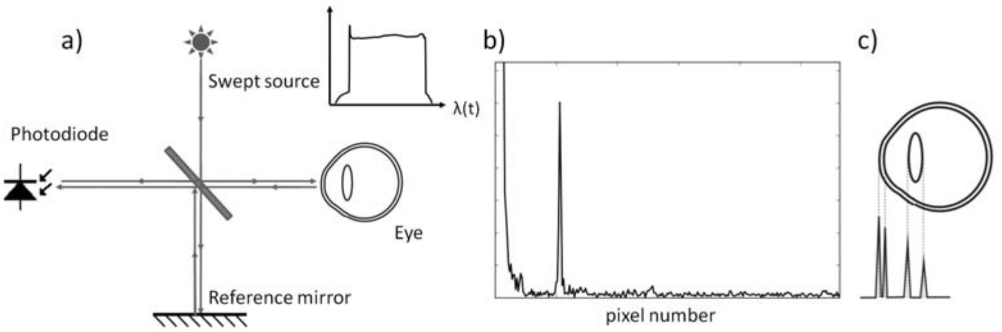

Fig. 2.a) OFDI system based on Michelson interferometer, b) one line of image (A-scan) represent in this case one reflection from mirror, c) rough representation of A-scan for eye.

object interfere with light reflected from reference arm resulting fringe pattern measured with detector (Fig. 2a).

$$I(k) = I_0(k)(R_s + R_r + 2\sqrt{R_s R_r}\cos(2\Delta zk)) \qquad (1),$$

where I_o denotes source intensity in wavenumber domain, R_s R_r — reflection form sample and reference mirror accordingly, Δz — path difference between arms, *k* — wavenumber.

By increasing path difference, modulation frequency will also increase. To recover information about *z* (scattered centres position) from *k* domain signal, Fast Fourier Transform should be applied. Every image represent in Fig. 4. (B-scan) is combined from axial scans (A scans (Fig. 2b) represent in gray scale.

Materials and methods

Figure 3 represents scheme of experimental setup. This is dual interferometric OCT system. Interference signals are detected by the two dual balanced photodiodes, used to minimize the background noise. The additional interferometer provides reference fringe pattern necessary for further data post-processing.

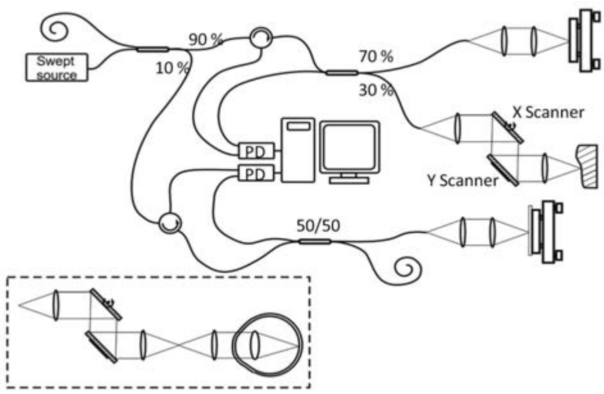

Fig. 3. Experimental setup. PD — Dual Balanced Photodiodes. Inset: modified objective arm for eye examination.

This system works with commercially available swept source laser (Axsun Technology). It operates at central wavelength of 1040 nm with 110 nm bandwidth (Fig. 1b). Repetition rate of this laser is 100 kHz. Average laser output power is 10 mW.

Results

Preliminary results are presented in Fig. 4. Measurements represent eye and skin images. At first, system performance was checked by imaging well known structures. At now in case of posterior segment measurements, the deepest visible structure is Retinal Pigment Epithelium. In aim to finally measure choroid (deeper layer) system sensitivity should be improved.

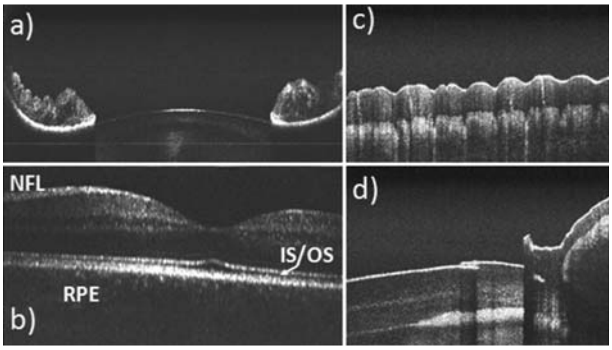

Fig. 4. a) Anterior segment of the eye with lens and iris, b) posterior segment of the eye — fovea area on retina, NFL — Nerve Fiber Layer, IS/OS — junction between Inner and Outer Segments of Photoreceptors, RPE — Retinal Pigment Epithelium, c) finger with distinguished skin surfaces and sweat glands in epidermis. d) nail root of human finger.

Table 1. System parameters for skin examination.

Axial resolution	10.4 μm
Imaging depth	2.6 mm
2D range	6.67 mm
Light power / Sensitivity	1.8 mW at the sample/100 dB
Objective lens	f = 50 mm

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