Multilayered structures examination using polarization sensitive optical coherence tomography

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Abstract— Optical Coherence Tomography (OCT) is an optical method for non-contact and non-destructive examination of inner structure of multi-layered materials. Polarization sensitive OCT (PS-OCT) is also capable of measuring local optical anisotropy changes. The measurement results obtained with our custom-built PS-OCT setup for multilayered birefringent structures demonstrate the applicability of the PS-OCT for characterization of multilayered material stacks containing birefringent polymer layers used, e.g. in display technology. In this paper we present some aspects of our research and experiments and discuss the usefulness of polarization sensitive analysis in OCT for the examination of technical materials.

Non-invasive measurement methods are a versatile tool employed in materials science, process control and quality control. Moreover, they can be used for real-time monitoring of a broad range of devices. Our research has been concentrated on Optical Coherence Tomography (OCT) for technical materials examination. OCT is a unique technique of cross-sectional and three-dimensional visualization of inner structure of different types of materials. This method enables *in-situ* investigation in non-contact and non-destructive way. Using OCT one can analyze the depth structure of investigated materials with measurement resolution of a few μm, high sensitivity and high dynamic range [1, 2]. Nowadays, the advantages of OCT make it applied in medical diagnosis, especially in ophthalmology, dermatology, stomatology and endoscopy [3, 4] and also in industry and science. Apart from medical applications, the OCT is used for material characterization, surface and subsurface defect detection, strain fields mapping in polymers, ceramic materials examination [5-8], as well as art conservation [9]. Our research interests have been concentrated on OCT with polarization sensitive analysis (PS-OCT). Polarization sensitive analysis provides unique benefits to OCT measurements, which allow studying phenomena occurring in a tested sample that cannot be investigated by conventional OCT methods. This measurement method gives structural information about an investigated sample and also enables selective visualization of an optical anisotropic structure [1, 2, 7]. Hence we applied this method investigate optical polymer retarders and liquid crystals cells.

The research work described in this paper was carried out using the PS-OCT presented in Fig. 1 and described in more detail in [10].

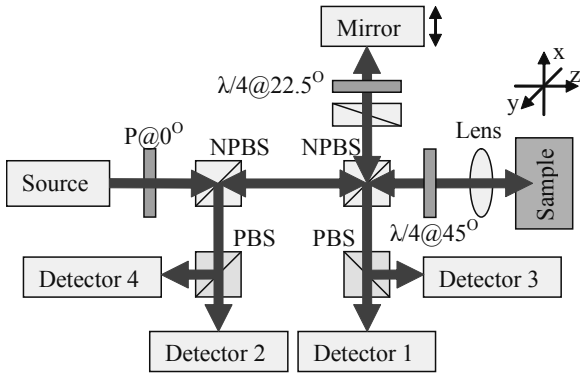

Fig. 1. The experimental PS-OCT system setup; NPBS 1÷2 - non-polarization beamsplitter, P – polarization plate, λ/4 – quarter-wave plate.

The PS-OCT system (Fig. 1) is based on the Michelson interferometer where the movable mirror driven by a piezo actuator is placed in the reference arm. The interferometer is illuminated by broadband light with a circular polarization state. The backscattered light from the sample and light reflected from the mirror are recombined and subsequently separated by a polarization beam splitter into orthogonal components which are recorded by two pairs of photodetectors (in Fig. 1: Detector 1 and 3, Detector 2 and 4). These detectors provide polarization diversity detection with excess noise elimination. In order to increase the signal to noise ratio, low noise balanced receivers Nirvana 2017 (New Focus) have been used. Polarization state analysis is based on Jones formalism, where the birefringent parameters of the investigated sample are calculated from the magnitude and phase of a received interference signal. Thus only non-depolarizing materials which do not provide diattenuation can be investigated. The features of the PS-OCT system have been summarized in Table 1.

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Table 1. Features of PS-OCT system

Feature	Value
Balanced detectors (type 2017 Nirvana by New Focus, USA)	
Wavelength range	800-1700 nm
Common mode rejection	50 dB
Max. AC conversion gain	$1 \cdot 10^6$ V/W
CW saturation power	0.5 mW
Current noise	1.5 pA/√Hz
3 dB bandwidth	150 kHz
Supercontinuum photonic fiber source (type Ultra-Broad Light Source TB 1550 by MenloSystem, Germany)	
Center wavelength	1550 nm
Optical source spectral width	400 nm
Optical source power	42 mW
Depth scanning resolution	4 μm
Measurement dynamic range	92 dB
Meas. accuracy of retardation angle	±6°
Meas. accuracy of axis orientation	±7°

Our experiment has been focused on the examination of tested sample structure as well as birefringence properties determination. The measurements were carried out using the PS-OCT system, which has been presented in Fig. 1. This system allows measurements of the fast axis orientation (θ(z)) and retardation (Γ(z)) provided by the sample as a function of depth. Those quantities are measured in the range of 0º to 180º (θ(z)) and 0º to 90º (Γ(z)) without unwrapping. In order to test the system, a multilayered birefringent sample was made. This sample consisted of three layers with different birefringence features. Each of them was made of a thin film of a polymer deposited on the BK7 glass. The glass substrate thickness was 150 μm. Every single layer had a different orientation and provided a different value of retardation. The layers were separated by an optically isotropic bonding layer. For such a prepared sample the cross-sectional tomography images of its structure and also fast axis orientation and retardation changes were obtained. Moreover, single A-scans of retardation and fast axis orientation changes have been shown in order to present the depth resolved profiles of those quantities. The results have been shown in Fig. 2 and Fig. 3.

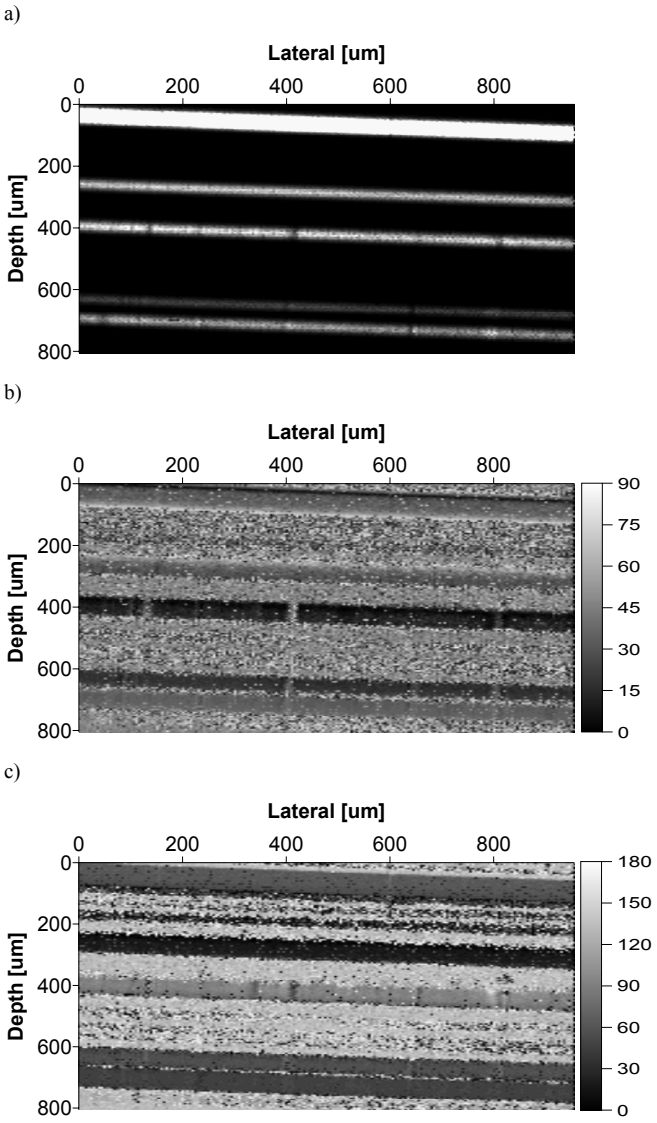
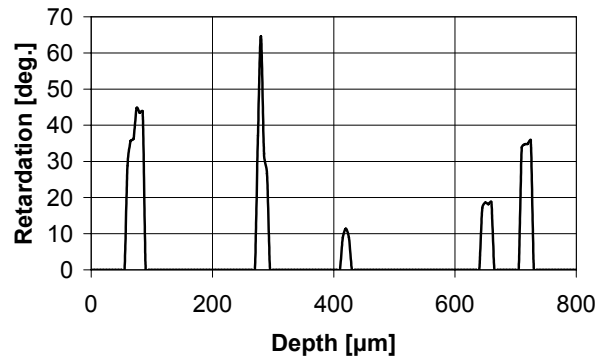


Fig. 2. Cross-sectional tomography images of a polymer optical retarder; a) intensity image; b) retardation image; c) fast axis orientation image

The intensity image (Fig. 2a) allows us to investigate the structure of the sample. It is possible to determine the boundaries of the layers and also their thickness. The first strong reflection corresponds to the surface of the sample. The next two are from rear and front surfaces of the glass-polymer layers separated by a bonding one. More information about the sample can be achieved from polarization sensitive analysis (Fig. 2b and Fig. 2c). The fields of homogeneus values, which correspond to the reflections from Fig. 1a, give additional information about material optical anisotropy. Analysing a single A-scan it is possible to determine birefringence parameters like fast axis orientation and retardation of a particular layer.

a)



b)

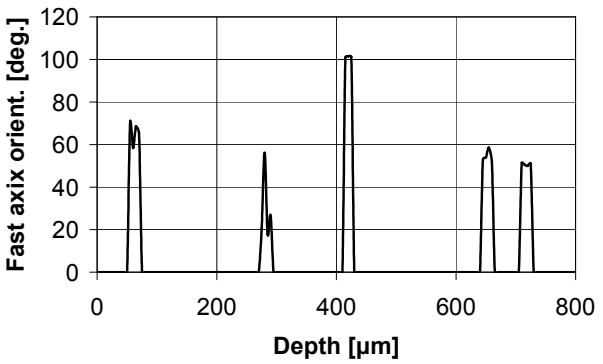


Fig. 3. A-scan profiles of the measured quantities; a) retardation angle; b) fast axis orientation

In conclusion, the PS-OCT takes advantage of the OCT system as well as gives more information about the material features at particular points inside the sample. It enables not only structural examination of a tested sample but also might be useful for materials characterization as well as their physical state monitoring. Thus the PS-OCT has great application potential to enable quality control of the material inner structure and also it might be an interesting and expected tool for materials science.

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