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Optical samples measurement based on orthogonally polarized light over phase-shifting FD-OCT

[1]Jen-Fa Huang, [2]Hsu-Chih Cheng, [3]Chia-Tsai Huang

[1,3]Advanced Optoelectronic Technology Center, Institute of Computer&Communications Engineering, Department of Electrical Engineering, National Cheng Kung University, Tainan, Taiwan.
huajf@ee.ncku.edu.tw

[2]Department of Electro-Optical Engineering, National Formosa University, Yunlin, Taiwan.
chenghc@nfu.edu.tw

Abstract: An improved structure of Frequency-Domain Optical Coherence Tomography (FD-OCT) is proposed to simultaneously measure thickness and refractive index of unknown samples. In conventional FD-OCT, the generated mirror signals will cause the measurement range be cut half. The goal of this study is to increase measurement range and to eliminate unnecessary correlation and mirror signals. By phase-shifting algorithms over orthogonally polarized light, eliminating those unnecessary noise terms becomes possible, and the measurement range is doubled. The proposed FD-OCT thus achieve simultaneous measurements of optical samples in a full-range and one-shot scheme.

As shown in Figure 1, the proposed FD-OCT setup consists of a low-coherence light source, two polarizers, two beam splitters, a polarization beam splitter, a quarter-wave plate, three mirrors and a spectrometer. The SLD light source is divided into three optical paths (M1-arm, M2-arm, M3-arm) by beam splitters BS1 and BS2. The path M1-arm is a reference arm used to detect, M2-arm is another reference arm, and M3-arm is a sample arm. $E_o(\omega)$ is the electric field emitted from the SLD light source, passing through the polarizer P1 placing 45° and then through a quarter-wave plate Q placing 0°.[1] The emerged light is a circularly polarized electric field $E_i(\omega)$. The electric field $E_o(\omega)$ and $E_i(\omega)$ can be expressed as follows:

$$E_o(\omega) = a(\omega)exp[-i(\omega t + \kappa z)] \quad (1)$$

$$E_i(\omega) = J_Q(0°)J_P(45°)E_o(\omega) = a(\omega)exp(-i\tfrac{\pi}{4})\begin{bmatrix} exp[-i(\omega t + \kappa z)] \\ i\ exp[-i(\omega t + \kappa z)] \end{bmatrix}$$

$$= a(\omega)exp(-i\tfrac{\pi}{4})\begin{bmatrix} exp[-i(\omega t + \kappa z)] \\ exp[-i(\omega t + \kappa z) + \tfrac{\pi}{2}] \end{bmatrix} \quad (2)$$

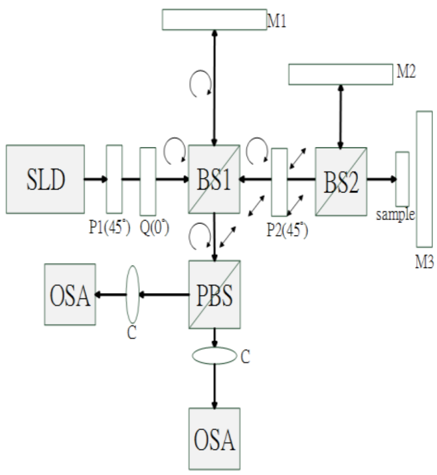

Fig. 1: Schematic illustration of the proposed FD-OCT scheme. (**SLD**: Super-luminescent diode; **P1, P2**: polarizer; **Q**: Quarter wave plate; **BS**: beam splitter; **PBS**: polarization beam splitter; **M1, M2, M3**: mirrors; **C**: collimator; **OSA**: optical spectrum analyzer.)

where $a(\omega)$ is the electric field amplitude, ω, t, κ, z are frequency, time, wave number and distance, respectively. $J_Q(0°)$ and $J_P(45°)$ are the Jones matrix formalism of quarter-wave and polarizer.

The horizontal and vertical polarized light is received by the OSA. The intensity of polarization light is the dot product of electric fields[2] and can be expressed as:

$$I_i(\omega,\Delta z) = \langle E_i(\omega,\Delta z), E_i^*(\omega,\Delta z)\rangle$$
$$= \langle E_{si}(\omega,\Delta z), E_{si}^*(\omega,\Delta z)\rangle + \langle E_{ri}(\omega,\Delta z), E_{ri}^*(\omega,\Delta z)\rangle$$
$$+2\Re\{\langle E_{si}(\omega,\Delta z), E_{ri}^*(\omega,\Delta z)\rangle\} \quad (3)$$

where the index i can be replaced with h or v to denote horizontal and vertical polarization channels. In (3), the first and the second terms are self-coherence interference, and the third term is cross-coherence interference.

The complex intensity consists of $I_H(\omega, \Delta z)$ and $I_V(\omega, \Delta z, \phi=\pi/2)$, which can be expressed as[3]

$$I(\omega) = I_H(\omega,\Delta z) + i\, I_V(\omega,\Delta z,\varphi = \pi/2) \quad (4)$$

$$\Delta S(\tau) = \mathcal{F}^{-1}\{I(\omega)\} - \mathcal{F}^{-1}\{I^{*}(\omega)\} \tag{5}$$

When (4) substituted into (5), the symmetry mirror image and autocorrelation terms are eliminated. It is with such $\pi/2$-phase-shifting algorithm we can achieve a double measurement range.

The reason on adding the second reference arm is that the conventional FD-OCT needs two stages of measurements (place sample and remove sample) on the refractive index of the unknown samples. After adding the second reference arm, it needs only one-shot measurement on the thickness and the refractive index of the unknown samples.

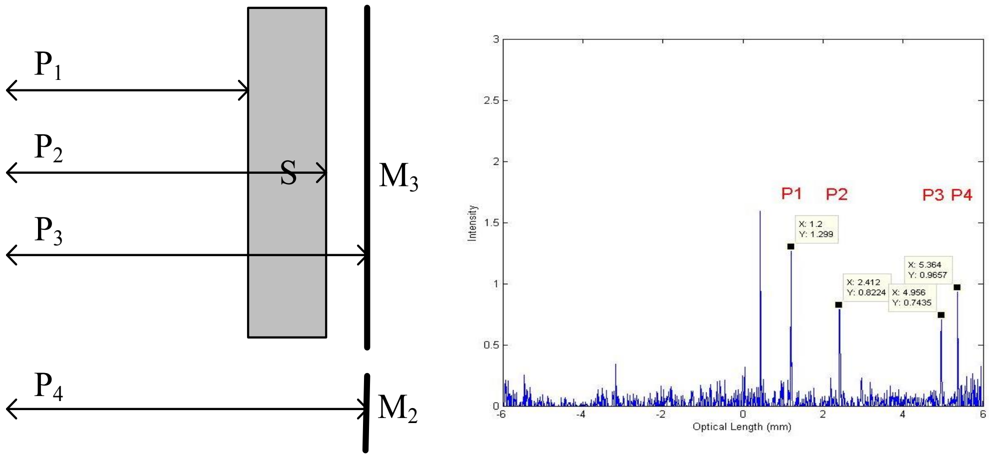

Fig. 2. (a). The optical path length of each surface by the M2 and M3 arm. (P_1~P_4 are optical path length of reflected light from different surface.) (b). The demodulated signal of the interferogram.

The simultaneous measurement method is shown in Figure 2(a). The demodulated signal of the interferogram is as shown in Figure 2(b). The optical path difference (i.e., P_2-P_1 and P_3-P_4) can be obtained by the experiment when substituted into (6) and (7). The thickness L and the refractive index n_s of the unknown sample can therefore be obtained:[4]

$$n_s = n_a \times \frac{P_2 - P_1}{(P_2 - P_1) - (P_3 - P_4)} \tag{6}$$

$$P_2 - P_1 = n_s \times L \tag{7}$$

Where n_s is the refractive index of samples, n_a is the refractive index of air, L is the thickness of the unknown sample. The values of the thickness and refractive index are calculated to be 0.82 mm (the real thickness is 0.8 mm) and 1.4878 (the real refractive index is 1.502), respectively.

References

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