Real-time Thickness Measurement with a Modified Sagnac Interferometer Using Phase Shift Technique

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***Abstract*- The modified Sagnac interferometer with a phase-shift approach is given here for measuring Ta_2O_5 thin-film thickness. The input light is split into reference and sample beams. A real-time signal measurement is performed to get the output intensities of both beams with four different polarizer settings. These intensities can then be effectively converted into film thickness.**

I. INTRODUCTION

Multiple-step algorithms based on a modified Sagnac interferometer have been reported, for example, by replication of two coupling arrangements [1], or by adjusting polarizing beam splitter (PBS) [2]. It was established that the linear polarizer at the interferometer's output must be rotated to use this phases shift approach. An automatic phase-shifting approach was also developed by tilting the mirror coupled to a piezoelectric transducer (PZT) to produce a path length difference. The linear polarizer in this configuration is fixed at an angle (θ). However, the nonlinearity and unstable signals are the potential sources of systematic inaccuracies in the phase production [3]. Several methods for achieving automated phase shift have been published. It can be achieved by using the cyclic polarized light [4], a nanoscale of tilt angle using a piezoelectric transducer (PZT) [5-8]. Those reports, however, employ a single beam with a single detection at the output, which can lead to certain inaccuracies owing to frequency-time domain. The inserted wave plate has no influence on the measurement. The Sagnac interferometer in [8] is modified in this work to measure a phase-shift in real time by dividing the beam into a reference arm and a sample arm using a beam splitter (BS). Besides, to obtain the required intensities for phase shift and thickness measurement, four stepping algorithms are utilized.

II. METHODS

The input electric field vectors of transmitted (in *x*-direction) and reflected (in *y*-direction) beams can be express in (1) and (2), respectively.

$$E_{iT_s} = \frac{1}{2}\left\{\begin{bmatrix} T_1 \\ -iT_1 \end{bmatrix} e^{i(\delta_2 x(t)+\delta_1 x)}\right\} \tag{1}$$

$$E_{iR_s} = \frac{1}{2}\left\{\begin{bmatrix} -iT_2 \\ T_2 \end{bmatrix} e^{i(\delta_2 y(t)+\delta_1 y+\Delta s)}\right\} \tag{2}$$

where δ_1 and δ_2 are the phase retardations introduced by mirrors M1 and M2, respectively. T_1 and T_2 are transmission coefficients along the principal axes of the sample, t is time, and Δ_S is the phase retardation introduced by the sample. A polarizer at the output is fixed at 45° relative to the reference axis. The polarization states are set at 0°, 45°, 90° and 135° to the reference. Thus, the intensities as a function of set angles can be found as:

$$I_{(0^o)} = \frac{1}{4}\left[T_1^2 + T_2^2 + 2T_1T_2 sin\left(\beta - \alpha\right)\right] \tag{3}$$

$$I_{(45^o)} = \frac{1}{4}\left[T_1^2 + T_2^2 + 2T_1T_2 cos\left(\beta - \alpha\right)\right] \tag{4}$$

$$I_{(90^o)} = \frac{1}{4}\left[T_1^2 + T_2^2 - 2T_1T_2 sin\left(\beta - \alpha\right)\right] \tag{5}$$

$$I_{(135^o)} = \frac{1}{4}\left[T_1^2 + T_2^2 - 2T_1T_2 cos\left(\beta - \alpha\right)\right] \tag{6}$$

where $\alpha = \delta_2 x\left(t\right) + \delta_1 x$ and $\beta = \delta_2 y\left(t\right) + \delta_1 y + \phi$.

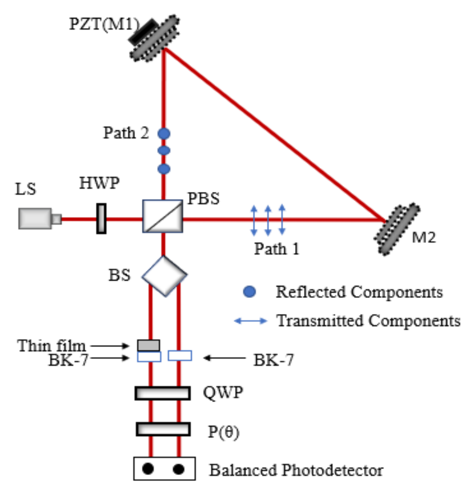

Fig. 1 The schematic diagram of the modified Sagnac interferometer.

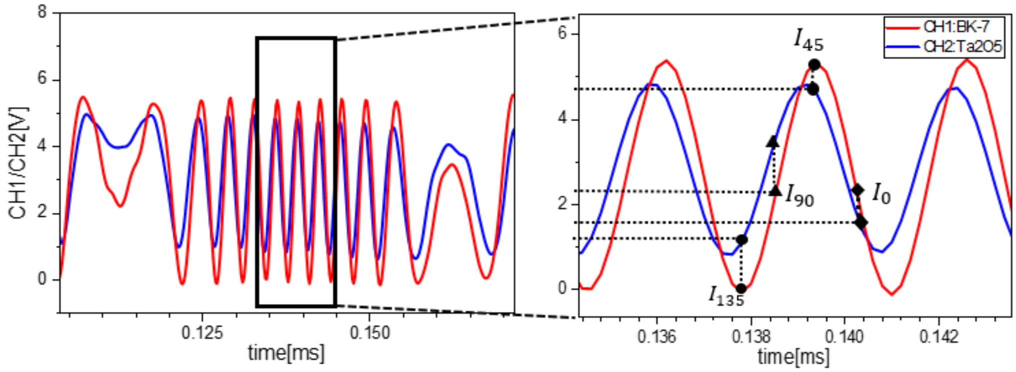

Fig. 2 The real-time intensities of reference and sample beams at various settings of an output polarizer.

The phase retardation ϕ for each beam can be found as

$$\phi = tan^{-1}\left[\frac{I_{(90^{\circ})} - I_{(0^{\circ})}}{I_{(135^{\circ})} - I_{(45^{\circ})}}\right] \tag{7}$$

Consequently, the thickness d of deposited thin film can be evaluated as.

$$d = \frac{\Delta\lambda}{4\pi n} \tag{8}$$

where Δ is the difference between the phase retardation ϕ introduced by the sample and the reference, λ is a light wavelength and n is a refractive index of the film.

III. RESULTS

The thin layer of Ta_2O_5 (n = 2.136) was deposited on the BK-7 substrate. The real-time intensities of the reference and sample beams at different polarizer settings were depicted in Fig. 2.

The reference intensity at 45 could be derived from the peak shown in Fig. 2, while those at 0 and 90 could be acquired from the middle points. Then, the sample intensities were determined by drawing vertical lines from the points of each reference, as demonstrated in Fig. 2. The obtained intensities were done with utmost caution. Eventually, the phase shift value Δ with the presence of Ta_20_5 film was found to be 11° and it was then converted to thin-film thickness measurement using (8) and 259.32nm is accomplished.

IV. CONCLUSION

The simultaneous phase-shift measurement was accomplished in real time by employing an automated self-reference. The four-step algorithms could genuinely minimize errors since more points at each polarization state were assessed for intensity.

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