White Light Interferometer for Inspecting Thickness of Flexible Glass

[1]Shyh-Tsong Lin, [1]Sheng-Yu Lin and [2]Ming-Hong Chang

[1]Department of Electro-optical Engineering, National Taipei University of Technology, Taiwan
[2]Shuz Tung Machinery Industrial Co., Ltd., Taiwan

Abstract: This research proposes an innovative interferometer capable of inspecting the thickness of flexible glass. It is composed of a light source module, phase modulation module and interferometric module; and it is able to achieve the inspections using minimum-intensity identification technology. This paper is to introduce the configuration, measurement theory, experimental setup, experiments and experimental results of the proposed interferometer. The results confirm the validity and applicability of the interferometer. Furthermore the results show that the inspections have a standard deviation of 0.02 μm.

Key words: Interferometer · Phase-scanning · Flexible glass

INTRODUCTION

It is known that flat panel displays (FPDs) are becoming lighter and bendable. This makes the use of flexible glass be indispensable and, accordingly, motivates the researchers to look for adequate instruments capable of inspecting them. Up to date, two types of techniques have been proposed, both of them are able to precisely examine glass-thickness in contactless situation.

The first type is synthetic wavelength interferometry (SWI) [1-7], it replaces the laser source of conventional phase-shifting interferometry (CPSI) [8, 9] by a two-wavelength (or wavelength tunable) laser and examines glass-thickness at a synthetic wavelength by subtracting two phase measurements made respectively at two wavelengths. In general, the synthetic wavelength is much longer than any of the two wavelength, the measurement range of the SWI is therefore much larger than that of CPSI. However the plane-parallel surfaces may repeatedly reflect the light beam [10] and the cross-talk of the multiple-reflected beams may introduce unwanted noise to the interference pattern.

The second type is scanning white light interferometry (SWLI) [11-16], it replaces the laser of CPSI by a white light source (e.g. a halogen lamp) and detects glass-thickness using the algorithm of zero-order fringe identification. It is therefore with a measurement range comparable to that of SWI while no disturbance and error due to multiple-reflection are observed and it is hence even more acceptable than SWI.

This research proposes an innovative white light interferometer capable of inspecting glass-thickness. Apart from exhibiting the excellent performance of SWLI (i.e., non-contact, high precision, large measurement range and no perturbation due to multiple-reflection), the proposed interferometer removes the necessity of using a reference beam. In the following of this paper, the configuration, measurement theory and experimental setup of the proposed interferometer are introduced sequentially. The experiments and experimental results accomplished by using of the setup are demonstrated and discussed thereafter. And the paper finally concludes by summering the measurement concept and performance of the proposed interferometer.

Configuration and Measurement Theory: A schematic diagram of the proposed interferometer is shown in Figure 1(a). It is composed of a light source module (LSM), a phase modulation module (PMM) and an interference module (IM). Where the LSM is a white light laser and it emits a broad-band beam to the PMM. The PMM, which consists of two retro-reflectors (RR_1 and RR_2), a non-polarized beam-splitter (NPBS), a mirror (M) and a nano-stage, outputs two co-axial beams (i.e. E_1 and E_2) to IM. And the IM is made up of a beam expander, a sample (i.e. a plate of flexible glass) under examination and a CCD camera; of which the beam expander expands the beams from the PMM and the sample reflects the incident beams to the CCD camera to generate an interference pattern.

Corresponding Author: Shyh-Tsong Lin, Department of Electro-optical Engineering,
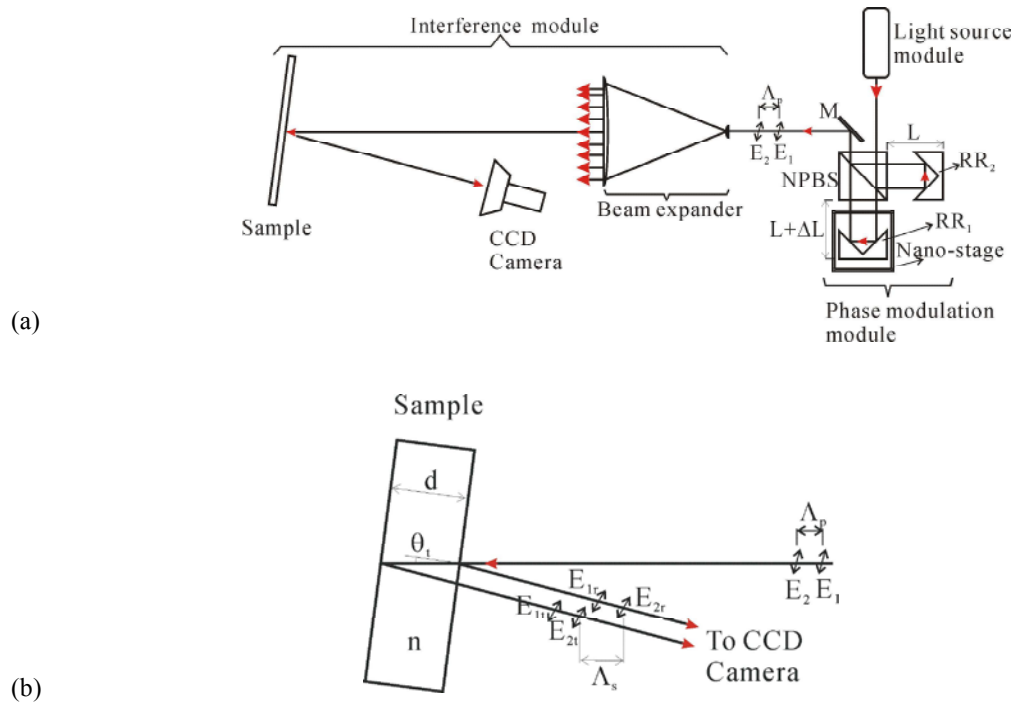National Taipei University of Technology, Taiwan.

Fig. 1: (a) Schematic diagram of the proposed interferometer; (b) a magnification of the sample

A magnification of the sample is exhibited in Figure 1(b), it is found that both of the incident beams are reflected by the front and rear surfaces of the sample. Let us symbolize the beams reflected from the front surface as E_{1r} and E_{2r} and the beams from the rear surface as E_{1t} and E_{2t}; these reflected beams have complex amplitudes of

$$E_{1r} = rE_0 e^{-i(k\Lambda_p + \pi)} \tag{1a}$$

$$E_{2r} = rE_0 e^{-i\pi} \tag{1b}$$

$$E_{1t} = t^2 rE_0 e^{-ik(\Lambda_p + \Lambda_s)} \tag{1c}$$

and

$$E_{2t} = t^2 rE_0 e^{-ik\Lambda_s} \tag{1d}$$

where E_0 represents the amplitude of the incident beams, k is the propagation number of the light source, π in Eqs.(1a) and (1b) is the phase-shift due to external reflection, r and t are amplitude reflectance and transmittance, respectively, Λ_p depicts the optical path difference (OPD) for E_1 and E_2 and Λ_s symbolizes the OPD for two reflected beams (one from front and one from rear surface). Referring to Figure 1 and Ref.[9], it is found that

$$\Lambda_p = 2\Delta L \tag{2a}$$

and

$$\Lambda_s = 2dn\cos\theta_t \tag{2b}$$

where ΔL represents the amount by which the distance between RR_1 and NPBS exceeds that between RR_2 and NPBS, d and n are thickness and refractive index, respectively, of the sample and θ_t denotes the refraction angle of the incident beams.

The electric field on the CCD camera is therefore the superposition of the four beams, i.e. $E = E_{1r} + E_{2r} + E_{1t} + E_{2t}$. Accordingly, the interference pattern on the CCD camera has an intensity of $I = E . E^*$ or

$$I = r^2 E_0^2 \{2(1+t^4)(1+\cos k\Lambda_p) + 2t^2[2\cos(k\Lambda_s - \pi) + \cos(k(\Lambda_s - \Lambda_p) - \pi) + \cos(k(\Lambda_s + \Lambda_p) - \pi)]\} \tag{3}$$

where the arterisk (*) denotes complex conjugate. Note that Eq.(3) is available only for narrow-band source. For broad-band source centered at λ_c, it has to be modified as [8]

$$I = r^2 E_0^2 \{2(1+t^4)(1+\gamma\cos k_c\Lambda_p) + 2t^2\gamma[2\cos(k_c\Lambda_s - \pi) + \cos(k_c(\Lambda_s - \Lambda_p) - \pi) + \cos(k_c(\Lambda_s + \Lambda_p) - \pi)]\} \tag{4}$$
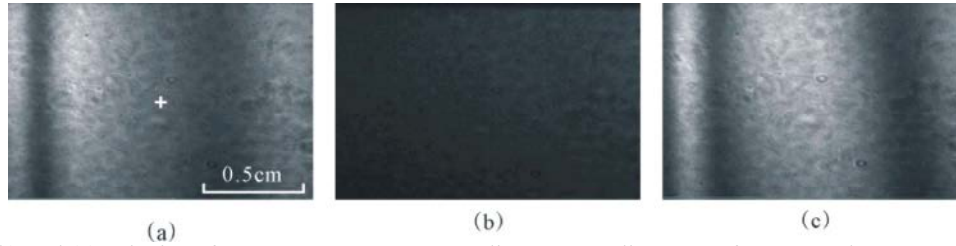
Fig. 2: (a), (b) and (c): The interference patterns corresponding to scan distances of 10, 93 and 174 μm, respectively
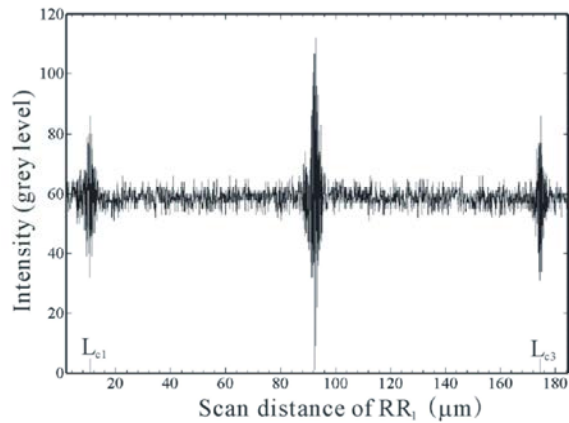

Fig. 3: The correlogram at the point + shown in Figure 2(a).

or, after some arrangements,

$$I = I_0[1 - \gamma_0 \cos k_c \Lambda_s - \gamma_1 \cos k_c(\Lambda_s + \Lambda_p) + \gamma_2 \cos k_c \Lambda_p - \gamma_3 \cos k_c(\Lambda_s - \Lambda_p)] \tag{5}$$

where $k_c = 2\pi/\lambda_c$ and $\gamma's$ are envelope functions. In case of the flexible glass (d=25-210mm), $\Lambda_s > I_c$ (i.e. the coherent length of the source); this indicates that the second term on the right-hand side of Eq. (5) can removed and leads to

$$I = I_0[1 - \gamma_1 \cos k_c(\Lambda_s + \Lambda_p) + \gamma_2 \cos k_c \Lambda_p - \gamma_3 \cos k_c(\Lambda_s - \Lambda_p)] \tag{6}$$

From Eqs.(2) and (6), It is found that the correlogram of I (i.e. plot of I versus ΔL) is with an outline composed of three envelopes. The 1st one centers on $\Delta L = - \Lambda_s/2$ and I inside which has a minimum value at this point; the 2nd one centers on $\Delta L = 0$ and I inside which is with a maximum value at this point and the 3rd one centers on $\Delta L = \Lambda_s/2$ and I inside which has a minimum value at this point.

The proposed interferometer is to examine the sample using the aforementioned phenomenon. It instructs the nano-stage to carry RR_1 to experience a moving scan, records the scan distances corresponding to the 1st and 3rd centers of every point and determine **d** of the sample using

$$d = \frac{L_{c3} - L_{c1}}{2n \cos \theta_t} \tag{7}$$

where L_{c1} and L_{c3} are scan distances with respect to the 1st and 3rd centers, respectively

Experimental Setup: To implement the measurement concept introduced in this paper, an experimental setup composed of the proposed interferometer and a control and image processing system was installed. Where the proposed interferometer is configured as that shown Figure 1. Of which, the LSM is SuperK Compact from NKT Photonics Inc., Denmark. The nano-stage of the PMM is P-622.1 CD from Physik Instrumente GmbH & Co., German; it is equipped with a PZT actuator and capacitive sensor and it is with a closed-loop travel of 250μm. And the refracted light beams of the IM have a refraction angle of $\theta_t \approx 3°$.

The control and image processing system comprises a frame grabber, stage controller/driver and personal computer. Among them, the personal computer grabs interference images on the camera through the use of the frame grabber, communicates with the nano-stage by way of the stage controller/driver and executes two programs: measurement and display. The measurement program inspects the samples using the above-mentioned scanning method and the display program exhibits the measurement results on the screen of the computer.

Experimental Results: To verify the proposed interferometer, the abovementioned setup was conducted to examine a piece of flexible glass having nominal thickness of 50μm and refractive index of n=1.52. Where the moving scan of RR_1 was proceeded in stepping manner with stepping increment of 0.01 μm and the results regarding this examination are shown in Figures 3, 4 and 5. Where Figures 3(a), (b) and (c) display the interference
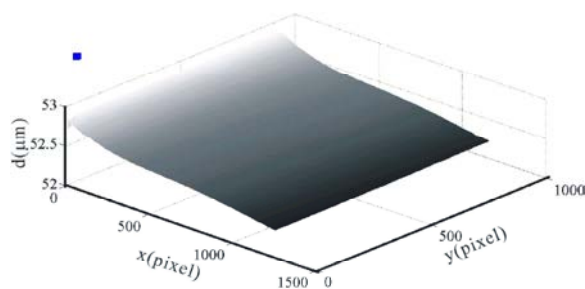
Fig. 4: The measured thickness of the flexible glass

patterns captured at the scan distances of 10, 93 and 174 μm, respectively; Figure 4 exhibits the correlogram of the point + marked at Figure 2(a), it demonstrates that every effective point has two distinguishable minimum intensities in 1st and 3^d envelopes, respectively, accordingly the thickness of every point of the sample can be retrieved without ambiguity using the scan method.

Figure 4 displays the distribution of the measured thickness. The average of which is 52.58 μm, this is agreed by that (54.9μm) measured by the use of a micrometer. To realize the repeatability of the examination, the above measurement was actually repeated for 30 times and the averages of all the repeated measurements were used to compute the standard deviation (σ) of the examination. The result is 0.02μm, put a filter onto the measured data can eliminate the data noise and accordingly decrease the standard deviation.

Moreover, the experimental setup was also adopted to examine an another piece of flexible glass having nominal thickness of 100μm and refractive index of n=1.52. The outputs are d=100.31μm and σ=0.09μm.

DISCUSSIONS

Although the IM is a common-path configuration, the interference fringes were slightly trembling during the measurements. This was caused by the unsteady of the PMM. The PMM is a two-arm structure, its steady state can easily be destroyed by low-frequency vibrations, air turbulence and temperature variation Isolating the environmental perturbations and using heavy optic mounts with low degree of freedom would suppress the impact due to the those disturbances.

Due to the travel range of the nano-stage, the measurement range of the proposed interferometer is 125/n (μm), this is small but not its limit. Replacing the

stage by that having a larger travel range and with a high sensitivity sensor would provide the interferometer the ability of inspecting transparent plates with larger thickness.

CONCLUSIONS

In summary, this research has successfully developed an innovative interferometer capable of examining the thickness of flexible glass using minimum-intensity identification technology. This paper has introduced the detail of the interferometer, an experimental setup for realizing the interferometer and, experimental results from the uses of the setup. The results confirm the validity and applicability of the interferometer. Furthermore the results show that the inspections have a standard deviation of 0.02 μm.

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