A miniature interferometry sensor for monitoring the changes of film thickness and refractive index

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A new miniature interferometer has recently been developed for monitoring the changes of film thickness and refractive index, wherein a semiconductor laser and a photodiode detector are integrated to form a laser/detector hybrid. The laser light is collimated by a lens. When the laser light hits a film, it is reflected twice by the two interfaces between the film and the surrounding mediums. The two reflected light beams are interfered at the detector by the same lens. Due to the interference, the detected intensity is a function of the film thickness. The swelling of thin gelatin gel film has been used to demonstrate the use of this novel sensor. The sensor is ready to be used in many applications, such as inside a vacuum chamber, on a robot arm, and in a small reaction container, wherever a conventional interferometric setup cannot be easily implemented because of its size.

I. INTRODUCTION

For a long time, the interferometry method has been used to detect the changes of film thickness and refractive index,[1-3] where a He–Ne laser and a photodiode detector are normally used. As shown in Fig. 1, when the laser light enters a film at a very small angle (θ), it is reflected twice by the two interfaces between the film and the surrounding mediums. Two reflected light beams ($E_{R,1}$ and $E_{R,2}$) interference with each other. The resulted intensity (I) at the detector will be[3-5]

$$I=E_{R,1}^2+E_{R,2}^2+2E_{R,1}E_{R,2}\cos\left(2\pi\frac{2nd\cos(\theta')}{\lambda_0}\right), \quad (1)$$

where λ_0, n, and d are the wavelength of the laser in vacuum, the refractive index, and the film thickness, respectively. According to Eq. (1), if the thickness (d) or the refractive index (n) is a function of time, the intensity (I) will vary between the minimum $(E_{R,1}-E_{R,2})^2$ and the maximum $(E_{R,1}+E_{R,2})^2$. Therefore, the change in d or in n can be monitored by the change of I.

However, there are many cases, such as inside a vacuum chamber, on a robot arm in the production line, and in a small reaction container, where a normal interferometer cannot be easily implemented simply due to its size. In the following, we report a new miniature interferometry sensor.

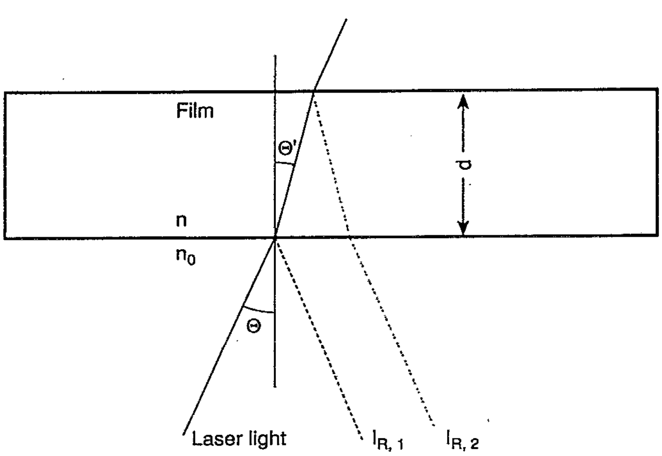

FIG. 1. Schematic of a laser light reflected by a thin film. The optical path difference between $I_{R,1}$ and $I_{R,2}$ is $2nd\cos(\theta')$, where $n_0\sin(\theta)=n\sin(\theta')$.

II. INSTRUMENTATION

Figure 2 shows a schematic presentation of our miniature interferometry sensor (HOETRON, Inc. 776 Palomar Avenue, Sunnyvale, CA, U.S.A.) which is made by slightly modifying the detector used in most compact disk (CD)

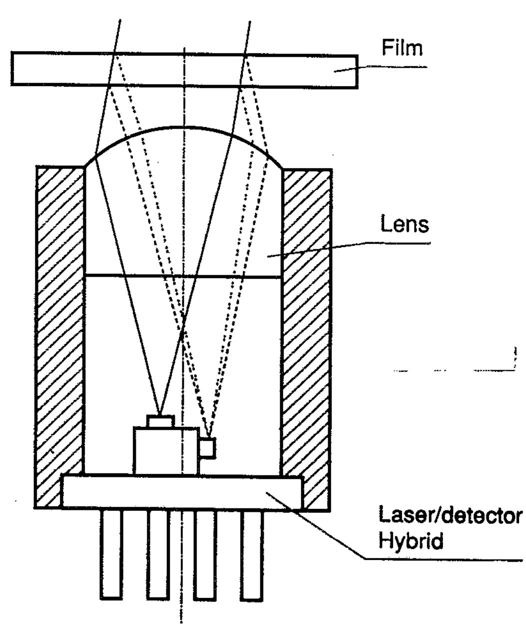

FIG. 2. Schematic of a novel miniature interferometry sensor.

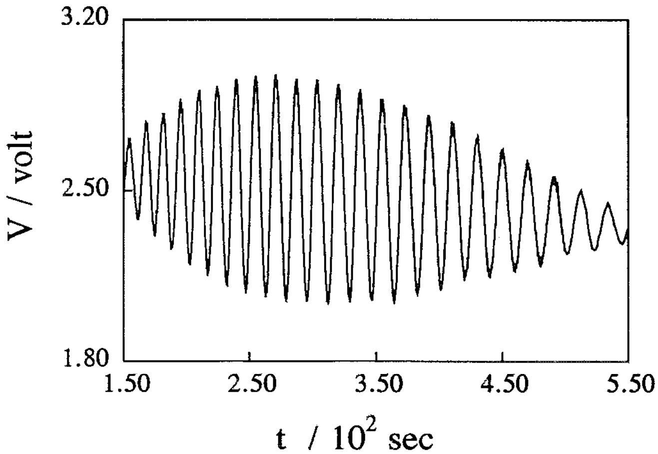

FIG. 3. Portion of typical intensity profile measured during a thin gelatin film swelling process.

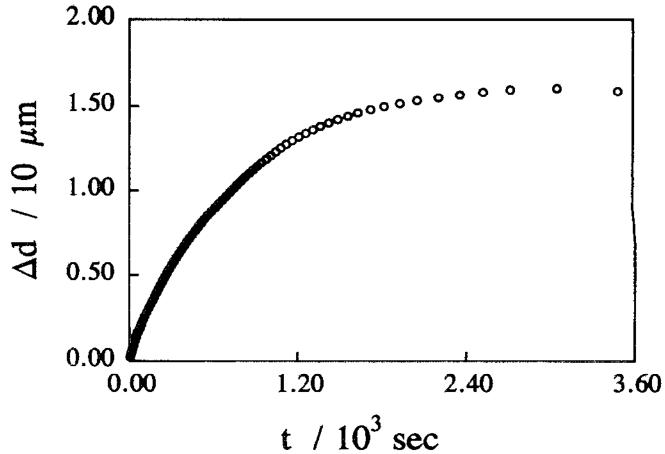

FIG. 4. Film thickness change (Δz) vs time (t) in a thin gelatin film swelling process.

players. A semiconductor laser (SONY, 1 mW and $\lambda_0=730$ nm) and a photodiode detector (0.8 mm$\times$0.4 mm) with a sensitivity of 0.4 μA/μW are integrated to form a laser/detector hybrid. The laser chip and detector chip are placed symmetrically about the optical axis of the lens. The distance between the laser chip and the detector chip is 1.0 ± 0.1 mm. The laser light is collimated by the lens (NA=0.25; $f=9$ mm). The collimated laser beam comes out from the sensor at an angle of $\sim 2°$ to the optical axis. After the collimated beam hits the film, it is reflected by the two interfaces between the film and the surrounding mediums. The two reflected beams are focused by the same collimating lens to the photodiode detector. The outside dimension of the sensor is 13×22 mm^2. The working distance between the lens and the film can be as long as 50 mm. The sensor can be operated by a laser driver together with an amplifier for the detector. The sensor is mounted on a plate with two tilt freedoms. The alignment requires only a few minutes.

III. RESULTS AND DISCUSSION

We used this sensor to monitor the swelling process of a thin gelatin film. The initial film thickness is 60 μm. Figure 3 shows a typical intensity profile during the swelling, i.e., the output voltage signal from the detector. According to Eq. (1), a change of the intensity from one peak to another peak corresponds to a phase change of π or a film thickness change of $\Delta d_{p\text{-}p}=\lambda_0/[4n\cos(\theta')]$. Since $\theta\sim 2°$, $\theta\cong\theta'$, and $\cos(\theta')\cong 1$. With the known value of n, we can easily convert the intensity profile in Fig. 3 into the film thickness change (Δd) versus time (t) as shown in Fig. 4, which shows that the swelling process slows down as time increases and finally approaches the swelling equilibrium.

On the other hand, if the film thickness is a constant, e.g., a sample is confined inside a glass cuvette, the intensity profile can be used to monitor the change of n which can be further related to concentration or chemical reaction. On the basis of Eq. (1), the intensity change from one peak to another peak corresponds to a phase change of π or a refractive index change of $\Delta n_{p\text{-}p}=\lambda_0/[4d\cos(\theta')]$.

We have shown the design of a novel interferometry sensor together with its basic principle, and only demonstrated the feasibility of its application. This miniature sensor will certainly introduce many innovative applications in both research and industrial application.

[1] D. Beysens, Rev. Sci. Instrum. **50**, 509 (1979).
[2] V. Gurfein, F. Perrot, and D. Beysens, J. Colloid. Interface Sci. **149**, 373 (1992).
[3] J. de Bore, R. J. Visser, and G. P. Melis, Polymer **33**, 1123 (1992).
[4] P. A. Heimann, J. Electrochem. Soc. **132**, 2003 (1985).
[5] O. S. Heavens, *Optical Properties of Thin Films* (Academic, New York, 1955), p. 56.