A method for measuring the concentration of a solution

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ABSTRACT

When a linearly polarized light beam enters a surface-plasmon-resonanse (SPR) apparatus and is incident on the boundary surface with tested solution at the resonant angle, the phase difference between s- and p- polarizations is changed with the concentration of the solution. And the phase difference can be measured accurately by the heterodyne interferometry. Based on these effects, a method for measuring the concentration of a solution is presented.

Keywords: Surface-plasmon resonance, Heterodyne interferometry, Concentration.

SUMMARY

A schematic diagram of our method is designed and shown in Fig. 1. The heterodyne light source[1] consists of a linearly polarized laser, a half-wave plate H, and an electro-optical modulator EO driven by a function generator FG. The angular frequency difference between s- and p- polarizations is ω. A light beam coming from this heterodyne light source enters the SPR apparatus[2] being an isosceles right-angle prism with a thin metal film deposited on the hypotenuse surface being contacted with the test solution. If the light beam is incident at the resonant angle θ_{sp} on this boundary surface, then the reflection coefficients r_p and r_s of p- and s- polarizations of the reflected light can be derived from the Airy's formulas[3], and can be written as

$$r_q = \frac{r_{01}^q + r_{12}^q e^{i2kd}}{1 + r_{01}^q r_{12}^q e^{i2kd}} = |r_q| e^{i\phi_q} \qquad (q = p, s), \tag{1}$$

where r_{01} and r_{12} are the reflection coefficients of prism-metal boundary and metal-solution boundary, respectively, d is the thickness of metal film, k is the wave vector in metal, ϕ_s and ϕ_p are the phases of s- and p- polarizations of the reflected light., and ϕ is the phase difference between s- and p- polarizations, respectively.

From these equations, it is clear that ϕ is dependent on the refractive index of the tested solution and the refractive index is related to its concentration[4]. Consequently it can be seen that ϕ is dependent on the concentration. Next the reflected light passes an analyzer AN with the transmission axis at α to the horizontal axis and is detected by a photodetector D. Then the intensity measured by D is the test signal and can be derived as

$$I_t = |E_t|^2 = \frac{1}{4}\left[r_p^2 \cos^2\alpha + r_s^2 \sin^2\alpha + 2 r_p r_s \cos\alpha \sin\alpha \cos(\omega t + \phi)\right] \tag{2}$$

On the other hand, the electrical signal generated by the function generator FG is filtered and becomes the reference signal. It has the form as

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$$I_r = \frac{1}{2}[1+\cos(\omega t)]. \tag{3}$$

Both of these two sinusoidal signals are sent to a phase meter PM, ϕ can be measured accurately. The concentration can be estimated from its associated data of ϕ with the specified relation curve of phase difference versus concentration.

In order to demonstrate the feasibility of this method, an SPR apparatus consisting of a BK7 prism and a thin gold film of thickness 35nm to measure the concentration of glucose solution. Their refractive indices are measured with an ellipsometer and they are 1.5151 and 0.1973+i3.5631, respectively. A high-resolution rotation stage with angular resolution 0.001° is used to mount the SPR apparatus. A phase meter with angular resolution 0.01° is used and a personal computer is used to record and analyze the data. The frequency difference of the heterodyne light source is 1 kHz and θ_{sp} equals to 71.03°. The measured results and its fitting curve are shown in Fig. 2. And the concentration of other glucose solution can be estimated from its associated data of ϕ with this fitting curve.

Because r_p is very small in this method, so the fast axis of the half-wave plate should be located moderately to enhance the contrast of the test signal. Considering the angular resolution of the phase meter, second harmonic error, and polarization-mixing errors, the angular resolution is decreased to is 0.03°, the sensitivity of our method is 3.31×10^{-2} (*mg/ml*). This method has the advantages of both the common-path interferometry and the heterodyne interferometry, such as high stability, high resolution, and easy operation.

REFERENCES

1. D. C. Su, M. H. Chiu, and C. D. Chen, "Simple two-frequency laser", Prec. Eng. 18,161-163 (1996).
2. S. Shen, T. Liu and J. Guo, "Optical phase-shift detection of surface plasmon resonance", Appl. Opt. 37, NO. 10, 1747-1751(1998).
3. P. Yeh, "Optical waves in layered media", John Wiley & Sons, Inc. , 86-88, (1988).
4. E. Kretschmann, "The determination of the optical constants of metals by excitation of surface plasmons," Z. Phys. 241, 313 (1971).

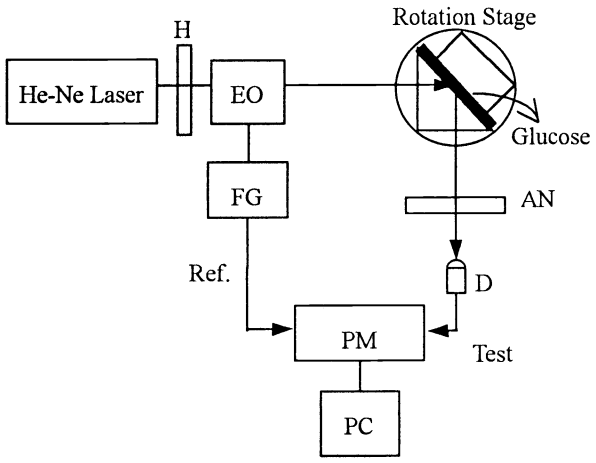

Fig. 1 Schematic for measuring the concentration of a solution.

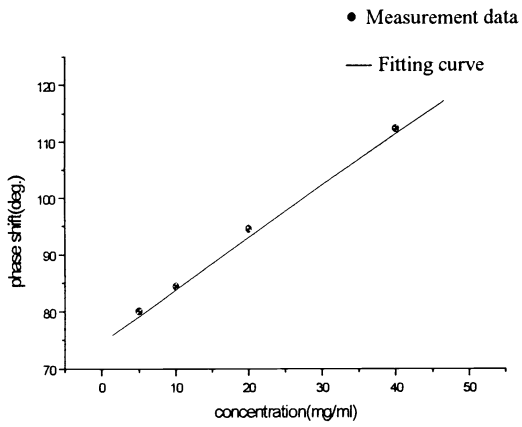

Fig. 2 Measurement data of phase difference at different concentration and the fitting curve.