

DEVELOPMENT OF GEL-TYPE TEMPERATURE SENSOR USING FLUORESCENCE POLARIZATION METHOD

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1. INTRODUCTION

In this study, we are developing a gel-type sensor that can measure the surface temperature of human body and the biochemicals contained in the sweat and urine of human to diagnose health and stress conditions^[1]. To obtain the gel temperature, we mix the fluorescence probe in the gel and measure the fluorescence polarization characteristics. Linearly polarized excitation light is irradiated to the gel, and the polarization degree of the fluorescence is measured to evaluate the gel temperature^[2]. Fluorescence polarization (FP) is less affected by the intensity variation of the excitation light and ambient light, and is believed to give the temperature of high accuracy. On the other hand, the temperature distribution in the gel and evaporation can affect the performance of the temperature measurement of the surface to which the gel is attached. In this study, we measured the FP of the gel attached to the isothermal wall, and analyzed the time distribution of the FP. We evaluated the effects of the gel thickness and evaporation, and developed a model based on the heat transfer characteristic of the gel to improve the measurement accuracy and also reduce the measurement time.

2. MEASUREMENT PRINCIPLES AND METHODS

2.1 Fluorescence polarization method As shown in Fig. 1(a), when fluorescent molecules are irradiated with linearly polarized excitation light, molecules with absorption moments parallel to the polarization direction are selectively excited. The excited fluorescent molecules emit fluorescence polarized in the direction parallel to the absorption moment. If the fluorescent molecules are dissolved, the molecules experience rotational Brownian motion resulting in depolarization. The Brownian motion of fluorescent molecules varies with the solution

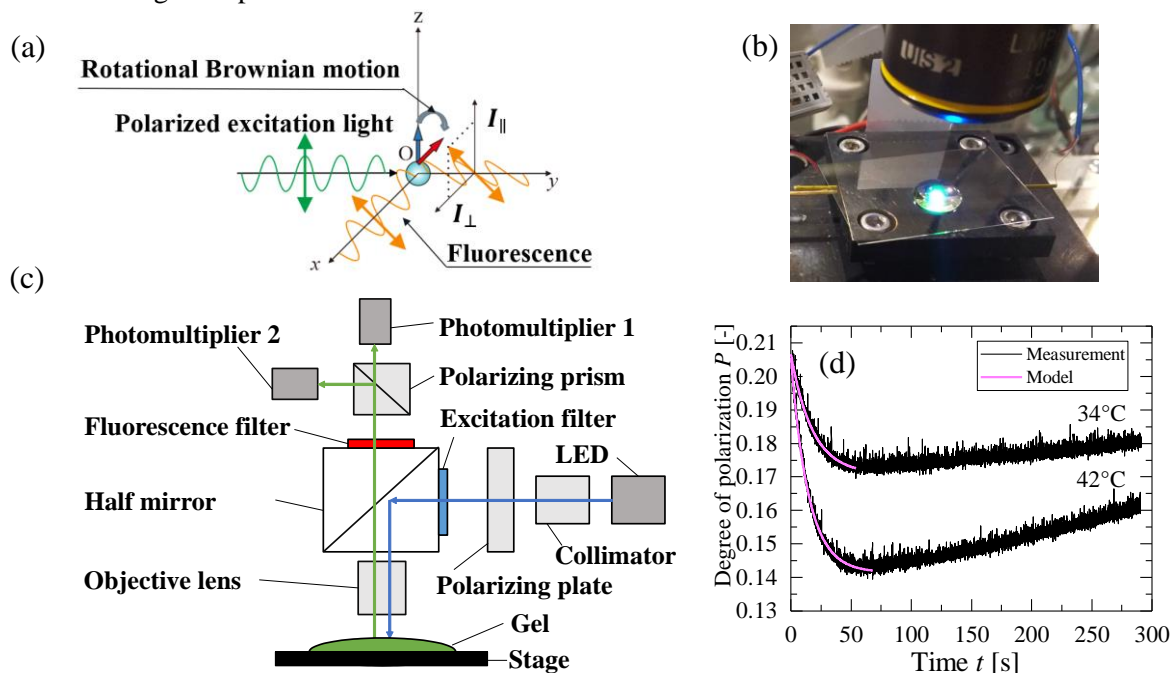


Fig. 1 Schematic images of (a) principle of fluorescence polarization of molecule with rotational Brownian motion, (b) photograph of the gel sample during measurement, (c) measurement system, (d) relationship between polarization degree P of fluorescence and time t .

temperature, including the effect of changes in the viscosity of the solution. Therefore, the solution temperature can be measured by measuring FP. Here, let the polarization degree of the fluorescence be P , and the fluorescence intensities in the parallel and perpendicular directions to the polarization direction of the excitation light be I_{\parallel} and I_{\perp} , respectively: P can be defined as $P = (I_{\parallel} - I_{\perp}) / (I_{\parallel} + I_{\perp})$.

2.2 Experimental apparatus and conditions Figures 1(b) and (c) show the sample and the optical system of the measurement, respectively. The light from the LED is linearly polarized. The I_{\parallel} and I_{\perp} components of the fluorescence emitted from the gel are measured by two photomultipliers. The gel consisted of 2.5 wt% hydroxyethyl cellulose (HEC), 50 wt% sucrose, and 1.0×10^{-6} mol/L uranin. A droplet of the gel was attached on a cover glass, which was set on the temperature-controlled stage for measurement. In order to obtain the calibration equation for the relationship between P and the temperature of the gel, preliminary measurements were performed using a gel-sealed preparation glass. Preparation is made by placing a 1-mm silicon sheet on both ends of a cover glass and sandwiching the solution between the cover glasses.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The temperature of the gel changes over time due to heat transfer with the stage surface and the ambient air after it is placed on the stage. Therefore, we need to estimate the wall temperature from the distribution of the polarization degree. Figure 1(d) shows the distribution of the polarization degree P measured after the cover glass with gel droplet was placed on the stage (stage temperature was set to 34 °C). Polarization degree decreases with time, and the time P reaches a minimum is when the average temperature of the gel is closest to T_w . We obtain the wall temperature from this P applying the calibration formula for P and T . In the range of wall temperature 34 °C to 42 °C, the maximum error of the measurement from the wall temperature was 4.67%.

It should be noted that the reason P is not constant after the minimum value in Fig. 1(d) is attributed to water evaporation. The evaporation increases the sucrose concentration, which leads to increase of viscosity and P . However, the time when the polarization degree reached its minimum, the effect of evaporation was 0.46 °C.

To model the time variation of the P , we used Eq. (1) and fitting it to the region of decreasing P as shown in Fig. 1(d). The minimum value of P was obtained from the asymptotic value ($t \rightarrow \infty$). c_p , k , ρ , and d are the specific heat capacity, thermal conductivity, density, and the thickness of gel, respectively. α is the correction factor.

$$P(t) = P(\infty) + (P(0) - P(\infty)) \exp\left(-\frac{\alpha k}{\rho c_p d^2} t\right) \quad (1)$$

The error of the temperature obtained from $P(t \rightarrow \infty)$ was 2.24 % showing that the model can accurately predict the wall temperature. It can also help reducing the measurement time.

However, the correction factor α was dependent on d . We measured the relationship between P and d using the preparation with gel of thickness of 0.5, 1, 1.5, 2, 2.5 and 3 mm. In this case, the solution in the preparation is not affected by evaporation and the effect of heat transfer only can be considered. The relationship between α and d was $\alpha = 0.94 d$. In addition to this, the minimum value of P was also affected by d . This error was due to the temperature gradient generated in the gel even in steady state. Therefore, thickness should be evaluated from the time distribution of P and be applied to correct the measured surface temperature. We will discuss this effect and the applied model in the presentation.

4. CONCLUSIONS

To improve the accuracy and speed of wall temperature measurement by fluorescence polarization method, a heat transfer model was applied to the time distribution of the polarization degree. The correction factor in the model varied linearly with the thickness of the gel. We needed to apply the effect of the thickness to also correct the measurement error due to the temperature gradient generated in the gel. From these modifications, the wall surface temperature was measured reasonably well.

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