Micro-lens as a Sensor for Detecting Variations of Solution Concentration in Inhomogeneous Medium with Time/Region/Temperature

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***Abstract*—We report here a novel optical sensor technology which uses micro-lens as the sensor to perform real time monitoring of the Refractive Index (RI) of a solution, and the applications of the method in detecting the local concentration variation with time and temperature in inhomogeneous solutions.**

Keywords-Micro-lens; refractive index; temperature; solution concentration

I. INTRODUCTION

The concentration variations of solutions with temperature are important topics in biomedical research [1][2]. Since optical methods have the advantage of performing fast and accurate measurements without perturbation, they have been a powerful tool in measuring the refractive index of solutions [3][4]. Based on our previous RI detection method using microspheres [5], the present paper developed a new type of RI measurement technology which uses micro-lens for imaging and has higher precision to measure the local concentration variation in inhomogeneous solutions.

II. EXPERIMENT

A. Principle

As microsphere is RI sensor in inhomogeneous media [5], when a micro-lens is immersed in a liquid medium and illuminated by a parallel light propagating along its optical axis, a dark ring appears in the image of the micro-lens if there is a difference between the refractive index of the micro-lens n_2 and the refractive index of the surrounding medium n_1, as shown in Figure 1. Therefore, by using a micro-lens with known refractive index n_2 and measuring the ratio X (r/R) from the image of the micro-lens, one can easily determine the refractive index n_1 of its surrounding medium with the following equation (length of the micro-lens is 2.5 folds of radius):

$$\begin{aligned} n_1 = n_2 \times (&13.172968X^8 + 67.604493X^7 - 150.372939X^6 \\ &+ 189.176433X^5 - 147.260928X^4 + 72.6673X^3 \\ &- 22.408722X^2 + 4.408178X + 0.359321) \end{aligned} \quad (1)$$

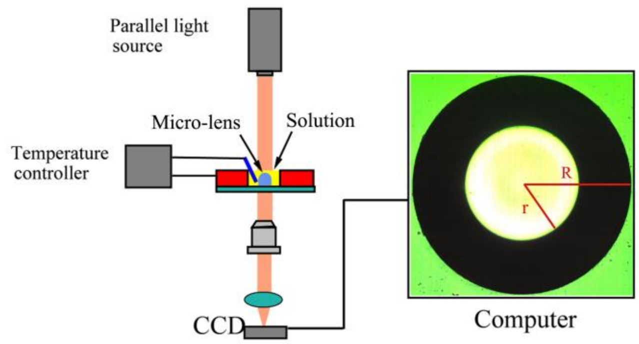

Figure 1. Schematic diagram of the measuring system and the image of a micro-lens immersed in solution.

B. Setup of the measurement

The measuring setup is shown in Figure 1. The parallel light from a LED light source is incident to the microsphere which was immersed in the target micro-region of an inhomogeneous solution, and the image of the micro-lens was taken by a CCD camera via a 40× objective. The r and R values of the micro-lens' image were measured using a homemade image processing software with a calibrated scale.

III. RESULTS AND DISCUSSION

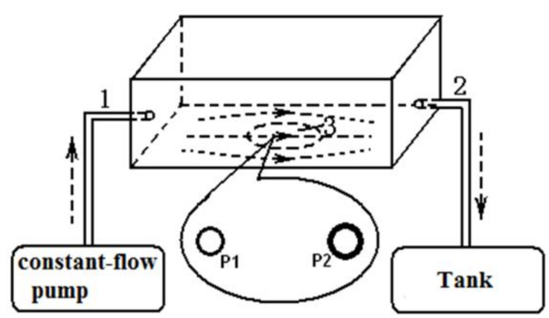

Figure 2. Two micro-lenses were used to monitor the variations of normal saline in a cell-culturing pool.

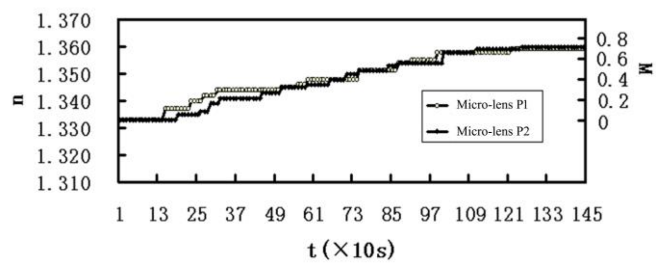

Figure 3. The variations of the refractive indices and the mole fraction (M) of the normal saline at the two micro-regions monitored by P1 and P2 respectively.

Figure 2 shows a setup of using micro-lenses to monitor the variations of local solution concentrations in micro-regions within a cell-culturing pool. The micro-lenses P1 and P2 were 50 μm in diameterandthey were separated by a distance of 200 μm. A constant-flow pump perfused normal saline into the pool. Figure 3 illustrates the variations of the refractive indices and the mole fraction (M) of the normal saline with time at the two micro-regions monitored by P1 and P2, respectively; it gives detailed information about the dynamic process of the diffusion. We can see that though the two micro-regions were just separated by a small distance of 200 μm, their normal saline concentrations were slightly different and had different rates of incensement. Since the micro-lens sensor was demonstrated to be able to detect refractive index change to as small as 10^{-5} or even to 10^{-6}, it has high resolution power to distinguish small changes in concentration. Its small size also enables it to identify the slight differences of concentration in the micro-regions separated by distance as small as ~100 μm.

By placing a silica microsphere beside the micro-lenses P1 and P2 as the sensor of the local temperature, we could determine the real-time local temperature variation. By this means, we obtained the refractive index variations of NaCl as a function of both concentration and temperature, as shown in Figure 4.

IV. CONCLUSION

In summary, we have developed a micro-lens imaging method for measuring the liquid RI. It can measure trace liquid RI accurately, and monitor the instantaneous concentration variation in different micro regions. Since the refractive index of a solution is a function of the solute concentration and temperature [6], by using our method, micro-lens can be considered as sensitive and accurate sensors for monitoring concentration and temperature variations in different regions within an inhomogeneous solution.

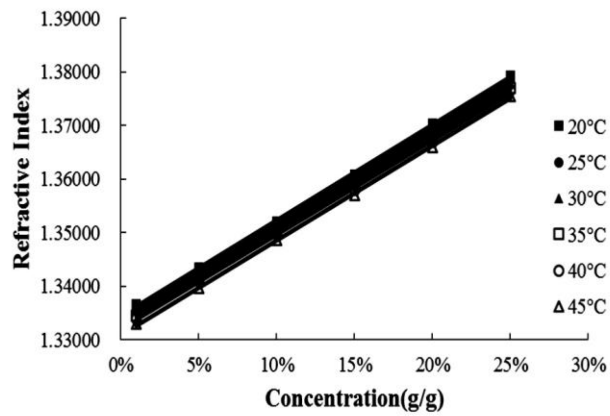

Figure 4. Refractive index of NaCl in solution as a function of concentration and temperature. RI of different concentration solution were determined at different temperature by micro-lens.

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