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Measuring Various Biochemical Concentration Using Micro-Ball Lens Probe

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Abstract. A simple sensor design is proposed and demonstrated using polymeric micro ball-lens (MBL) at the cleaved tip of microfiber couple (MFC) for detection of different concentration of biochemical solutions. A beaker with a mirror attached to it was used to contain the biochemical with various concentrations. The MBL probe is fixed perpendicular to a flat mirror which is placed at the bottom of the biochemical container at a fixed distance of 1.3 mm throughout the experiment. The micro-ball lens was first immersed in de-ionized water to measure the output voltage of a 0 ppm solution concentration, followed by glucose, sodium chloride, and uric acid solution with concentrations vary from 100 to 500 ppm. The sensitivity of the sensor to the glucose solution is 0.011 dB / ppm and the slope shows a good linearity of more than 99%. For the sodium chloride and uric acid solution, the sensitivity of the sensor is 0.010 dB/ppm and 0.020 dB /ppm respectively.

Keywords: Micro-ball lens, tapered fiber, glucose sensor, sodium chloride sensor, uric acid sensor

1. Introduction

Spherical tips and ball lenses have been used for various applications such as optical probes for biomedical applications [1], add–drop multiplexers [2], optical encoder systems [3], and optical resonators [4]. Ball-lens structures are also developed for profile measurement of high-aspect-ratio micro-structured surfaces. Precise measurement of such surfaces is very important for the assurance of the machining accuracy [5]. The optical detection nature of ball-lens structures has been extensively utilized for the design of sensors [6], [7]. For instance, it was used in the detection and identification of atoms or molecules of a certain chemical under scrutiny.

Sensing of biochemicals concentration is important in health, medical and clinical application. Some common compounds that associated with the human body and health are glucose, uric acid and sodium chloride. Glucose is a carbohydrate and plays the most important role in human body which is providing the energy needed through a process called metabolism [8]. Uric acid is a chemical created when the metabolic breakdown of substances called purines occur inside human body [9]. Sodium chloride is an ionic substances found in medical treatment, and also referred to as "salt" which commonly used as seasoning in many foods. Sodium chloride also often related to the salinity level in industrial water supply, as well as in seawater [10]. Monitoring this biochemical is essential because abnormal levels of concentration may cause diseases such as diabetes, renal failure, hyperuricaemia, heart disease and gastric cancer.

In this experiment, we propose and experimentally demonstrate a new micro-ball lens (MBL) based sensor for measurement of various concentrations of glucose, sodium chloride and uric acid. The micro-ball

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lens probe structure is fabricated and formed at the cleaved tip of microfiber coupler waist, by an arcing technique using a fusion splicing machine. It is an optical micro interferometer device based on the possibility of multiple-beam interference within this micro-ball lens where the beams of light can be reflected from two reflecting surfaces which is one represent the inner surface of the micro-ball lens and the second can be any targets surface from outdoor the ball lens. Therefore, it is suitable for various sensor applications such as refractive index sensor.

2. Experiment

2.1. Fabrication of Microfiber Coupler

The microfiber coupler (MFC) structure was fabricated by laterally fusing and tapering two optical fibers. Two standard telecom fibers (Corning SMF-28) were brought together and twisted to make an overlapping contact. Then, the twisted fibers were tapered using flame brushing technique [11]. During the tapering process, an amplified spontaneous emission (ASE) light source and a power meter were used to monitor the coupling ratio. The tapering process stopped when the coupling ratio 50/50 achieved. The resulting microfiber coupler has a waist diameter of about 20 μm, and the lengths of tapered region and uniform waist are 70 mm and 40 mm respectively.

2.2. Micro-Ball Lens Probe

The micro-ball lens (MBL) probe was fabricated by arching technique using a fusion splicer [12]. The MFC was cleaved at the center of its minimum waist region to produce a micro-ball lens at the tip. The fabrication process involves two important steps; loading and arching. In the first process, the windshield of the splicer, fiber holders and the fiber clamps were opened and the prepared MFC tip was loaded into the left side of the fiber holder with the tapered region in the V-groove. When the MFC tip aligned properly, the windshield was closed and the arching process can be started. The most important step in arching process is setting the arc power, the cleaning arc power offset, and the cleaning time of the fusion splicer. Once this step completed, the formation of the micro-ball lens was launched.

The MFC tip absorbs the arc discharging heat and melt instantaneously. By utilizing the arc discharging energy and the surface tension of the melting MFC tips, a spherical tip was formed gradually during solidification. During the solidification process, the MFC tip was rotated slowly to avoid misalignment to the offset distance between the center of the sphere and the axis of the fiber stylus. The offset distance can increase or decrease due to the effect of gravity pulling the spherical tip towards the ground. Fig. 1 shows the microscope image of the micro-ball lens at the tip of the MFC. The ball lens has a diameter of about 85 μm, which fixed throughout the experiment.

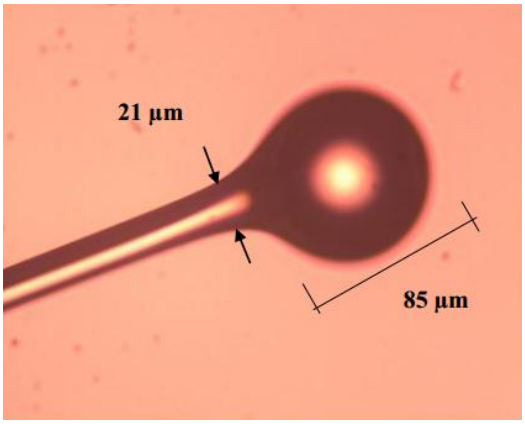

Fig. 1: Microscope images of the micro-ball lens fabricated at the cleaved tip of MFC.

The experimental setup for the sensor is illustrated in Fig. 2. The setup consists of an ASE light source, an MBL probe immersed in biochemical solution, a reflective flat mirror and an optical spectrum analyzer (OSA). The flat mirror placed at the bottom of the beaker containing the biochemical solution being tested. The MBL probe is fixed perpendicular to the flat mirror at a fixed distance of 1.3 mm throughout the experiment. The separated fiber ends are connected to the ASE light source operating at 1550 nm and OSA

accordingly as shown in Fig. 2. The micro-ball lens was first immersed in de-ionized water as to measure the output voltage of a 0 ppm solution concentration, followed by glucose solutions with concentrations from 100 to 500 ppm. During the experiment, the errors caused by temperature were taken to be negligible and the temperature is kept constant at 25˚C. The experiment was then repeated using sodium chloride and uric acid solution.

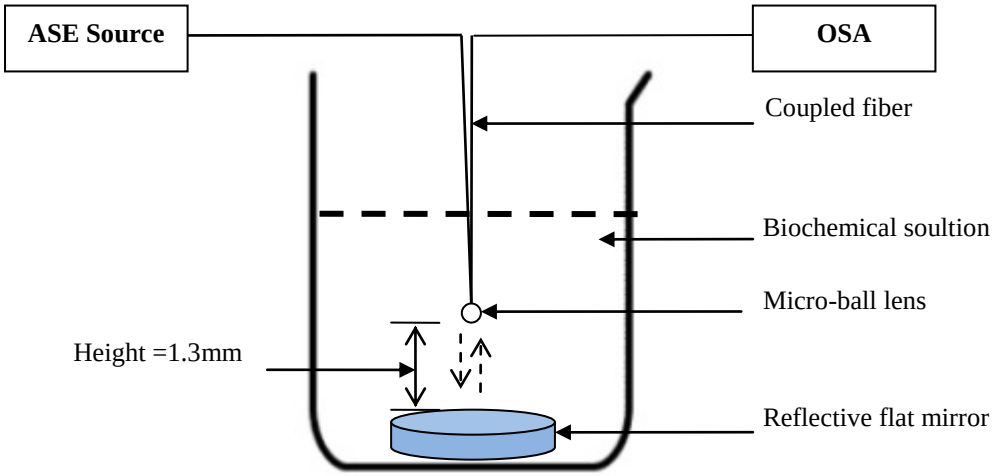

Fig. 2: Experimental setup for measuring various biochemical concentrations using a micro-ball lens probe.

When the ASE light is injected into the micro-ball lens through the input port of the MFC, a portion of the light is reflected by the micro-ball lens surface while some portion passes through the micro-ball lens and reflected by the mirror reflector. The reflected beams interfere in the micro-ball lens and in the medium as they travel to the output port of the coupler. The interference spectrum can be modelled by using the two-beam optical interference as;

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(\Delta Ø) \tag{1}$$

where I_1 as the part of light beam that is directly reflected by the inner surface of the micro-ball lens and I_2 as the portion that passes through the micro-ball lens and travels across the gap with a distance d before being reflected by the reflector. The $\Delta Ø$ is the phase difference between the two interfering beams of light, which is given by;

$$\Delta? = \left(\pi \frac{n_d d}{\lambda} ?_{o} \right) \tag{2}$$

n_d is the refractive index of the air gap which is 1 and d is the gap displacement. Thus, the equation (1) can be simplified as:

$$I = a + b\cos\Delta Ø \tag{3}$$

where a and b are arbitrary constants. The fringe spacing or free spectral range (FSR) is defined as the spacing between two adjacent minima or maxima in the reflection spectrum, which is given by

$$\Delta\lambda = \lambda^2 / 2d \tag{4}$$

where λ is the operating wavelength, meanwhile the contrast of the fringes is determined by

$$F = FSR / FWHM \tag{5}$$

where F is the finesse of the cavity and FWHM is full-width half maximum of the spectrum.

3. Result and Discussion

Fig. 3 shows the output spectra recorded using OSA before and after the beaker was filled with the glucose solution. The output spectrum shows more interference fringe when exposed to air (green line). When the ASE light is injected into the MBL through the input port of MFC, the reflection occurs at two places; at the inner surface of the lens and at the surface of the reflector as explained before. Reflection at lens inner surface is mainly from the Fresnel reflection, which caused by the high index contrast between the silica glass and air. Both reflected beams interfere inside the MBL before transferred into the output port of

the MFC. The interference produces optical comb due to the phase difference as two beams propagate with two different path length. However, the interference comb almost disappears as the gap between the MBL probe and the reflector is filled with glucose solution as shown in Fig. 3 (blue line). This is due to the significant decrease in the reflection at the microsphere wall which caused by the significant decrease in the index contrast between two media. Subsequently, the intensity of the overall output spectrum for glucose solution is slightly reduced compared to the output spectrum of air.

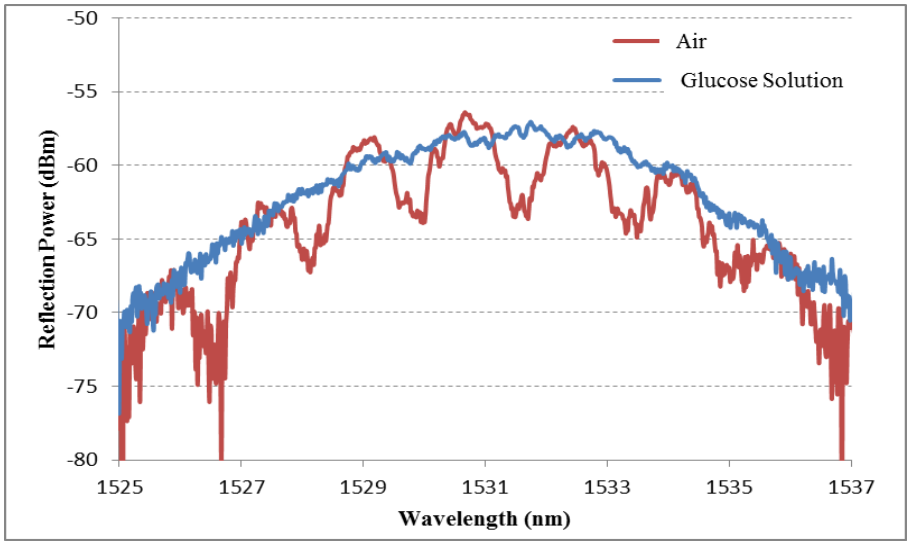

Fig. 3: Output spectra for immersion of micro-ball lens in air and glucose solution.

Fig. 4 shows the peak output power of the micro-ball lens probe when immersed in different concentration for three biochemical solutions; glucose, sodium chloride and uric acid. The results show that there is a linear inverse relationship between the signals received in the receiving fiber as a function of the concentration of the solution. Output power denoted as the light intensity received at the receiving fiber. The reduction of the received light intensity is due to the change of the refractive index of the solution, which increases as the concentration of the solution increases. As the solution concentration increases, the index contrast between the two media reduces and thus decreases the reflection at the MBL wall. From the experimental results it is concluded that an increase in solution concentration can be detected by a decrease in the output power.

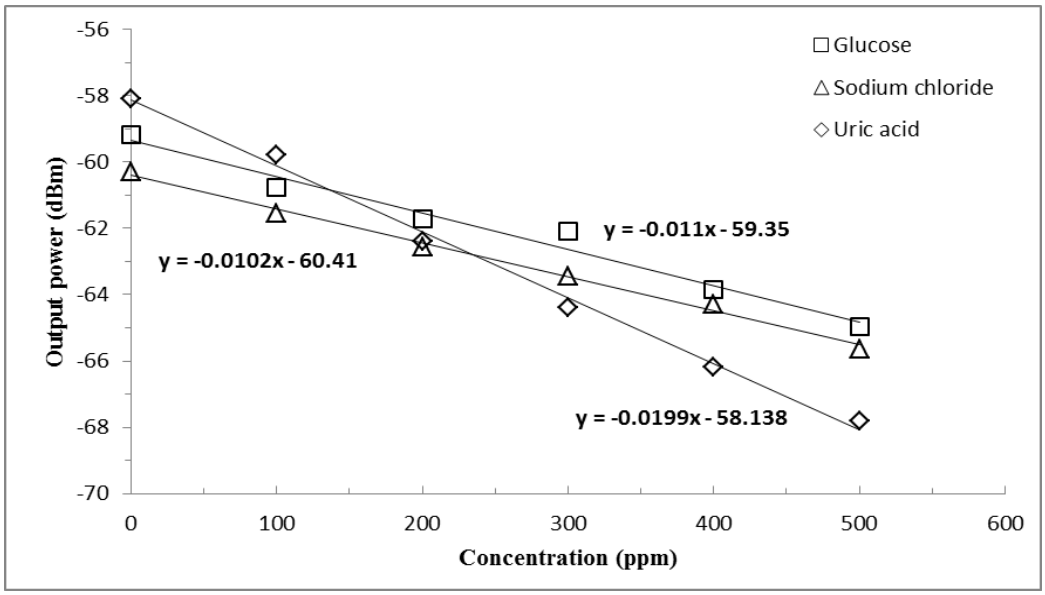

Fig. 4: Output power against the different biochemical concentration.

The output power of the glucose sensor decreases linearly from -59.14 dBm to -64.95 dBm as the concentration of glucose is increased from 0 to 500 ppm, as shown in Fig. 4. The sensitivity of the sensor to

glucose solution is obtained at 0.011 dB / ppm and the slope shows a good linearity of more than 99%. For the sodium chloride solution, the sensitivity of the sensor is 0.010 dB/ ppm while the sensor for uric acid solution shows the highest sensitivity at 0.020 dB / ppm.

4. Conclusion

In summary, we have proposed and demonstrated a simple detection system using micro-ball lens probe for measurement of different biochemical solution. The detection system was tested for three commonly found biochemical solutions; glucose, uric acid and sodium chloride. The preliminary results show that the micro-ball lens probe has the potential of detection and measurement of different concentration for various biochemical.

For future work, measurements with lower concentration of biochemical should be implemented. For instance, in the case of glucose, the changes in the refractive index should be in steps of 0.001 to 0.01 so that the sensitivity of the device can be increased. To increase the stability and reliability of the device, the normal glucose concentration range, which is 70 to less than 180 mg/dL A should also be included in the sensor setup.

5. References

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