Abstract — Optical sensors based on Fabry-Perot interferometer to detect cadmium ions is proposed. The sensor was fabricated by coating the tip of the optical fiber by chitosan. The two chitosan surfaces serve as mirrors which form a Fabry-Perot interferometer. The characterization results indicate that the sensor has a linear response with sensitivity of 0.0884 dBm/ppm with a correlation factor of 0.9665. The sensor reach steady state response in 5 minutes.

Keywords — Cadmium ions, chitosan, Fabry-Perot interferometer, optical fiber sensor

I. INTRODUCTION

The presence of heavy metal ions is a serious threat to human health and environment [1]. Heavy metals are very dangerous since it tends to bio-accumulate [2], is not readily biodegradable (persistent) in the human body, and toxic [3].

Optical sensors to detect heavy metal ions have been developed by various methods such as reflectance [4, 5], absorption [6], Fabry-Perot interferometer [7, 8], and fluorescence [9]. Fabry-Perot interferometer (FPI) method has the ease of fabrication, high sensitivity, and fast response, making it suitable to be used as distributed optical sensors.

To realize the optical fiber as heavy metal ions, specific material is required to be coated on the optical fiber. Various coating materials have been utilized in optical fiber-based heavy metal ions sensor, such as ditizone for the detection of mercury and lead [10], Pyrrole and chitosan for detection of cadmium, lead and mercury [11]. Compared to other materials, such as activated carbon, ditizone, and Pyrrole, Chitosan has advantages of having abundant sources and containing amino and high hydroxyl [12].

Optical sensor with a FPI method was also developed for various applications such as pressure measurement [13], humidity sensor [7, 14], liquid level measurement [15], temperature and strain sensor [16], acoustic emissions measurement [17], and gas detection [18]. However, the FPI-based optical sensor for the detection of cadmium ion has not been fully explored. Therefore, this research studied the fabrication and characterization of FPI based-optical sensors to detect the presence of cadmium ion in water.

II. FPI BASED-OPTICAL SENSOR WORKING PRINCIPLE

In principle, FPI consists of two reflectance mirrors, which are separated by cavity. The FPI can be realized in optical fiber by coating the end of optical fiber with thin layer material such as chitosan, as shown in Fig 1. The two chitosan layer surfaces serve as mirror. Meanwhile, the coating thickness serves as cavity.

Fig 1 Chitosan layer FPI on the optical fiber tip.

Light incident (I_in) into the FPI will be reflected back (ρ) and forth between the two mirrors. Beside the reflected light, there also exist transmitted light (t), as shown in Fig 2.

The changes of FPI cavity length will cause a phase shift of the reflected light as determined by:
where $n$ is the effective refractive index of the optical fiber, $d$ is the cavity length and $\lambda$ is the light wavelength. The complex amplitude coefficient of the reflected ($\rho_{FP}$) spectrum is defined by:

$$\rho_{FP} = \frac{\rho_{12} + i[\rho_{21} - \rho_{23}] \rho_{23} \exp(-j\phi)}{1 - \rho_{21}\rho_{23}\exp(-j\phi)}$$

where $\rho_{ij}$ and $t_{ij}$ is the complex amplitude coefficient of the reflected and transmitted of the light propagates from region $i$ to region $j$, as shown in Fig. 2. Meanwhile, the power reflectivity of the FPI is defined by

$$R_{FP} = |\rho_{FP}|^2$$

In chitosan layer FPI, the cavity length changes as the chitosan adsorbs cadmium ions which further results in the change of reflected power. The change of cavity length highly depends on the cadmium ion concentration. Therefore, by monitoring the change of the reflected power, the cadmium ion concentration can be determined.

III. EXPERIMENT

Sensor fabrication was done in three stages. The first stage was preparing the optical fiber. The optical fiber used was multimode silica optical fiber with cladding and core diameter of 125 $\mu$m and 50 $\mu$m, respectively. The optical fiber was cut in to 50 cm long. Then, at the tip of the fiber, the jacket and the buffer were removed for 1cm of length by using a stripper. The second stage was coating the jacket-removed optical fiber tip by chitosan using dip coating technique [19]. Before coated on the fiber, the chitosan solution was prepared by mixing chitosan with 1% acetat acid on the magnetic stirrer for 30 minutes at temperature of 100°C. Finally, the optical fiber connector was installed on the other end of the optical fiber.

Characterization of the sensor was done by immersing the optical fiber that has been coated with chitosan in a solution of cadmium in varying concentrations which are 1, 2, 3, 4, 5, and 6 ppm. The light from optical light source (OLS) was launched to the sensor through an optical isolator to prevent the reflected light from propagating back to the light source. Then, an optical coupler was located between the optical isolator and the sensor head. The reflected power from optical sensor was observed by connecting one of the ports of the coupler to an optical power meter (OPM), as shown in Figure 3. By measuring the reflected optical power for different concentration values, the sensor sensitivity can be obtained.

IV. RESULTS AND DISCUSSIONS

The reflected optical power for various cadmium ion concentration values is shown in Fig 4. It is shown that the sensor has a linear response with sensitivity of 0.0884 dBm/ppm and with correlation factor of 0.9665.

![Fig. 4 Reflected optical power as function of cadmium ion concentrations.](image-url)

The change of the reflected optical power was caused by the interaction between the chitosan and cadmium ions. After chitosan adsorbs cadmium ions, the density of the chitosan is increased and the surface becomes more porous. The density of a material is proportional to the refractive index. The greater the density is, the higher the refractive index will be [20]. The change of the refractive index of chitosan will affect the effective refractive index between chitosan and core optical fiber. In addition, as chitosan adsorbs cadmium ions, the chitosan coating swells which results in the change of FPI cavity length. It is shown in Figure 4 that the higher the concentration of the cadmium ion, the higher the reflected optical power is.

Basically, since the working principle of the sensor is based on interferometry, then the sensor response would be cyclic due to sinusoidal function of the reflected power. However, the cyclic response was not observed in the characterization results. The cyclic response may occur if the concentration is further decreased or is further increased. Therefore, it can be concluded that the linear working range of the proposed sensor is in the concentration range of 1ppm-6ppm.

Sensor characterization has also been done for time response performance. The response time defines as the time needed to reach steady state response during measurement. The sensor’s response time is shown in Fig 5.
The measurement results show that for concentration of 1 ppm -6ppm, the average response time is 5 minutes. It is also shown that power fluctuation occurred before it reaches steady state. The fluctuations occurred due to the process of cadmium ions diffusion to the chitosan requires several minutes before it reach steady state. The pore size of the membrane on the surface of the chitosan layer, which depends on the amount of amine groups of the chitosan, determines the speed of the diffusion rate of the cadmium ion. Beside the diffusion rate, the chitosan coating thickness also affects the response time of the sensor. Higher coating thickness requires longer time to reach steady state response.

V. CONCLUSIONS

The optical sensor for cadmium ion detection has been fabricated by adopting Fabry-Perot interferometer techniques. The characterization shows that the fabricated sensor provides high sensitivity and good linearity. However, in terms of response time, the sensor needs further improvement which is the goal of our future work.

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