

Highly sensitive fiber optics evanescent wave sensor for detection of zinc in water

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Optical fiber chemical sensors provide a promising solution for determination of contaminants elements like Zinc, present in drinking water in ppm level & are a big challenge in present scenario. In the present work, designed a multimode evanescent wave fiber optic chemical sensors have been reported for zinc detection. The whole experiment has been performed by fixing the fibers in a horizontal position with the sensor regions at the center of the fiber, making it less prone to disturbance and breaking. This experimental study explores the detection of zinc in water using multimode optical fiber and sensitivity shows that 0.0042 mW change in power per ppm for core mode and 0.228 mW changes in power per ppm for cladding mode. Variation in the refractive index of different concentration of sample (at ppm) leads to change in output power. The highly sensitive fiber optic evanescent wave sensors provide low-cost and most effective device for chemical species detection and widely used in various medical, biological and chemical applications.

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1. Introduction

In the recent decades the environment is being polluted by very hazardous materials [1]. It is directly affecting the living organism on earth. Zinc is one of the common elements found in the earth crust and increases acidity in water on addition. Zinc is one among them which naturally occurs in air, water and soil in nature [2]. Due to human activities the level of zinc is rising at alarm rate to disturb the ecological system. Zinc is available in drinking water and is safe, if it is consumed within range of 5 ppm specified by WHO. Consuming too much zinc into the body through food, water or dietary supplements can also affect human health [3–5]. If it is consumed with higher level may suffer with loss in taste, smell, decrease in hunger and also wound healing capacity may decrease. Acute toxicity arises from the ingestion of excessive amounts of zinc salts either accidentally or deliberately. Many chemical and spectroscopic methods are evolved to find the concentration of zinc in water [1-2, 6-7]. Here, we are presenting a simple and effective measurement technique using optical fiber sensor using evanescent wave absorption technique in detection of trace amount of zinc in water. Fiber optic sensor technology has shown an effective sensing mechanism as a various types of sensors; viz. strain, gas, temperature etc., due to its optical properties [7–12]. Optical fiber sensors have shown greater interest in the sensing technology due to its unique

and effective property [13,14]. Fiber optic sensor principle is based on change in refractive index of the medium surrounding its core and the corresponding change can be studied due to the variation in the output power as well as in the wavelength of transmitted light. Surface Plasmon resonance (SPR) is very sensitive refractive index based technique is widely used as detection principle for many sensors that operates at different areas [15]. So far, fiber optic sensors have shown enormous applications in measurement for various parameters [16–18]. Fiber optic sensor principle is based on change in refractive index of the medium surrounding to its core [19]. These sensors are simple and accurate sensing technique over other sensing devices. Optical fibers sensor technology promises us sensing at lower concentration (ppm/ppb) in a real sophisticated manner [20–22]. Thus, it will be having promising future and give an unprecedented insight for low cost fiber optic sensors.

1.1. Evanescent Wave Fiber Optic Chemical Sensor (EWFOCS)

Now a day's fiber optic sensors (FOS) are playing a curtail role in sensor field. Various types of FOS are developed for detection of a variety of chemical species in water and different liquids. Among them evanescent wave absorption technique is found to be most useful technique

due to its unique and efficient properties of fiber sensor [4,8,23].

1.2. Theory of EWFOCS

The Fiber optic chemical sensor is the simplest and cost effective sensor, which is based on Evanescent wave modulation. Evanescent field interacts with surrounding region in variety of ways such as absorption, variation of refractive index or may be coating with suitable dye/reagent [10]. Among them evanescent wave absorption technique is popular one. Based on total internal reflection light propagates inside the optical fiber. At core-cladding interface the incident and reflected wave interacts to form a standing wave [24]. It has finite electric field amplitude, which decay in to cladding section is known as attenuated total reflection (ATR). Suppose if we consider an unclad region of fiber and when light is entering in this region, there is a decrease in amplitude of total internal reflected wave takes place. This is due to absorption by surrounding region around unclad portion of the fiber and power transmitted is given by [25]

$$P(L) = P(0) \exp(-\gamma CL) \quad (1)$$

where, L = is the length of unclad region, P (0) = Input power, γ = Evanescent wave absorption coefficient, C = Concentration of surrounding region.

Using Beer – Lambert's law the γ is given by

$$\gamma = \alpha L \eta \quad (2)$$

where, α =Absorption coefficient, L=Interaction length and η = fraction of light in the evanescent field.

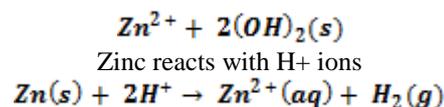
The extent to which evanescent wave entering in cladding region is known as penetration depth (dp). It is the region where power of electric field decays exponentially to (1/e)th value which is related as below

$$dp = \frac{A}{2\alpha \sqrt{n_1^2 \sin^2 \theta - n_2^2}} \quad (3)$$

With above equations it is clearly evident that sensitivity of EWFOCS depends on fiber dimension and geometry, incident wavelength and absorption coefficient of analytic. With such a responsive measurement technique we have undertaken EWFOCS for the detection of zinc in water.

1.3. Zinc reaction in water

Elementary zinc does not react with water molecules directly. The ion does form a protective, water insoluble zinc hydroxide (Zn(OH)₂) layer with dissolved hydroxide ions



This reaction releases hydrogen, which reacts with oxygen explosively.

Zinc salts cause a milky turbidity in water in higher concentrations. Additionally, Zinc may add an unwanted flavor to water.

2. Experimental arrangement

A Sensor grade multimode step index PCS fiber (F-MBC from Newport) with NA 0.37 and core-cladding diameters 1000 μm and 1035 μm respectively of length 75 cm is taken for experiment. Around 4 cm region of cladding is removed using razor at the centre of fiber. Fiber was stripped at the sensing region to make more sensitive to surrounding environment. Designed sensor is used for further experiment for detection of zinc species in water. The experimental setup is shown in Fig.1. White LED Source (Holmarc, Cochin, INDIA) is launched in to PCS fiber through an objective. Central unclad portion of fiber is positioned around centre of sensor cell. Fiber terminal portion is connected to the optical power meter (2936-C) from Newport. Two detectors from Newport 918D –UV – OD3 is situated over unclad portion of fiber region while the 818 –UV/DB is used to detect the output power from fiber end and inturn these two detectors are connected to optical power meter (2936-C) to read output power.

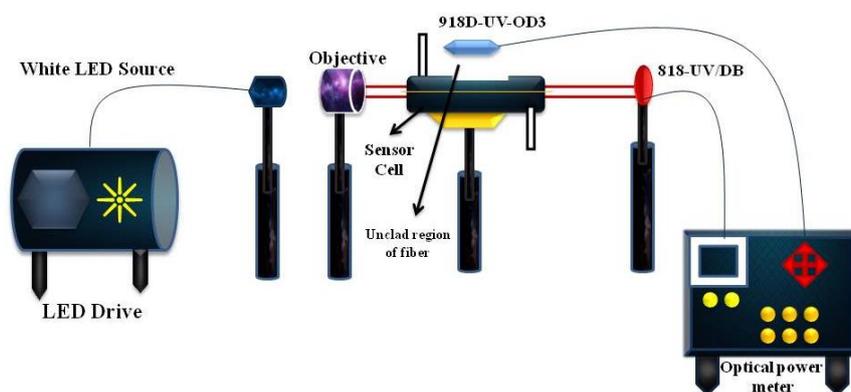


Fig. 1. Experimental arrangement (color online)

The test solution of zinc of various concentrations between 0.25 ppm to 5 ppm is prepared out by dissolving $ZnSO_4$ salt in double distilled water. Different concentration solution were prepared and kept in separate test tube for experiment. Potassium cyanide of suitable quantity is mixed with the test tube containing Zn solution and stirred well. For each samples prepared the chloral hydrate ($C_2H_3Cl_3O_2$) is mixed to take out zinc ions present in prepared solution. As the concentration goes on increasing Zinc solutions turns to bark bluish color. The respective Zinc reagents (Nanocolor REF 91895) were added to zinc solutions and Zinc is identified selectively over various different particles present.

White LED source is launched into fiber and in unclad fiber region the direct interaction of evanescent wave takes with surrounding test solution. This results in decrease in output power. This variation depends on surrounding concentration of solution.

The prepared sample solutions were added from lower to higher concentration in sensor cell.

The stabilization time of one minute is taken to record the both core and cladding mode readings. After each sample replacement the sensing region of fiber was washed to avoid contaminants and monitored continuously. Thus various concentration of Zinc solution using fiber sensor were recorded and noted.

3. Results and discussion

The graph of evanescent field sensors for zinc detection shows that with increase in the concentration of zinc solution, output power goes on decreasing. It is because the concentration of zinc solution increases, the refractive index surrounding sensing region of evanescent fiber also increases resulting decrease in output power. This matches the theoretical prediction as surrounding solution concentration increases the sensing medium of the evanescent fiber.

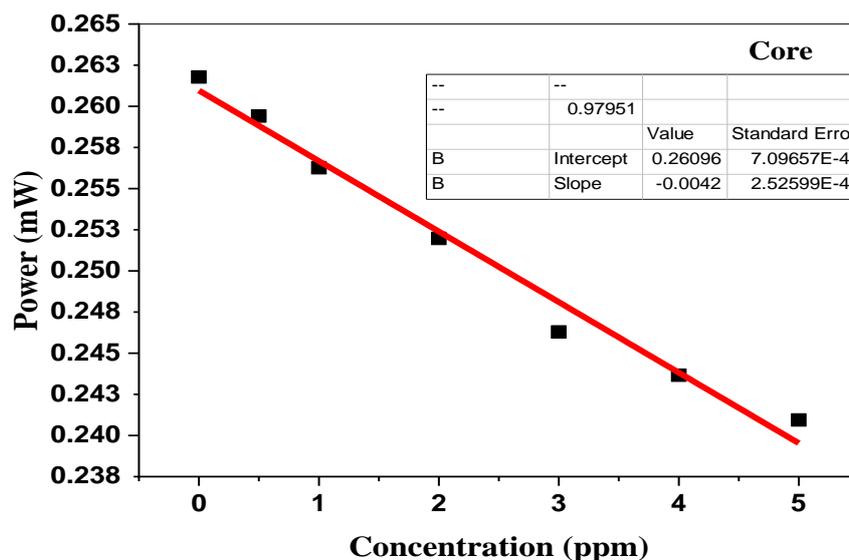


Fig. 2. Experimentally determined concentration (ppm) Vs output Power (mW) for core mode (color online)

There is a large coupling of evanescent wave with the surrounding region happens and leads to decrease in output power.

The obtained result by our designed evanescent fiber sensor in measuring Zinc ions in water is more accurate. When White LED source injected in to unclad sensing region of PCS fiber, evanescent wave is absorbed by the

surrounding test solution and eventually leads to decrease in output power. Fig. 2, clearly shows that output power variation with concentration of test solution is quite linear in nature. This core mode variation for zinc is 0.0042 mW/ppm.

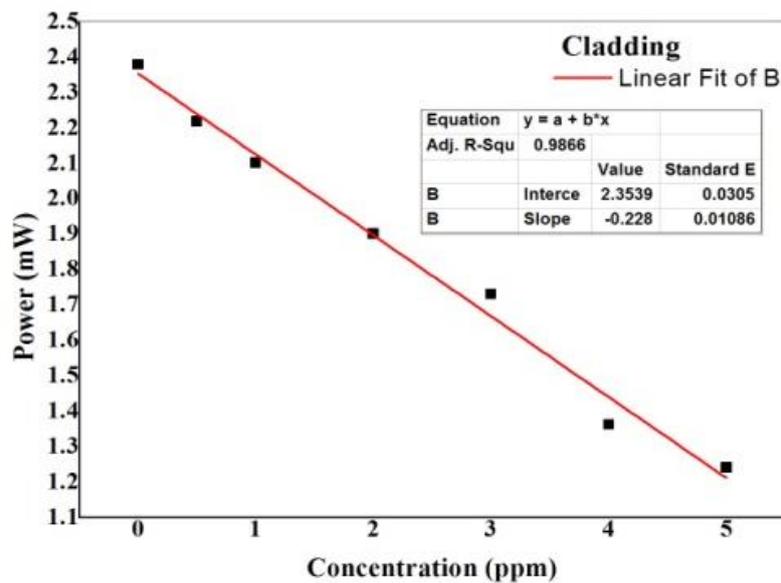


Fig. 3. Experimentally determined concentration (ppm) Vs output Power (mW) for cladding mode (color online)

The interaction of evanescent wave at unclad sensing section is detected by the detector which is known as cladding modes power (detector 918D –UV – OD3). From Fig.3, it is evident that this cladding mode sensitivity is found to be 0.228 mW/ppm.

4. Conclusions

The results obtained by our designed evanescent field sensor for detection and determination of zinc traces in water. Detection of zinc in water is developed based on evanescent wave absorption technique. Our sensor developed is quite sensitive with both core and cladding mode power detection. This experimental shown the sensitivity of 0.0042 mW/ppm for core mode and 0.228 mW/ppm for cladding mode. Variation in the refractive index of different concentration of samples (ppm) leads to change is output power (mW). Since this sensor utilizes fewer components with simple in design and handling with good repeatability in identifying the concentration of zinc in water. Further it is said that optical fiber sensors are one of the best methods in detecting contaminates in water/liquid for lower concentration. However, designed sensor can be a better candidate as a chemical sensor due to its stability, simplicity, reliability and better response to surrounding refractive index.

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