Comparison of Evanescent Absorption Coefficient & Sensitivity For Different Pollutants In Water Using FIBER OPTICS EVANESCENT WAVE SENSOR

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Abstract - *Fiber optics evanescent wave sensor is use to detect concentration of various pollutants in water by calculation the value of evanescent absorption coefficient and hence calculates the sensitivity of sensor for a particular pollutant. This paper describes the calculation of evanescent absorption coefficient and sensitivity of various pollutants such as nitrite, potassium permanganate, mercury, chromium, copper sulfate, lead sulfide.*

***Key Words*: Fiber optic sensor, Intrinsic Sensor, Application Based Sensors, Evanescent Wave, Evanescent wave for Sensing Application, Evanescent Absorption Coefficient, sensitivity of evanescent sensor, Evanescent Field Absorption Sensor, Practical Set Up Details For Measuring The Concentration In Water, Graph of absorption coefficient with concentration and sensitivity with length for different pollutants.**

1. INTRODUCTION

Pollution occurs when pollutants contaminate the natural surroundings mainly air, water and noise which brings about changes that affect our day to day life. Pollutants are the main elements or components of pollution which are generally in different forms of waste materials. Pollution disturbs our ecosystem and cause imbalance in the environment. With modernization and development in our lives pollution has reached its peak; giving rise to global warming and human illness.

Pollution occurs in different forms such as air, water, soil, radioactive, noise, heat/ thermal and light. Every form of pollution has two sources of occurrence; the point and the non-point sources. The point sources are easy to identify, monitor and control, whereas the non-point sources are hard to control [1].

Water pollution is an appalling problem, powerful enough to lead the world on a path of destruction. Water is an easy solvent, so that most of the pollutants dissolve in it easily and contaminate it. The most basic effect of water pollution is directly suffered by the organisms and vegetation that survive in water, including amphibians. On a human level, several people die each day due to consumption of polluted and infected water [2].

One of the most important advantages of optical fiber sensor is the distributed sensing. It enables the measurements of a physical or a chemical parameter as a function of position along the length on an optical fiber, and hence provides a unique capability to measure spatial variations of these quantities using a compact, inert and non – electrical sensing cable. Such systems are finding applications in industrial and environmental sensing [3].

Because of public concern about the quality of drinking water, continuous monitoring of ground water has become a necessity. By introducing fibers down to the ground water level one can monitor the pH of the water and the amount of chloride, uranium, organic pollutants and tracer substances present in water before digging a well. This will save drilling cost because fibers hold (1 – 2 cm diameter) allows the use of small bare-holes. There will not be any need to take sample and get it analyzed in laboratory [4].

2. EVANESCENT WAVE, COEFFICIENT AND SENSITIVITY

Fig.1 shows a plane wave incident at the core - cladding interface. The direction of arrows indicates the incident and reflected light beams which results in the formation of standing wave where the wavefront is perpendicular to the interface. The energy is maximum in the core on the axis of the fiber and falls off exponentially in the cladding. If a part of fiber optic is unclad and is exposed by an absorbing fluid then some of the evanescent field will be absorbed and hence the power transmitted by the fiber will reduce. This is the basis of the Fiber Optics Evanescent wave Sensor.

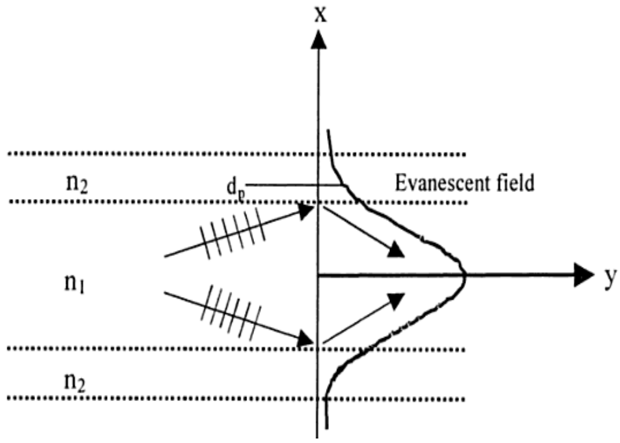


Fig -1: Evanescent wave phenomenon at the core-cladding interface in an optical fiber [3].

The absorption of the evanescent field in an optical fiber has been applied for the development of the large number of chemical and biological sensors.

Evanescent field absorption spectroscopy is a powerful well-established laboratory technique for chemical analysis for detection of various pollutants traces in water. In this technique the evanescent wave penetrates at the boundary between two dielectric media in conditions of attenuated total reflection. One of the media is a thin slab-shaped non absorbing crystal called as waveguide, while the other medium of lower refractive index is the absorbing sample being studied. At each reflection at the boundary of the crystal and the sample, the penetration of the evanescent wave of the guided ray into the absorbing sample gives rise to a reduction of the power propagating in the crystal [3].

The number of reflections can also be increased by increasing the length of the waveguide. Thus to achieve maximum absorption, an unclad optical fiber is well suited for evanescent wave absorption spectroscopy. The exponentially decaying evanescent fields in the lower index region of a waveguide have been offering high potential in the design and fabrication of a variety of sensors [3].

Evanescent Absorption Coefficient is given by,

$$\gamma = \frac{\alpha\lambda n_2}{2\pi p(n_1^2 - n_2^2)} \cdot \frac{\sin^2\theta_i}{\sqrt{(n_1^2 - \sin^2\theta_i)(n_1^2 - n_2^2 - \sin^2\theta_i)}} \quad \text{..........(1)}$$

Sensitivity is given by,

$$S = L\varepsilon\,(\gamma/\alpha) \quad \text{..........(2)}$$

Where,
γ is evanescent absorption coefficient,
α is bulk absorption coefficient,
λ is wavelength of incident light,
θ_i is incidence angle,
η_1 is refractive index of core,
η_2 is refractive index of cladding,
p is core radius.

3. FIBER OPTICS EVANESCENT WAVE SENSOR & VARIOUS OPTICAL PARAMETERS

3.1 FIBER OPTICS EVANESCENT WAVE SENSOR

Simplest evanescent field absorption sensor used for measurement of different concentration in water is shown in fig.2. Light source such as laser is focused on one side of silica core fiber using microscopic objective. For guiding all the rays to propagate in the fiber, numerical aperture of objective is chosen to be greater than numerical aperture of fiber. For a sensor, the cladding is removed from middle portion of the fiber and it is called as sensing region, hence it is kept in a glass cell having facilities for filling and draining of the absorption fluid. The other end of the fiber is connected to detector (power meter) for measuring the output power [5].

Powers are measured when the glass cell is filled initially with solvent (Po) and then with absorption fluid (P), both the measurements are done separately. These powers along the length of the unclad portion of the fiber are used to calculate the evanescent absorption coefficient from equation,

$$P = P_o \exp(-\gamma L) \quad \text{..............(3)}$$

Theoretically for various pollutants, evanescent absorption coefficient are calculated using equation (1) and hence power is calculated using equation (3).

When the fiber is immersed in the test solution, the evanescent field from the unclad region penetrates into the liquid and interacts with it. Since the wavelength of incident light in the fiber is almost close to the peak absorption wavelength of the solution, strong evanescent wave absorption occurs and it increases with increase in concentration.

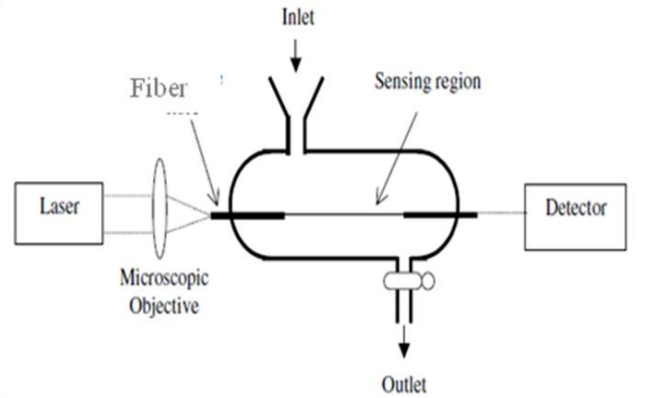


Fig -2: Practical Set up for measuring concentration.[6]

3.2 VARIOUS OPTICAL PARAMETERS

- Refractive index of core (silica) = 1.46
- Refractive index of cladding (water) = 1.33
- For total internal reflection, critical angle is 65.63
  $\theta > 65.63$, $\theta i < 37.03$.

In my thesis, I have selected $\theta i = 30°$.

3.3 FOR NITRITE SOLUTION

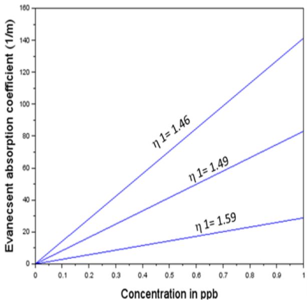


Fig -3

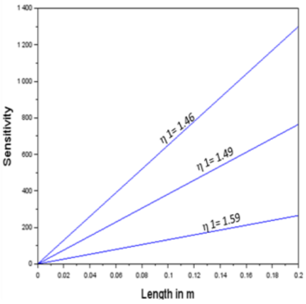


Fig -4

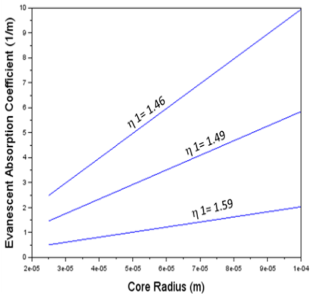


Fig -5

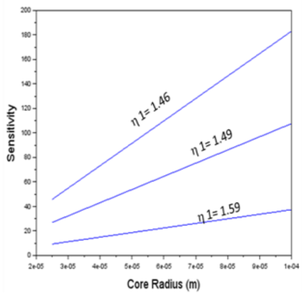


Fig -6

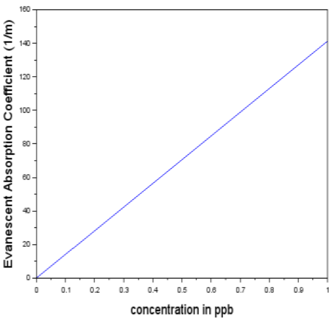
Fig -3: Graph of concentration v/s Evanescent absorption coefficient for different refractive indices of core
Fig -4: Graph of length v/s sensitivity for different refractive indices of core
Fig -5: Graph of length v/s sensitivity for different refractive indices of core
Fig -6: Graph of length v/s sensitivity for different refractive indices of core

From graphs for nitrite, we can conclude that evanescent absorption coefficient and sensitivity are maximum when we choose,

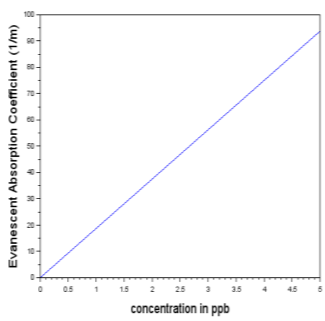
- Core radius - 100 µm
- Refractive index of core – 1.46
- Length = 20 cm

4. SIMULATION RESULTS

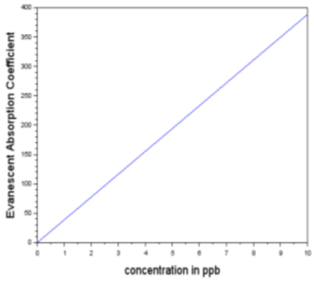
4. 1Effect of variation of evanescent absorption coefficient with concentration



(a)



(b)



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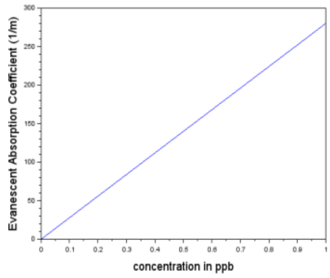
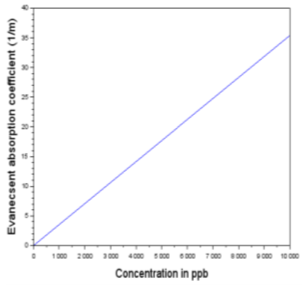


(d)



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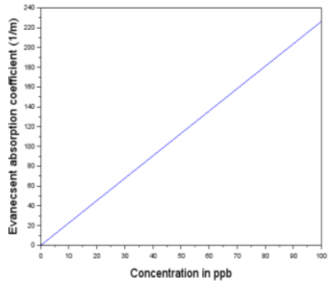
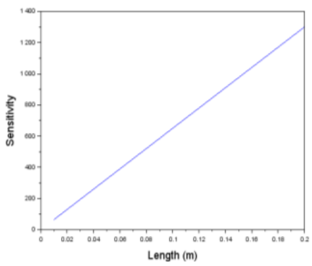


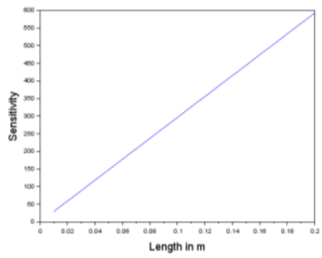
(f)

Fig -7: Graph of concentration v/s Evanescent absorption coefficient for (a) nitrite, (b) potassium permanganate, (c) mercury, (d) chromium, (e) copper sulfate (f) lead sulfide.

4. 2Effect of variation of sensitivity with length varying for 1 to 20 cm:



(a)



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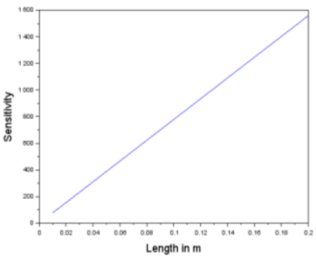

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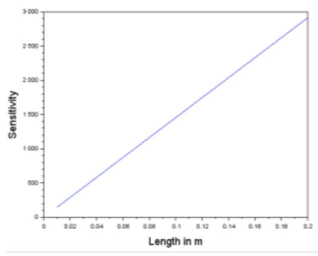

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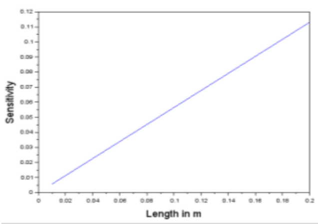

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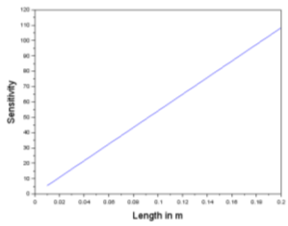

(f)

Fig -8: Graph of length v/s sensitivity for (a) nitrite, (b) potassium permanganate, (c) mercury, (d) chromium, (e) copper sulfate (f) lead sulfide.

5. RESULTS

Table -1: Comparison of various reagents with respect to their concentration, evanescent absorption coefficient and sensitivity.

Reagents	Concentration (ppb)	Evanescent absorption coefficient	Sensitivity
Nitrite	0 to 1	150	1400
Potassium permanganate	0 to 5	100	600
Mercury	0 to 10	40	160
Chromium	0 to 1	300	3000
Copper sulphate	0 to 10000	40	0.12
Lead sulphide	0 to 100	250	120
Arsenic	0 to 10	36	55
Phosphorus	0 to 1	240	1400

6. CONCLUSIONS

For a particular wavelength and angle of incidence, evanescent wave absorption coefficient (γ) is directly proportional to the concentration that is, as concentration increases, γ also increases. γ is not dependent on length of unclad portion of fiber that is, for length of 5 cm, 10 cm and 20 cm, graph of γ with concentration remains the same.

But, sensitivity of fiber is directly proportional to length of unclad portion of fiber, for a particular concentration as length increases, sensitivity also increases.

Results clearly show the usefulness of the technique for detecting very low concentrations of the order of 1 ppb of some pollutants and also with a large dynamic range of 1–10000 ppb of some pollutants

Such a high sensitivity enables the present device to be used for measuring the various contents in drinking water.

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