Abstract — In this work the effort has been made to develop simple and inexpensive sensor for sensing the toxic gas (ammonia). The sensor design is based on the modified cladding approach, i.e. the cladding of the optical fiber was removed and the ammonia sensitive material; the conducting polymer film such as polyaniline sensitive to ammonia gas with optimized process parameters was coated on a small section of the fiber (sensing probe). The experimental results show a positive response to ammonia vapor at room temperature. The sensing probe length, source intensity and source wavelength, shows an influence on the sensor response. The theoretical designing of sensing probe has also been presented here.

Keywords — Sensor technology, fiber-optic chemical sensor, modified cladding. Conducting polymer.

I. INTRODUCTION

Optical fiber sensors are being used to for various sensing applications e.g. the optical fiber sensors have found many application in chemical [1-5], biochemical and biomedical [6-8], and environmental sensing[9-10]. There are several advantages of optical fiber sensor in chemical sensing such as suitability for in-situ measurement, free from electromagnetic interference. Optical fiber evanescent wave chemical sensor uses a light modulation, i.e. one of the light parameter changes according to the analytes presence. Organic conducting polymer such as polypyrrole, polyaniline, polythiophene shows a reversible change in their resistance when exposed to certain vapors [11]. These material are easy to prepare, shows excellent ambient stability and show vary rapid and reversible adsorption/desorption kinetics. Therefore, they have attracted significant attention in the area of gas sensing. The change in conductivity will change permittivity, which leads to change in the refractive index. The analytes reacts with the coating to change the optical properties i.e. refractive index, absorbance, and fluorescence which is coupled to the core to change the transmission properties through the optical fiber. An extrinsic fiber-optic evanescent wave chemical sensor can be developed by replacing a certain portion of the original cladding with chemically sensitive material specifically e.g. polyaniline [12]. The conducting polymers are sensitive to different gases e.g. polyaniline film shows sensitive response to ammonia gas [13-14].

The sensor structure in which the small section of the cladding is replaced with chemically sensitive layer is as shown in Fig.1.

Any change in the refractive index of the modified cladding due to the analyte can change the condition of total internal reflection between the modified cladding and air and can result in an intensity change. Therefore, optimization of n1, n2, critical angle (θc) and acceptance angle (θin) plays important role in the for the estimation of evanescent field.

When light propagates through the fiber, it is limited to discrete modes. The approximate number of modes supported by the step index optical fiber is $\frac{1}{2} V^2$, where the V is wave guide parameter called as cutoff parameter or V-number, which is directly proportional to radius, can be expressed as

$$V = \frac{2\pi}{\lambda} a(NA)$$

Where $a$ – radius of core of fiber, NA - numerical aperture, 
$\lambda$ - wavelength.

The percent of the power in evanescent wave can be calculated by using following equation
This equation is useful for the optimization of evanescent field.

The conducting polymers which are being used for coating in the sensing region, will result in the change in the refractive index, modulates the intensity of light received at the output end of the sensor. The complex refractive index of conducting polymer film is given by

\[ n_{cp(\text{complex})} = n_{(cp)} + ik_{(cp)} \]

where

\[ n_{(cp)} \] – real part of refractive index of conducting polymer cladding,
\[ ik_{(cp)} \] – imaginary part of refractive index of conducting polymer cladding.

The real part governs the light propagation through sensing element and complex part governs the absorption in the modified cladding. This causes a change in the propagation as well as absorption of light through the modified section (cladding) causes intensity modulation through the optical fiber.

It is important to determine the extent of evanescent interaction in the lower index media for the optimal design of evanescent sensor. This quantity is characterized by penetration depth \( d_p \), which is a perpendicular distance from the interface at which the electric field \( E \) has fallen to \( 1/e \) of its value \( E_0 \) at interface. The electric filed \( E \) can be expressed as

\[ E = E_0 \exp(-z/d_p) \]

and the penetration depth of EW field is expressed as

\[ d_p = \frac{\lambda}{2\pi n_1^2 \sin^2 \theta - n_2^2} \]

Where

\( \lambda \) – wavelength of light,
\( n_1 \) – refractive index of core,
\( n_2 \) – refractive index of cladding,
\( \theta \) – Angle of incidence at core/cladding interface.

The penetration depth should be large for higher sensitivity. Although \( d_p \) is typically less than \( \lambda \), it rises sharply as incidence angle (\( \theta \)) approaches critical angle (\( \theta_c \)).

The critical angle can be expressed as

\[ \theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) \]

The number of meridional ray interaction \( N_m \) at core cladding interface can be calculated by

\[ N_m = \left[ L \left(\frac{\tan \theta_r}{2a}\right)\right] \]

where

\( L \) - fiber length
\( a \) - core diameter,
\( \theta_r \) - refractive angle in the fiber

The intensity ratio \( \frac{I_r}{I_i} \) of the reflected light at the interface (core/modified cladding) of one interaction can be calculated using following relationship

\[ \frac{I_r}{I_i} = \frac{1}{2} \left[ \left(\frac{\tan(\theta_i - \theta_{rcp})}{\tan(\theta_i + \theta_{rcp})}\right)^2 + \left(\frac{\sin(\theta_i - \theta_{rcp})}{\sin(\theta_i + \theta_{rcp})}\right)^2\right] \]

where

\( I_r \) = Intensity of the reflected light.
\( I_i \) = Intensity of incident light.
\( \theta_i \) = Angle of incidence on the modified cladding from the core.
\( \theta_{rcp} \) = Angle of refraction in the modified cladding.

II. EXPERIMENTAL

Preparation of the sensing element i.e. the modified cladding region involves three steps, (a) stripping off the jacket (b) removal of the passive cladding, and (c) application of active cladding. In the present investigation we have used a plastic multimode fiber with core/cladding/jacket dimension of 960/40/250 \( \mu m \). A meter length of optical fiber was used and a small section the jacket was stripped off at the center of the optical fiber. The SEM images of the optical fiber sensor with cladding and without cladding (sensing probe) are shown in Fig. 2 and Fig. 3.

The fiber with removed cladding is coated with the ammonia sensitive layer i.e. the aniline, ammonium peroxidisulphate and dopant acid with the optimized process parameters. Then the resulting coated fiber was removed from the solution, washed with distilled water and dried. Fig.4 shows the SEM micrograph of the optical fiber sensor coated with polyaniline film by in situ chemical deposition method.

III. RESULTS AND DISCUSSION

The sensing probe was exposed to various concentrations (20-200 ppm) of ammonia and change in intensity was measured at other end of the fiber. It shows excellent sensing response with response time and recovery time for ammonia.
as shown in fig. 5. The influence of the sensing length, source wavelength and power variations of the source on the sensor response has also been studied.

IV. CONCLUSION

We have designed and developed optical fiber based chemical sensor for ammonia gas sensing. The sensor is based on modified cladding approach. i.e. ammonia sensitive layer was deposited on the sensing region of the sensor.

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