Erbium Doped Fiber Sensor for Ammonia Detection into Water

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Abstract. The water pollution is a health problem around the world. One of the most common pollutants in water is the Ammonia. Some sensors have been developed for Ammoniac detection even though most of them are not in real time and could be expensive. In this work an Erbium-doped fibre-sensor for Ammonia detection with a mechanical long period fibre grating and a taper in cascade for improving the sensitivity; the detection bandwidth is in the 1550 nm region from 1460 nm to 1640 nm. Output optical spectrum for Ammonia concentrations from 1 ml to 5 ml is shown

1. Introduction
In some under-developed countries water treatment is not sufficient, and in most cases the water after domestic or industrial usage travels down the streets were time ago river existed. One of the most common pollutants in water is ammonia. Ammonia pollution in water is a serious health problem. Exposure to ammonia at environmental concentrations is unlikely to have adverse effects on health. However, exposure to high concentrations following an accidental release or in occupational settings could cause irritation of the eyes, nose and throat as well as burning the skin on direct contact. Some methods for pollution detection in water have been developed on which luminescence methods, nanotechnology, chemical, spectroscopy are included [1-5].

In this work, we propose an easy to implement sensor for amoniac detection in real time with no aggressive methods. The sensor is implemented with an Erbium superluminiscent source along with one of the most used fibre components: a LPFG. It consists of a periodic perturbation of the refractive index of the fibre core that couples energy between two co-propagating modes, typically the fundamental mode and a cladding mode. LPFGs formed by press-induced methods have generated great interest due to the simplicity in their process of fabrication. In these grating the fibre is subject to periodical stress, which results in alternated regions under compression and stretching that modulate the refractive index via photo-elastic effect and micro bending. For the testing probe a tapered region is proposed for detecting the refractive index change when different concentrations are in contact with the fibre.
2. Er ASE theoretical model

We used the model in [6]. Whose solution allows describing the evolution of pump and signaling powers along the fibre:

\[
\frac{dP_p(z)}{dz} = -\gamma_p(z)P_p(z)
\]  

\[
\frac{dP_s(z,\lambda_i)}{dz} = \pm \left\{ G_s(z,\lambda_i) \left[ P_s^e(z,\lambda_i) + P_0 \right] - G_s(z,\lambda_i)P_s^e(z,\lambda_i) \right\}
\]

Where \( P_p(z) \) is the pump power propagating in \( z \) direction parallel to the doped optical fibre axis and \( P_s^e(z,\lambda_i) \) is the output power in forward and backward direction, \( \gamma_p(z) \) is the absorption coefficient, \( G_s(z,\lambda_i) \) is the amplification of spontaneous emission, \( G_s(z,\lambda_i) \) is the absorption coefficient of spontaneous emission and \( P_0 \) represents an equivalent input noise power:

\[
P_0 = 2\hbar v_s \Delta s
\]

\[
\Delta s = \left( \frac{c}{\lambda_i^2} \right) \Delta \lambda_i
\]

When \( P_p(z) \gg P_p^{th} \) we can consider \( \gamma_p(z) \) as a constant [7]. \( P_p^{th} \) is the threshold power

\[
P_p^{th} = \pi a^2 \frac{\hbar v_p}{\sigma_p \tau}
\]

From [7] we consider eq. (1) as:

\[
\frac{dP_p(z)}{dz} = -N_p \pi a^2 \frac{\hbar v_p}{\tau}
\]

Solving (6) with boundary conditions \( P_p(0) = P_{in} \), where \( P_{in} \) is the initial pump power, then:

\[
P_p(z) = P_{in} - \left( N_p \pi a^2 \frac{\hbar v_p}{\tau} \right) z
\]

And from eq. (2) we obtain:

\[
P_s(z,\lambda_i) = \frac{G_s(z,\lambda_i)}{G_b(z,\lambda_i)} \left[ P_s^e(z,\lambda_i) + P_0 \right] - G_s(z,\lambda_i)P_s^e(z,\lambda_i)
\]

\[
P_s(z,\lambda_i) = \frac{G_s(z,\lambda_i)}{G_b(z,\lambda_i)} P_0 e^{(1-z)G_b(z,\lambda_i)} - G_s(z,\lambda_i)
\]

\[
G_b(z,\lambda_i) = G_e(z,\lambda_i) - G_s(z,\lambda_i)
\]
3. Long Period Fibre Grating working principle

A LPFG can couple light between the fundamental guided mode and forward-propagating cladding modes inside the fibre. As a result, several resonant modes are manifested as loss notches in the corresponding transmission spectrum. The resonant wavelength of the mth order mode $\lambda_m$ is defined by the phase matching condition: $\lambda_m = (n_{eff1} - n_{eff2}) \Lambda$; where $\Lambda$ is the grating period $n_{eff1}$ and $n_{eff2}$ are the effective indexes of the LP01 fundamental mode and the mth cladding mode, respectively [8-10]. The coupled-mode equations are:

$$\frac{dA}{dz} = \kappa B e^{i\gamma z} \tag{11}$$

$$\frac{dB}{dz} = \kappa A e^{-i\gamma z} \tag{12}$$

$$\Gamma = \beta_1 - \beta_2 - \kappa \tag{13}$$

$\kappa$ is the coupling coefficient and the LPFG period is defined as $\Lambda = \frac{2\pi}{\beta_1 - \beta_2}$ where $\beta_1 = \frac{2\pi n_{eff1}}{\lambda_0}$ and $\beta_2 = \frac{2\pi n_{eff2}}{\lambda_0}$ are propagation constants of the core and the cladding respectively.

4. Experimental results

For the experiment the sensor array consists of a 980 nm pump power laser at 350 mW connected to an Erbium-doped fiber segment; at the end of the fiber, another SMF-28 fibre segment is connected, a long period fibre grating is allocated on to the fiber with 147 N force; at the end segment a taper fibre section is connected as a testing probe. The output power spectrum is observed in an optical spectrum analyzer.

![Figure 1 Experimental sensor setup.](image)
The testing probe was introduced in deionized water and the output spectrum was captured. Afterwards, ammoniac percentages from 1% to 9% were added and measured. In figure 2 we can observe the output power responses for different ammonia concentrations. From figure 2 from 1460 nm to 1520 nm it is possible to observe how the output power decreases when the ammoniac concentration increases, also it is possible to observe at 1505 nm that a filtered band is deeper for higher ammonia concentrations.

We have to take into account that the fibre tapered probe detects the changes of refractive index when it is exposed to certain substances. Clearly, the erbium doping increases the sensitive at around 1550nm.

5. Conclusions
An erbium-doped fibre sensor for ammonia detection was proposed with encouraging experimental results which were included. The present work shows a broad spectrum from 1460nm to 1640 nm, even though the higher sensitivity is centred at 1505 nm with 2.5 dBm extinction ratio. Future work is to process de optical results with an opto-electronic device for obtaining a portable sensor.

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