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UNCLAD LENGTH DEPENDENT PERFORMANCE OF SILVER COATED SURFACE PLASMON RESONANCE WAVEGUIDE AS A CHEMICAL CONCENTRATION SENSOR

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ABSTRACT

Chemical sensors are having very high significance in the present day environment where the presence of toxic and nontoxic chemicals is widespread. Of these, optical fibre based chemical sensors are gaining importance as the advantages of the chemical sensing using fibres surpass the merits of similar field technologies. In this context, the present work aims at fabricating and studying the performance characteristics of a Surface Plasmon Resonance (SPR) basedfibre optic chemical sensor. Here, vacuum coating method using thermal evaporation technique is employed for the fabrication of the silver coated fibre optic sensor element. The sensor element coated with silver is subjected to chemical exposure. The optical output from a broadband source is used as the light source to the sensing area. The wavelength shift in the absorption spectrum is recorded using a wavelength meter. The variations in the output of the sensor are recorded for different concentrations of the chemical species. The sensor elements are also fabricated for different unclad lengths of the fibres coated with silver. The output variation in each case on chemical exposure is recorded in terms of shift in wavelength and intensity variation. The performances of the sensor for different sensing lengths promise to give optimum design parameters for the SPR based chemical sensor development. In the present studies, $KMnO_4$ solution which has broad absorption in the visible wavelength range is used as the chemical species for the sensing purpose.

KEYWORDS: Surface Plasmon Resonance, Optical Fibre

Optical fibre based sensing methods are gaining maturity and competency over the other sensing methods recently (B.D.Gupta, 2006). Tremendous research efforts put in this particular area of the development of fibre optic bio chemical sensors has started showing positive results that eventually lead to the contribution of a competent technology for sensing applications (P.Suresh Kumar et. al; 2002). The available results and reviews show that in the possible usage of fibre as a medium for sensing, Surface Plasmon Resonance (SPR) based sensing is comparatively giving better performance parameters (E.Klantsataya et. al; 2017). Feasible methods of fabrication for obtaining a repeatable performance in bio-chemical species sensing is a major challenge in the area of fibre optic sensor development. Hence optimization of the performance of the sensors with respect to various fabrication parameters is essential for the confirmed and effective performance of the sensor (C.Caucheteur et. al., 2015). In this context, here an attempt is made to evaluate the performance of a silver coated fibre optic sensor based on the change in the unclad length of the fibre. Variations in the unclad length of the fibres along with the metallic coating unclad portion are subjected to various concentration of a chemical species. The absorbance variations observed in each case is recorded and the measurements are repeated to obtain a confirmed pattern of variations. Here the chemical species used for the analysis is Potassium Permanganate ($KMnO_4$) solution in distilled water.

MATERIALS AND METHODS

Fabrication of the Sensor

The optical fibre used for the present analysis is a PCS (Plastic Cladded Silica) fibre with 400μm core diameter form PolyMicro Technologies. The coating of the fibre is easily stripped off mechanically using a sharp blade. The cladding of the fibre is made of Hard Clad Plastic and the core of the fibre is Silica. The cladding of the fibre is removed by putting the uncoated portion of the fibre in acetone. The fibres put in acetone are periodically taken out and carefully wiped off using a lint free tissue dipped in acetone. The cladding is completely removed from the fibre core by keeping it in acetone for about 10-12 hours (Figs 1&2).

The uncladdedfibres are coated with silver plasmonic layers using a vacuum coating unit by thermal evaporation technique. The evaporation duration is controlled in such way that a plasmonic layer is coated over the unclad region of the fibre with a layer thickness ~ 100nm. SEM images of the unclad fibres before and after silver coating are shown in figures (3-5).

[1]Corresponding Author

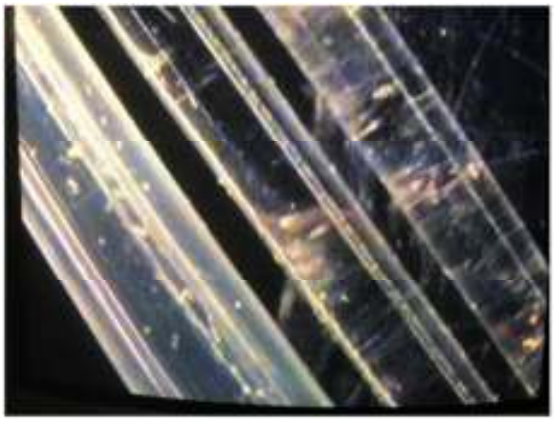

Figure 1: Optical fibrescope image of a coated, cladded and uncladded PCS fibre

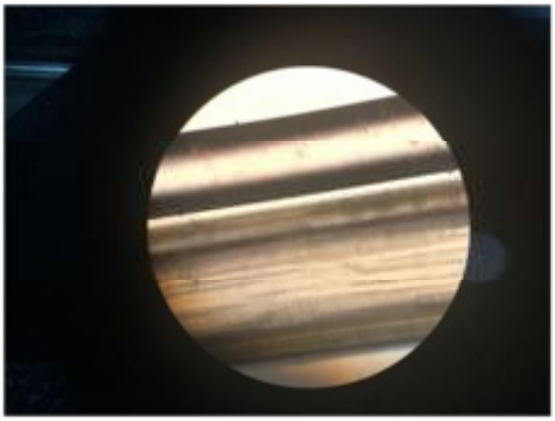

Figure 2: The view of an uncladdedfibre through a microscope along with a cladded and coated fibre

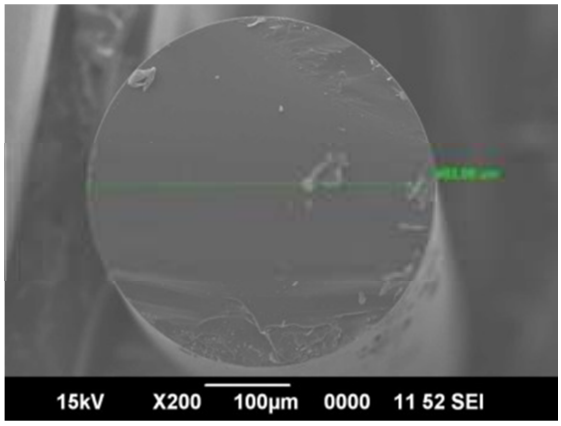

Figure 3: Unclad fibre cross section

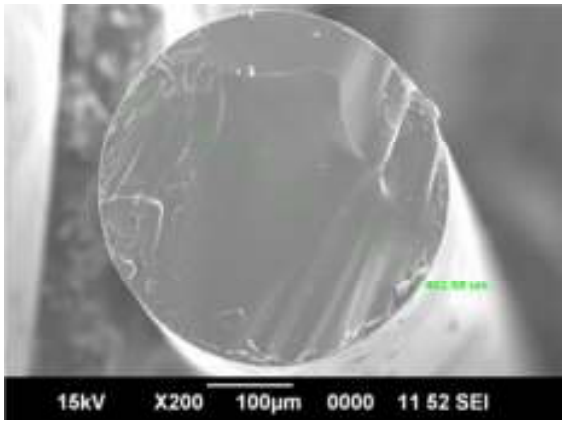

Figure 4: Unclad and silver coated fibre cross section

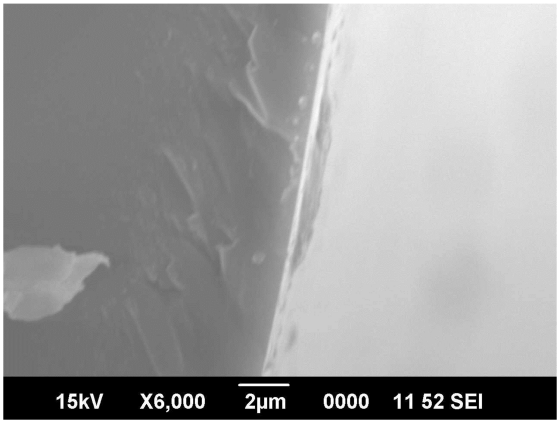

Figure 5: More magnified view of the silver coated edge of the fibre

Fabrication of the fibres with different sensing lengths coated with silver was carried out repeatedly till the optimum thermal evaporation parameters are arrived at, so that the plasmonic silver layer thickness was maintained below 100nm.

Characterization

The fabricated Plasmonic sensors were characterized for observing the changes in the sensing properties. The experimental setup used for the study is shown below (Fig 6). A Broadband source (300-1800)nm is used as the source for the sensing purpose. The absorption spectrum of the sensor output is obtained using a UV-NIR Spectrometer from Ocean Optics (HR4000), interfaced to a PC.

Experimental Setup

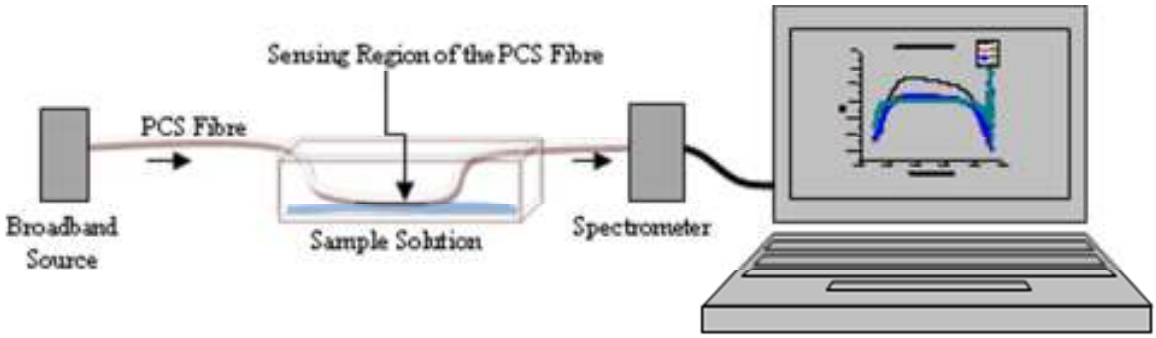

Figure 6: The experimental setup used for characterizing the silver coated plasmonic fibre sensors

Experimental Observations

The sensing evaluation of the fabricated plasmonic sensors was carried out using a sample solution of $KMnO_4$. The $KMnO_4$ solution prepared in distilled water shows a broad absorption in visible region (Fig 7). The sample solution is prepared for 0.1M concentration (S1). The solution is diluted to different concentrations by adding distilled water and the minimum concentration obtained was 10^{-8}M (S7).

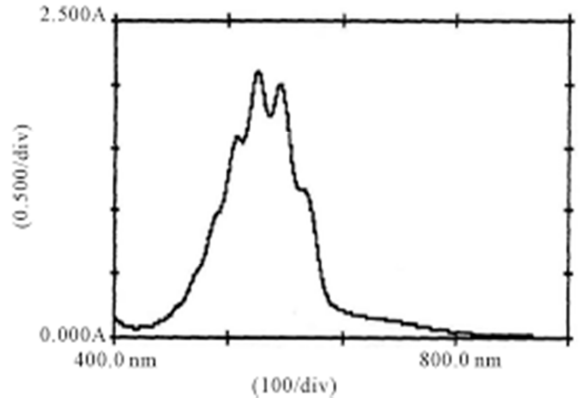

Figure 7: Absroption spectrum of $KMnO_4$ solution in distilled water(from web resource)

First, unclad fibres of different lengths (1cm, 3cm and 5cm) were prepared. Then the sample solutions of different concentrations were poured on the unclad region of the fibre by placing the fibre as shown in figure 6. The absorption spectrum of the fibre sensor for each concentration is recorded. The same experiment is repeated for different unclad lengths of the fibre and the absorption changes were recorded. The observed absorption spectra from the fibre sensor are shown in figures (8-10).

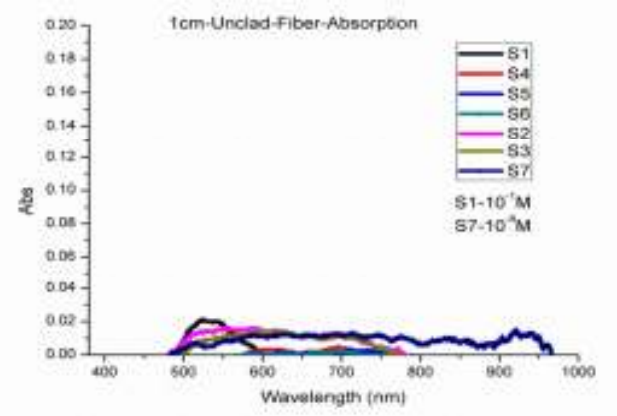

Figure 8: Absorption response of 1cm unclad PCS fibre for different concentration of $KMnO_4$ solution

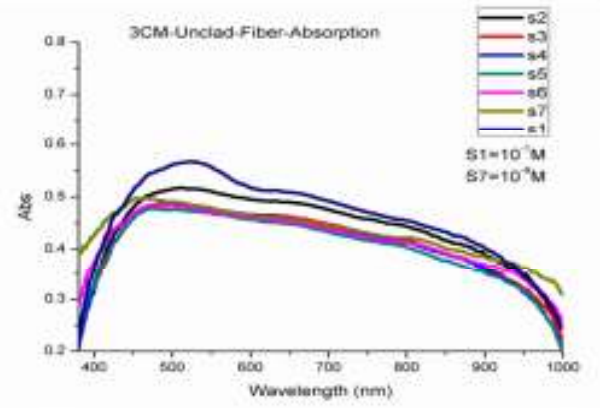

Figure 9: Absorption response of 3cm unclad PCS fibre for different concentrations of $KMnO_4$ solution

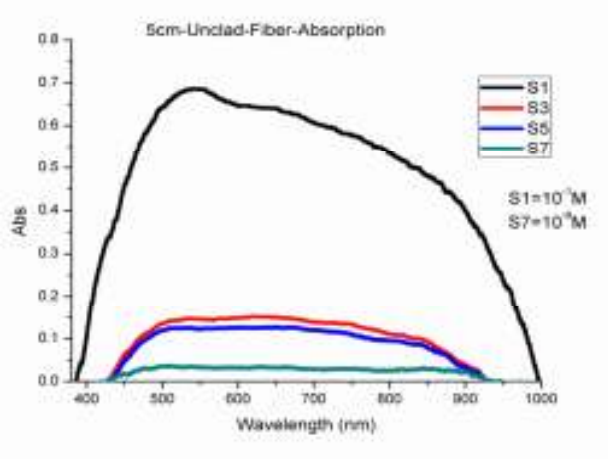

Figure 10: Absorption response of 5cm unclad PCS fibre for four different concentrations of $KMnO_4$ solution

The experiment is then repeated with unladded PCS fibres coated with silver plasmonic layers using thermal evaporation technique. The result obtained for 5cm uncladded silver coated fibre, for three different sample concentrations is shown in figure 11. Now, the Absorption spectrum obtained for 5cm unclad silver coated fibre is compared with the absorption spectrum obtained for an uncoated fibre, for a concentration of 0.1M (Fig 12).

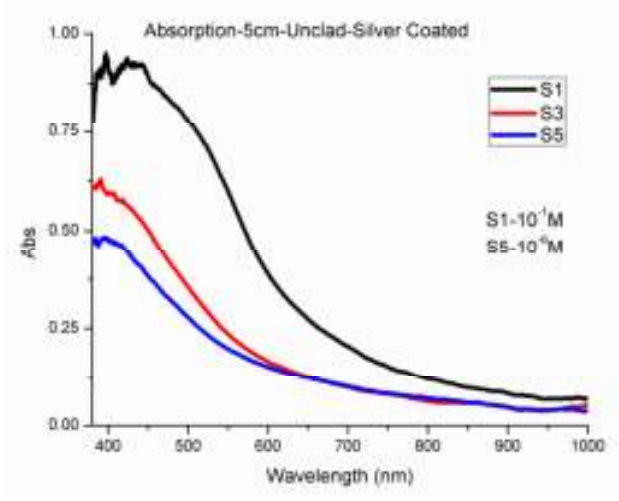

Figure 11: Absorption response of 5cm unclad silver coated fibre for 3 different concentrations of $KMnO_4$ solutions

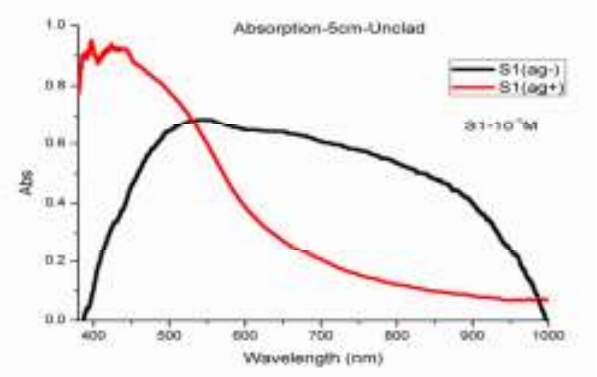

Figure 12: Comparison of absorption responses of 5cm silver coated and uncoated fibres for 0.1M concentration of $KMnO_4$ solution.

The spectral response of the fibre sensors were now separately analysed for the maximum (S1) and minimum (S7) concentrations of the sample solutions. The uncoated and the silver coated fibre responses for different sensing lengths were analysed. The observations are given in figures 13-15 for the maximum concentrations.

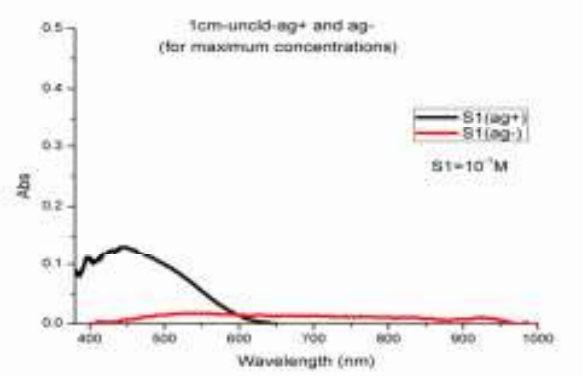

Figure 13: Comparison of absorption response of 1cm coated and uncoated fibres for 0.1M concentration of KMnO4 solution

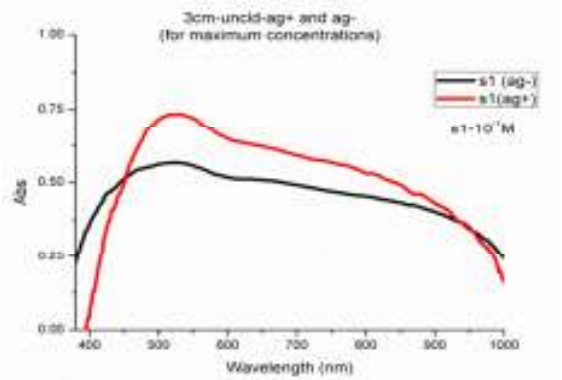

Figure 14: Comparison of absorption response of 3cm coated and uncoated fibres for 0.1M concentration of KMnO4 solution

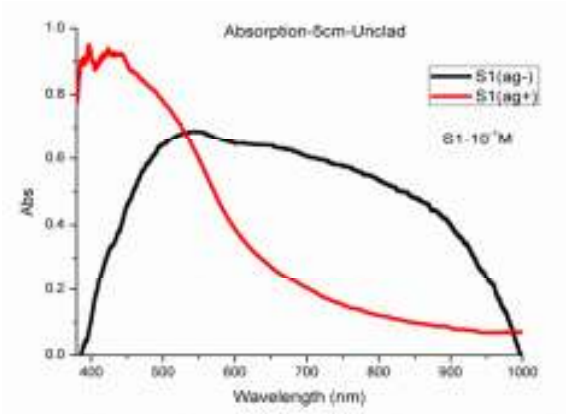

Figure 15: Comparison of absorption response of 5cm coated and uncoated fibres for 0.1M concentration of $KMnO_4$ solution

Similarly, the spectral responses observed for 10^{-8}M concentration of the sample solution for different sensing lengths of the coated and uncoated fibres are given in figures 16-18.

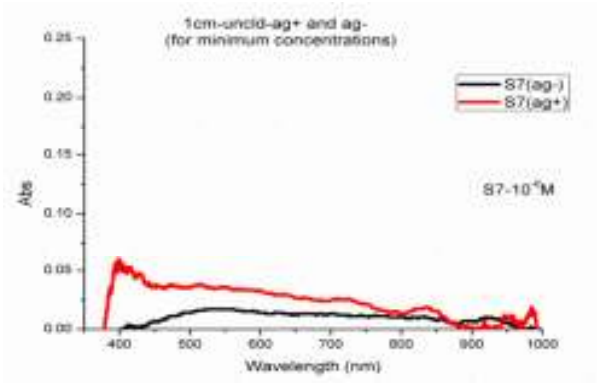

Figure 16: Comparison of absorption response of 1cm coated and uncoated fibres for 10^{-8}M concentration of $KMnO_4$ solution

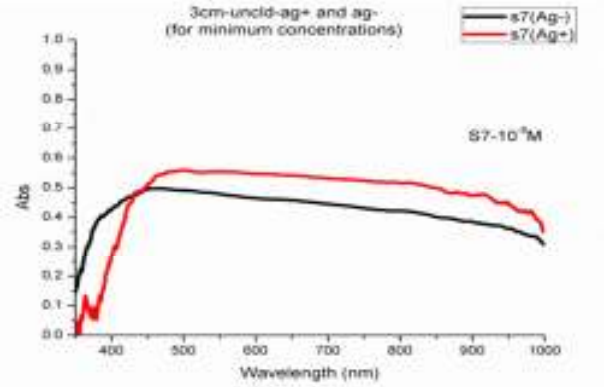

Figure 17: Comparison of absorption response of 3cm coated and uncoated fibres for 10^{-8}M concentration of $KMnO_4$ solution

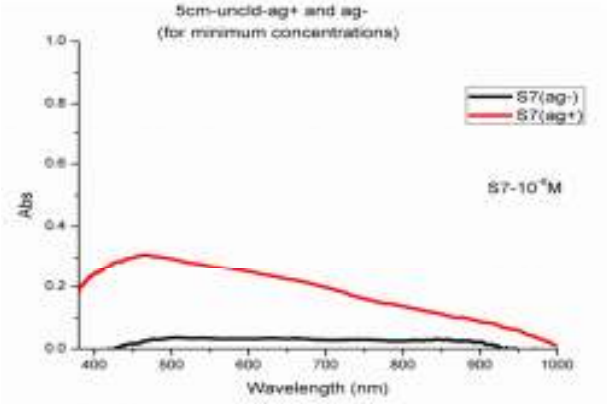

Figure 18: Comparison of absorption response of 5cm coated and uncoated fibres for 10^{-8}M concentration of $KMnO_4$ solution

RESULTS AND DISCUSSION

The experimental observations made on silver coated as well as uncoated fibre sensors are given in the previous sections (Figs 8-18). In the case of unclad and uncoated fibres having different sensing lengths, the results (Figs 8-10) indicate that it is only for 5cm unclad length some significant evanescent wave absorption is taking place for the sample solutions with varying concentrations ($0.1 - 10^{-8}$M). The length dependency of the unclad portion of the fibre in evanescent wave absorption is revealed in these observations. Absorption is maximum for maximum concentrated sample solution (S1) at 5cm unclad length.

Hence the plasmonic effect of this particular unclad length (5cm) of the fibre is verified by coating it with a silver layer of thickness ~50nm. The results (Figs 11&12) clearly show the plasmonic effect of the coated silver layers. The absorption spectra obtained for the $KMnO_4$ sample solutions of different concentrations show a peak nearing 400nm which indicate the presence of silver plasmonicnano layer and its plasmonic effect. With varying concentrations (from S1 to S5) the peak of this absorption is also showing a significant shift towards the blue region (Fig 11). In figure 12, the comparison is made for absorption response of the 5cm silver coated fibre and 5cm uncoated fibre for the maximum concentration of the sample solution (S1). The result very clearly indicates a sharp absorption enhancement in the presence of a plasmonic silver layer towards blue region of the spectrum.

Comparisons of maximum (S1) and minimum concentration (S7) responses for different sensing lengths of the silver coated and uncoated fibres are recorded in

figures 13-18. All the observations indicate an enhancement in absorption if silver nano layer is attached to the fibre. Also for the unclad silver coated fibre, the absorption in the presence of the chemical species is maximum at a wavelength with a blue shift towards 400nm region of the spectrum for the sample solutions with different concentrations. For example, in the case of 5cm uncladded silver coated fiber, due to the presence of the plasmonic layer the absorption is twice compared to that made by uncoated 5cm uncladded fibre (Fig 15). Even when the concentration is reduced to a minimum value S7 (10^{-8}M), the absorption enhancement is significant for the 5cm uncladded and silver coated fibre, which is almost nil in the case of uncoated 5cm uncladded fibre (Fig 18). Tables 1&2 compile the results for the different unclad length fiber performances with out and with silver coating.

Table 1: Different unclad length fiber absorption for different sample concentrations

Unclad Length (cm)	Abs (10^{-1}M)	Abs (10^{-8}M)	λ_{max}* (nm)	Coated /Uncoated
1	0.021	0.004	530.81	Uncoated
3	0.571	0.484		
5	0.686	0.034		

*Unshifted for the maximum and minimum sample concentrations

Table 2: Different unclad length silver coated fiber absorption for different sample concentrations

Unclad Length (cm)	Abs (10^{-1}M)	λ_{max}** (nm)	Abs (10^{-8}M)	λ_{max}** (nm)	Coated /Uncoated
1	0.132	447.67	0.06	399.38	Coated
3	0.737	520.99	0.56	501.41	
5	0.95	397.73	0.31	464.27	

**Blue shifted for the different concentrations of sample solution due to the presence of silver plasmonic layer

Here, a deviation in the expected performance for the coated 3cm uncladdedfiber is attributed to imperfect plasmonic layer formation upon the core of the fiber.

CONCLUSION

The above results point out that plasmonic effect of silver can be utilized for enhancing the sensing capability of a chemical sensor. The unclad length dependency as well as the presence of a silver nano layer on the core of the fibre can together enhance the sensitivity almost double. The dependence on the unclad length and also the performance of the sensor with respect to a wide range of concentrations are found to be repeatable and reliable. Hence the results obtained from these preliminary studies can be extended to characterize the properties of the chemical species (in this case $KMnO_4$). The sensor configurations can be made to sense and analyse different other potentially harmful chemical species as well as the bio samples.

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