Nanomaterial-coated etched Fiber Bragg Grating sensors

B. N. Shivananju[1, 4], Parama Pal[2], S.Yamdagni[3], M. M. Varma[2, 4, 5, 6] and S. Asokan[1, 2, 6, *]

[1]Department of Instrumentation and Applied Physics, Indian Institute of Science, India
[2]Robert Bosch Centre for Cyber Physical Systems, Indian Institute of Science, India
[3]Instrumentation Scientific Technologies, Indian Institute of Science, India
[4]Center for Nano Science and Engineering, Indian Institute of Science, India
[5]Deptartment of Electrical Communication Engineering, Indian Institute of Science, India
[6]Applied Photonics Initiative, Indian Institute of Science, India
*sasokan@iap.iisc.ernet.in

Abstract—**Multi-parameter sensing in the form of sensor arrays functionalized with multiple receptors, is an approach for attaining selectivity in sensing. We have demonstrated a novel fiber sensor based on an etched Bragg grating whose core is coated with materials such as polyelectrolytes, carbon nanotubes, and polyallylamine-amino-carbon nanotubes, and can be used for detecting gases, pH, humidity, refractive index, proteins and other biomolecules. In this approach, the target molecules interact with the functionalized core of the etched FBG resulting in a change in the effective refractive index of the fiber core leading to a subsequent shift in the Bragg wavelength. The experimental data shows that the wavelength shift varies linearly with the concentration of the target analyte. Besides being reproducible and repeatable, the technique is fast, compact, and highly sensitive.**

***Keywords*— Etched Fiber Bragg Grating (EFBG), Nano materials Coating, Biochemical Sensing.**

I. INTRODUCTION

Fiber Bragg Grating (FBG) sensors have been exploited for a variety of sensing applications, due to attributes such as high sensitivities, compact form, an inherent multiplexing capability, multi-functionality, long term stability, immunity to electromagnetic interference, amongst many others [1].

An FBG is essentially an optical fiber (typically single mode) whose core refractive index is periodically modulated [2]. When light is guided along the core of the FBG, it gets reflected by successive grating planes; the contributions of reflected light from these grating planes add constructively for a particular wavelength (λ_B), if the following condition is satisfied:

$$\Delta\lambda_B = 2n_{eff}\Lambda \qquad (1)$$

Where n_{eff} is the effective refractive index of the core and Λ is the grating period [2].FBGs have been widely used as sensors for measuring strain, load, temperature and light [1-3]. In this manuscript, we demonstrate etched FBG (EFBG) sensors [4] whose core has been exposed via etching and has been subsequently functionalized with various nanomaterials for biochemical sensing or multi-parameter sensing.

II. RESULTS AND DISCUSSION

A schematic of the etched, functionalized FBG sensor is shown in Fig.1 for biochemical sensing. Data is obtained on a four-channel FBG interrogation system (SM130, Micron Optics) with a 1 pm resolution and a sampling rate of 1 kHz.

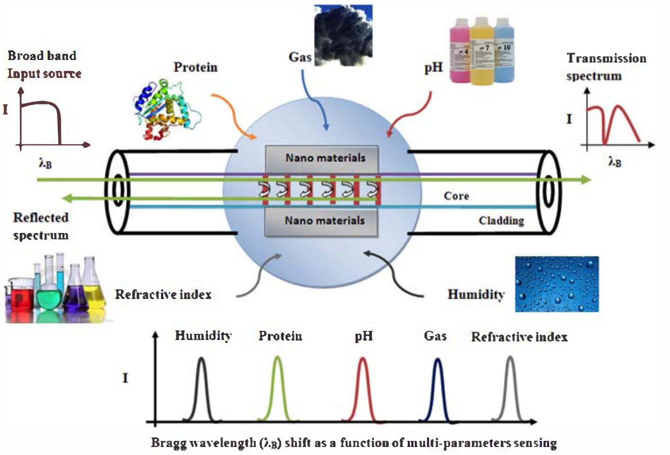

Figure 1: Schematic of the experimental set up for biomolecular/biochemical sensing using nano materials-coated EFBGs.

We have used our EFBG sensor for refractive index measurements,observing reversible and irreversible pH induced conformational changes in weak polyelectrolytes,real-time monitoring of protein kinetics, highly sensitive humidity sensing at room temperature using carbon nanotubes coated EFBGs, CO_2 gas sensing using polyallylamine-amino-carbon nanotube-coated EFBGs, and carbon nanotubes coated FBG for photomechanical optic modulator[3-6]. In this manuscript, we briefly describe the gas and humidity sensing capability of our sensor in detail.

A. *Poly(acrylic) acid (PAA)-amino-carbon nanotube (CNT) functionalization of EFBGs for Gas sensing.*

Gas sensing measurements with the PAA-amino-CNT-functionalized EFBGs were carried out at room temperature

(~ 25 ^{0}C) and constant humidity (RH 47%) with varying CO_2 concentrations. The test sequence consisted of repeated exposures of the sensor to gases with different CO_2 concentrations balanced with pure N_2. The experimental results as a function of time are shown in Fig.2(a).

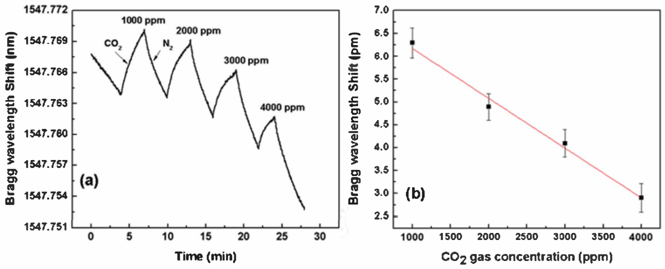

Figure 2:(a) The λ_B shift of PAA-amino-CNT-EFBG for various CO_2 concentrations at room temperature (b) The λ_B shift as a function of CO_2 concentration, calculated from figure a, after base line subtraction, showing good linearity in the measured interval.

When the concentration of CO_2 increases, λ_B shifts towards the shorter wavelength. The shift in λ_B is due to the change in the n_{eff} of the core due to the adsorption of CO_2 in the PAA-amino-CNTs coating [5].

It has been reported earlier that the relative permittivity ε_r of the nanotubes shifts to lower values when exposed to reducing gases like CO_2.Since the relative permittivity ε_r is proportional to n_{eff} of the fiber core, this results in λ_B shifting to shorter wavelengths corresponding to the concentration of the CO_2 molecule adsorbed by the nanotubes. Although we have kept the relative humidity (RH) constant (~47%), there is still some residual change in humidity when different concentrations of CO_2 are purged from the sensor chamber, leading to a shift in the base line (Figure 2a).

Fig.2(b) shows the λ_B shift versus different CO_2 concentrations between 1000 ppm and 4000 ppm after subtracting the base line. It can be seen that the sensor shows good sensitivity across the whole range of concentrations studied and the λ_B shift versus CO_2 concentration exhibits a linear trend [5].

B. *Carbon nanotubes-coated EFBG(CNT-EFBG) sensors for humidity sensing.*

The relative humidity (%RH) characteristics of the CNT-EFBG sensor were investigated by exposing the sensor sequentially to a range of different humidity conditions at a constant temperature. Fig.3 shows the performance of the CNT-EFBG sensor to varying humidity (20-90% RH in steps of 10% RH). The test sequence consists of repeated exposures of the sensor with different %RH concentrations balanced with wet air and dry air [6].

Water vapor in air has a strong influence on the conductivity of CNTs, which in turns affects n_{eff} of the fiber core [6]. This results in λ_B shifting to longer wavelengths, corresponding to the concentration of the %RH molecule adsorbed by the nanotubes.

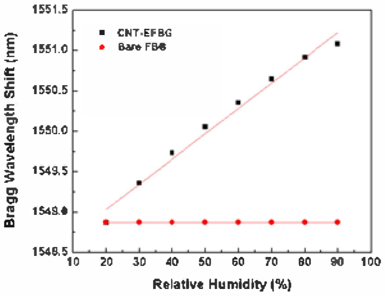

Figure 3: λ_B shift of CNT-coated EFBG for various %RH concentrations at room temperature showing good linearity in the measured interval. The effect of temperature during %RH concentration measurement was normalized by using an uncoated FBG sensor which is sensitive only to temperature effects and not to surrounding refractive index.

The λ_B shift due to the refractive index change of the CNTs is shown to be effectively linear with increasing RH% as seen from Fig.3. The sensor is, therefore, optimized over the RH range of 20-90%.The sensitivity of the CNT-EFBG system is calculated to be around 31 pm/ %RH, which is 6 times higher compared to sensitivities of existing FBG based humidity sensors (~ 5.6 pm / % RH) and has a detection limit of 0.03 RH [6].

III. CONCLUSIONS

We have fabricated FBGs and EFBGS, which have been subsequently functionalized with various nano materials such as polyelectrolytes, carbon nanotubes, and polyallylamine-amino-carbon nanotubes and demonstrated its capabilities for sensing biomolecules and measuring various parameters such as pH, humidity, gases, proteins, refractive indices, and light [3-6].

ACKNOWLEDGMENT

This work was partially supported by the Robert Bosch Centre for Cyber Physical Systems (RBCCPS), Indian Institute of Science.

REFERENCES

[1] Y.J.Rao,“ Recent Progress in applications of in-fibre Bragg grating sensors,” Optics and Laser in Engineering .31, 297-324 (1999).

[2] A. Othonos, “Fiber Bragg gratings,” Rev. Sci. Instrum. 68, 4309-4341 (1997).

[3] B.N. Shivananju, A. Suri, S. Asokan, and A. Misra, “Carbon nanotube coated fiber Bragg grating for photomechanical optic modulator,” Rev. Sci. Instrum.84, 095101(2013).

[4] B.N. Shivananju, M. Renilkumar, G.R. Prashanth, S. Asokan and M. M. Varma, "Detection Limit of Etched Fiber Bragg Grating Sensors," J. Lightwave. Technol. 31, 2441-2447(2013).

[5] B.N. Shivananju, S. Yamdagni, R. Fazuldeen, A.K. Sarin Kumar, G.M. Hegde,M.M. Varma, and S. Asokan, “CO_2 sensing at room temperature using carbon nanotubes coated core fiber Bragg grating,” Rev. Sci. Instrum. 84, 065002 (2013).

[6] B.N. Shivananju, S. Yamdagni, R. Fazuldeen, A.K. Sarin Kumar, S.P. Nithin, M.M. Varma, and S. Asokan, “Highly sensitive carbon nanotubes coated etched fiber Bragg grating sensor for humidity sensing,” IEEE Sensors Journal, 10.1109/JSEN.2014.2312353 (2014).