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Optomechanical Behaviour of Coated FBG Sensor with Side Hole Package Technology for Underwater Acoustic Applications

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Abstract

Ocean is receiving global attention for research in underwater communication. Acoustic wave is the main carrier of information in underwater sensing technology. In the proposed work we developed cylindrical and side hole package fibre optic based acoustic pressure sensor. Sensitivity of both the package and bragg wavelength for each change is strain is investigated. Both cylindrical and side hole package is optimized for two different types of coating material. i.e. Silicon rubber and poly methyl methacrylate (PMMA). Both the package is designed in Ansys tool. Strain generated at the core part of package due to applied pressure, effective refractive index change and Bragg wavelength shift is explored. Larger strain variation and with step size of 0.01 for side hole package with PMMA material. Maximum sensitivity of 851nm/RIU is obtained for PMMA with side hole package enhanced pressure sensitivity of proposed design opens the more possibilities for different applications of underwater acoustic and feasibility for fabrication. Remarkable sensitivity of 162nm/RIU is for cylindrical package with silicon rubber and 158nm/RIU for silicon rubber with side hole package and 161nm/RIU for PMMA with cylindrical package is obtained. Designed side hole package with PMMA coating shows more feasibility for fabrication for underwater application in future.

Keywords; *FBG, Underwater, PMMA, Silicon rubber, Ansys, Optical Sensor*

I. INTRODUCTION

It is seen from the history that important of underwater acoustic sensor came front in the era of 1912 after the titanic it at the iceberg. First underwater echo ranging system is developed and patent by Briton Lewis Richardson [1][2][3]. Hit of titanic at the iceberg provided impetus for the next wave of progress in underwater acoustic not only about safety transportation, but also in terms of security, safety marine echo system development. Main physical properties and factor to be determined in underwater application is temperature, salinity and pressure. All these three factors affect the density and directly influence the speed of sound in the ocean or in any underwater sources[4][5][6][7].

There is vast application of underwater acoustic sensor, data collection from oceanographic system, offshore exploration, pollution monitoring and safety naval transportation monitoring and many other military vehicle applications, disaster prevention and navigational application. There is lot of disadvantages faced by underwater research community in terms of traditional sensing system. Few examples we can see that failure in real time monitoring system in major disaster like tsunami or in any type of seismic activities. Second main disadvantage we can see that failure in interaction between sensing system and offshore control systems. If such type of failure occurs, it may not possible for underwater sensor network to serve at right time for purpose it meant for. Limited amount

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of data collection also a drawback of traditional underwater acoustic sensing system [8][9][10]. Electromagnetic Interference to signal and signal processing is major root cause of loss of signal during monitoring. With the development of fibre optic sensing technology and its miniaturization, insensitivity to electromagnetic interference. Cylindrical hydrophone with polyurethane material coated on cladding of fibre optic system is proposed. Designed packages has shown high sensitivity for underwater application. Two types of hydrophone package are designed i.e. cylindrical and ellipsoidal [11] [12][13]. Both the package is designed in Ansys. Result obtained is compared with experimental result and strain monitoring in ansys tool. Fabryperot acoustic underwater sensor has been proposed with micro machined centred diaphragm design. Proposed design has shown ability to detect small amount of pressure to huge hydrostatic underwater pressure. Centred embossed diaphragm is considered as sensitive structure in the proposed concept [14] [15]. As the water is pressurised on the sensor, embossed diaphragm undergoes deflection and changes the overall refractive index of medium. This results into change in wavelength and shift in peak resonance value. If the shift in wavelength is more from normal condition to abnormal condition sensitivity of designed structure will remain high. Major challenges in the design of underwater acoustic sensor network will be limited battery power or availability or recharge for proper working of sensor network. secondly propagation delays, multi path and signal fading problems, sensor exposure to corrosion environments. Titanium casing with aluminium ring encapsulated for fiber bragg grating (FBG) sensor for diving application underwater and work carried out on underwater FBG sensor for diving application has shown sensitivity of 0.04644nm/RIU sensitivity [16]. FBG sensor is designed with hollow suspended core fibre for refractive index measurement shown sensitivity of 8.9nm/RIU [17]. Nanostructured Titanium dioxide coating on FBG sensor for refractive index measurement has shown sensitivity of 1.257nm/RIU [18].

Fiber bragg grating based sensor highly sensitive to micro pressure, temperature and any external environmental property which effects on fibre. Therefore, to get rid of above disadvantages mentioned in traditional sensing system this paper focuses on FBG encapsulated cylindrical and side hole packages. Proposed sensing structure investigated for two different types of coating i.e. Silicon rubber and poly methyl methacrylate (PMMA) material.

II. DESIGN AND WORKING PRINCIPLE OF PROPOSED SENSOR

Proposed work consists of FBG sensor package with two different type of coating material such as PMMA and Silicon rubber. Core and cladding is designed in ansys workbench. Parameter of FBG package design is specified in Table 1. Mapped face grid is generated for each part of FBG sensor package as shown in Figure 1 and Figure 2 for side hole package and cylindrical package. Silicon rubber and PMMA material properties such density, young’s modulus and poissons ration is assigned as per the standard mechanical properties.

Table 1. Design parameter used for strain investigation in Ansys

Item	Value
Core diameter	8 µm
Cladding diameter	125 µm
Coating diameter	130 µm
Side holes radius	30 µm
Thickness of coating	5 µm
Coating material assigned	Silicon Rubber, PMMA
Length	3750 µm

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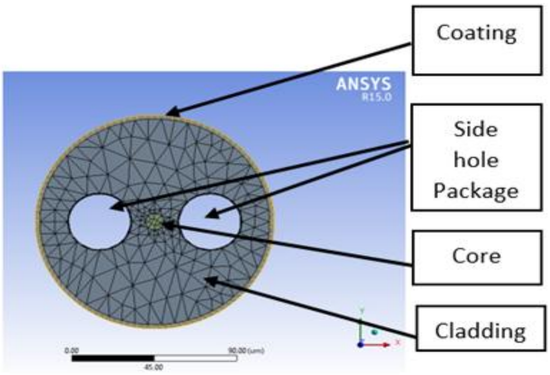

Figure 1: Side hole package

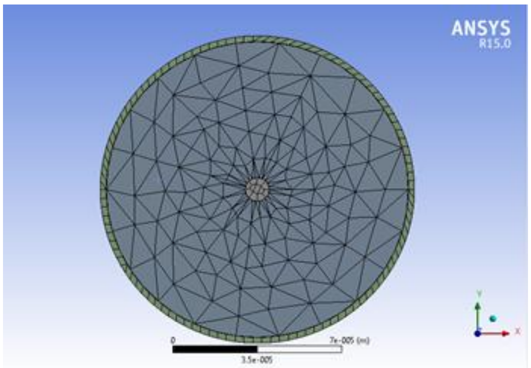

Figure 2: Cylindrical package

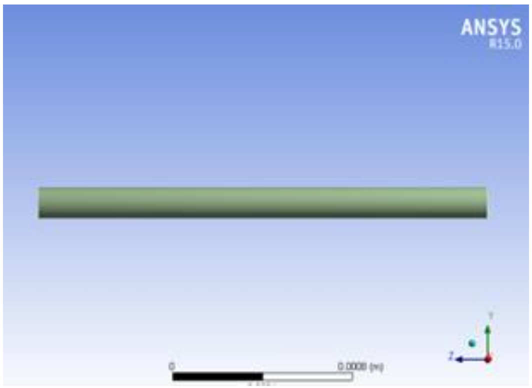

Figure 3: Side view of fibre

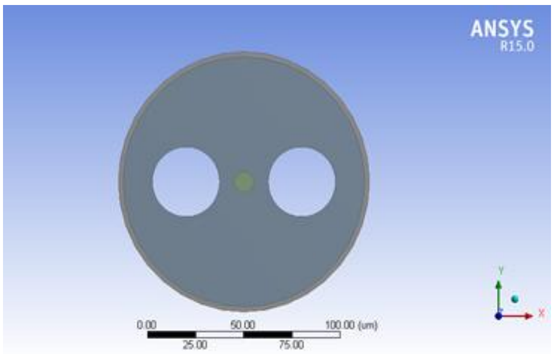

Figure 4. CAD model of side hole fiber

Table 2. Parameter used for optical simulation

Simulation Item	Parameter
Profile type, Structure Type, Grating Type	Step Index Fiber, Fiber, Volume Index
Depth of Modulation	0.0013µm
Waveguide width	4.26 µm
Waveguide height	4.26 µm
Period	0.5 µm
Length	1750 µm
Number of grating	3500 µm

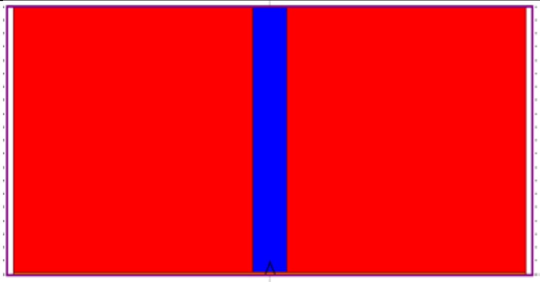

Figure 5. FBG Design in Rsoft

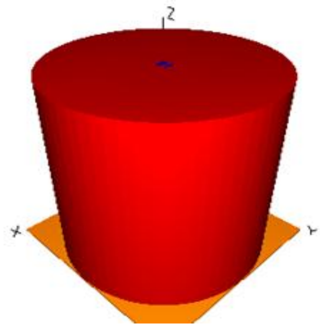

Figure 6. 3D view of FBG Sesnor

III. RESULTS AND DISCUSSIONS

Both side hole package and cylinderical packages designed and descritised in ansys model. Descritisation of model generated FBG incoporated side hole packages and cylindrical packages. Model is generated in Ansys modeler and obtained stress and strain incoporated into FBG sensor design. Figure 1 to Figure 4 shows different design stages of FBG packages. Axial strain develped at the centre of FBG is invetigated for both the configuration.

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$\Delta\lambda_{Bragg}$ is change in bragg wavelength, λ_{bragg} centre wavelength. P_e is strain optic coefficeent , Λ represents grating period, P_{11}, P_{12} strain optic tensor constant. Equation 1 to Equation 3 assist in calcuating the bragg wavelength , change in bragg waelength and strain optic coeffieicent for change in effective refrative index N_{eff}.

$\Delta\lambda_{Bragg} = \lambda_{bragg}(1\text{-}P_e)\Delta\varepsilon$ ---------------------- [1]

$P_e = (N_{eff}^2/2)\,[P_{12}\text{-}\,(P_{11}+P_{12}]$-----------------[2]

$\lambda_{bragg} = 2\Lambda N_{eff}$ ----------------------------------[3]

P_{11}=0.113

P_{12}=0.252,

Poissons Ratio=0.33

Stress modified refrative index value reduces to $n=n_o\text{-}2C_2\sigma$; $C_2 = 4.50\ E^{-12}$

Properties of Silicon rubber: Youngs moduls:0.05Gpa, Poissons ratio = 0.47, Density = 1.1Mg/m^3

Proerties of PMMA: Youngs Moduls=3Gpa, Density=1.19g/cm3 Poission Ratio = 0.35

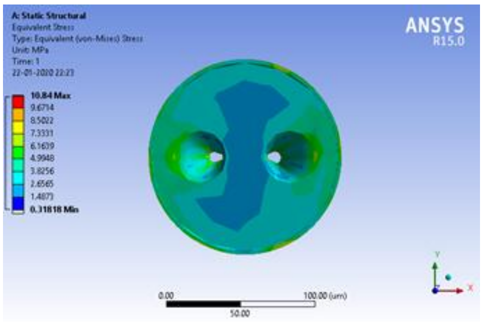

Figure 7. vonmises stress in side hole package

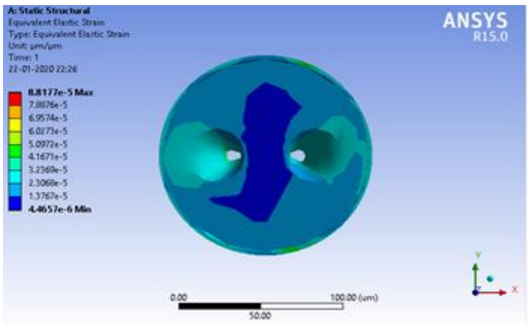

Figure 8. Vonmises Strain in side hole package

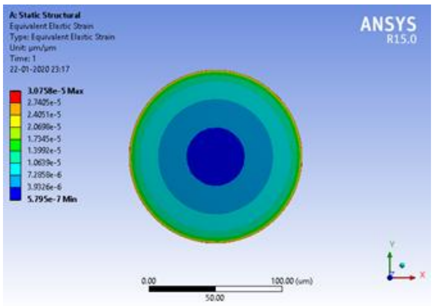

Figure 9. vonmises stress in side hole package

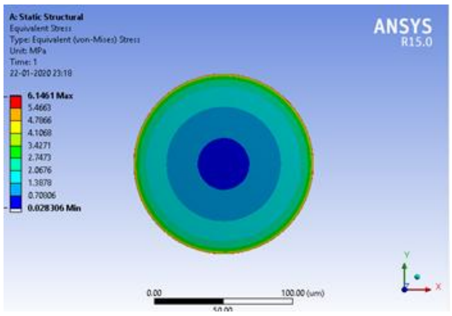

Figure 10. Vonmises Strain in side hole package

Table 3. Wavelength shift for Silicon Rubber with cylindrical package

Pressure (Pa)	Strain (Δε)	Stress(Mpa)	Δλ Bragg	Centre Wavelength Change	n(R.I)	Sensitivity nm/RIU
1100	0.3375E-3	330	0.4887nm	1550.4887	1.4570	162
1400	0.3756E-3	380	0.5439nm	1550.5439	1.4566	160
1700	0.3945E-3	430	0.5712nm	1550.5712	1.4561	146
2000	0.4367E-3	480	0.6323nm	1550.6323	1.4557	147

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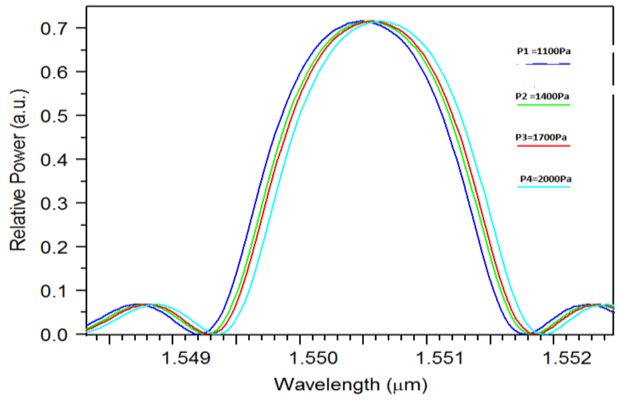

Figure 11. Wavelength shift for Silicon Rubber with cylindrical package

From the result obtained for cylindrical package with silicon rubber package indicates that change in wavelnegth shift otbained smaller values for varying pressure from 1100 Pascal to 2000 Pascal. Small change in strain value indicates the package is having remarkable sensitivity. Refelectivity of 90% obained for this particular FBG package.

Table 4. Wavelength shift for silicon rubber with side hole package

Pressure (Pa)	Strain (Δε)	Stress(Mpa)	Δλ Bragg	Centre Wavelength Change	n(R.I)	Sensitivity nm/RIU
1100	0.3645E-3	400	0.5278	1550.5278	1.4564	146
1400	0.3987E-3	440	0.5773	1550.5773	1.4560	144
1700	0.4323E-3	500	0.6260	1550.6260	1.4555	139
2000	0.5465E-3	560	0.7913	1550.7913	1.4550	158

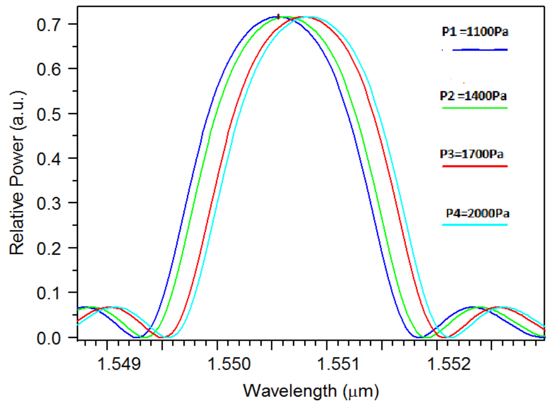

Figure 12. Wavelength shift for silicon rubber with side hole package

Table 5. Wavelength shift for PMMA with cylindrical package

Pressure (Pa)	Strain (Δε)	Stress(Mpa)	Δλ Bragg	Centre Wavelength Change	n(R.I)	Sensitivity nm/RIU
1100	0.3834E-3	500	0.5552	1550.5552	1.4555	123
1400	0.4323E-3	530	0.6260	1550.6260	1.4552	130
1700	0.5434E-3	560	0.7868	1550.7868	1.4550	157
2000	0.5789E-3	580	0.8383	1550.8383	1.4548	161

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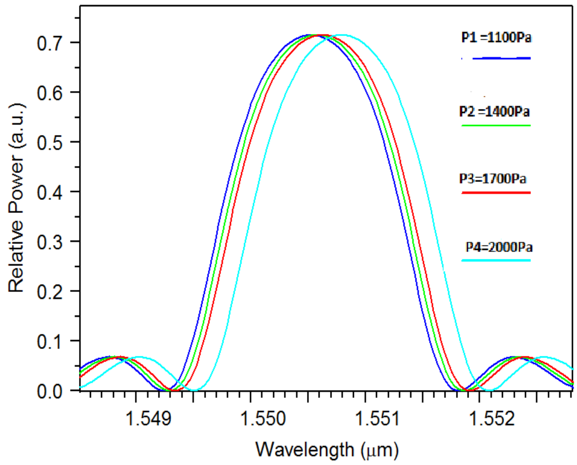

Figure 13. Wavelength shift for PMMA with cylindrical package

Table 5. Wavelength shift for PMMA with side hole package

Pressure (Pa)	Strain (Δε)	Stress(Mpa)	Δλ Bragg	Centre Wavelength Change	n(R.I)	Sensitivity nm/RIU
1100	0.4564E-3	113	0.6609	1550.6609	1.4590	660
1400	0.5646E-3	123	0.8175	1550.8175	1.4589	743
1700	0.6754E-3	133	0.9780	1550.9780	1.4588	815
2000	0.7645E-3	143	1.1070	1551.1070	1.4587	851

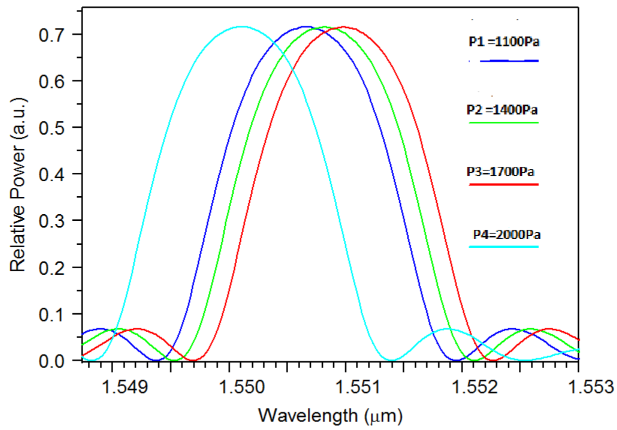

Figure14. Wavelength shift for PMMA with side hole package

Table 6. Compariison with previous work

Sl.No	References.No	Type of FBG, Material	Sensitivity
1	16	Titanium casing as coating material	0.04644nm/RIU
2	17	Hollow suspende core fibre	8.9nm/RIU
3	18	Titanium dioxide	1.257nm/RIU
4	Proopsed Work	PMMA Coating (side hole)	851nm/RIU

From the Figure 11 to Figure 14 show wavelength for different coating materials such as silicon rubber, PMMA with two different FBG encapsulations such cylindrical and side hole packages. Cylindrical package has how less change in strain value compared to side hole package. Change in strain value obtain with step size of 0.01 and shift in

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wavelength observed within the range of 1550nm. Strain step size of 0.1 is obtained for side hole package with PMMA coated material. This indicate that creating the side hole for pressure act as stress concentration region over the axis of FBG package, in turn induces more axial strain. Shift in wavelength obtained is high in case of PMMA with side hole packages compared to other coating with cylindrical packages. Maximum sensitivity of 851nm/RIU is obtained for side hole FBG package with PMMA coating. Significant sensitivity obtained for remaining packages with coating material such as for cylindrical package with silicon rubber (162nm/RIU), Silicon rubber with side hole package (160nm/RIU) and PMMA with cylindrical package approximately 165nm/RIU.

IV. CONCLUSION

Proposed work consists of coating of FBG with different material for underwater pressure sensing application. Two FBG sensing package has been designed i.e. side hole package and cylindrical package. Obtained result has shown better strain response for side hole package with strain step size of 0.1. Other coating package on FBG has shown strain step size of 0.01 and has shown remarkable wavelength shift values compared to side hole package with PMMA coating. Maximum sensitivity of 851nm/RIU is obtained for PMMA with side hole packages. Proposed FBG sensor designed shows significant sensitivity compared to the previous literature carried out and shows more feasibility towards future fabrication purpose.

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