A REVIEW ON UNDERWATER SIGNAL DETECTION USING FIBER OPTIC INTERFEROMETRIC TECHNIQUE

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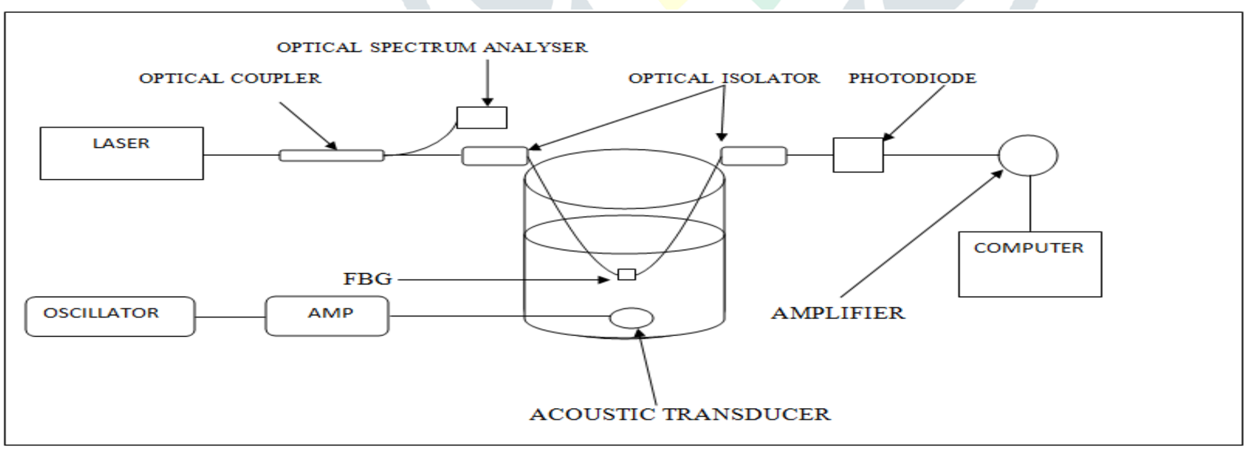
ABSTRACT
The present paper review recent advancement in the field of Distributed Feedback-Fiber Laser (DFB-FL) or Fiber Bragg Grating (FBG) based hydrophone that was performed in the past three decades. Some of the key developments like the use of the coating material, the laser required and the length of the fiber etc are discussed because all of these factors as a whole effect the sensitivity of the FBG present in the receiving end of setup. Development of DFB-FL in step by step mode is also discussed in the present paper.

Key words: Hydrophone, Fiber Bragg grating, Coating material

INTRODUCTION

The necessity for the advancement in the deep sea signal detection calls for implementation of some of the most precise measurement techniques. Previously the use of piezoelectric material was very common and was widely used in the previous century [1] for e.g. geophysics [2], military[3] etc. but the biggest shortcome of that device was the inaccuracy in measuring acoustic signal and adaptability to various harsh condition so those previously used piezoelectric hydrophones were replaced with more accurate, lightweight, cheap, flexible, low loss and fast response DFB FL Hydrophone [3]. Nowadays because of the presence of fiber Bragg grating (FBG) many more advantage are observed including a smaller size, reliability, stability, durability in harsh condition, multiplexing based on wavelength division multiplexing (WDM). The FBG based hydrophone basically work on the principle of modulation of intensity of laser light under the influence of acoustic field. Recently there are a lot of research going on to increase the sensitivity of the device. In DFB-FL hydrophone, a Fabry-Perot laser cavity is formed on an erbium- Ytterbium doped optical fiber by a $\pi/2$ shift in the Bragg grating, the resonance cavity is maintained at $\lambda/4$[4], DFB Lasers can achieve single mode operation that generates a very narrowband laser at a frequency centered at the stop band of the Bragg grating [4].



The figure shows the description of a system dedicated to underwater acoustic sensing. Some of these features make the DFB FL or FBG hydrophone the next stepping stone, after their ancestor PZT hydrophone going up the ladder of advancement in underwater acoustic signal detection.

REVIEW OF LITERATURE

In 1998 Nobuaki TAKAHASHI, Akihiro HIROSE and Sumio TAKAHASHI gave the first idea of one of the most simple hydrophone design [14].When the sound signal or acoustic signal interact with the hydrophone modulating the fiber Bragg grating wavelength thus changing the intensity of laser light transmitted through the FBG. The optical isolator is responsible for the stability of this device, without the isolator the signal is not stable in low frequency due to Fabry-Perot interference effect between the FBG and various facets.

Xingjie Ni, Yong Zhao, Jian Yang in the year 2007 discussed about making of an underwater acoustic sensor using a pair of matched fiber Bragg grating and self-demodulation method present in it [6]. This device works on the principle of intensity modulation of laser light transmitting through and reflecting back from a pair of matched FBGs under influence of sound. This hydrophone had a cylindrical structure which solved the problem of low sensitivity and cross sensitivity of bare fiber Bragg grating acoustic sensor. The output of the acoustic signal detection device is directly proportional to the sound pressure applied. This structure provides greater sensitivity than bare Bragg grating. It uses a self demodulation method which handles sensing and demodulation as a whole. All these together make this a compatible and simple device to use.

Wentao Zhang, Yuliang Liu and Fang Li in the year 2008 published a paper titled as "Fiber Bragg grating hydrophone with high sensitivity" [5]. This paper discuss how this hydrophone used a copper hard core and rubber diaphragm as sensing element and to compensate the pressure a capillary tube was used at the end of the hydrophone. They have demonstrated a technique to enhance the pressure of a FBG hydrophone using diaphragm with a hard core as its centre. They showed when the young's modulus of a diaphragm is higher a flatter frequency is obtained [5]. This hydrophone obtained a three folds better sensitivity then the conventionally used PZT hydrophone.

Stefania Campopiano etal. in the year 2009 tested the two hydrophone sensors under water, one is a PZT and other is a fiber optic hydrophone coated with Damival [7]. Here it was a attempt to prove the superiority of FBG hydrophone over a PZT hydrophone because PZT hydrophone had already reached a great deal of development but compared to that the FBG hydrophone which was still a new but over all a cheap, low loss and better advanced technology. Both this technology was tested in similar condition and the FBG hydrophone proved as a worthy competitor for the traditional one. The FBG hydrophone provided a good sensitivity to the PZT one.

Nobuaki Takahashi, Kazuto Yoshimura etal. discussed about creating a hydrophone constructed with fiber Bragg grating based on the intensity modulation of laser light under the influence of acoustic or sound pressure. In the operation of the hydrophone the measured signal output is directly proportional to the sound pressure received by the hydrophone. This paper states the dynamic range of the hydrophone as of70 Db. It can operate in a wide range of acoustic frequency and measure amplitude and phase of an acoustic field in real time, at least from 1 kHz to 3 MHz [8]. No signal distortion was observed.

Zhi Zhong Li, Yuan Zheng, etal. discusses about how the low pressure sensitivity, low demodulation accuracy and fragile character of the hydrophone makes this wonderful low loss device incapable for application purpose. They presented an unsymmetrical structure which was different from the then axis symmetrical structure which was in capable of detection to broad range signal because of its low range sensitivity. By this small change in structure a greater sensitivity was obtained and also the problem of low pressure sensitivity and low demodulation accuracy was solved. As a result a much low frequency was detected then previous ones.

In the year 2011,Unnikrishnan Kuttan Chandrika, Venugopalan Pallayil etal. discussed that DFB hydrophone has been encapsulation with 3 different coating namely Fluid filled, Air filled Teflon and Resin molded. This encapsulations serves two purposes, first it improves the sensitivity and then isolates it from water. The air filled Teflon coating provided the most sensitivity improving the sensitivity by 15 to 20 dB over a band of frequency from 2 to 10 kHz [10]. But the noise floor of this device is quite high.

Massimo Moccia, Marco Consales, etal. published a paper in which three hydrophones were tested which is made up of different fiber Bragg grating coated with ring shaped polymer. The coating material were selected and designed specifically to provide mechanical amplification. Here this experiment not only puts emphasis on the type of material to be used but also on the dimension of the material [11].The material used here are

1. Damival sensor, with coating diameter and length of 5 and 40 mm, respectively
2. Araldite sensor, with coating diameter and length of 5 and 38 mm, respectively
3. Damival sensor, with coating diameter and length of 10 and 40 mm, respectively

Here it is also stated how an Araldite material works better at high frequency range(15-30 kHz) whereas the Damival based sensor works better in sensing at low frequency range(0-20 kHz) [11]. It is also stated that the cutoff frequency of the low pass filter decrease with increase in diameter.

Kenji Saijyou, Chiaki Okawara, etal. uses an interferometric hydrophone comprising a pair of fiber Bragg grating using a polarization maintaining fiber (PMF). This PMF was introduced to reduce the signal fading. Then they compared the conventional FBG hydrophone to the hydrophone using PMF [12]. The visibility of PMF FBG hydrophone remained almost constant when environmental condition was perturbed, unlike SMF FBG hydrophone. The noise level in PMF FBG hydrophone was very low compared to SMF hydrophone.

Shengye HUANG, Xiaofeng JIN, etal. uses an optical fiber hydrophone using equivalent phase shift fiber Bragg grating with temperature compensation package was used. This hydrophone provided large sensitivity at a wide range of frequency from 2.5 kHz to 12 kHz. From the regular FBG hydrophone this EPS FBG Hydrophone provides significantly higher acoustic pressure sensitivity [13].This hydrophone is temperature independent, provides isotropic response, is small in size and is highly sensitive. By using multiple equivalent phase shift (EPS) FBG hydrophones a very efficient array can be formed. By efficiently optimizing the metal material and packing size the sensitivity of a hydrophone can be efficiently altered.

CONCLUSION

The above discussion shows that all the research and development is not just as to increase the sensitivity of this device but also to make an overall more efficient hydrophone. Starting from the material that it is coated with, the dimensions of the hydrophone or the type of optical fiber in which the fiber Bragg grating is constructed all this parameter must be taken into account for an efficient hydrophone. This device has a lot of potential to be used in military and even for some other under water signal detection purposes. This device is best used as array which will provide us with a more precise location of the cause of the acoustic wave. The use of EPS optical fiber results in different level of output clarity. We also found that the use of Araldite material works best at high frequency, where as the use of Damival is better at low frequency. If both materials are used in an array we have a better chance of wide range frequency detection. To achieve betterment in output the noise levels are reduces by using PMF optical fiber. It can also be concluded from the above discussion the use of air filled Teflon increase the sensitivity and also the coating acts not only as a material to increase sensitivity but it also isolates it from the environment.

These kind of small adjustments are what are required to build a more sensitive device.

REFERENCES

[1] Huidong Li, Z. Daniel Deng and Thomas J. Carlson (2012):Piezoelectric Materials Used in Underwater Acoustic Transducers /Energy and Environment Directorate, Pacific Northwet National Laboratory, P.O. Box 999, Richland, Washington 99352, USA.

[2] Wolfgang R. HABEL and Katerina KREBBER (2011): “Fiber-Optic Sensor Applications in Civil and geotechnical Engineering”/ Photonic Sensors Vol. 1, No. 3:pp. 268–280.

[3] Thomas G. Muir, David L. Bradley (2016): Underwater Acoustics: A Brief Historical Overview through World War II/ Acoustics Today, fall, volume 12, issue 3:pp. 40-48.

[4] U Kuttan Chandrika, V Pallayil, KM Lim, CH Heng:DESIGN CONSIDERATIONS FOR A DFB FIBRE LASERBASED HIGH SENSITIVITY BROADBAND HYDROPHONE/ Proceedings of the 11th European Conference on Underwater Acoustics.

[5] Wentao Zhang, Yuliang Liu and Fang Li (2008):“Fiber Bragg grating hydrophone with high sensitivity”, CHINESE OPTICS LETTERS /Vol. 6, No. 9, pp. 631-632.

[6] Xingjie Ni, Yong Zhao, Jian Yang (2007):” Research of a novel fiber Bragg grating underwater acoustic sensor”, X. Ni et al. / Sensors and Actuators A 138 /pp. 76–80.

[7] Stefania Campopiano, Antonello Cutolo, Andrea Cusano, Michele Giordano, Giuseppe Parente , Giuseppe Lanza and Armando Laudati (2009):” Underwater Acoustic Sensors Based on Fiber Bragg Gratings”, Sensors, 9, 4446- 4454; doi:10.3390/s90604446.

[8] Nobuaki Takahashi, Kazuto Yoshimura, Sumio Takahashi, Kazuo Imamura(2000): “Development of an optical fiber hydrophone with fiber Bragg grating”/ N. Takahashi et al. / Ultrasonics 38/ pp.581–585.

[9] Zhi Zhong Li, Yuan Zheng, Wei Guo Dai and Yi Chuan Wang (2011): “A new underwater acoustic sensor based on fiber Bragg grating packaged with polymer material”/ Materials Science Forum Vols. 663-665/ pp. 926-929.

[10] Unnikrishnan Kuttan Chandrika, Venugopalan Pallayil, Chen Zhihao and Ng Jun Hong: “Development of a High Sensitivity DFB Fibre Laser Hydrophone – Work in Progress at National University of Singapore”/ Unnikrishnan K.C. et al.: Development of a high sensitivity DFB Laser Hydrophone.

[11] Massimo Moccia, Marco Consales, Agostino Iadicicco, Marco Pisco, Antonello Cutolo,Vincenzo Galdi, Senior Member, IEEE, and Andrea Cusano (2012): “Resonant Hydrophones Based on Coated Fiber Bragg Gratings”/ JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 30, NO. 15,2012.

[12] Kenji Saijyou, Chiaki Okawara, Tomonao Okuyama,Yasuyuki Nakajima and Ryotaku Sato (2012): “Fiber Bragg grating hydrophone with polarization maintaining fiber for mitigation of polarization-induced fading”/ Acoust. Sci. & Tech. 33,vol 4, pp.239-246.

[13] Shengye HUANG, Xiaofeng JIN, Jun ZHANG, Yi CHEN, Yuebin WANG, Zhijun ZHOU, and Juan NI (2011): “An optical fiber hydrophone using equivalent phase shift fiber Bragg grating for underwater acoustic measurement”/ Photonic Sensors Vol. 1, No. 3: pp. 289-294

[14] Nobuaki TAKAHASHI, Akihiro HIROSE and Sumio TAKAHASHI (1997): “Underwater Acoustic Sensor with Fiber Bragg Grating”/ OPTICAL REVIEW Vol. 4, No. 6/ pp. 691-694.