Fiber Bragg Grating in Biomedical Application

Arwa A. Moosa
Network Eng. Dep.
Al- Iraqia University
eng.arwa.amir@gmail.com

Abstract

The aim of this work is to use Fiber Bragg Grating (FBG) to detect the breast cancer at its earliest stages based on the Photoacoustic (PA) hybrid technique. The fiber Bragg gratings sensitivity to acoustic wave, effect of grating length, effect of grating refractive index modification, and ultrasonic frequency on the wavelength sensitivity and intensity sensitivity of the ultrasonic sensor (FBG) for ultrasonic waves were investigated using a simulation programs. A wavelength for the photoacoustic (PA) excitation laser was chosen with respect to a high absorption by the tumor and with low absorption to the surrounding tissue (normal tissue); for higher contrast absorption between them. Fiber Bragg can be used as a sensor to detect the acoustic wave emitted from the tumor (depending on the photoacoustic principle). In this study, k-wave a MATLAB toolbox was used to simulate photoacoustic wave which is detected with fiber Bragg grating simulation, using Optisystem program. The acoustic wave was transferred to FBG by using Optisystem-MTLAB communication programs to detect tumors.

Keywords: Fiber Bragg grating (FBG), lasers, Matlab Optisystem communication programs, Photoacoustic detection, and Pressure wave.

1 Introduction:

In the last decade, Fibber Bragg Grating have shown a great potential advantages in biomedical application [1], due to their prominent features such as their very small size, lightweight, , immunity to electromagnetic interference (EMI), and electrically neutral and can be easily embedded into a structure without having any effects on the mechanical properties of the structure of the object under investigation[2][3]. Fibber Bragg Grating used Photoacoustic (PA) detection technique ,to detect tumor existing, due to its ability of converting the absorbed energy exclusively into heat without generating PA signals caused by scattering particles[4]. Photoacoustic is a unique method that combine the contrast of light with the ultrasound resolution[5]. This technique is used in tumor detection due to its advantages of noninvasive nature and has high detection sensitivity and can detect small element size[6][7].

In this paper, FBG was proposed as a sensor to detect the acoustic wave emitted from the detect tumor. The response of FBGs to acoustic waves is theoretically analyzed first, and then simulation implemented ,in MATLAB and Optysystem programs, as FBG based sensors with its interrogation system. Using k-wave MATLAB Toolbox to simulate photoacoustic wave propagation in 2D, and then detect the acoustic wave by Fiber Bragg Grating by using Optisystem simulation.

2 Methodology:

2.1 Fiber Bragg Grating (FBG) Working Principles

The Fiber Bragg Grating (FBG) is a single mode fiber with a periodic modulation of refractive index (n) along its core[1][8] as shown in figure1. When a single mode optical fiber expose to intense ultraviolet light the reflective index of fiber core will increase, this exposure area will create a fixed index modulation that known as grating[9]. When use FBG is exposed to a particular wavelenght, part of light will be reflected due to the grating area has a period is approximately half the input light's wavelength, this reflected wavelength known as Bragg's wavelength (maximum reflectivity), as shown in the equation(1) [1][3][8]

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

Where $\lambda_B$is the Bragg grating wavelength in the free-space center wavelength of the input light that will be back reflected from the FBG, n_{eff} is the effective refractive index of the fiber core, and Λ is the FBG period. The other part of the light transmit through the fiber.

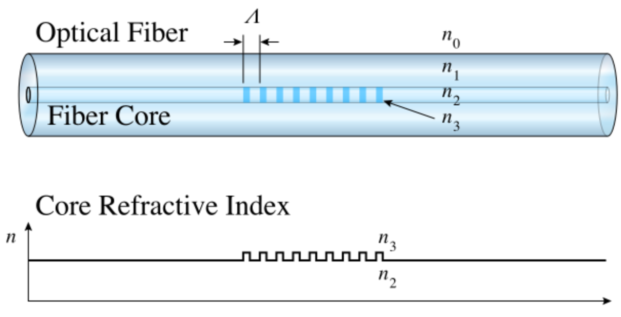


Figure 1: Fiber Bragg Grating structure

When photoacoustic wave impinging on the FBG, the Bragg grating wavelength will be shifted because of the reflective index and the period which modulated due to the mechanical strain in the fiber, elasto-optic effect, express as:[8][10]:

$$\frac{\Delta\Lambda}{L} = \frac{(1-2\nu)\Delta P}{E} \qquad (2)$$

$$\frac{\Delta n}{n} = \frac{n^2 \Delta P}{2E}(1-2\nu)(2P_{12}+P_{11}) \qquad (3)$$

Where E is Young's modulus and ν Poisson's ratio of the fiber, ΔP is the pressure variation that is caused by the photoacoustic pressure, and P_{12} and P_{11} are components of the strain-optic tensor for the fiber material.
Because of $\frac{\Delta L}{L} = \frac{\Delta\Lambda}{\Lambda}$ the spectral shift of the Fiber Bragg Grating becomes:

$$\Delta\lambda_B = \lambda_B \left[-\frac{(1-2\nu)}{E} + \frac{n^2}{2E}(1-2\nu)(2P_{12}+P_{11})\right]\Delta P \qquad (4)$$

Equation 4 shows that the spectral shift of the Fiber Bragg Grating is directly proportional to ΔP (acoustic pressure).

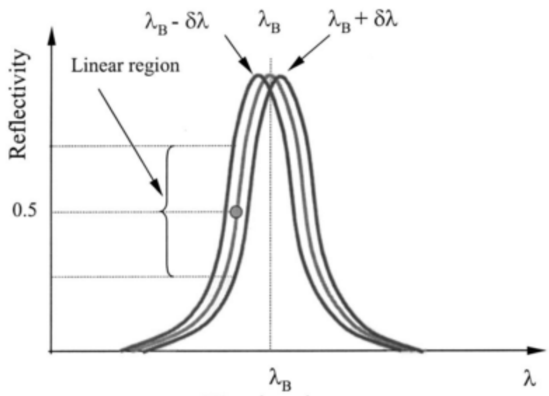


Figure 2: wavelengths Spectrum Shift in the FBG

2.2 Photoacoustic (PA) waves Principle

The photoacoustic (PA) principle is as shown in figure 3, pulse laser light is used to illuminate tissue with tumor in order to generate PA signal.
For the generation of photoacoustic signals.The succession of phenomena that occur after light exposure is shown in the following list:

1. Light absorption : The molecules, that absorb light, start vibrating, partly absorbed by object (like tumor)
2. Temperature rise: The vibration locally increases the temperature.
3. Thermoelastic expansion: Because of the thermoelastic effect, the heated area expands.
4. Acoustic emission: The surrounding tissue is correspondingly compressed and the pressure variation propagates away from the source

The generated pressure wave is then propagate through the surrounding tissue, which is finally detect by the FBG sensor.[11][12]

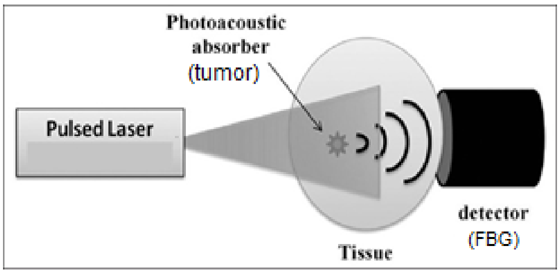


Figure 3: Photoacoustic principle

3 Design and Consideration

The system was simulated by using Matlab-Optisystem communication, first to generate the photoacoustic signal K-wave matlab toolbox was used. k-Wave is a free accessed MATLAB based simulation toolbox which provide the ability to simulate photoacoustic signal in time domain given the initial pressure distribution from the object target [13]. k-wave toolbox is freely available http://www.k-wave.org, used in this paper to simulate the 2D photoacoustic wave propagation from the object.

The sound speed in the simulation assumed to be 1570 m/s. For simplicity the medium was assumed as a homogeneous media and there was no absorption or dispersion of the wave signal. This wave was triggered to the optisystem program to fetch the system by the acoustic wave and then it will be detected by FBG sensor simulated in Optisystem program.

The Optisystem the system is operated with basic optical system which consist of Fiber Bragg Grating , CW laser, circulator, photodetector, oscilloscope, optical spectrum analyser, optical time domain visualizer, amplifiers, and Matlab component to communicate with Matlab program.

For the transmitted reflected detection (TRD) circuit a CW laser with 1550nm was utilized as the laser source. Light from the laser was then coordinated to the Fiber Bragg Grating via a circulator. The light transmitted through the FBG was then distinguished to one of the two photodetectors, while the light reflected was coordinated to the second beneficiary by means of the circulator. The yield of the two collectors was opened up utilizing an enhancer. In this work, amplifier with gain of 10 was used. Figure 4 shows the optoelectronic circuit, including the power supply, receivers, and amplifiers.

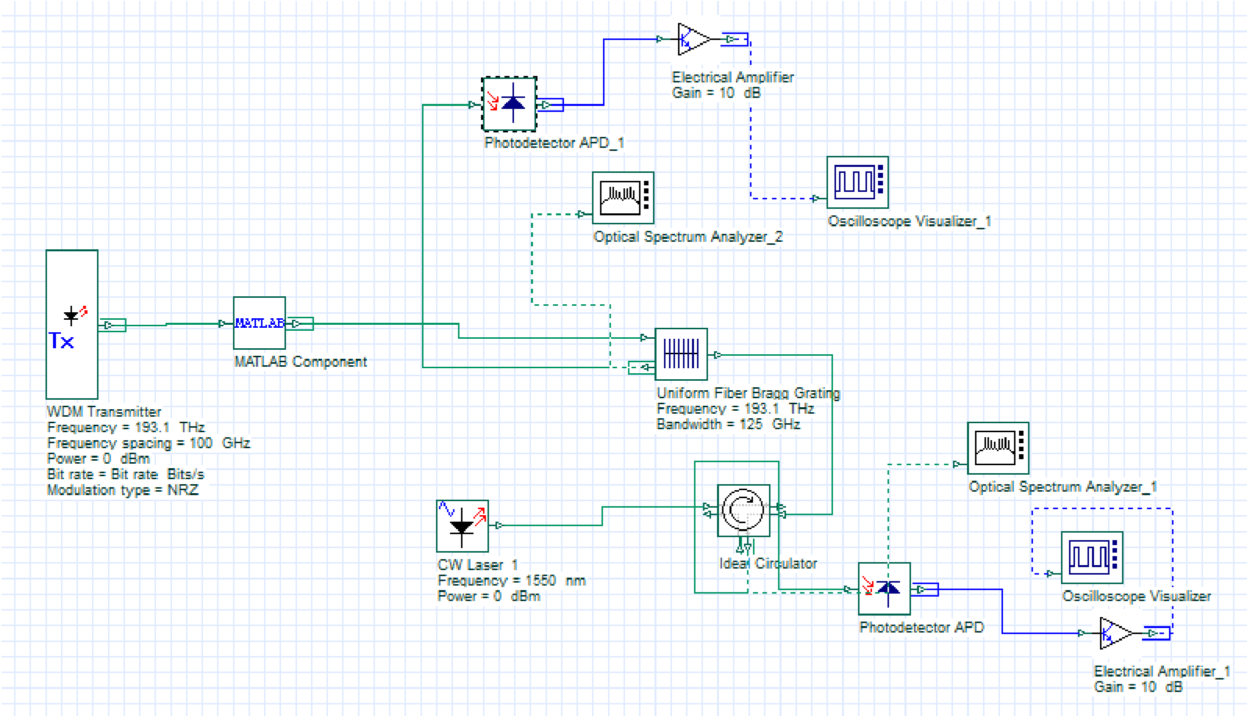


Figure 4: TRD system designed

The static strain sensitivity of Fiber Bragg Grating (FBG) sensor was measured by utilizing optical spectrum analyzer. The associated of oscilloscope and optical spectrum analyzer were utilized to record the applied stress, and the resultant strain created by the acoustic wave was displayed as shown in fig.(6).

4 Results and Discussions

The model described in figure (4) is a simulation of Fiber Bragg Grating system, which it's used to measure the reflection spectrum of Fiber Bragg Grating impinged by a pressure wave, given by (2), which allows us to study Fiber Bragg Grating performance and how it can be used as a sensor. This method improves the resolution and contrast of the reconstructed image.

The acoustic signal was generated by a numerical simulation in Matlab program as shown in figure 5.

K-wave MATLAB Toolbox was used to generate the photoacoustic wave in 2D as shown in figure 5.This wave was propagate in a circular shape due to it's a transverse mechanical wave type as shown in figure 6 and then its transfer to detect it by FBG.

The acoustic signal was transmit from the object and then propagate through the tissue. This wave is transmit to optisystem through Matlab component to detect by FBG which it also illuminate by 1550nm, with line width 10MHz CW laser, these signals were visualize using optical spectrum analyzer as shown in figure 7.

When laser light is incident in the FBG sensor part of light will be reflect (Bragg grating wavelength) and the other part will be transmit. The impinging of photoacoustic wave cause to shift the Bragg grating wavelength because of the mechanical strain effect as mention in equation (4). This amount of shift can be used to detect the tumor exist.

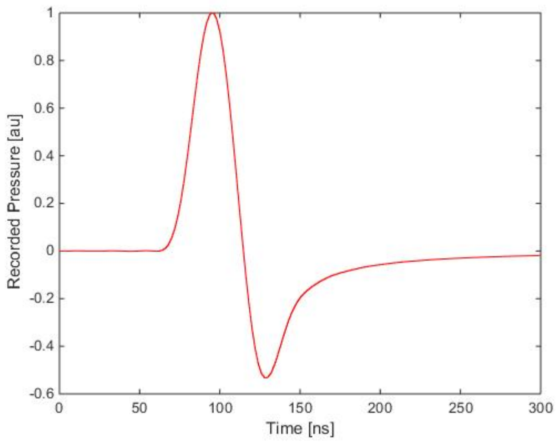


Figure 5: Photoacoustic signal

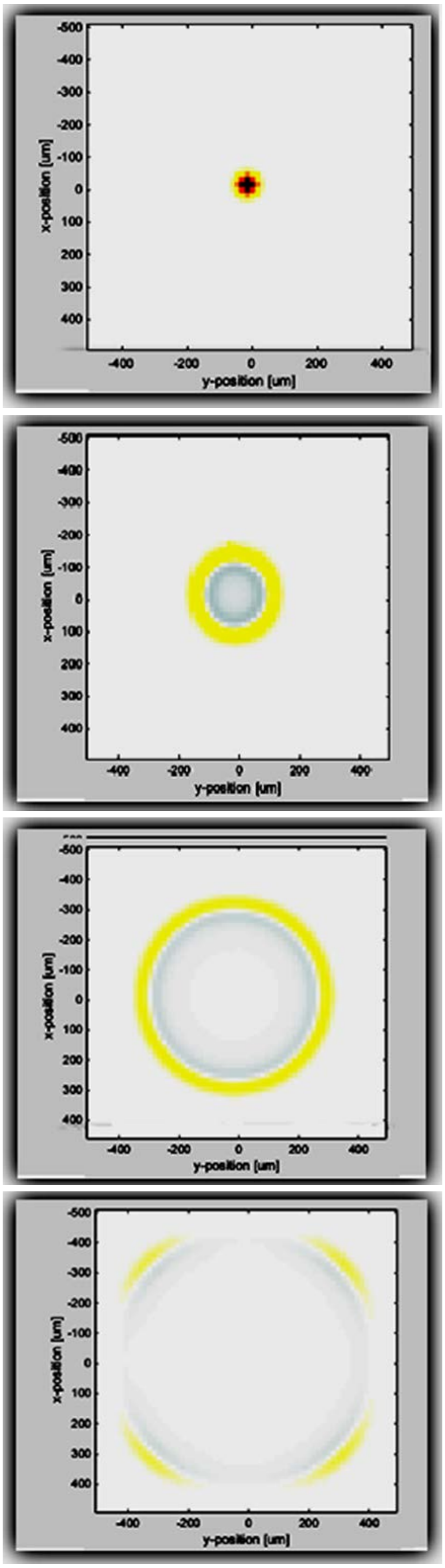
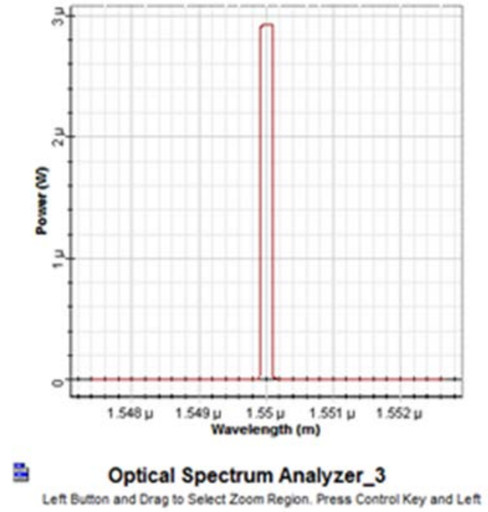
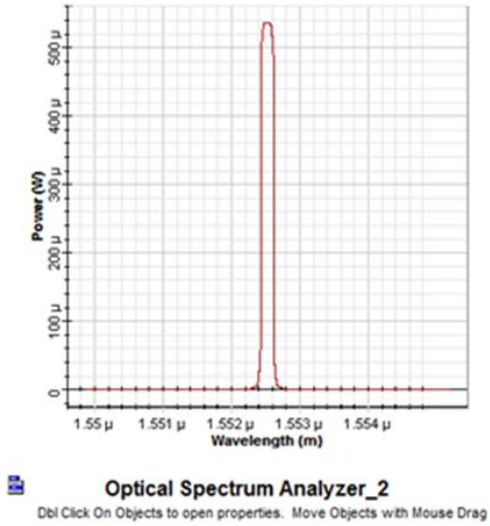


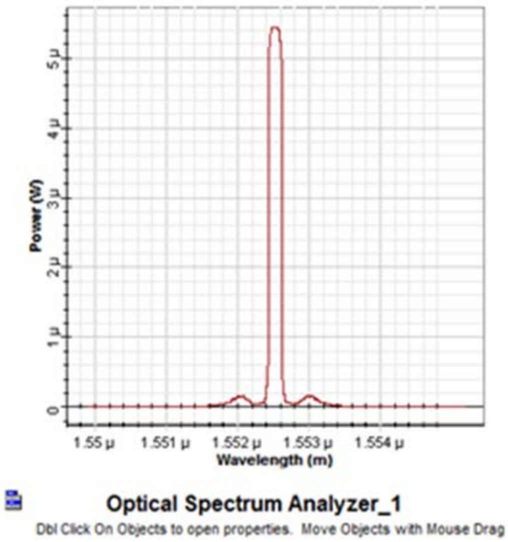
Figure 6: A 2D Photoacoustic signal generate in K-wave Toolbox



(a)



(b)



(c)

Figure 7: (a) Bragg grating wavelength in the free-space (b) Reflected spectrums (c) Transmitted spectrum of the FBG detected acoustic wave

5 Conclusion

In future work Fiber Bragg Gratings (FBGs) can be effectively utilized in an extensive variety of biomedical applications, one of them is tumor detection. From the experiments that have been performed and analyzed, the following conclusions have been deduced:

1. The laser used to illuminate the tumor should be in the NIR or visible range, due to its high absorption by tumor (full with blood).
2. It is a good way to use photoacoustic technique in tumor mass detection because it doesn't require surgical intervention , as well as , this project helps in the detection of breast tumor in its earliest stages.
3. Tumor existing can be detect by using FBG sensor, when photoacoustic wave impinging on the FBG, the Bragg grating wavelength will be shifted because of the reflective index and the period which will be modulated due to the mechanical strain in the fiber.
4. The Transmit Reflect Detection (TRD) system used in this project appeared to have an expanded sensitivity over the routine narrow bandwidth of the data transfer capacity and has a good dynamic resolution.
5. The FBG sensors will have a major role and gives effective responses for a wide assortment of usages in biomedical application, such as, tumor mass detection of this project .

6 References:

[1] E. Al-Fakih, N. A. Abu Osman, and F. R. Mahamd Adikan, "The Use of Fiber Bragg Grating Sensors in Biomechanics and Rehabilitation Applications: The State-of-the-Art and Ongoing Research Topics," *Sensors*, vol. 12, no. 12, pp. 12890–12926, 2012.

[2] T. Fink, Q. Zhang, W. Ahrens, and M. Han, "Study of π-phase-shifted, fiber Bragg gratings for ultrasonic detection," *Fiber Opt. Sensors Appl. IX*, vol. 8370, no. 7, pp. 1–7, 2012.

[3] G. Wild and S. Hinckley, "Optical Fibre Bragg Gratings for Acoustic Sensors," *Int. Congr. Acoust.*, no. August, pp. 1–7, 2010.

[4] A. Yarai and T. Nakanishi, "Fiber Bragg grating applied pulsed photoacoustic detection technique for online monitoring concentration of liquid," *J. Acoust. Soc. Am.*, vol. 123, no. 5, p. 3285, 2008.

[5] C. Li and L. V Wang, "Photoacoustic tomography and sensing in biomedicine," *Phys. Med. Biol.*, vol. 54, no. 19, pp. R59–R97, 2009.

[6] M. Xu and L. V. Wang, "Photoacoustic imaging in biomedicine," *Rev. Sci. Instrum.*, vol. 77, no. 4, p. 041101, 2006.

[7] J. Xia, J. Yao, and L. V Wang, "Photoacoustic Tomography : Principles and Advances," *Prog. eletromagnic Res.*, vol. 147, no. May, pp. 1–22, 2014.

[8] P. Fomitchov and S. Krishnaswamy, "Response of a fiber Bragg grating ultrasonic sensor," *Opt. Eng.*, vol. 42, no. 4, pp. 956–963, 2003.

[9] M. A. Othman, M. M. Ismail, H. A. Sulaiman, et.al., "An Analysis of 10 Gbits / s Optical Transmission System using Fiber Bragg Grating (FBG)," *IOSR J. Eng.*, vol. 2, no. 7, pp. 55–61, 2012.

[10] B. Barua, "E Valuate the P Erformance of O Ptical C Ross C Onnect Based on F Iber B Ragg G Rating Under D Ifferent B It R Ate," vol. 3, no. 5, pp. 123–136, 2011.

[11] L. Fieramonti, "Feasibility , Development and Characterization of a Photoacoustic Microscopy System for Biomedical Applications," no. September, p. 120, 2010.

[12] J. Horstmann, A. Baade, and R. Brinkmann, "Photoacoustic blood vessel detection during surgical laser interventions," *Med. Laser Appl. Laser-Tissue Interact. V*, p. 80920Z, 2011.

[13] B. E. Treeby, J. Jaros, D. Rohrbach, and B. T. Cox, "Modelling Elastic Wave Propagation Using the k-Wave MATLAB Toolbox," no. 5, 2014.

مشروع استخدام الياف الترشيح الضوئي في التطبيقات الطبية

اروى عامر موسى
قسم هندسة الشبكات
الجامعة العراقية

الخلاصة

الهدف من هذا العمل هو استخدام الياف الترشيح الضوئي مستقبلا للكشف عن سرطان الثدي في مراحله المبكرة على اساس استخدام التقنية الضوئي-الصوتي الهجينة. لقد تم التحقق من تحسس الياف الترشيح الضوئي وتأثير طول المرشح وتأثير تعديل معامل الانكسار وتأثير الموجات فوق الصوتية على متحسس الموجات (الياف الترشيح الضوئي) على حساسية الطول الموجي والشدة ،باستخدام برامج المحاكات. حيث تم اختيار محفز الليزر في العملية الضوئي-الصوتي بأعلى تباين بين المنطقتين ،على ان يكون اعلى امتصاص له في منطقة الورم (ان وجد) واقل امتصاص في المنطقة المحيطة (النسيج الطبيعي). ان الياف الترشيح الضوئي يمكن استخدامها مستقبلا كأجهزة استشعار للموجات المبعوثة من الورم بشكل تطبيقي (اعتماد على المبدأ الضوئي- الصوتي). في هذه الدراسة تم استخدام أدوات الكي- ويف (k-wave) لبرنامج المحاكاة المات لاب (Matlab) لمحاكاة الموجة الضوئية-الصوتية والتي تم الكشف عنها باستخدام الياف الترشيح الضوئي باستخدام برنامج المحاكاة الاوبتي سستم(Optisystem)، وقد تم نقل هذه الموجات الى الياف الترشيح الضوئي باستخدام برامج الاتصال بين المات لاب والاوبتي سستم (Optisystem).