Breast Cancer Detection Using Photoacoustic Imaging

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Abstract

This work is about a tumor detection using photoacoustic technique, the photoacoustic waves generation and detection in tissue phantom (liver in chicken breast) which used to representing the real tissue. The one dimensional photoacoustic signal was generated using Nd:YAG laser, detected using piezoelectric detector and displayed on a storage oscilloscope, the experimental work is done at Different depth, thickness and the distance to the detector for several phantoms and different laser energy 250,400 and 500 mJ.

***Keyword*:** Breast cancer, photoacoustic imaging, PA

الكشف عن سرطان الثدي باستخدام التصوير الضوئي- الصوتي

م.م. لمى وليد جميل

الخلاصة

هذا البحث للكشف عن الاورام باستخدام تقنية التصوير الضوئي الصوتي، ان توليد الموجه الضوئية الصوتية وكشف عنها في الخلية باستخدام نسيج تجريبي يستخدم لتمثيل الخلايا الحقيقة.الاشارة احادية البعد تولدة باستخدام Nd:YAG ليزر وتكشف باستخدام كاشف البيزو وتعرض باستخدام عارض الموجات، التجربة العملية تمت باستخدام عمق وعرض ومسافة مختلفة وطاقات مختلفة.

الكلمات المفتاحية **:** سرطان الثدي, التصوير الضوئي –الصوتي, الضوئي-الصوتي .

Introduction

Medical imaging is very important for medical diagnostics and research. There are so many medical imaging techniques, and some of them have weaknesses. For instances, x-ray computerized tomography is limited by the accumulation of ionizing radiation which are harmful to human body, ultrasound imaging is limited by its poor contrast and pure optical imaging techniques are unable to effectively visualize the structures several centimeters deep in the tissue due to the strong scattering of biological tissue etc [1].

A sound or stress wave is produced because of the thermoelastic expansion by absorption of short EM pulse that is induced by a slight temperature rise, typically in millikelvin range, as a result PA signal is emitted. The excited PA signal is locally determined by the EM absorption and scattering properties, the thermal properties, including the thermal diffusivity, thermal expansion coefficient, and the elastic properties of the sample [2].

The experimental work using a phantom to simulate a real tissue.

Theory

EM energy in the optical (from visible (400–700 nm) to near-IR (700–1100 nm)) and RF regions is used for PA excitation in soft tissues because the waves in these regions are nonionizing, safe for human and can provide the high contrast and enough penetration depths [1].

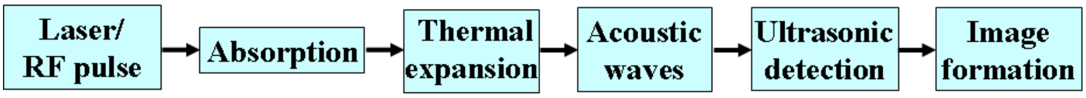

Figure (1): Schematic illustration of PA imaging

The optical absorption in biological tissues can be due to endogenous molecules such as Hb or melanin, or exogenously delivered contrast agents (exogenous Hb, for example). Blood usually has orders of magnitude larger absorption than surrounding tissues, so there is sufficient endogenous contrast for PA imaging to visualize blood vessels, for imaging *in vivo* subcutaneous vasculature (the arrangement or the distribution of blood vessels in an organ or body part) in small animals and human, monitoring tumor or cancer, mapping blood oxygenation, imaging functional brain, detecting skin melanoma (a malignant tumor of melanocytes which are found in skin, also in the bowel and the eye), monitoring of vascular damage during tumor photodynamic therapy [1].

Laser Tissue Interaction

When the laser light strikes a tissue surface, it can be reflected and refracted, scattered, absorbed or transmitted. The fractional intensity that goes into these different processes depends on the optical properties of the tissue like it is reflectivity, scattering and absorption coefficients, particle size, as well as the laser parameters like wavelength, energy, pulse duration, operation mode and output spectral profile [3].

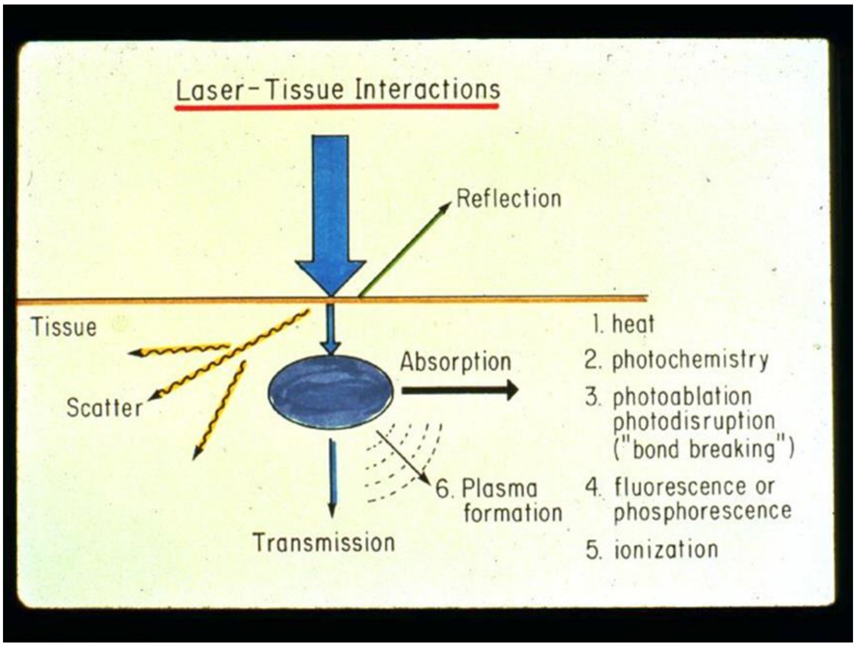

Figure (2): Laser-tissue interaction [4].

Two laws are frequently applied; they describe the effect of either the thickness or concentration on absorption, respectively. They are commonly Lambert's law and Beer's law (Beer-Lambert's law) and are expressed by:

$$I_{(z)} = I_{\circ} exp(-\mu_a z) \quad (1)$$

$$I_{(z)} = I_{\circ} \exp(-kcz) \quad (2)$$

Where, z is the optical axis, I_z is the intensity at a distance z, I is the incident intensity, μ_a is the absorption coefficient of medium, c is the concentration of the absorbing agent and k depends on the internal parameter other than concentration.

Photoacoustic Tissue Interaction

EM-pulse excited pressure acts as an acoustic source and initiates further acoustic wave propagation in three-dimensional (3D) space. In the low-megahertz frequency range, ultrasound in soft tissues has the properties of low scattering and deep penetration. The total attenuation results from the combined losses due to both absorption and scattering, while the scatter component accounts for about 10%–15% of the total attenuation. The attenuation of all tissues is temperature and frequency dependent. The frequency dependency of ultrasonic attenuation can be represented by the expression μ =*afb*, where μ is the ultrasonic attenuation coefficient, *a* and *b* are constants, and *f* is the frequency of ultrasound. A mean value of ultrasound attenuation equals ~0.6 dB cm−1 MHz−1 for soft tissues [2].

Acoustic Impedance is the resistance to travel that a sound beam encounters as it passes through a medium, such as human tissue. Just as velocity is dependent on density, so is acoustic impedance. The acoustic impedance is directly proportional to tissue density.

In human soft tissue, acoustic impedance is defined as the product of the density and velocity.

$$Z = \rho V \qquad (3)$$

Where Z: acoustic impedance, ρ: density of medium, V: velocity of sound. Slight difference in acoustic impedance between two tissues create an interface that will cause a portion of the ultrasound wave to be reflected [5].

This report is concerned with the thermoelestic production of sound in an optically absorbing medium. Is essence, thermoelestic sound is produced by the transient heating of a restricted volume by light energy. This condition is referred to as "stress confinement" and it requires that the optical irradiance, often done with a laser, occurs over a very short amount of time. More specifically, the laser pulse duration must be less than the amount of time needed for acoustic energy to propagate out of the area of absorption.

If the condition for stress confinement is met, and if the fluid is stationary with isotropic acoustic properties, the wave equation for acoustic pressure,

P, generated within the laser-irradiated volume is [6]:

$$\nabla^2 P(r,t) - \frac{1}{v^2}\frac{\partial''}{\partial t^2}\ P(r,t) = \frac{\beta}{c_p}\frac{\partial}{\partial t} H(r,t) \qquad (4)$$

Where H(r,t) is the heating function defied as the thermal energy deposited by the EM radiation per time per volume (υ-the speed of sound, β is the isobaric volume expansion coefficient, and c_p is the specific heat capacity). In general P and H depend on the positive r=(x,y,z) and time t. Instantaneous laser irradiation (denoted by the impulse function, $\delta(t)$, the heating function can be modeled as:

$$H(r,t) = H(r)\ \delta(t) \qquad (5)$$

Where: H(r) is the volumetric heat density, $\delta(t)$ is optical absorption depths.

Experimental work

The work will done using Q-Switch Nd-YAG laser consists of many parts and systems such as: light route system, power supply, control system and cooling system. The light route system is installed into the hand piece, while the other systems are installed into the machine box of power supply. Nd:YAG laser with power supply, control panel and hand piece are shown in figure 3.

This type of laser is used in medical applications for removing eyebrow and tattoos as is can penetrate into deep layers of the skin with wavelength 1064 nm, so it is easily absorbed by blue, black and green color pigment; therefore, it is very suitable to treat the pigment disease in the dermal layer.

While for wavelength 532 nm it can penetrate into superficial layers of the skin; therefore, it is very easily absorbed by the brown, red and deep-brown color pigment. For example, eliminating freckles, pigment spots and other light-color tattoos. Technical Specifications of a Q-Switched Nd:YAG laser are illustrated in table 1 [7].

Table 1: Nd:YAG laser Technical Specifications

Laser type	Q switch Nd: YAG laser
Laser wavelength	1064nm/ 532nm
Maximum pulse energy	1000 mJ
Pulse width	10 ns
Frequency	1-6 Hz
Display	Button Control Screen
Cooling method	Inner loop water cooling circuit with air cooled external heat exchanger
Power supply	AC220V/ 5A/ 50Hz

Figure (3): Nd:YAG laser

Piezoelectric detector (LDT1-028K) can be used for detecting physical phenomena such as vibration or impact, so that it was chosen for detecting the photoacoustic wave which was resulted from Nd:YAG laser after passing through the phantom. The piezo film element is laminated by a sheet of polyester (Mylar), and produces a useable electrical signal output when forces are applied to the sensing area. The dual wire lead attached to the sensor allows a circuit or monitoring device to process the signal as shown in figure 4 [8].

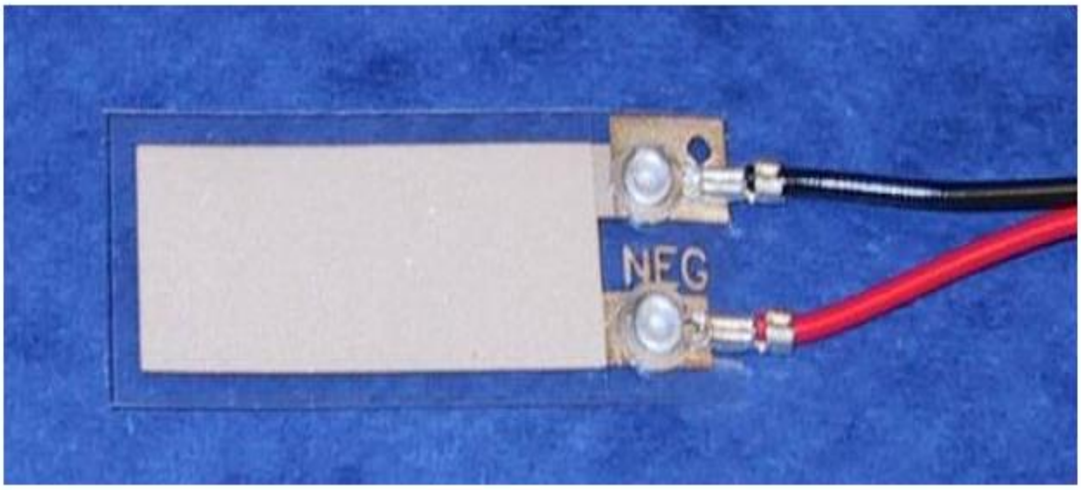

Figure (4): Piezoelectric Sensor (LDT1-028K) with lead attachment.

The Phantom

To demonstrate the ability of the photoacoustic imaging and provide one dimensional measurements of the object, several phantoms have been prepared of well-defined absorption structure. A sandwich of chicken breast (test sample simulating normal tissue) and piece of liver (test sample simulating blood vessel or tumor).

The liver was embedded within the chicken breast with different thicknesses and depths as listed in table 2.

Table 2: Different depth, thickness and the distance to the detector for several phantoms

Phantom	Depth (cm)	Thickness (cm)	Distance to detector (cm)
No.1	0.2	0.3	0.8
No.2	1	0.4	1.2
No.3	0.5	0.65	0.8
No.4	0.8	0.8	0.3
No.5	0.7	0.9	1.1
No.6	0.8	1.3	0.6

The distance between the phantom and the detector was varied with changing the thickness and the depth of the liver. The phantom which is used in the present work is shown in figure 5.

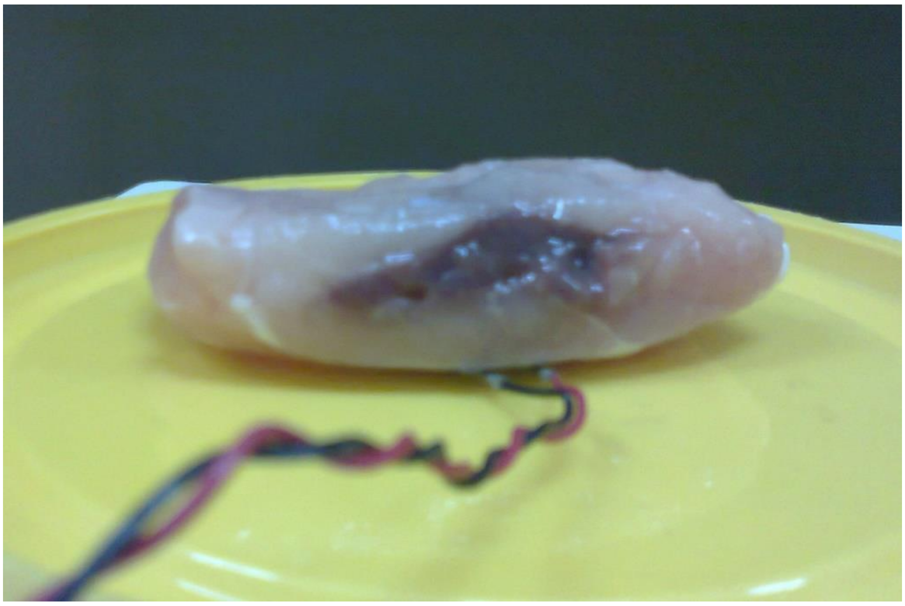

Figure (5): Phantom with liver inside it.

Storage Oscilloscope

Storage oscilloscope type PDS5022S (Portable Color Digital Storage Oscilloscope) has been used in this experiment to save the signal detected from the piezoelectric detector.

Photoacoustic Experimental Arrangement

In this arrangement, Nd:YAG laser with wavelength 1064 nm and different energies of 250, 400 and 500mJ was used to provide a photoacoustic wave which is consisted when the laser radiation is incident perpendicular to the bulk phantom and detector. The generated wave was detected using piezoelectric detector and the signal was displayed on the screen of the storage oscilloscope.

3. Experimental Results

This part presents the experimental results of the phantom shown in table 2 signals collected from the PA experiments performed on the phantoms explained in chapter3. These signals are time-domain voltage amplitude detected by the piezoelectric transducer that represents the acoustic pressure waves induced by the phantom.

Figure 6, 7 and 8 show a photoacoustic voltage signal with time of phantom no.1 which has 0.2 cm depth of target, 0.3 cm thickness of target and 0.8 cm distance to the detector at 500, 400 and 250mJ pulse energy respectively.

The peak amplitude of positive photoacoustic signal is 180mV, 150mV and 110mV respectively, the thickness measured from the signal is 0.4125 cm, 0.45cm and 0.4875cm.

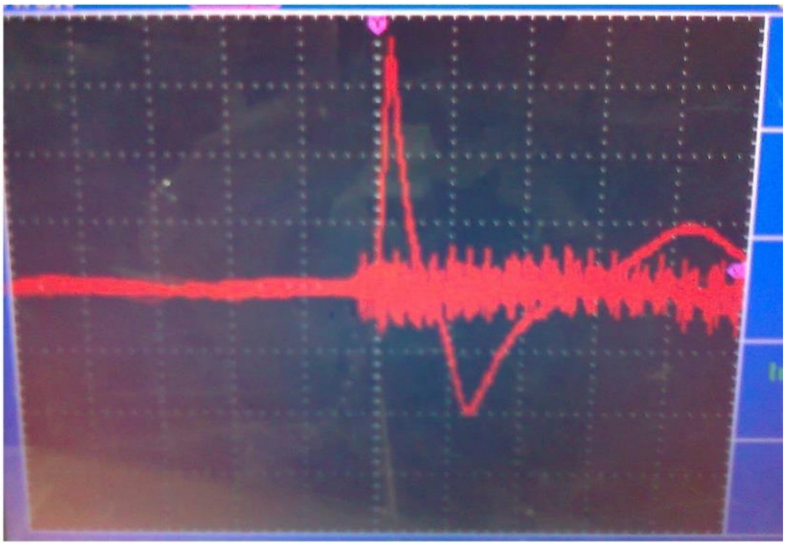

Figure (6): Voltage waveform resulting experimentally at 500mJ pulse energy of phantom no.1.

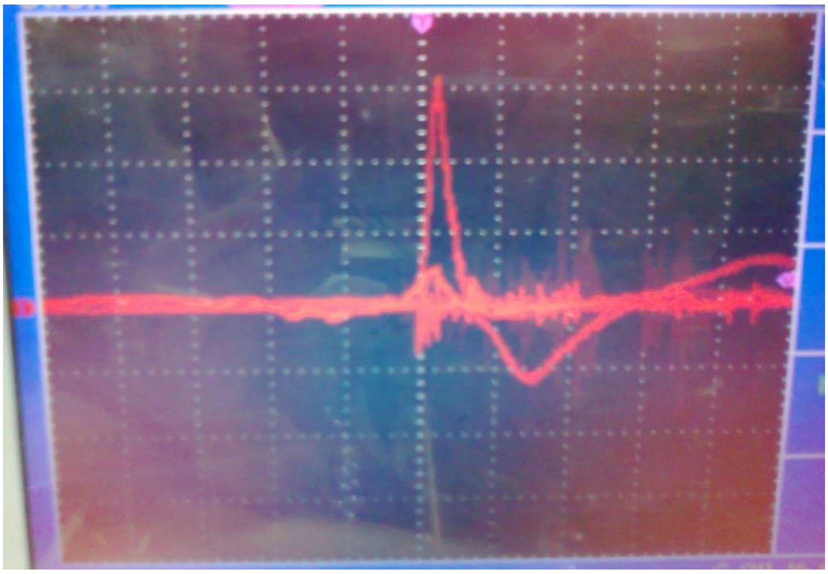

Figure (7): Voltage waveform resulting experimentally at 400mJ pulse energy of phantom no1.

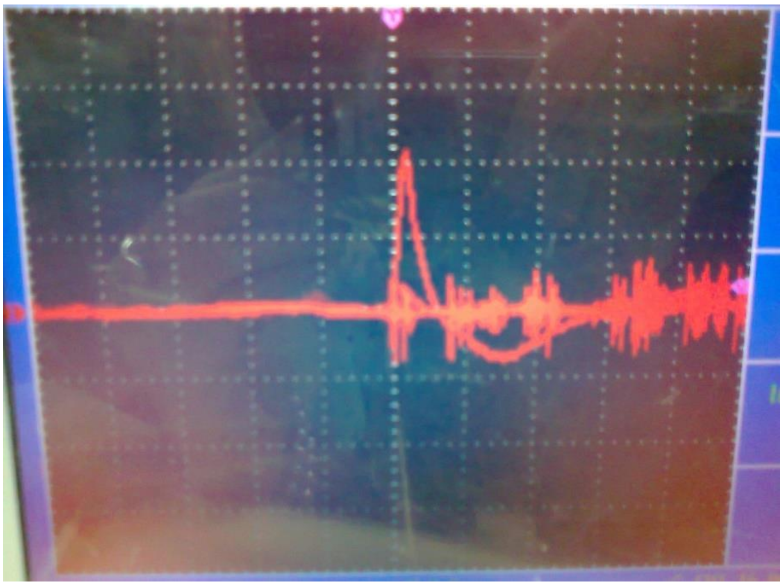

Figure (8): Voltage waveform resulting experimentally at 250mJ pulse energy of phantom no.1.

Figure 9, 10 and 11 show a photoacoustic voltage signal with time of phantom no.2 which has 1 cm depth of target, 0.4 cm thickness of target and 1.2 cm distance to the detector at 500, 400 and 250mJ pulse energy respectively.

The peak amplitude of positive photoacoustic signal is 200mV, 170mV and 160mV respectively, the thickness measured from the signal is 0.4875 cm and 0.56cm.

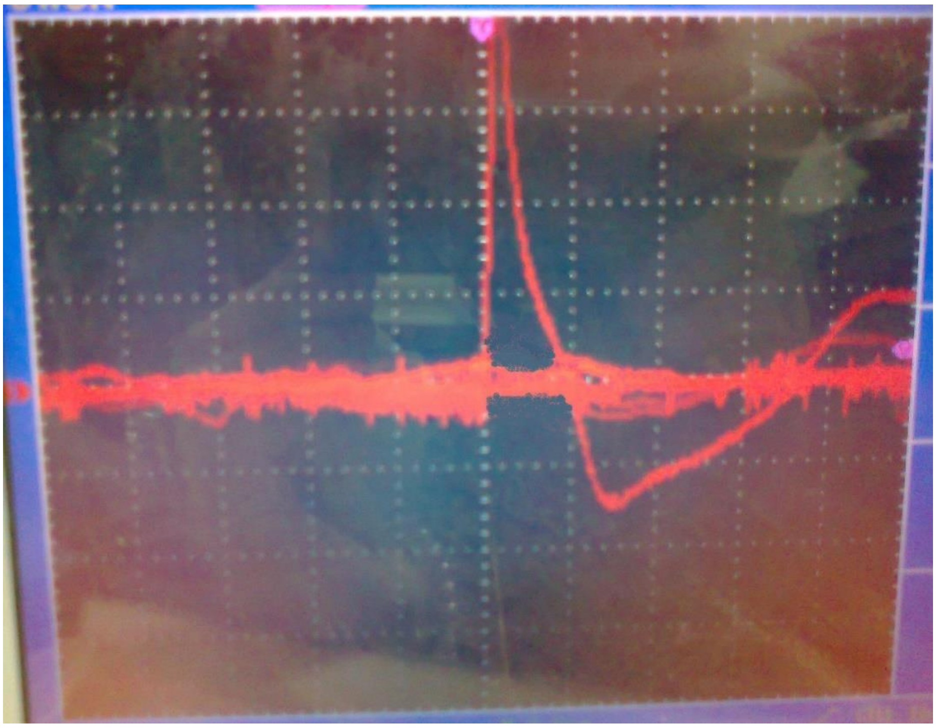

Figure (9): Voltage waveform resulting experimentally at 500mJ pulse energy of phantom no.2.

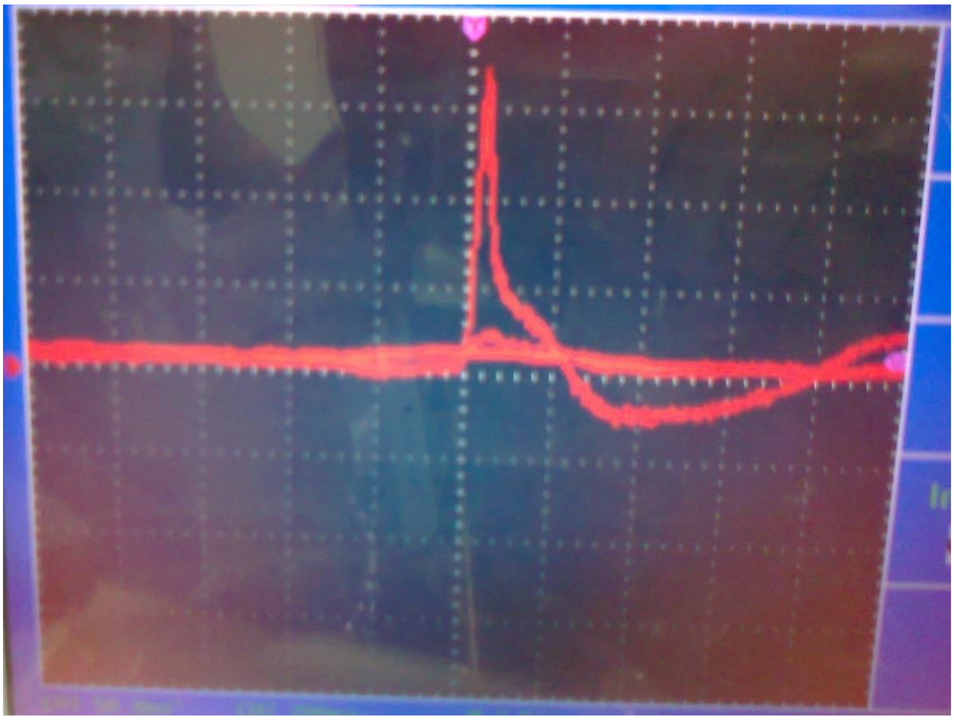

Figure (10): Voltage waveform resulting experimentally at 400mJ pulse energy.

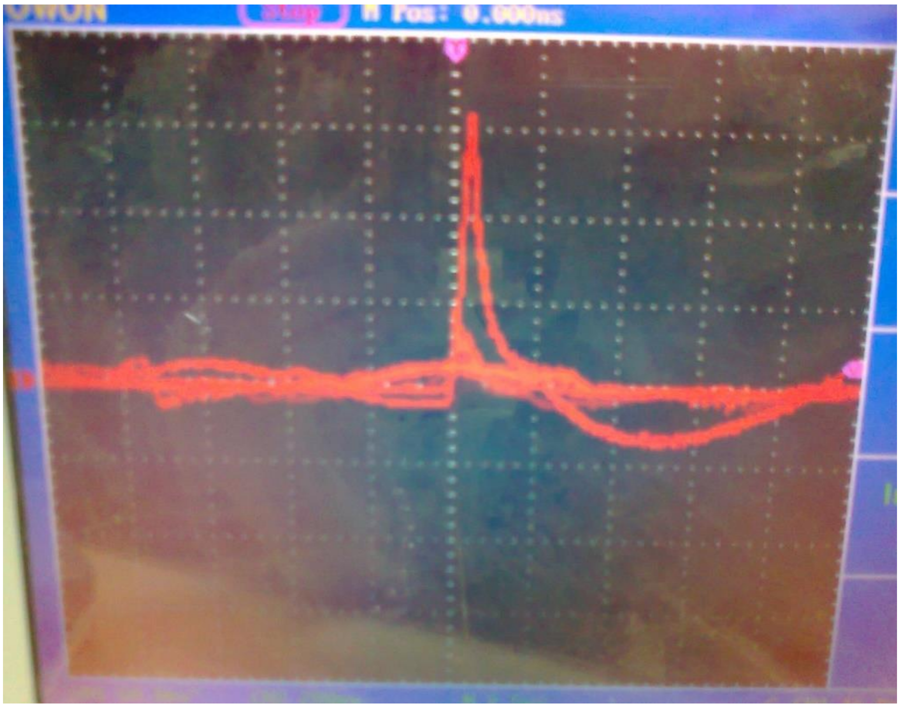

Figure (11): Voltage waveform resulting experimentally at 250mJ pulse energy.

Figure 12, 13 and 14 show a photoacoustic voltage signal with time of phantom no.3 which has 0.5 cm depth of target, 0.65 cm diameter of target and 0.8 cm distance to the detector at 500, 400 and 250mJ pulse energy respectively.

The peak amplitude of positive photoacoustic signal is 200mV, 110mV and 90mV respectively, the thickness measured from the signal is 0.45 cm, 0.675cm and 0.45cm.

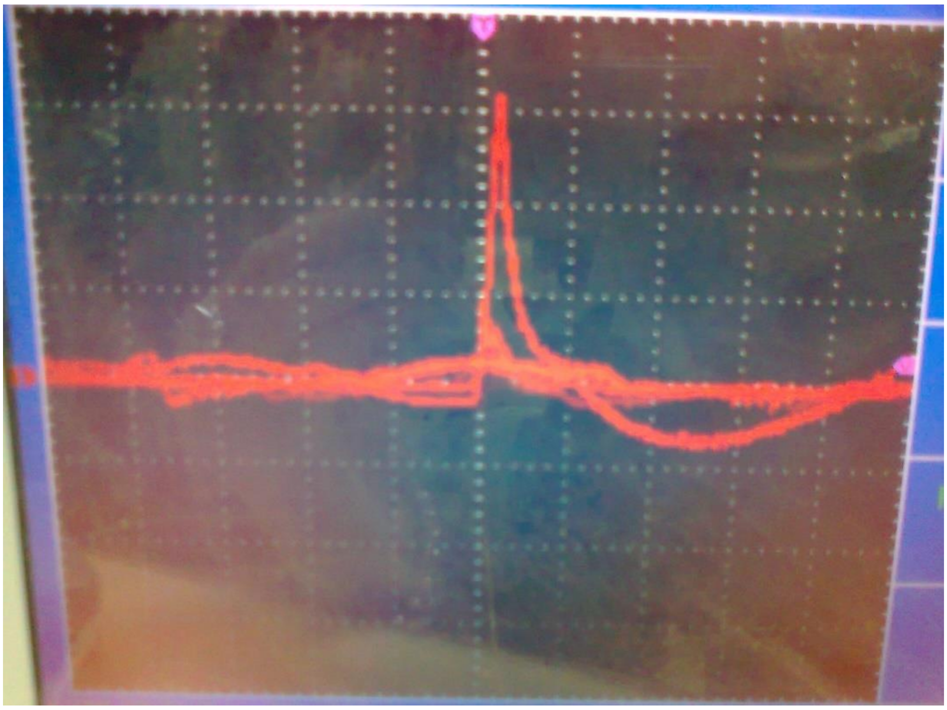

Figure (12): Voltage waveform resulting experimentally at 500mJ pulse energy.

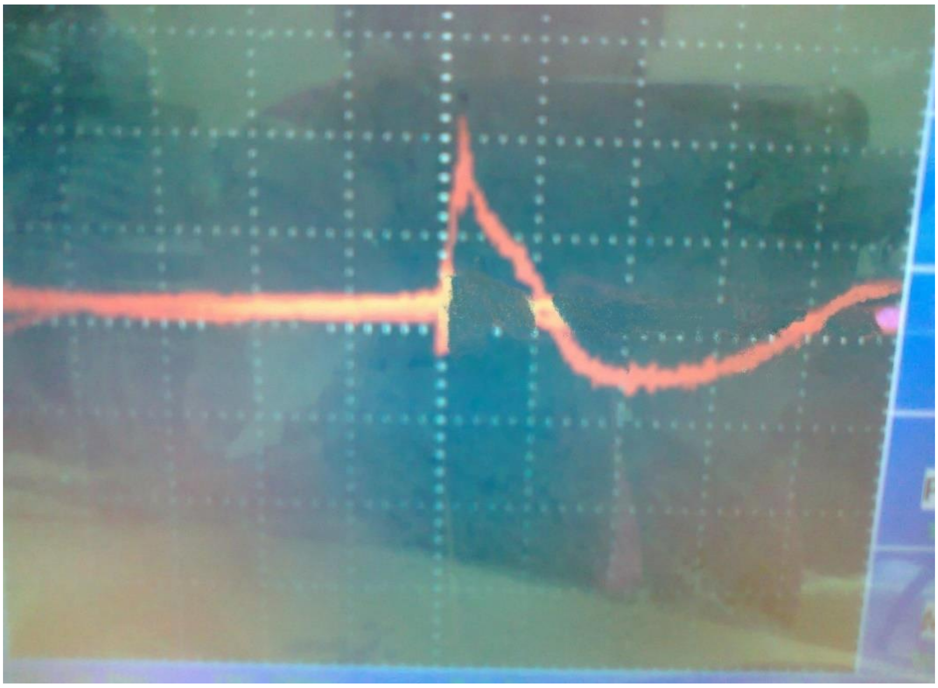

Figure (13): Voltage waveform resulting experimentally at 400mJ pulse energy.

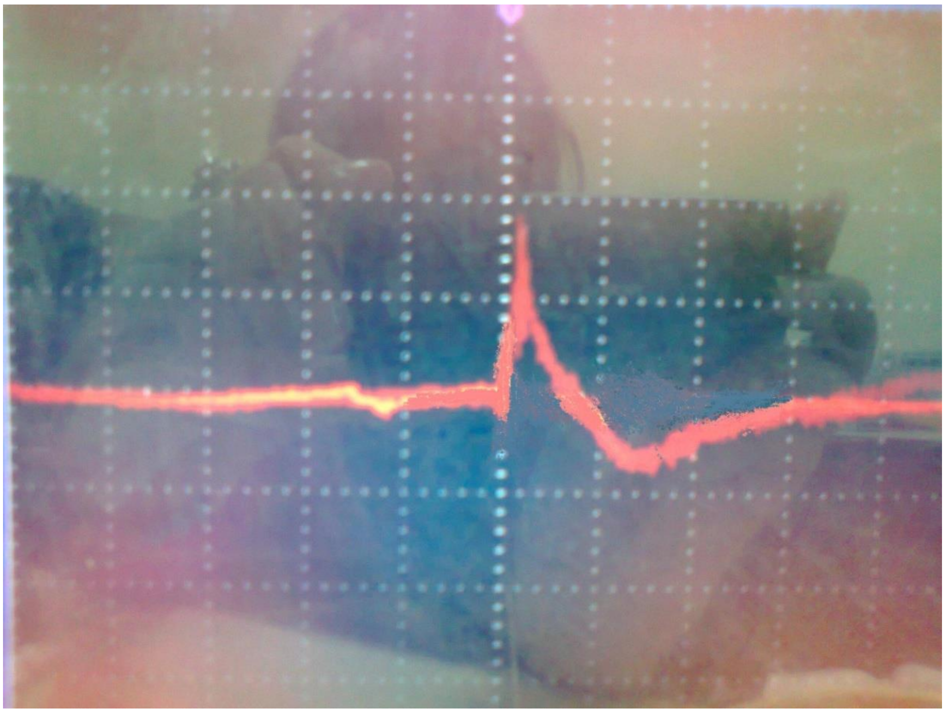

Figure (13): Voltage waveform resulting experimentally at 250mJ pulse energy.

Figure 14, 15 and 16 show a photoacoustic voltage signal with time of phantom no.4 which has 0.8 cm depth of target, 0.8 cm thickness of target and 0.3 cm distance to the detector at 500, 400 and 250mJ pulse energy respectively.

The peak amplitude of positive photoacoustic signal is 120mV, 90mV and 70mV respectively, the thickness measured from the signal is 0.675 cm, 0.405cm and 0.45cm.

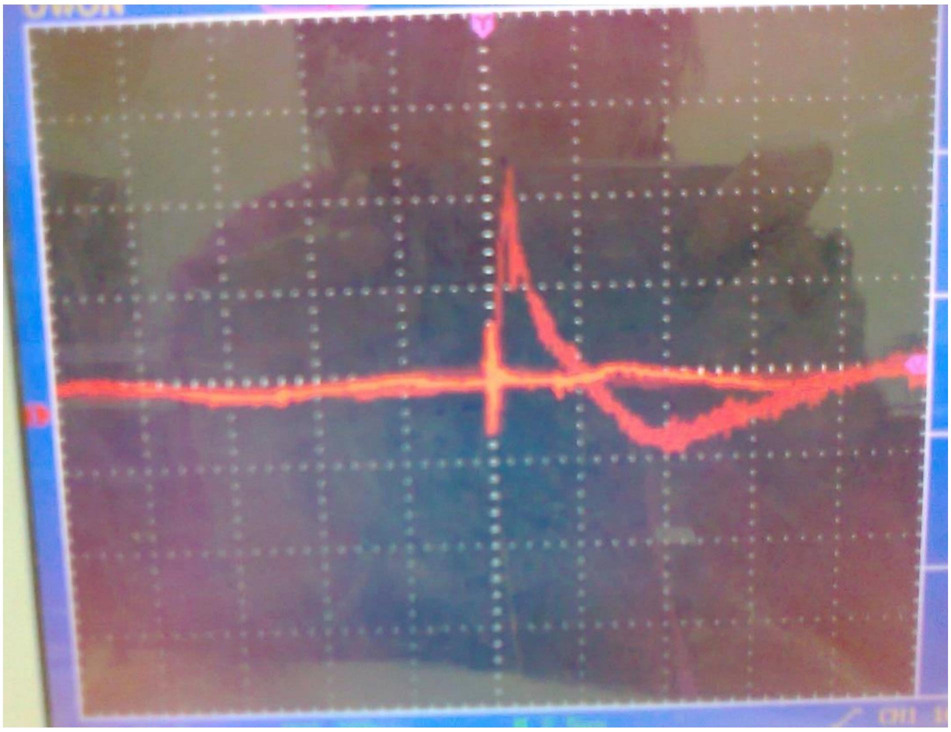

Figure (14): Voltage waveform resulting experimentally at 500mJ pulse energy.

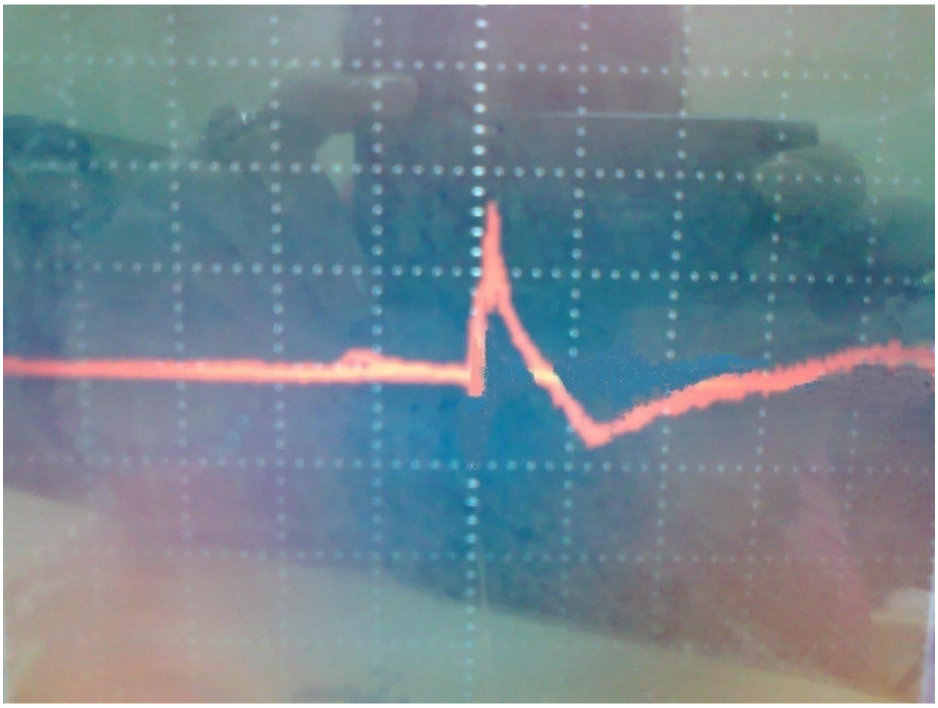

Figure (15): Voltage waveform resulting experimentally at 400mJ pulse energy.

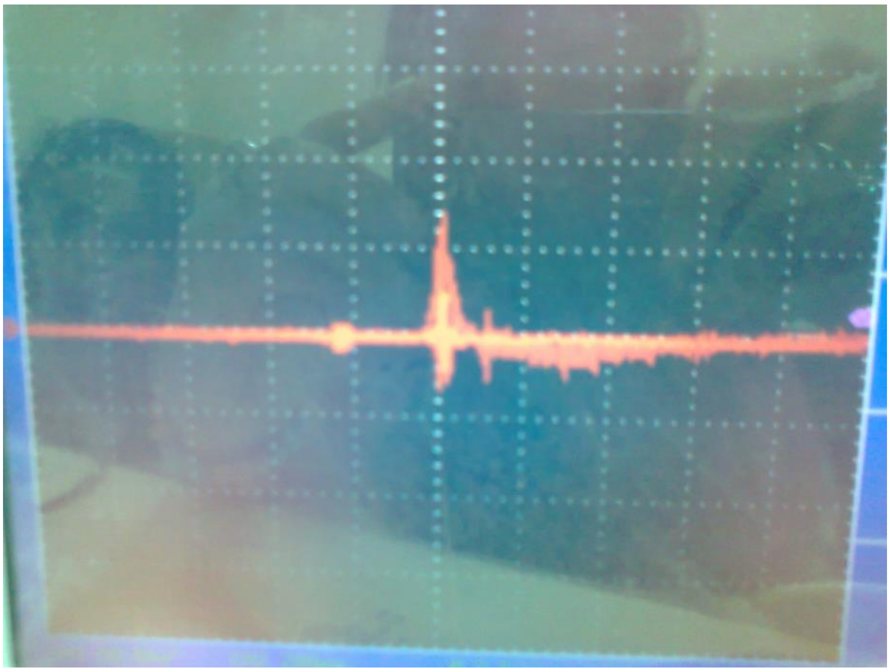

Figure (16): Voltage waveform resulting experimentally at 250mJ pulse energy.

Figure 17 and 18 shows a photoacoustic voltage signal with time of phantom no.5 which has 0.7cm depth of target, 0.9 cm diameter of target and 1.1 cm distance to the detector at 500 and 400mJ pulse energy respectively.

The peak amplitude of positive photoacoustic signal is 250mV and 180mV respectively, the thickness measured from the signal is 0.375 cm and 0.4125cm.

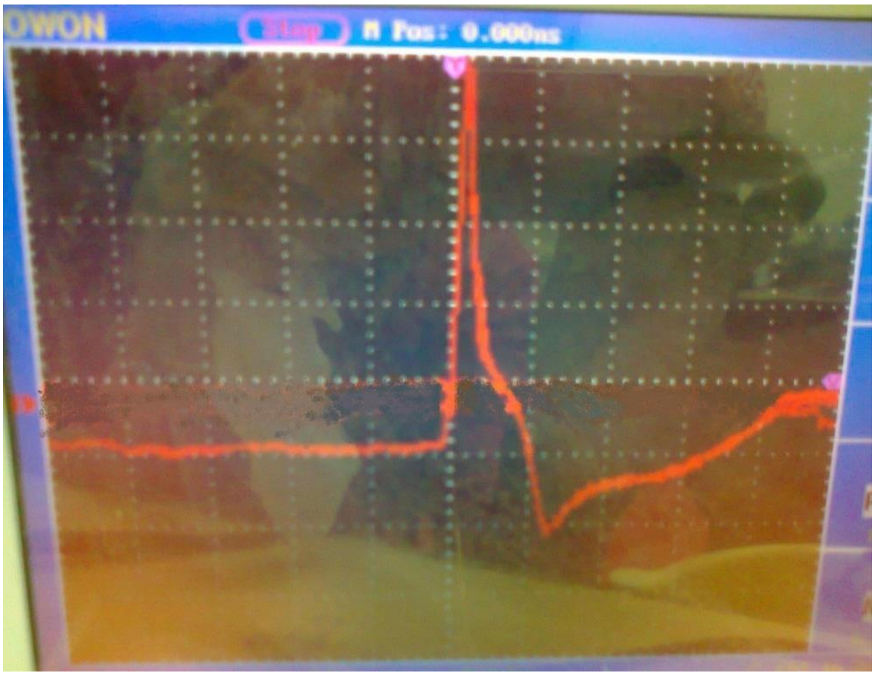

Figure (17): Voltage waveform resulting experimentally at 500mJ pulse energy.

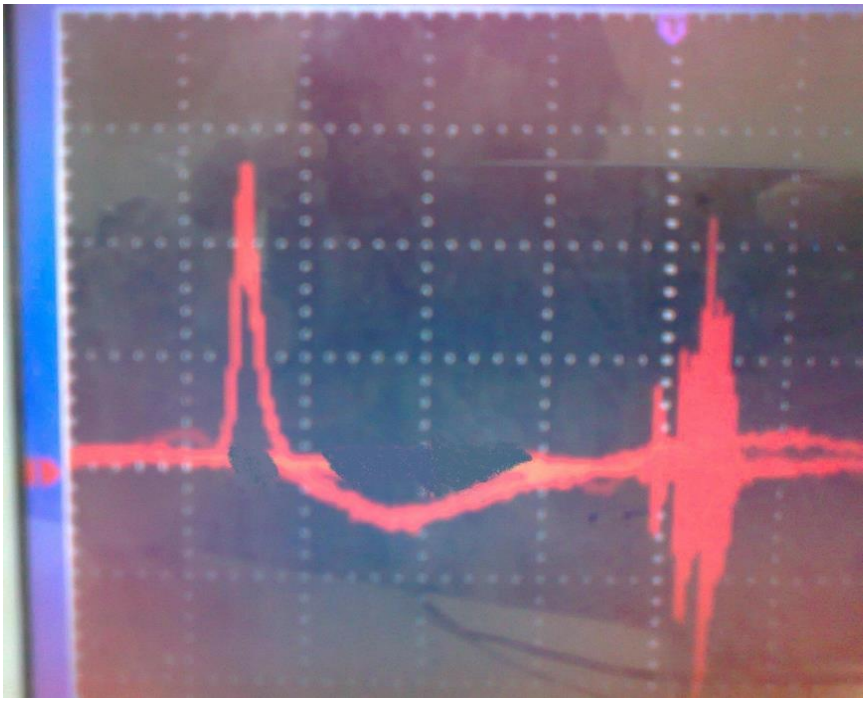

Figure (18): Voltage waveform resulting experimentally at 400mJ pulse energy.

Figures 19, 20 and 21 show a photoacoustic voltage signal with time of phantom no.6 which has 0.8 cm depth of target, 1.3 cm thickness of target and 0.6 cm distance to the detector at 500, 400 and 250mJ pulse energy respectively.

The peak amplitude of positive photoacoustic signal is 170mV, 140mV and 120mV respectively, the thickness measured from the signal is 0.5625 cm, 0.5625cm and 0.525cm.

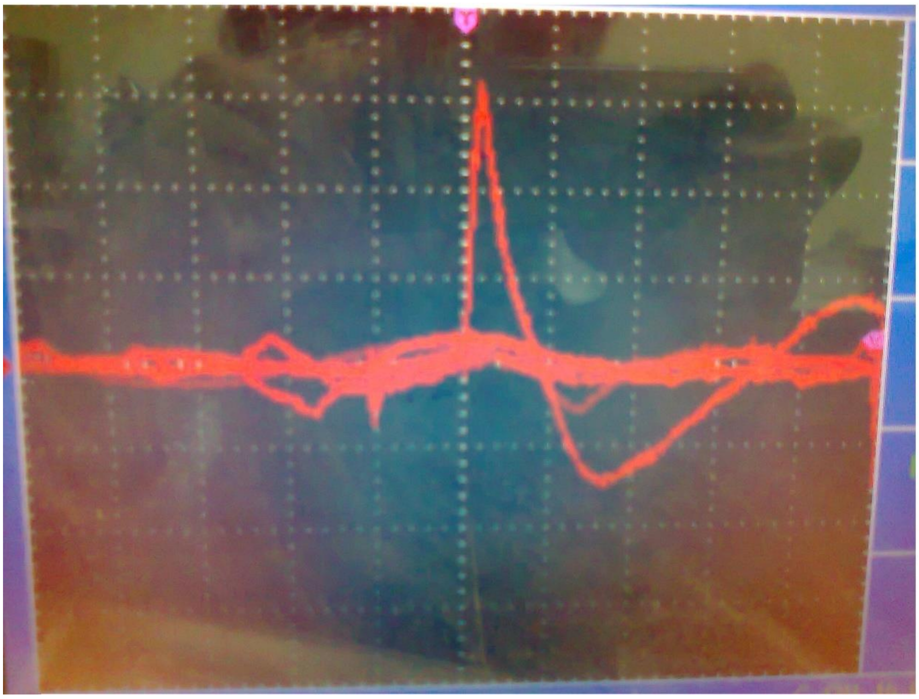

Figure (19): Voltage waveform resulting experimentally at 500 mJ pulse energy.

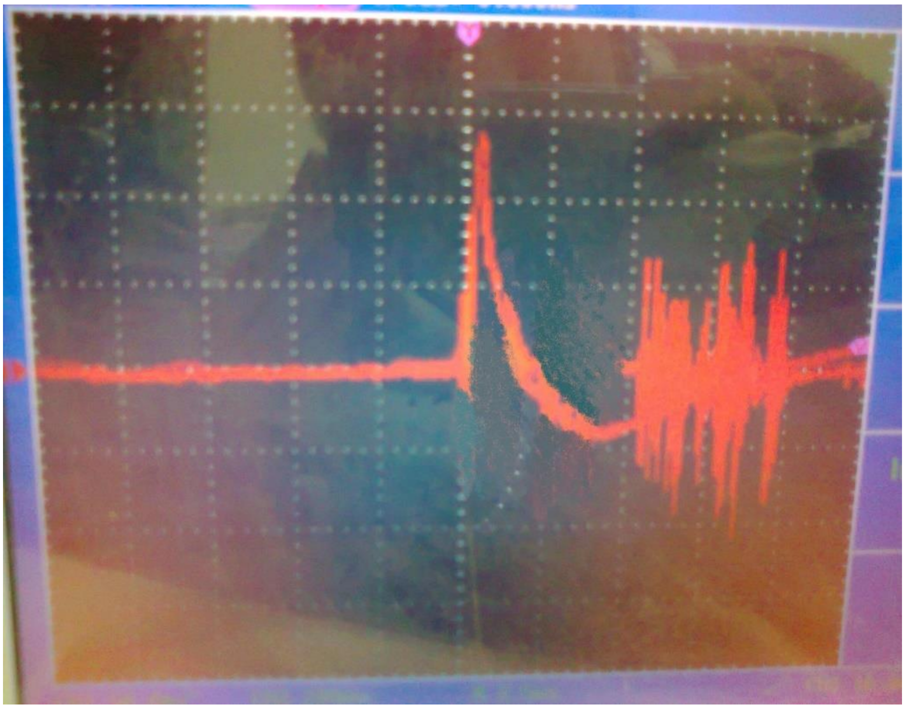

Figure (20): Voltage waveform resulting experimentally at 400mJ pulse energy.

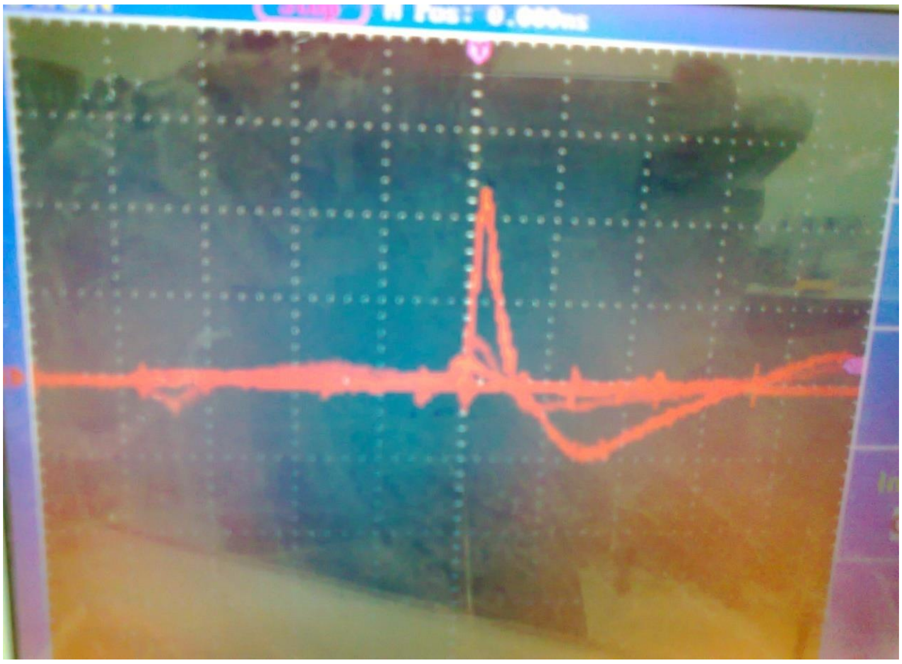

Figure (21): Voltage waveform resulting experimentally at 250mJ pulse energy

The amplitude of photoacoustic signal is linearly proportional to the laser pulse energy so the amplitude of signal has reduced when the pulse energy has decreased as shown in the results above.

The positive peak of the experimental results represents the absorption properties of the target and its amplitude is much larger than the negative peak which represents the acoustic wave generated from a short laser pulse which is must be shorter than the stress confinement time.

The second small positive peak in the figures represents reflection of acoustic wave by the walls of sample and it can be considered as noise. There are many noise sources which may affect the photoacoustic signal, the vibration of Nd:YAG laser, the noise from a digital oscilloscope and the noise comes from the coupling of the wire between the piezoelectric detector and the oscilloscope.

The photoacoustic signal amplitude as a function of depth can be used to measure the light attenuation, the effective attenuation coefficient of chicken breast tissue was fitted to 1.2 cm^{-1} based on Beer-Lambert's law. This light attenuation in chicken breast muscle is similar to that in some human tissues.

A long wavelength allows light to penetrate deeply with less attenuation, but it is not absorbed as great a degree as light with a shorter wavelength.

Conclusion

The acoustic signal in the experimental results has a larger amplitude for the positive peaks than the negative peaks. The time between the maximum positive peak and minimum negative peak is measured as the one-dimensional size of the liver piece. No consistent correlation has been done between the actual thickness and the measured from the experiment results for many reasons as that could be related to use a slab sample not a spherical one which is difficult to build and coupling in the breast chicken tissue, the coupling of the liver piece with the surrounding tissue, the coupling of the piezoelectric detector with the phantom, noise from the surrounding tissue (breast chicken) and other noise from laser, detector and oscilloscope.

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