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Sound Speed Measurement using Photoacoustic Effect

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ABSTRACT *A simple experiment is presented to show the photoacoustic effect, a well established but not widely known effect which has many applications. The photoacoustic effect consists of the generation of acoustic waves by pulsed radiation incident on a sample. In the present case, the Nd:YAG laser is used as a source of pulsed light for different samples in order to measure the speed of sound. The Nd:YAG laser is emitting nanosecond pulses in the infrared region of the spectrum (λ = 1064 nm). The acoustic waves generated on the surface of the samples travel through the material and are detected with a piezoelectric sensor. The electric signals are registered by a 100 MHz oscilloscope triggered by the light produced at the laser discharge. Knowing the thickness of the sample and the arrival time of the acoustic wave we can precisely measure the speed of sound.*

Introduction.

The speed of sound c is a characteristic property of a material, dependent on the thermodynamic variables of temperature (T), pressure (p) and density (ρ). The theoretical value for the speed of sound in air at 0^0C is: c=331.6 m/s.

The theoretical prediction of the speed of sound for liquids and solid materials is considerably more difficult than the gases. However, it is possible to show theoretically that for longitudinal waves on bars the speed of sound is expressed by [1]: $c=\sqrt{(Y/\rho)}$

where Y is Young´s modulus or modulus of elasticity, characteristic of the material.

The photoacoustic effect was discovered by A. Bell [2] in 1880 and consists in the generation of sound waves in a material caused by the excitation with pulsed or modulated light.

In the case of using pulsed lasers, ultrasonic waves are generated, and can be detected with piezoelectric transducers. In the present experiment this technique is used to characterize properties of diverse materials. An immediate application is to measure the speed of the sound in different materials such as metals, polymers, inorganic materials, and material compounds applying a photoacoustic method [3-5].

Currently, there are many diverse techniques based on the photoacoustic effect and it is one of the more active researches and technological development areas.

The main idea of this work is to present a simple experiment, using the photoacoustic effect to measure the speed of sound in solid materials. This experiment can be accomplished at the undergraduate level and with a low budget.

Photoacoustic Method.

The photoacoustic technique using pulsed lasers has become a new experimental tool for material characterization. This technique uses a mechanical wave generated on the surface of the material that travels at the speed of sound and is detected by using a piezoelectric transducer. The important advantages of this method are that special sample preparation is not required and no signal amplification is required due to the high signal to noise ratio obtained with piezoelectric transducers.

In photoacoustic experiments the interaction between the laser beam and the lattice produces an acoustic signal PA (t) which contains phenomenological information of the material. PA refers to the photoacoustic nature of the signal, and the index t indicates that PA is function of time. Once the signals are displayed on an oscilloscope, it is possible to measure the arrival time, or, they can be mathematically treated to extract the important physical information to obtain for example, phase transitions if the experiment is performed with a temperature variation [6-9].

As the photoacoustic signal is generated on the surface of the sample, and travels at the characteristic speed of sound of the material, we only need to know the thickness of the sample and the time required to travel in it.

Experimental Setup.

Figure 1 presents an experimental scheme for the photoacoustic method where the Nd:YAG laser is used to excite a sample coupled to a piezoelectric sensor. Figure 2 shows a picture of the setup of the experiment. The transducer is also easy to build and a schematic diagram is presented in figure 3. Figure 4 shows a typical signal obtained. The oscilloscope was triggered by the photo detector with an extent of about ms. Figure 5 shows the samples for which the speed of sound was measured.

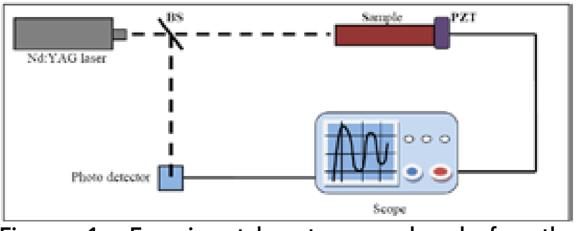

Figure 1. Experimental setup employed for the photoacoustic technique. BS= beam splitter, PZT = piezoelectric sensor

It is necessary to ensure that the acoustic signal measured is synchronized with each pulse of the laser. Therefore, a photo detector is used that sensed part of the laser light through a beam splitter, and was connected to one of the channels of a 100 MHz oscilloscope as a trigger source. This reference signal will be the zero in time with respect to the arrival of the acoustics signal.

To decouple the noise from the acoustic signal, thick samples can be used But depending on the kind of material, the attenuation may be strong.

The acoustic coupling is very important for an efficient transmission of the acoustic energy. So it is recommendable to attach the sample and the transducer together.

The amplitude of the acoustic signal is directly dependent of the energy and depends on the absorption coefficient as ($1-10^{-A}$), where A is the optical absorbance of the sample. So, high absorption assures high amplitude. If the front side of the sample reflects the laser wavelength, painting in black allows signal amplitude enhancement.

Figure 2: The setup of the experiment.

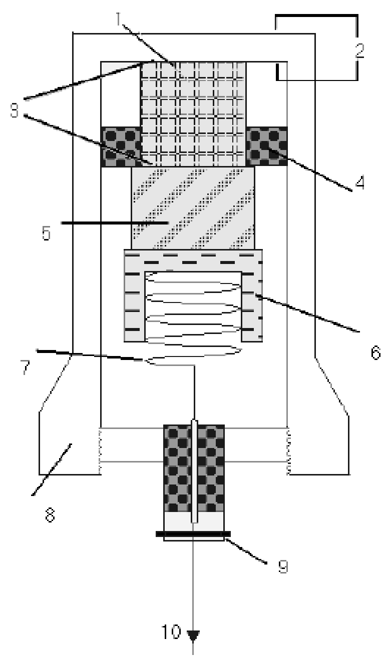

Figure 3: Scheme of microphone: 1) piezoelectric (PZT), 2) polished surfaces, 3) silicon grease, 4) hoop of Teflon^{TM}, 5) lead 6) copper, 7) spring, 8) stainless steel, 9) BNC connector, 10) to oscilloscope.

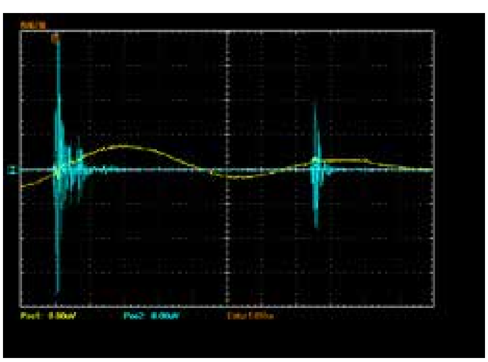

Figure 4 shows a typical signal obtained. The oscilloscope was triggered by the photo detector as explained before, with an extent of about μs.

Figure 5: Samples for which the speed of sound was measured. 1)Fe, 2)Al, 3)Cu, 4,5)hard bone.

Table 1 shows the arrival times measured, obtained by averaging several pulses together with the thickness of the samples and the calculated speed of sound and the reported values found in the literature.

It could be observed that the agreement for inhomogeneous organic materials is quite good. The hard bone has a small error (about 3 %), due to the fact that it has good absorption properties in the IR, giving a high acoustic signal amplitude. The maximum deviation is presented for iron where we have an error of 3.77% since its absorption properties in the IR is not very good. The Copper presents a smaller error (less than 0.76%) and that for Aluminum is about 1.3%.

Table 1. Results of Photoacoustic measurements.

Material	Thickness [mm]	Arrival time [s]	Calculated speed of sound [m/s]	Literature speed of sound [m/s]
Copper	42.5 mm	10.6e-6	3728	3700
Aluminum	50.0 mm	10.3e-6	5165	5100
Hard bone	15.5 mm	6.3 e-6	2552	2724
Harder bone	38.5 mm	10.5 e-6	3944	4080
Iron	35.0 mm	8.4 e-6	4937	5130

For these experiments it is only important to measure the thickness of the sample from the laser spot to the transducer, therefore thickness and size of the sample are not important. In these experiments three homogeneous materials were employed (Copper, Aluminum and Iron in a cylindrical shape) and two inhomogeneous organic materials (two types of hard bone, one of them is softer, in an irregular form). In the case of the inhomogeneous materials, it is necessary to take into account the laser spot diameter. The spot must illuminate a broad area of the sample in order to obtain a global average of the sound speed in this material.

Conclusions.

The present method is a photoacoustic versatile tool to measure the speed of sound in different materials to generate the acoustic signal. Good results were obtained in the determination of the arrival times of the photoacoustic signals for both homogeneous inorganic and inhomogeneous organic materials.

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