WEB OF SCIENTIST: INTERNATIONAL SCIENTIFIC RESEARCH JOURNAL
ISSN: 2776-0979, Volume 3, Issue 6, June, 2022

A METHOD FOR MEASURING THE PIEZOELECTRIC EFFECT ON A MICHELSON INTERFEROMETER

A. I. Mamadjanov
Teacher of Physics Namangan Engineering-Construction Institute,
Uzbekistan, Namangan, Islam Karimov Street 12

M. N. Izatullayeva
Magister, Namangan State University, Uzbekistan, Namangan, Uychi Street 316,
Teacher of Fisic at the School Number 6, in Kasansay District

Introduction

In 1880, the brothers Jacques and Pierre Curie discovered that when certain natural crystals were compressed or stretched, electric charges appeared on the crystal faces. The brothers called this phenomenon “piezoelectricity” (the Greek word “piezo” means “press”), and they themselves called such crystals piezoelectric crystals. As it turned out, tourmaline, quartz and other natural crystals, as well as many artificially grown crystals, have a piezoelectric effect. Such crystals regularly add to the list of already known piezoelectric crystals [1]. When such a piezoelectric crystal is stretched or compressed in the desired direction, opposite electric charges arise on some of its faces, which have a small potential difference.

If, however, interconnected electrodes are placed on these faces, then at the moment of compression or stretching of the crystal, a short electrical impulse will appear in the circuit formed by the electrodes. This will be a manifestation of the piezoelectric effect. At constant pressure, such an impulse will not occur. The inherent properties of these crystals make it possible to manufacture precise and sensitive instruments [2].

The piezoelectric crystal has high elasticity. When the deforming force is removed, the crystal, without inertia, returns to its original volume and shape. It is worth making an effort again or changing the one already applied, and it will immediately respond with a new current pulse [3]. It is the best recorder of very weak mechanical vibrations reaching it. The current strength in the circuit of an oscillating crystal is small, and this was a stumbling block at the time of the discovery of the piezoelectric effect by the Curie brothers.

In modern technology, this is not an obstacle, because the current can be amplified millions of times. Now some crystals are known that have a very significant piezoelectric effect. And the current received from them can be transmitted over wires over long distances even without prior amplification[4].

Piezoelectric crystals have found application in ultrasonic flaw detection, to detect defects inside metal products [5]. In electromechanical converters for radio frequency stabilization, in multi-channel telephone communication filters, when several conversations are carried out simultaneously on one wire, in pressure and gain sensors, in adapters, in ultrasonic soldering - in many technical fields, piezoelectric crystals have taken their unshakable position.

An important property of piezoelectric crystals turned out to be the inverse piezoelectric effect. If charges of opposite signs are applied to certain faces of a crystal, then the crystals themselves will be deformed. If you impose electrical vibrations of sound frequency on a crystal, it will begin to oscillate with the same frequency, and sound waves will be excited in the surrounding air. So the same crystal can act both as a microphone and as a speaker [6].

Another feature of piezoelectric crystals has made them an integral part of modern radio engineering. Possessing its own frequency of mechanical oscillations, the crystal begins to oscillate especially strongly at the moment when the frequency of the supplied alternating voltage coincides with it.

This is a manifestation of electromechanical resonance, on the basis of which piezoelectric stabilizers are created, thanks to which the frequency is maintained constant in the generators of continuous oscillations.

In a similar way, they also react to mechanical vibrations, the frequency of which coincides with the frequency of natural oscillations of the piezocrystal. This allows you to create acoustic devices that distinguish from all the sounds reaching them only those that are needed for certain purposes.

For piezo devices do not take whole crystals. Crystals are sawn into layers strictly oriented relative to their crystallographic axes, these layers are then used to make rectangular or round plates, which are then ground to a certain size. The thickness of the plates is carefully maintained, since the resonant frequency of oscillations depends on it. One or more plates connected to metal layers on two wide surfaces are called piezoelectric elements.

In this article we will consider the methods of measuring the linear size of the crystal when the reverse piezoelectric effect is applied to an external voltage on the Michelson interferometer.

Basic equations of light interference

Suppose that two coherent waves described by the following equations converge at some point M in space

$$x_1 = A_1 \cos\omega\left(t - \frac{s_1}{\upsilon_1}\right) \qquad x_2 = A_2 \cos\omega\left(t - \frac{s_2}{\upsilon_2}\right) \tag{1}$$

Where ω is the cyclic frequency of the light wave, S_1 and S_2 are the distance from the light source to the point where the wave joins, and υ_1 and υ_2 are the velocities of the waves [6].

Since electromagnetic waves consist of alternating electric and magnetic field strength vectors, their amplitude values are added by the cosine theorem, so the resulting amplitude of the waves is

$$A^2 = A_1^2 + A_2^2 + 2A_1A_2\cos\delta \tag{2}$$

Since the wave intensity is proportional to the square of its amplitude ($I \sim A^2$), the following equation can be determined

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\delta \tag{3}$$

The third term on the right side of the equation is called the interference limit, where δ is the phase difference of the waves joining at point M [7]

$$\delta = \omega\left(\frac{s_2}{\upsilon_2} - \frac{s_1}{\upsilon_1}\right) = \omega\left(\frac{s_2}{c/n_2} - \frac{s_1}{c/n_1}\right) = \frac{\omega}{c}\left(s_2n_2 - s_1n_1\right) = \frac{2\pi\nu}{c}\left(L_2 - L_1\right) = \frac{2\pi}{\lambda_0}\Delta \tag{4}$$

The following known equations are used here

$$\upsilon = c/n, \qquad \omega = 2\pi\nu, \qquad c/\nu = \lambda_0 \tag{5}$$

The product of the geometric path length of a light wave in an environment to the refractive index of that medium is called the optical path length

$$L = s \cdot n \tag{6}$$

The following is the difference in path lengths traveled by the optical wave

$$\Delta = L_2 - L_1 = s_2n_2 - s_1n_1 \tag{7}$$

this is called the optical path difference.

If the difference in optical path Δ is an integer multiple of the wavelength in a vacuum

$$\Delta = \pm m\lambda_0 = \pm 2m\frac{\lambda_0}{2} \qquad m = (0,1,2,\ldots) \tag{8}$$

In this case, the waves joining at point M generate oscillations in the same phase, and the condition of maxima is satisfied. Here the phase difference is as follows

$$\delta = \pm 2m\pi \tag{9}$$

and the amplitude of the resulting wave increases at this point

If the difference in the optical path of the waves is an odd number of times the half-wavelength

$$\Delta = \pm\left(2m+1\right)\frac{\lambda_0}{2} \qquad m = (0,1,2,\ldots) \tag{10}$$

In this case, the waves joining at point M generate oscillations in the opposite phase, and the minimum condition is satisfied [7]. Here the phase difference is as follows

$$\delta = \pm(2m+1)\pi \tag{11}$$

and the amplitude of the resulting wave decreases. We will use the above formulas in the following sections.

Measuring the piezoelectric effect on a Michelson interferometer

With the aid of two mirrors in a Michelson arrangement, light is brought to interference. Due to the piezoelectric effect, one of the mirrors is shifted by variation in the electric field applied to a sample, and the change in the interference pattern is observed. Can be testing tourmaline, quartz and other natural crystal materials with regard to their piezoelectric properties.

The piezoelectric effect can be direct or reverse [8]. The direct piezoelectric effect is characterized by the electric polarization of the dielectric, which occurs due to the action of an external mechanical stress on it, while the charge induced on the surface of the dielectric is proportional to the applied mechanical stress:

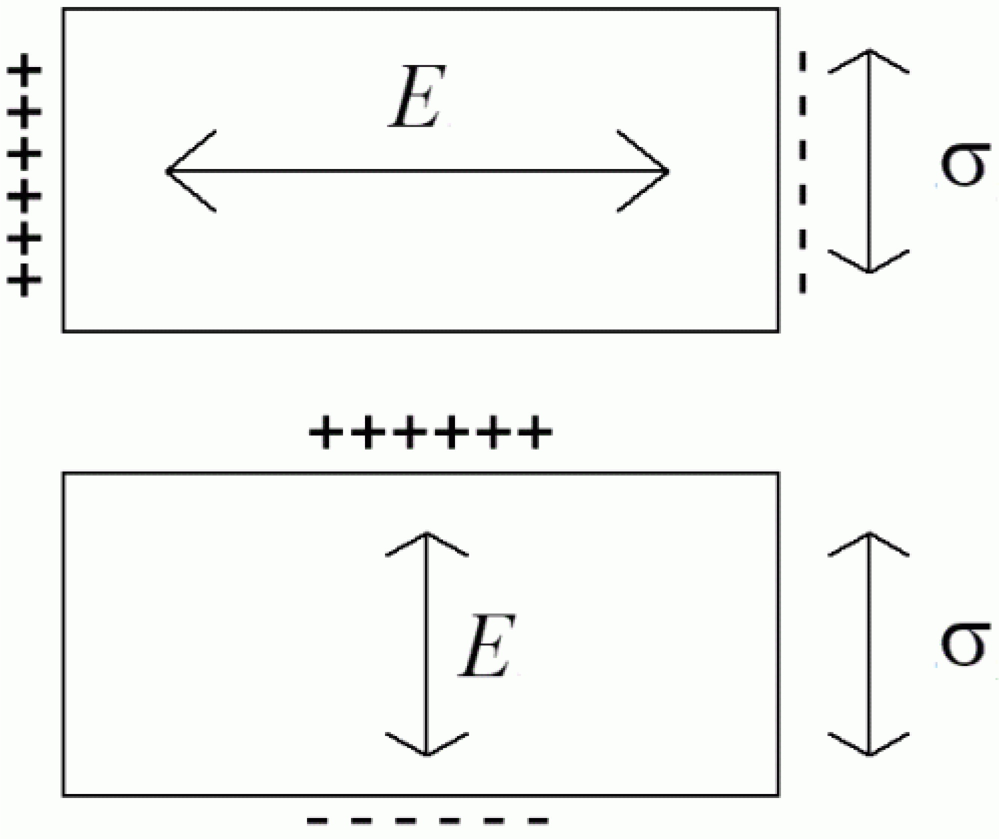
$$q = \sigma d_{dir} \tag{12}$$

With the reverse piezoelectric effect, the phenomenon manifests itself in the opposite way - the dielectric changes its dimensions under the action of an external electric field applied to it, while the magnitude of the mechanical deformation (relative deformation) will be proportional to the strength of the electric field applied to the sample

$$\xi = Ed_{rev} \tag{13}$$

The coefficient of proportionality in both cases is the piezoelectric modulus d. For the same piezoelectric, the piezoelectric modules for the direct and reverse piezoelectric effect are equal to each other. Thus, piezoelectrics are a kind of reversible electromechanical transducers [9].

The piezoelectric effect, depending on the type of sample, can be longitudinal or transverse. In the case of the longitudinal piezoelectric effect, charges in response to deformation, or deformation in response to the action of an external electric field, arise in the same direction as the initiating action. With a transverse piezoelectric effect, the occurrence of charges or the direction of deformation will be perpendicular to the direction of the action causing them



If an alternating electric field begins to act on a piezoelectric, then an alternating deformation of the same frequency will occur in it. If the piezoelectric effect is longitudinal, then the deformations will be in the nature of compression and tension in the direction of the applied electric field, and if it is transverse, then transverse waves will be observed.
If the frequency of the applied alternating electric field is made equal to the resonant frequency of the piezoelectric, then the amplitude of mechanical deformation will be maximum. The resonant frequency of the sample can be determined by the formula (V is the propagation velocity of mechanical waves, h is the thickness of the sample):

$$f_{res} = \frac{V}{h} \tag{14}$$

The most important characteristic of a piezoelectric material is the electromechanical coupling coefficient, which shows the ratio between the power of mechanical vibrations P_a and the electrical power P_e expended on their excitation by acting on the sample. This coefficient usually takes a value from the range from 0.01 to 0.3

$$K^2 = \frac{P_a}{P_e} \tag{15}$$

Piezoelectrics are characterized by a crystal structure of a material with a covalent or ionic bond without a center of symmetry. Materials with low conductivity, in which there are negligibly few free charge carriers, are characterized by high piezoelectric performance. Piezoelectrics include all ferroelectrics, as well as an abundance of known materials, including the crystalline modification of quartz [10].
Figure 1 shows a schematic of the Michelson interferometer. When the condensator C is energized, electric field changes and length of cristall to Δl due to piezoelectric effect. As a result, it is possible to observe the interference pattern shift on the SC screen. This can be explained by the following equations. Assuming that the known intervals l_1 and l_2 correspond to the maximum interference

$$l_1 = \pm m_1 \lambda_0, \qquad l_2 = \pm m_2 \lambda_0 \tag{16}$$

Changes in optical path differences is

$$\Delta = l_2 - l_1 = \pm \Delta m \lambda_0 \tag{157}$$

Here Δ is the change in the linear dimensions of an object in a electric field. This change can be compared to the change in the path difference of light on the Michelson interferometer. From the above equation, it can be said that as the body changes at each wavelength, one interference pattern shifts into one order. This means that linear changes in an object can be detected graphically by shifting the interference pattern.

Conclusion

This paper discusses the possibilities of measuring the piezoelectric effect using a Michelson interferometer. It has been shown that with changes in the external electric field, it is possible to measure changes in the linear dimensions 10^{-7} of some crystals standing in the same field. The study of such materials could make a significant contribution to the further development of nanotechnology in the future.

References

1. M. A. Khashan, "Comparison of group and phase velocities of light using the Michelson interferometer," Optik 64, 285–297.(1983).
2. S. Diddams and J. C. Diels, "Dispersion measurements with white-light interferometry," J. Opt. Soc. Am. B 13, 1120–1129.(1996).
3. Z. Bor, K. Osvay, B. Racz, and G. Szabo, "Group refractive index measurement by Michelson interferometer," Opt. Commun. 78, 109–112. (1990).
4. M. Beck and I. A. Walmsley, "Measurement of group delay with high temporal and spectral resolution," Opt. Lett. 15, 492–494 .(1990).

5. M. Beck, I. A. Walmsley, and J. D. Kafka, “Group delay measurements
6. of optical components near 800 nm,” IEEE J. Quantum Electron. 27, 2074–2081. (1991).
7. C. Sainz, P. Jourdain, R. Escalona, and J. Calatroni, “Real time interferometric measurements of dispersion curves,” Opt. Commun. 110, 381–390 .(1994).
8. A. P. Kovacs, K. Osvay, and Z. Bor, “Group-delay measurement on laser mirrors by spectrally resolved white-light interferometry,” Opt. Lett. 20, 788–790 .(1995).
9. Savelev I.V. Course of general physics. Nauka. M. (1970).
10. Sivukhin.D.V, Course of general physics. Nauka. M. (1979)
11. Leno S. Pedrotti. Basic Physical Optics. Fundamentals of photonics. (2019)