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OPTICAL GENERATION OF ACOUSTIC WAVES

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This paper discusses optical generation of acoustic waves and gives preliminary results of experimental research. The acoustic wave was generated as a result of the interaction of two laser light beams of very high intensity and slightly different frequencies. The change in the frequency of the laser beams ($\Delta f = 116$ MHz) was achieved using the Bragg diffraction of laser light by the acoustic wave.

1. Introduction

The use of very powerful lasers in investigations of the acousto-optical interactions has permitted the study of a number of interesting nonlinear effects which occur in the diffraction of laser light by acoustic waves. From the large class of these phenomena, the effect of optical generation of coherent elastic waves, which KASTLER has predicted theoretically, is distinguished. The phenomenon was investigated preliminarily by American research workers [2, 3]. At present, in view of the large developments in theory [1], experimental research in this field has been resumed.

2. Short description of the phenomenon

When two electromagnetic waves with angular frequencies ω_1 and ω_2 propagate in a medium, the mutual interaction of these waves causes a periodic strain of the angular frequency $\omega_1 - \omega_2$ to occur. The coupling of these waves is a result of the electrostrictive effect.

The geometry of the phenomenon can be analysed on the basis of the principle of energy and momentum conservation in the photon – photon scattering.

$$\hbar\omega_1 - \hbar\omega_2 = \hbar\Omega; \tag{1a}$$

$$\hbar\boldsymbol{k}_1 - \hbar\boldsymbol{k}_2 = \hbar\boldsymbol{q}; \tag{1b}$$

where ω_1, ω_2, $\boldsymbol{k}_1$, $\boldsymbol{k}_2$ are respectively the angular frequencies and wave vectors of the interacting electromagnetic waves; Ω and $\boldsymbol{q}$ are the analogous quantities for the generated acoustic wave.

When the frequencies ω_1 and ω_2 of electromagnetic waves are not greatly different (which is most frequently the case), $|\boldsymbol{k}_1| \approx |\boldsymbol{k}_2|$. The angle which must be formed by the wave vectors $\boldsymbol{k}_1$ and $\boldsymbol{k}_2$ can be determined from equation (1b),

$$\psi = 2\theta_B = 2\sin^{-1}\frac{\lambda_0\Omega}{4\pi n v}, \tag{2}$$

where θ_B is the Bragg angle, λ_0 is the electromagnetic wave length in vacuum; and n and v are respectively the light refraction coefficient and the acoustic wave propagation velocity for the medium considered.

Fig. 1. shows the system of wave vectors for the photon – photon scattering (photon creation).

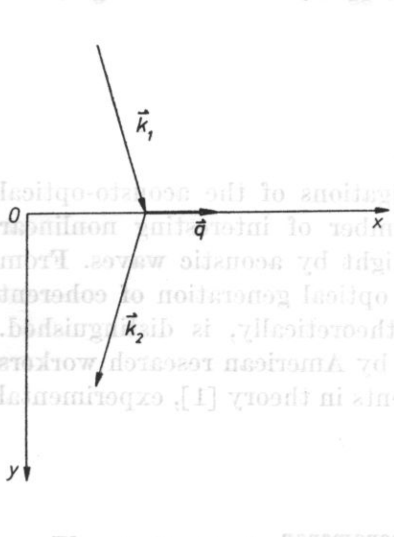

Fig. 1. The system of wave vectors $\boldsymbol{k}_1$ and $\boldsymbol{k}_2$ of the waves involved in the photon – photon scattering which generated an acoustic wave with the wave vector $\boldsymbol{q}$.

Theory [1, 2] also predicts that the power density P_s of the acoustic wave generated is proportional (in first approximation) to the product of the power densities of the interacting electromagnetic waves,

$$P_s = \frac{n^6 p^2}{8\varrho v^3 c^2}\Omega^2 L^2 P_1 P_2, \tag{3}$$

where L, P_1 and P_2 are respectively the interaction path length and the intensities of the electromagnetic waves, p is the photoelastic constant, ϱ is the density of the medium, and c is the light velocity in vacuum.

3. Experimental system. Discussion of the results

The investigation set-up which served for the observation of the generation of acoustic waves by the optical method is shown schematically in Fig. 2. The source of electromagnetic waves was a ruby laser working in a pulsed mode with an adjusted quality factor. In the acoustooptical modulator the beam was split into two parts of different frequency. In this experiment the frequency change was 116 MHz. The diffraction efficiency was about 10 per cent. The lens S_1 served to focus the laser beam in the modulator. The lens S_2 refocused the two beams in the material where they interacted. The geometry of the system was chosen so that the laser beam intersected at the angle $2\ \theta_B$. The material was glass SF $-$ 14 for which $n = 1.76$, $\varrho = 4.35 \times 10^3$ kg/m³, $v = 3.57 \times 10^3$ m/s and $p = 0.1$.

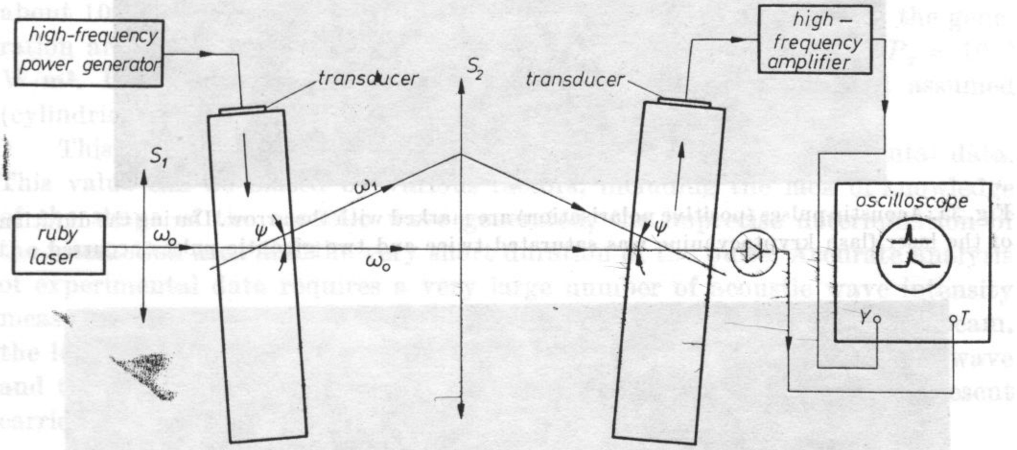

Fig. 2. A schematic diagram of the investigation system for the observation of the generation of acoustic waves by the optical method. ψ – the angle formed by the wave vectors $\boldsymbol{k}_1$ and $\boldsymbol{k}_2$, S_1 and S_2 – lenses, T – synchronisation

For these values $2\ \theta_B$ is 11.8 mrad. The acoustic wave generated was detected by a $LiNbO_3$ piezoelectric transducer, glued directly to the end of the sample. The signal from the transducer was amplified (selectively) and registered on the oscilloscope. An ultrasonic wave of the frequency $f = 116$ MHz was observed in the form of single pulses about several score nanoseconds long.

Fig. 3 shows the oscillograms registered.

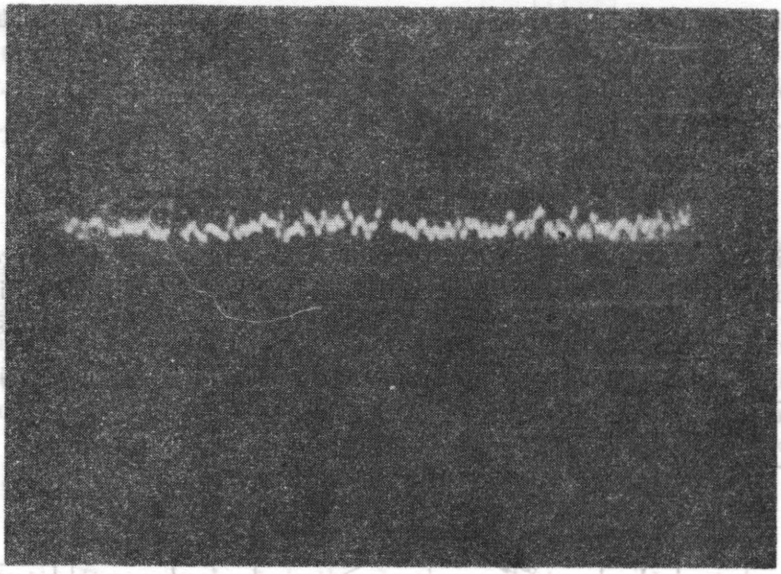

Fig. 3a. Acoustic pulses (positive polarisation) are marked with the arrow. During the duration of the laser flash kryptocyanine was saturated twice and two gigantic pulses occurred

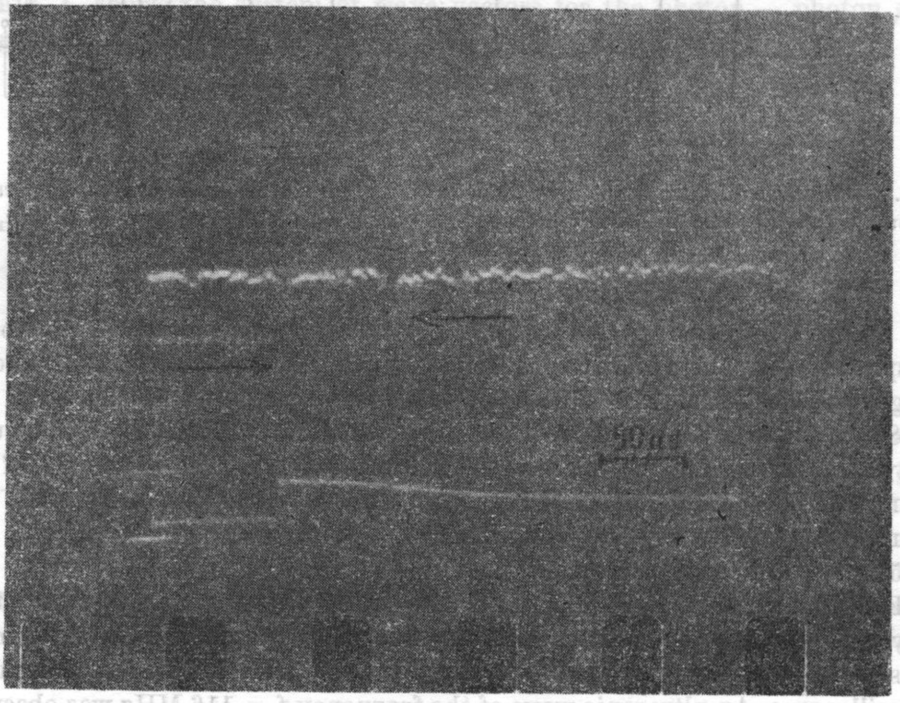

Fig. 3b. Acoustic pulses (negative polarisation) are marked with the arrow. The lower part represents the voltage at the photodiode; as a result of inertia, the second optical pulse is not visible and the back slope of the first is much widened

The high-frequency voltage amplitude on the receiving transducer varied from 40-80 μV, depending on the light intensity. For control, a signal from the photodiode illuminated by a laser flash was supplied to the time base B of the oscilloscope (Fig. 3*b*). The time correlation of the two pulses confirms the authenticity of the effect obtained. (The back slope of the laser pulse is greatly widened as a result of the inertia of the photodiode). Approximate calculations of the power flux of the acoustic wave generated were carried out. The generation area is the focus of the lens [4], i.e. a cylinder of a diameter of about 8×10^{-5} m and height of about 3×10^{-3} m (for the focal length of the lens S_1 being 15.8×10^{-2} m).

For the distance of the generation area from the lens assumed here at about 10^{-2} m, the approximate value of the wave amplitude close to the generation area is 3×10^{-14} m, which corresponds to the power density $P_s = 10^{-4}$ W/m^2. In view of the measurement method and approximations assumed (cylindrical waves), this value is rather underestimated.

This value is slightly higher than one estimated from experimental data. This value can be biased by various factors, including the lack of knowledge of the shape of the acoustic wave generated, the imprecise determination of the interaction area and the very short duration of the pulse. Accurate analysis of experimental data requires a very large number of acoustic wave intensity measurements to be carried out, depending on the power of the laser beam, the length of the interaction area, the angular frequency of the acoustic wave and the material constants of the medium. Such measurements are at present carried out by the authors.

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