PHYSICS

1957

SovietRxiv

Abstract

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PHYSICS

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EXCITATION OF HYPERSONIC-FREQUENCY OSCILLATIONS IN QUARTZ

(Presented by Academician G. S. Landsberg, 12 I 1957)

At present the only method for investigating the elastic properties of substances at hypersonic frequencies (10^9—10^{10} Hz) is the study of the fine structure of the spectral lines of light scattered by thermal waves (^{1}). For solids this technique is complicated by the low intensity of the scattered light. It is therefore natural to seek to use ultrasonic methods for exciting oscillations in the indicated range. However, at present the field of application of ultrasonic methods is limited in practice to frequencies of the order of 1—$2 \cdot 10^8$ Hz. Only in the work of Ringo et al. (^{2}) and of S. Ya. Sokolov (^{3}) was an ultrasonic frequency of $1 \cdot 10^9$ Hz attained. In order to reach the highest possible ultrasonic frequencies, the authors of these works proceeded by making very thin quartz plates with a high natural-oscillation frequency, so as to excite in them comparatively low harmonics at high frequencies*. The technique of applying voltage to piezoquartz remains unchanged in ultrasonics for all frequencies from 10^5 to 10^9 Hz. Ultra-high-frequency technique is not used for these purposes, even at a frequency of $1 \cdot 10^9$ Hz.

We considered that, in order to raise the frequency of ultrasound, it was necessary, using modern resonance methods of u.h.f., to develop a way of producing large intensities of a high-frequency electric field in quartz. The solution of this problem, basic for the generation of hypersonics, could additionally free experimental technique from the need to use thin quartz plates and, more importantly, make it possible to investigate optically the processes occurring at hypersonic frequencies in massive quartz.

As sources of the high-frequency field we chose generators of continuous sinusoidal oscillations, assembled with circuits in the form of coaxial resonators on ceramic tubes (GI-11b). These generators made it possible to vary the field frequency smoothly from $1 \cdot 10^8$ to $2 \cdot 10^9$ Hz and could deliver a useful power of 5-10 W (in the work of Ringo et al. the generator power was 50-100 W). The power of the generators we selected corresponded to the high resonance qualities of the systems into which the piezoquartz was included.

In accordance with the considerations set forth, the mounting of the quartz was carried out. Namely, at frequencies $1 \cdot 10^8$—$1 \cdot 10^9$ Hz the quartz plate was clamped between metallic plates, which were connected to a coaxial line, one end of which was connected to the generator and the other terminated by a piston. A system of standing electromagnetic waves was created in the line and, by moving the piston, one could bring to the point where the quartz plates were connected one of the antinodes of the electric field. In

[*] Thus, Ringo et al. used a quartz plate 0.038 mm thick and excited in it the hundredth harmonic of its fundamental tone.

at frequencies above $1 \cdot 10^9$ Hz the quartz plate was placed in a coaxial resonator tuned by a piston and connected to the generator by a 50-ohm cable.

Longitudinal oscillations along the X axis were excited in rectangular quartz plates whose edges were oriented along the crystallographic axes X, Y, Z and had dimensions, respectively, of 15, 50, and 20 mm. To detect the oscillations in quartz, the phenomenon of light diffraction by ultrasound was used.

The method employed made it possible to excite sound oscillations over a wide frequency range in a thick quartz plate, up to $2 \cdot 10^9$ Hz, and to observe first-order diffraction spectra. The natural frequency of the plate was 240 kHz. At frequencies above $3 \cdot 10^8$ Hz, even and odd harmonics were excited with equal intensity; therefore the ultrasonic frequencies followed one another at intervals of 240 kHz. In the frequency region above $6 \cdot 10^8$ Hz, oscillations in the plate were excited at any value of the generator frequency: the intensity of the diffraction spectra did not depend on frequency. This is due to the fact that the width of the resonance curve of the quartz plate at these frequencies becomes greater than the frequency interval between its harmonics. In this case traveling waves are excited in the quartz.

Thus, the use, in the hypersonic frequency region, of thick X-cut quartz plates made it possible, with the aid of a single plate, to obtain any sound frequency, which is very advantageous for carrying out investigations of the frequency dependence of the elastic properties of substances.

Measurements by the diffraction method of the velocity of longitudinal waves in quartz at 20° showed that, within the accuracy of our measurements ($\pm 1\%$), it remains constant throughout the frequency range investigated and is equal to 5750 m/sec. At a frequency of $1.64 \cdot 10^9$ Hz, this value of the velocity is obtained from the condition that the diffraction angle for the mercury line $\lambda = 5780$ Å is equal to $9°28'$, while the acoustic wavelength is $\Lambda = 3.52 \cdot 10^{-4}$ cm. The values of the Q factor of quartz plates at a frequency of $5 \cdot 10^8$ Hz, measured by the diffraction method, varied from 2500 to 7300.

As a first application of the method developed, an investigation was carried out of the features of the phenomenon of light diffraction by high-frequency ultrasound, considered theoretically and experimentally by S. M. Rytov in 1935[4]. He showed that, when the ratio $\lambda l / \Lambda^2$ (l is the length of the light path in the ultrasonic field) becomes greater than unity, the volume character of the ultrasonic grating must be manifested in the phenomenon of selective (Bragg) reflection of light. In this case the intensity of light of wavelength λ, diffracted through an angle φ, will be maximal if the angle θ between the direction of the incident light and the plane of the sound-wave front satisfies the condition $\theta = \lambda/2\Lambda = \varphi/2$.

Indeed, selective reflection occurs already at frequencies 1-$2 \cdot 10^8$ Hz and appears as an asymmetry in the intensities of the spectra of the +1st and −1st orders. At frequencies above $2 \cdot 10^8$ Hz, by changing the sign of the angle θ, one can observe only alternately either the +1st- or the −1st-order spectra. With a further increase in frequency, the requirements on the accuracy of setting the angle θ increase. For example, at frequencies of the order of $1 \cdot 10^9$ Hz, to observe the yellow or green mercury lines it is necessary to set different values of the angle θ.

According to the theory of S. M. Rytov, for a given value of the angle θ the intensity of the diffracted light differs from zero in the interval of angles from $\varphi_1 = 2\theta - n\Lambda/l$ to $\varphi_2 = 2\theta + n\Lambda/l$, to which there corresponds an interval of light wavelengths $\Delta\lambda = 2n\Lambda^2/l$, where n is the refractive index of the medium. Indeed, at frequencies above $2 \cdot 10^8$ Hz and when a continuous-spectrum lamp is used, only a narrow portion of the lamp spectrum is observed in the diffraction pattern. By changing the angle θ, it is possible to observe successively different portions of the lamp' s continuous spectrum in the diffraction spectrum; their width decreases sharply as the frequency is increased. At frequencies 1-$2 \cdot 10^9$ Hz

the diffraction spectrum from an incandescent lamp has the form of a separate line, whose angular width does not exceed the width of the lines in the diffraction spectrum of a high-pressure mercury lamp at the same frequencies. Thus, a hypersonic grating in quartz also monochromatizes light, just as a crystal grating monochromatizes X-radiation.

I express my gratitude to I. A. Yakovlev for suggesting the topic and for his attention to the work, and to G. P. Motulevich for valuable discussions in the course of the work.

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Received
9 I 1957

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Note: Figure translations are in progress. See original paper for figures.