EXCITATION OF HYPERSOUND

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EXCITATION OF HYPERSOUND

IN THE MILLIMETER RADIO RANGE

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1. The methods developed to date for the excitation and reception of hypersound make it possible to carry out hypersound studies of solid-state physics in the frequency range $1 \div 10$ GHz. Extension into the region of higher frequencies, into the millimeter radio range, where the hypersound wavelength is of the order of 10^2 Å, is very attractive. In this case the energy of hypersound quanta approaches the energy of thermal phonons in a solid at low temperatures, which makes it possible, with the aid of hypersound waves, to study directly the interaction of various quasiparticles with phonons and the phonon spectrum of a solid.

The previously proposed method of exciting hypersound by means of a surface slow electromagnetic wave ([1]) has important advantages in the millimeter range in comparison with other methods ([2], [3]). The essence of this method is as follows. In exciting hypersound in a piezoelectric crystal with dimensions $L \gg \lambda_s$ (λ_s is the hypersound wavelength), a boundary effect plays a substantial role: the intensity of the hypersound wave is determined by the square of the strength of the microwave electric field at the crystal surface ([1]). Therefore, concentration of the electric field at the crystal surface makes it possible to accomplish efficient conversion of the microwave electric field into hypersound and back. Such concentration of the electric field is achieved when, near the surface of the crystal, a slow electromagnetic wave propagates, for which the electromagnetic field is concentrated in a thin layer of space at the boundary of the slowing structure. In a piezocrystal located near the surface of the slowing structure, the electric field has the character of a surface wave and is concentrated in a thin layer at the boundary adjacent to the slowing structure. If the normal to this boundary is directed along the axis of second-order symmetry, then, because of the piezoelectric effect, pure longitudinal and transverse hypersound waves propagating along the normal will be excited in this crystal. The hypersound wave, propagating in the piezocrystal, produces a piezoelectric polarization which, at the crystal boundary, is a source exciting a slow electromagnetic wave in the periodic structure. The coefficient of double conversion—electric field into hy-

Figure 1

Figure 1: Figure 1

persound and back—in the case of a longitudinal hypersound wave is determined by the expression

$$\eta = \left(c_{\parallel} e_{\parallel}^{2} \frac{2 v_s \omega L}{\beta_e^2 c} \right)^2 , \tag{1}$$

where $c_{\parallel}$ and $e_{\parallel}$ are the elastic and piezoelectric moduli of the crystal; v_s is the sound velocity; L is the length of the excitation region in the direction of propagation of the electromagnetic wave; $\omega/2\pi$ is the hypersound frequency; β_e is the slowing coefficient, $\beta_e = v_e/c$; c is the velocity of light; v_e is the velocity of the slow wave in the periodic structure.

It follows from (1) that, with increasing frequency and with $L/\beta_e^2 = \text{const}$, η increases in proportion to ω^2. This makes it possible to use the slow-wave method successfully for excitation of hypersound waves in the millimeter and submillimeter ranges, since the frequency limitations for

of this method are the same as for backward-wave oscillators using similar slow-wave structures.

2. With the aid of the method described, excitation of longitudinal and transverse hypersonic waves with a frequency of 40 GHz in quartz at the temperature of liquid helium was previously achieved (1). The development of this method made it possible to excite longitudinal and transverse hypersonic waves with a frequency of 75 GHz in quartz.

Fig. 1. Device for exciting hypersonics in quartz at frequencies of 9.4 and 75 GHz. *1* —quartz, *2* —slow-wave helix, *3* —horn for exciting the helix, *4* —4-millimeter waveguide, *5* —slow-wave comb

The quartz single crystal had the form of a parallelepiped with dimensions $15 \times 20 \times 10$ mm^3, with edges oriented along the crystallographic axes X, Y, Z. The faces of the crystal perpendicular to the X axis were made optically flat and parallel. Irregularities on the planes were less than 0.05 μ, and the deviation from parallelism was $< 2''$. On one of the optically flat faces there is a slow-wave system in the form of a comb with a pitch of 0.2 mm and groove depth of 0.7 mm. The slowing coefficient is $\simeq 0.05$. The hypersonic head, containing the waveguide, comb, and quartz (Fig. 1), is placed in a nitrogen-helium cryostat and cooled to the temperature of liquid helium (4.2°K), since at higher temperatures waves with a frequency of 75 GHz are strongly attenuated in quartz and their observation becomes impossible.

Fig. 2. Echo signals of a longitudinal hypersonic wave at a frequency of 75 GHz

Figure 2

Figure 2: Figure 2

Fig. 3

Figure 3: Fig. 3

The source of microwave energy for excitation of hypersonics is a pulsed magnetron generator. The pulse duration is 0.05 μsec. The microwave pulse was directed into the hypersonic head, and the echo pulses arising in the head as a result of reverse conversion of hypersonics into an electromagnetic field were recorded by a receiver of the 4-millimeter range.

As a result, at the receiver output indicator one observes a sequence of echo pulses corresponding to hypersonic waves excited in the quartz and multiply reflected from its parallel faces.

Figure 2 shows the excitation of a longitudinal hypersonic wave with a fre-

the order of 75 GHz. The slowed wave in this case propagates along the Z axis. If the slowed wave is directed along the Y axis, then, along with the longitudinal wave, two more transverse hypersound waves are excited. In the oscillogram of Fig. 3 one can distinguish three groups of pulses with equal time intervals in each group, corresponding to longitudinal and transverse hypersound waves. The wavelengths of the hypersound waves are: longitudinal 760 Å, fast transverse 680 Å, slow transverse 440 Å.

Fig. 3. Echo signals of longitudinal (l), fast (t') and slow (t'') transverse hypersound waves at a frequency of 75 GHz

3. Since the wavelength of hypersound at a frequency of 75 GHz differs by only two orders of magnitude from the dimensions of the elementary cell of the crystal lattice, it is natural to attempt to observe Debye dispersion. For an ideal quartz crystal the expected change in the speed of sound due to dispersion is

$$\delta v_s = \frac{1}{2}(\hbar\omega/k\Theta)^2 = 2 \cdot 10^{-5}$$

(Θ is the Debye temperature). In a real crystal the presence of defects leads to a change in the phonon spectrum. In this case the dispersion may increase and become accessible for observation.

To this end, in the work an experiment was carried out to compare the velocities of hypersound at frequencies of 9.4 and 75 GHz. In order to eliminate temperature errors in determining δv_s, the hypersound waves at these frequencies were excited simultaneously. For this purpose, a slowing helix for exciting hypersound at a frequency of 9.4 GHz was placed at the second optically flat

Fig. 4

Figure 4: Fig. 4

surface of the quartz. Synchronized microwave pulses from generators of the 3-centimeter and 4-millimeter ranges were fed to both slowing systems. Echo signals at frequencies of 9.4 and 75 GHz were recorded by a receiver having two mixers and heterodynes tuned to the indicated frequencies, and a common intermediate-frequency amplifier channel. On the screen of the receiver output indicator two sequences of echo signals of longitudinal hypersound at frequencies of 9.4 GHz and 75 were observed (Fig. 4). The difference in velocity was determined by superposing the echo pulses of the two sequences. The error $\Delta(\delta v_s)$ did not exceed $5 \cdot 10^{-4}$. Under these conditions no dispersion of longitudinal hypersound was detected.

Fig. 4. Two sequences of hypersound echo signals at frequencies of 9.4 GHz (s) and 75 GHz (m)

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