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GIANT REGENERATIVE AMPLIFICATION WITH SOUND WAVE PHASE CONJUGATION IN FERRITE

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Abstract-New results of investigations of the parametrical sound wave phase conjugation (WPC) phenomena in magnets are reported.

1 - INTRODUCTION

The rf-pumping may be used for the wave phase conjugation accompanied by the amplification of sound. Piezoelectrics or magnets may be used as the media for the acoustic parametrical phenomena researches owing to the sound and electromagnetic waves coupling. The two-pulse parametrical echo of traveling sound waves in piezoelectrics was obtained by Thompson and Quate /1/. The ultrasonic WPC was found in the special type magnet-"easy-plane" antiferromagnet/2/. The medium has been selected taking into account specifically strong magnetoelastic nonlinearity of this crystal type /see 3/. The pointed out experiments dealt with shear magnetoelastic traveling waves. The WPC of longitudinal sound in magnet as well as shear one was observed recently in Ni-ferrite polycrystal/4/. The giant WPC gain (86dB) was obtained above the threshold of ultrasonic magnetoelastic waves absolute parametrical instability. The intensities of amplified waves in this regenerative regime reached the level of about 0.5 kW /sm². It is important for various applications to investigate the real intensity and phase spatial distribution correlations of initial wave and amplified one. The modification of WPC registration echo-method based on using the complicated ultrasonic transducer which radiated and received sound waves with quasi-random phase distribution was proposed earlier/5/. In the present paper we report the direct observation results of sound distribution formed by WPC-regenerative regime in ferrite. Theoretical treatment of WPC-regenerative amplification mechanism is considered.

2 - EXPERIMENTAL TECHNIQUE AND RESULTS

The experimental scheme is shown in fig.1. The studied acoustic field

Fig.1 - Experimental scheme: 1-fused quartz sample; 2-ultrasonic transducer; 3-ferrite sample; 4-coil.

was formed in optically transparent medium - the fused quartz sample 1. The ultrasonic transducer 2 has been placed on the side "A" of the sample. It

radiated the initial sound wave pulses at the frequency $\omega/2\pi=25$ MHz. The pulse duration could be varied from 0.1 to 10 μ s. The radiated pulse reflected from the cylindrical surface "C" was focused in the point "F". After focusing the radiated beam went to the side "B" where the ferrite sample 3 has been placed. The ferrite sample was statically magnetised along the direction of the alternating pumping field (so called "parallel pumping" geometry). When the initial sound pulse reached the active zone under the coil 4 the pumping electromagnetic pulse was switched on. The pumping frequency was tuned to doubled sound frequency $\omega_p=2\omega$. The alternating magnetic field of the coil modulated the sound velocity in the ferrite. The magnetic field dependence curves for shear and longitudinal sound wave velocities in ferrite are shown in fig.2. As a result of modulation the WPC with opposite to initial wave propagation direction was created. After the propagation time interval the WPC-pulse reaches the transducer 2. The oscillograph registers the signal on the transducer and pumping pulse (see fig.3).

Fig.2-Shear(x) and longitudinal(+) sound velocities vs magnetic field

Fig.3-Oscillograms: upper- pumping pulse, lower -initial(1) and WPC(2) sound pulse.

When the parametrical WPC takes place the sound echo-pulse must focus in the same point "F" as the initial pulse. If the ordinary reflection from the quartz side "B" occurs the reflected pulse evidently would not focus in the point "F".

In order to visualize the sound field distributions we used the "photoelastic technique"/6/. The polarized light ($\lambda=0.53\mu$ m) collimated in a wide beam $D=60$ mm has been directed to quartz normally to the sound propagation plane (Raman - Nath diffraction geometry). For registration of different stages of the sound pulses propagation we used the stroboscopic method. The laser light flash (duration 20 ns) and initial sound pulse have been switched on synchronically and with variable delay. Fig.4 shows three different stages: a) initial wave passes through the focus "F"; b) WPC-pulse passes through the focus; c) WPC-pulse goes through the focus after being reflected from the quartz' side "C".

a)

b)

c)

Fig.4 - Stages of sound wave propagation: a) incident wave ; b,c) WPC-wave.

One can see that the sound field intensity distribution has the waist near the focus point according to WPC-process. The field distribution of the free phonon parametrical generation in the absence of initial sound pulse is shown in fig.5. The random intensity flicker is the peculiarity of this regime. In the presence of initial sound signal flicker disappears and angular spectrum become tighter (see fig.6). The phenomenon may be treated as phonon mode synchronization and competition.

Fig. 5

Fig. 6

Fig. 7

Arrows "→" show the direction of sound beam propagation.
 Fig. 5-The free parametrical phonon generation without initial waves.
 Fig. 6-The "synchronization" of free parametrical phonon modes by initial waves.
 Fig. 7-The interference pattern of initial and WPC waves.

In order to indicate the phase distribution of WPC pulse we made a small variation of pumping frequency and have got the interference of WPC-pulse reflected from the "A" side and one of the initial sound pulses. As a result we observed the space oscillations of sound field intensity (fig. 7). The oscillations period may be defined from the relationship $\Delta\phi(\vec{r}, t) = \pi$, where $\Delta\phi$ - phase difference between WPC and initial wave. Assuming the phase of initial wave as known one can determine the phase distribution of WPC-pulse.

The digital processing of the sound-field image was made by translating the optical information to the TV-signal. PC-records the digital image to the external memory carrier and makes the processing.

3 - THEORY OF REGENERATIVE WPC-REGIME

A parametrical WPC by magnetic pumping $h_0 e^{-i\omega_p t}$ may be described in terms of the simplest parametrically connected equations system:

$$\frac{\partial A}{\partial t} + v \frac{\partial A}{\partial z} + hB^* = 0; \quad \frac{\partial B}{\partial t} - v \frac{\partial B}{\partial z} + hA = 0; \quad (1)$$

where $A(z, t), B(z, t)$ are slowly varying amplitudes of initial and conjugated waves, v - sound velocity, $h = \frac{\partial v}{\partial h} h_0 \frac{\omega}{v}$ - parametrical interaction coefficient. The solution of the equations (1) in the case of plane waves and constant in time and uniform (in the region $0 < z < L$) pumping amplitude was founded in /7/. When $h\tau < \pi$ ($\tau = 2L/v$) the solution describes the nonsteady-state WPC-process in the convective instability conditions. When $h\tau > \pi$ WPC-amplitude increases in time and instability becomes absolute /4/. Above the threshold of the absolute parametrical instability the WPC-amplitude really is limited by the finite pumping action time or nonlinear processes (pumping exhaustion, four-phonons phase mechanism et al). The pumping exhaustion seems to be the most important mechanism applying to the experimental situation. The "breafe" of pumping pulse can be clearly seen in fig. 4 (upper oscillographic line). The influence of the phonon field on pumping is described by the relationship:

$$h(t) = h[1 - \alpha \overline{A B} e^{i(\omega_p - 2\omega)t}] \quad , \quad (2)$$

where line means the space averaging along the active zone; α - phonon field-pumping source connection factor. The amplification coefficient of WPC at $t > \tau$ may be described in one mode approximation by the equation:

$$\frac{\partial S}{\partial t} = P - \beta N_0 e^S \quad , \quad (3)$$

where $N_0 \sim |A(t \rightarrow 0)|^2$, $\beta = \alpha h$, $P = \pi(h - h_c)$, $h_c = \pi/\tau$ - the threshold pumping amplitude. Assuming gain $\kappa = |B(z=0)/A(t, z=0)|$, the gain dependence on pumping time duration at different initial signal levels on transducer V_i is shown in fig 8 ($N_0 \sim V_i^2$). The calculations performed using the solution /7/

and equation (3) give the results shown in fig.8 by lines. The reliable region of the solution (3) may be spread to the time interval $0 < t < 10 \mu s$ ($\tau \approx 3.4 \mu s$),

Fig.8-The calculated (lines) and experimental (points) gain dependence on pumping time duration at different input voltage V_1 on the transducer.

where the gain increases up to 50 dB. The analysis of the equation (1) one mode solution applying to this region for space modulated sound beams shows that the regeneratively amplified echo-signal reproduces the initial wave amplitude and phase distribution.

4 - CONCLUSION

The results presented in this paper demonstrate new promising objects of study for investigating parametric processes of phase conjugation in solids and open up a real possibility for creating devices and systems based on the effect of a giant regenerative amplification of sound in phase conjugation.

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