PARAMETRIC SOUND WAVE PHASE CONJUGATION IN SOLIDS

固体中のパラメトリック音響位相共役

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The development of parametric wave phase conjugation (WPC) phenomena last year attracted the attention of specialists in ultrasonics and physical acoustics. In the most obvious form, WPC transformation may be interpreted as a time (or front) reversal of wave field. Intensification of fundamental researches in this scientific area has been stimulated by the succession of analogous investigations in nonlinear optics. On the other hand, applications of WPC have opened new possibilities such as forming and acoustic images, improvement of reliability of ultrasonic nondestructive evaluation and microscopy and the elaboration of new approaches to the problem of ultrasound energy concentration on points and extended scatterers in distorted media.

There are two general approaches to experimental realization of WPC in acoustics. The first is based on the time-reversal transformation of low frequency electric signals in multi-channel transmitting/receiving antena systems using adaptive time delay technique. The last achievements of this approach are presented in recent review of prof. M. Fink[1]. The second physical approach is based on the nonlinear or parametric phenomena in special acoustic media. The general ideas of this principle were reviewed by academician F. Bunkin et al[2]. In this aspect, the parametric interaction between acoustic field and electromagnetic field has attracted special attention. It makes WPC transformation possible in ultra and hypersound frequency bands with high quality and large and even giant amplification of phase conjugate wave (PCW).

In recent years, impressive results in the area of generating and optically visualizing of parametric WPC in acoustics were obtained in Department of Applied Physics and Applied Mechanics in Institute of Industrial Science (IIS), University of Tokyo [3, 4], in Department of Wave Phenomena of General Physics Institute of Russian Academy of Science, and Laboratory of Applied Magnetoacoustics of Moscow Institute of Radio Engineering, Electornics and Automation (MIREEA)[5)~7)]. The Guest Research Fellowship kindly offered to me by IIS became the first step to the collaboration of these scientific groups.

The program of the fellowship initially planned the following research activities: (1) analysis of accumulated experimental data on parametric WPC, (2) theoretical study of the nonlinear stage in WPC under the condition of giant amplification, including the construction of a computer model, (3) investigation of the quality of parametric ultrasound WPC, (4) preparation of the experimental setup for the generation and optical visualization of WPC fields by means of magnetic active materials. The program included the introduction to the scientific activities of laboratories specialized in ultrasonics in IIS, Tohoku University, Yamanashi Universitvy, and Olympus Optical Co., Lte. Participation in the 13th Ultrasonics Symposium (Nov. 30–Dec. 2, Sendai) and in the meeting on Multi-Wave Mixing and Phase Conjugation in Ultrasonics (Nov. 16, Tokyo) were also proposed. It is necessary to point out that the latter meeting, which was organized by prof. K. Takagi and prof. M. Ohno of IIS, may be regarded as the first conference specialized on WPC in acoustics. The success of the meeting, which was commonly recoginized by the participants, has evidently shown the importance of scientific problems in this field and has evoked the demand of holding such meetings desirably in a regular order.

These academic meetings at which high level of papers were presented, and the visits to the above-metioned

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research laboratories have made me from the following impression about the present state of ultrasonic science in Japan.

First of all, it is necessary to point out that the high level of experimental technique, which was historically formed in Japanese science, allowed to obtain unique results in fundamental and applied investigations. The achievements in ultrasonic spectroscopy of liquides by IIS scientists, prof. K. Takagi, prof. P-K Choi et al., are well known. The development of quantitative ultrasonic microscopy in Tohoku University achieved by prof. J. Kushibiki, prof. N. Chubachi et al. is impressive. I also recoginized the high level experimental investigations in industrial research laboratories such as Olympus Optical Co. Ltd., where in particular a new nonlinear acoustic phenomena in superfluid helium have been observed by Dr. K. Karaki et al.

In the area of physical methods of acoustic WPC and visualizing of phase conjugate fields, one of the leading positions belongs to the investigation of prof. M. Ohno of IIS. A sophisticated original idea of nonlinear stabilization of holograms in ultrasonic phase conjugator using microparticles suspended liquids has been suggested by prof. T. Sato with co-authors of Tokyo Institute of Technology. The results in parametric acoustooptic interaction in surface acoustic waves in piezoelectric-semiconductor structures obtained in Yamanashi University by prof. Y. Nakagawa et al. are generally recognized. The achievement of Japanese technology in the synthesis of piezoelectric and magnetostrictive materials are well known in the world.

At the same time, it is necessary to pay attention on the great experience of Russian scientists in the synthesis and the investigations of properties of new active magnetic materials including special ferrites, antiferromagnetic crystals and rare eath compounds with against magnetostriction. This experience seems to be useful in the promotion of magnetoacoustic branch of ultrasonic electronics in Japan. Complimenting of the highly developed Japanese experimental technique with the experience of Russian scientists in fundamental and applied theoretical investigations in nonlinear acoustics of solid may be especially fruitful.

A summary of academic activity during the period of stay in IIS can be presented as follows.

The most essential result was the elaboration of asymptotic theory of sound WPC in the overthreshold regime of giant amplification. It has been used as a basis for the computer simulation of WPC process taking into account the thermal noise amplification and the reverberations in active medium. The theory gave an explanation of the experimental data recently obtained with parametrically active magnetic materials. The details of the theory and the experimental results are reflected in an original paper submitted to the Japanese Journal of Applied Physics.

Theoretical study on WPC efficiency in nonlinear piezoceramic resonant layers has been carried out with the purpose to analyze new experimental results. Symmetrical properties of the system were determined and the possibility of applying the experimental method to the extreme condition was discussed.

The anomalous refractivity of anisotropic layer in overthreshold conditions has also been studied. Fundamentals of parametric phonon pair scattering theory for anisotropic active medium were elaborated.

A review on the subject of acoustic WPC by means of magnetic materials was reported at the meeting on Multi-Wave Mixing and Phase Conjugation in Ultrasonics. A paper on the nonlinearity of parametric sound WPC in solids was presented at the 13th Ultrasonics Symposium. Both papers were published in the proceedings of each meeting[8),9)].

The lectures on the last results of generation and visualization of parametrically induced phase conjugate ultrasonic fields in solids and liquids were given for the students and collaborators in Yamanashi University and for researches in Olympus Optical Co., Ltd.

The subjects of weekly discussion with colleagues in IIS included the problem of the experiments on the generation and the visualization of phase conjugate acoustic fields by means of magnetic and piezoelectric materials: a problem of the quality of parametric WPC in solids; dynamic properties of polydomain piezoceramics and magnets; the analysis of the present state of acoustic WPC problems and the orientation of the studies of WPC in solids. In particular, the investigation of the anomalous scattering of strongly coupled parametric shonon pair will be considered as important and prior, and can be attributed to a fundamental scientific problem. One can find a common treatment for those kind of phenomena in quite different are areas of physics. As an example, so-called Andreev's anomalous reflection of electrons at the boundary between a normal metal and a superconductor is illustrated. As it was noted by

prof. K. Takagi, the acoustoopic technique allow the possibility of visualizing wave-frots of WPC pulse fields which is usually difficult or impossible in other physical areas including nonlinear optics. Future work in this field will show importance and fundamental meaning which is unique to acoustic WPC.

In summary, I would like to note that the IIS Guest Research Fellowship has given me an opportunity of stimulating contacts and fruitful discussions with Japanese colleagues. This experience will be of great importance in the development of the investigation in the Laboratory of Applied Magnetoacoustics of MIREEA.

I want to thank the adminiptration of IIS for the invitation and the preparation of the comfortable condition for research work. I am very much thankful to my colleagues, prof. K. Takagi and prof. M. Ohno, for organizing the fellowship, fruitful discussions, help and pleasant personal contacts. Seizing the opportunity, I want to express my gratitude to prof. Y. Nakagawa for invitation to Yamanashi University and for this hospitality. I thank Dr. T. Matsuoka in Takagi Laboratory for his help in computer techniques.

(Manuscript received, August 19, 1994)

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