Secondary electron spin echo in quartz

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Secondary echo in an electron spin system is registered for the first time ever. An acoustic mechanism is proposed for the formation of this phenomenon.

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Investigations of spin echo in nuclear magnetically ordered system have shown it to have a number of singularities[1] not explained within the framework of the traditional Hahn model. One of the effects that take place in such systems is a secondary (supplementary) echo observed after the ordinary echo signal at a distance equal to the delay between the exciting pulses. No observation of analogous effects in other spin system is known at present.

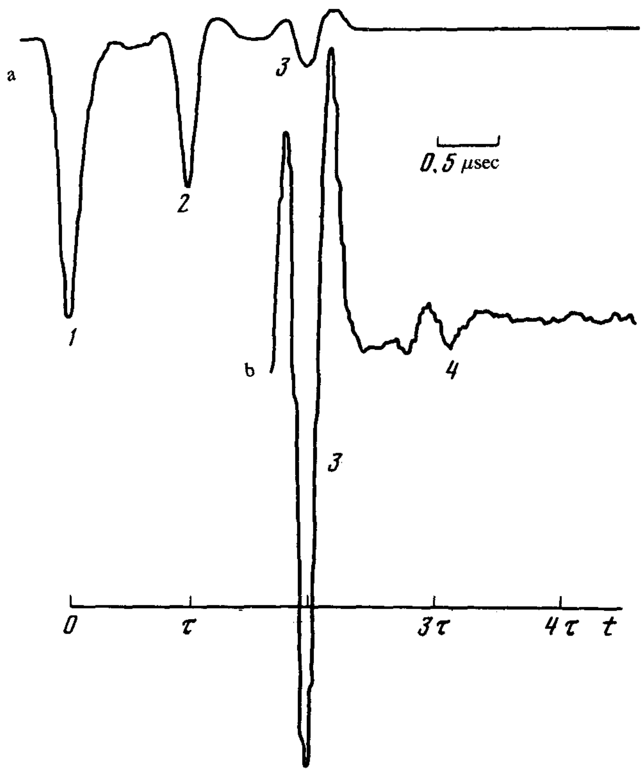

FIG. 1. Oscillograms of spin-echo signals.

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We report here the results of observation of the secondary echo in a system of electron spins.

The experiments were performed on crystalline quarz with E'_1 centers[2] produced by neutron bombardment and having a relatively long spin-lattice relaxation time (T_1) even at room temperature.[3] A typical plot of the secondary spin echo for these centers, obtained at 300 K, is shown in Fig. 1. The echo signals 3 and 4 were produced by pulses 1 and 2 of 200 nsec duration separated by $\tau = 1.0$ μsec. The intensity of the magnetic component of the microwave field at the sample location was about 0.2 Oe. Oscillogram *b* was recorded with the gain of the recording system 10 times larger than in the case of oscillogram *a*. In these experiments, the echo signal was recorded in the form of beats with a radio-frequency radiation (9.4 GHz). It is impossible to attribute the appearance of the secondary echo in our experiments to the known mechanisms. The frequency mechanism of echo formation[1] is excluded in this case because there was no dynamic frequency shift in the investigated system. Nor is the model that attributes the additional echo signals to excitation of various transitions in a complex energy spectrum[4] suitable, since the investigated paramagnetic centers have a spin $S = 1/2$.[2]

The onset of the secondary echo in our case can be described by the following mechanism. The first RF pulse excites in the crystal acoustic waves (phonons). The interaction of the second pulse with the spin system, whose states reflect the phonon field produce by the first pulse, produces backward acoustic waves. The interference between the waves produced by the first and second pulses leads to coincidence of the phases of the components at instants of times that are multiples of τ.

In the experiment, the duration of the echo pulses is inversely proportional to the width of the spectrum of the excited waves; this agrees with the interference nature of the phenomenon.

According to the proposed mechanism, the interference pattern should attenuate like $\exp(-2t/T_1)[\exp(-\tau/T_1)+1]^2$. For the given centers, the value of T_1 measured by the stimulated-echo method is approximately 1.5×10^{-5} sec. The difference between the experimentally obtained ratio of the amplitudes of the first and second echo pulses from the calculated value is attributed to the fact that generation of the primary-echo signal is accompanied by a partial dumping of the inverted spin state, by a concomitant conversion of the phonon-field energy into electromagnetic energy, and the emergence of the latter from the crystal. Since the generation process has a threshold, observation of the additional echo signals is possible only when the residual inverted state of the spin system exceeds the threshold value. At the same time, a nonradiative interference exists during the time T_1 as confirmed by the observation of the stimulated echo, in which the energy added by the third pulse makes it possible to exceed the generation threshold.

Also favoring the acoustic mechanism of echo formation is the fact that an echo is excited by a combination of electromagnetic and acoustic pulses.[4]

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[1]Yu.M. Bun'kov and B.S. Dumesh, Zh. Eksp. Teor. Fiz. **68**, 1161 (1975) [Sov. Phys. JETP **41**, 576 (1975)].

[2]V.P. Solntsev, R.I. Mashkovets, and M. Ya. Shcherbakova, Zhur. strukturnoĭ khimii **18**, 729 (1977).
[3]D.A. Bozanic, D. Mergerian, and R.W. Minarik, Phys. Rev. Lett. **21**, 541 (1968).
[4]V.A. Golenishchev-Kutuzov, A.I. Siraziev, N.K. Solovarov, and V.F. Tarasov, Zh. Eksp. Teor. Fiz. **71**, 1074 (1976) [Sov. Phys. JETP **44**, 562 (1976)].