Observation of pulsed spin transparency of a metal

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Selective pulsed spin transparency of a metal is observed for the first time. The characteristics of the nonstationary method are discussed and the kinetic characteristics of conduction electrons in lithium are determined.

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To study paramagnetic resonance on conduction electrons (PRCE) in metals, the so-called transmission method, in which resonant observation of the spin system of conduction electrons (CE) is realized on one surface of a plane-parallel specimen, while the signal is recorded on the opposite surface, is used successfully. This method is based on the phenomenon of selective transparency of metals, which is related to diffusion transport of spin magnetization of CE into the bulk of the metal over a distance greatly exceeding the depth of the skin layer.[1] Until now, this phenomenon has been observed in the stationary regime (see, for example, the reviews in Ref. 2). It has been demonstrated that the transmission method has a number of advantages, which permit studying metals that are inaccessible to the traditional PRCE method and observing some spin-wave effects.

In this paper, we report the first observation of pulsed spin transparency of a metal. The theory of pulsed spin transparency was developed in Ref. 3.

To observe pulsed PRCE in transmission, we developed a setup that includes a generator based on a magnetron (pulse power 7×10^3 W, frequency 9.4×10^9 Hz, pulse duration 30–100 ns), a wave-guide channel with decoupling exceeding 150 dB, transmitting and receiving resonators, and a data storage system based on a minicomputer. The specimens consisted of metallic lithium, deposited in a vacuum in the form of films with thicknesses of 20, 25, and 35 μm. The films served as the common wall of the transmitting and receiving resonators.

A typical spin induction signal, recorded in the receiving resonator with the transmitting resonator excited by single 30-ns pulses, is shown in Fig. 1 (curve 1).

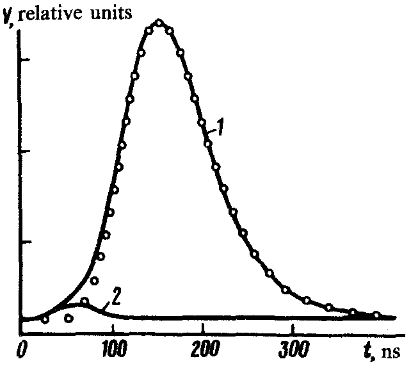

FIG. 1. Curve 1 shows the induction signal for conduction electrons in a lithium film 35 μm thick, measured by the transmission method at room temperature. The magnitude of the constant magnetic field H_0 corresponds to the resonant value. Curve 2 shows the transmitter pulse, observed with strong detuning of H_0 from the resonant value. The circles indicate the theoretical form of the induction signal $W(t)$ for the values $d = 35\ \mu$m, $T_V = 40$ ns, and $D = 12$ cm^2/s.

Curve 2 in Fig. 1 corresponds to the "parasitic" signal caused by the power that leaks into the receiving resonator, by-passing the spin channel.

The theoretical form of the induction signal in the transmission regime from an infinitely short pulse generator is given by the expression[3]

$$V(t) = A\frac{1}{\sqrt{t}}\exp\left\{-\frac{d^2}{2Dt} - \frac{t}{T_V}\right\}, \tag{1}$$

where A is a coefficient that does not depend on time, d is the thickness of the metal film, T_V is the spin relaxation time in the bulk of the metal, and T is the diffusion coefficient of conduction electrons in the metal. As is evident from expression (1), due to diffusion of CE the amplitude of the induction signal at first increases with time, since the excited conduction electrons in this case flow to the opposite side of the metal film. On the other hand, relaxation in the bulk of the metal decreases the observed signal. For a pulse of finite duration, expression (1) can be integrated with respect to the shape $f(\tau)$ of the generator pulse: $W(t) = \int_0^t f(\tau)V(t-\tau)d\tau$. Good agreement between theory and experiment can be obtained by varying the parameters D and T_V in $W(t)$ (see Fig. 1). It should be noted that the induction signal contains unique information both on the quantity D and on T_V, since the increase in the signal is primarily determined by the diffusion coefficient D, while the drop is determined by the relaxation time T_V. In addition, a 10% deviation of one of these parameters leads to an appreciable disagreement between the theoretical and experimental curves. Thus the method of pulsed transparency permits determining the kinetic and relaxation characteristics of conduction electrons. In particular, we found that the diffusion coefficient of conduction electrons in lithium is $D = 12 \pm 3$ cm^2/s at room temperature,(1) in agreement with previously measured values.[4]

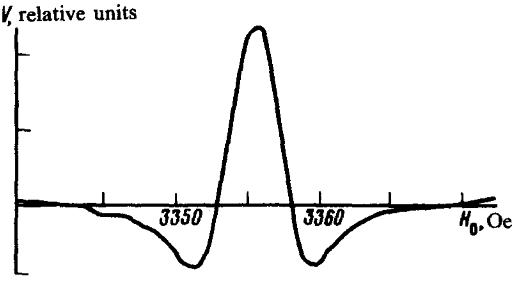

FIG. 2. Dependence of the amplitude of the induction signal on the constant magnetic field H_0.

In conclusion, we note that the pulsed method completely retains the information that is usually obtained in the stationary transmission method. As an illustration of this fact, Fig. 2 shows the dependence of the amplitude of the induction signal on the detuning of the resonance (of the constant magnetic field), which is the analog of the resonance curve in the stationary transmission method.

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[1)] The comparatively large error in determining D is attributable to the errors in the measurements of the thicknesses of the specimens in our experiment.

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[1] M. Ya. Azbel', V. I. Gerasimenko, and I. M. Lifshitz, Zh. Eksp. Teor. Fiz. **31**, 357 (1957).
[2] R. B. Lewis and T. R. Carver, Phys. Rev. **155**, 309 (1967); V. P. Silin, Fiz. Met. Metalloved. **29**, 681 (1970).
[3] V. A. Zhikharev and A. R. Kessel', Zh. Eksp. Teor. Fiz. **67**, 1758 (1974) [Sov. Phys. JETP **40**, 874 (1975)].
[4] F. G. Cherkasov, E. G. Kharakhash'yan, and V. F. Yudanov, Phys. Lett. A **50**, 399 (1975); I. G. Zamaleev and E. G. Kharakhash'yan, Pis'ma Zh. Eksp. Teor. Fiz. **27**, 677 (1978) [JETP Lett. **27**, 641 (1978)].

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