CONDUCTION ELECTRON SPIN TRANSMISSION IN LITHIUM*

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Azbel', Gerasimenko, and Lifshitz[1,2] predict selective transparency of metal films to microwaves at the resonant frequency of the conduction electron spins; energy transport being assumed due to a diffusion of precessing conduction electrons through the metal. We report the observation of such resonance transmission in lithium at room temperature.

Figure 1 shows the arrangement of microwave fields, static magnetic field H_0, and the lithium film. The cavities were sections of RG 52/U waveguide with coupling irises clamped to the ends. They operated at 9200 Mc/sec in the TE_{101} mode. A 600-mW afc-stabilized klystron drove the excitation cavity through a magic tee so that the reflected absorption signal could be observed with a crystal detector. This cavity contained a sample of Mn^{++} in ZnS deliberately introduced to detect any leaks in the lithium film. The detection cavity was coupled through a phase shifter to a phase-sensitive super heterodyne receiver with local oscillator power supplied by a 30-Mc/sec modulation sideband from the klystron. Both absorption and transmission signals were amplified synchronously with the 85-cps modulation of H_0.

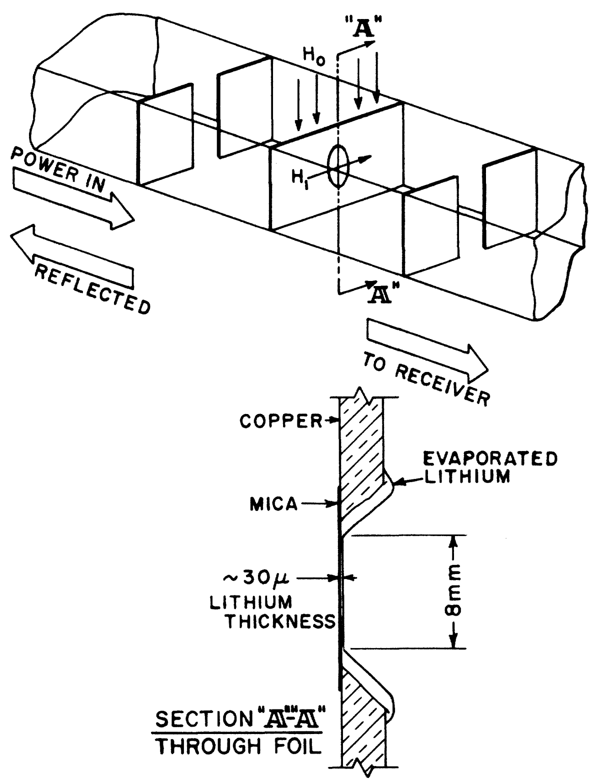

FIG. 1. Cavity and sample arrangement.

Figure 2 shows the observed (derivative) signals. The top trace is the absorption signal reflected from the excitation cavity. The lithium electron resonance is to the right and has the proper Dyson[3,4] shape for diffusing spins in thick samples. To the left of this is one of the six hyperfine components of the Mn^{++} line. The lower trace shows the transmitted signal with no indication of direct leakage transmission of the Mn^{++} resonance. To rule out radiation by the receiver as a cause of the transmission cavity response, a phase shift of π was introduced between the receiver and the cavity. The shape of the transmission response changed markedly. If receiver radiation had been exciting absorption in the transmission cavity, the phase of the signal back at the receiver would have been shifted by 2π and no change in line shape would have been observed. We conclude that the signal is due to spin diffusion.

The transmitted power, 5×10^{-12} watts, agrees with estimates assuming the following parameters: spin relaxation time $T_1 = 2\times10^{-8}$ sec, electron mean free path = 110 Å, Fermi velocity $v_F = 1.3\times10^8$ cm/sec, skin depth = 1.5 microns, and film thickness = 30 microns.

The strikingly good signal-to-noise ratio in the transmitted signal deserves attention. If there

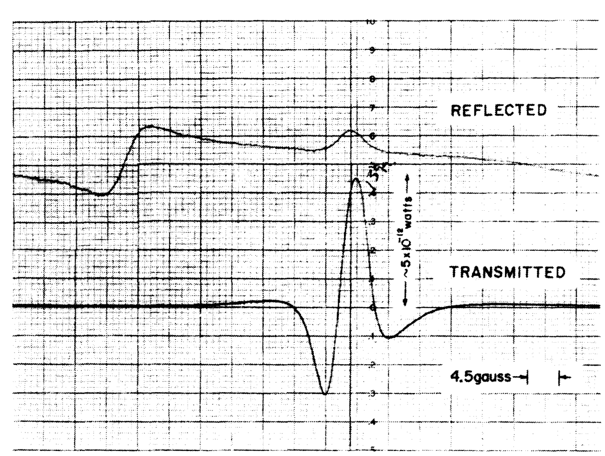

FIG. 2. Reflected and transmitted signals.

were no spin relaxation the lithium would be uniformly magnetized and the reflected and transmitted signal powers would be the same. In a real film the transmitted signal is reduced by spin relaxation, but the skin depth attenuation serves to filter out the exciting radiation and the transmitted signal may be observed against a quiet cavity. Under these conditions a sensitive superheterodyne receiver can detect 10^{-18} watts whereas the reflected signal is lost in generator noise and bridge balance microphonics at considerably higher powers. This is a useful feature in the study of metals requiring incident powers of hundreds of watts to saturate the conduction resonance. Notice that one may now use pulse- or amplitude-modulated excitation. In materials in which spin relaxation time is comparable to momentum relaxation time, samples of thickness comparable to skin depth may be used provided the cavities are placed so their microwave H fields are crossed and each perpendicular to H_0. The circular polarization of the lithium magnetization will excite the transmission cavity; skin depth transmission will not. Our intention to work at low temperatures and the size of our Dewar prevented the use of this geometry.

We will not attempt in this note to make a detailed comparison of line shape with the theories of magnetization in a thick slab.[1,3,5] However, in spite of the complexity of these theories, a simple and adequate description of the phenomenon can be made by adding the phases of the x-y spin components at the detection side of the film using a distribution of their departure times from the excitation side, and weighting their population by the exponential relaxation decay. This amounts to a magnetization proportional to

$$\exp(i\omega t)\int_0^\infty \exp[i(\omega_0-\omega)t']n(t')\exp(-t'/T_1)dt'$$

where we have chosen

$$n(t')=(t')^{-1/2}\exp(-Z^2/kt')$$

as an adequate expression for time of diffusion across the slab. Here $t'=t-t_0$ is the transit time across the slab, Z is the thickness of the film, and k is an appropriate diffusion constant. Since the signal is detected at an arbitrary phase θ with respect to the exciting field, the line shape is $\sin\theta S(\omega_0-\omega)+\cos\theta C(\omega_0-\omega)$ where S and C are the sine and cosine transforms of the arrival time and decay functions. This result, too lengthy to describe here,[6] shows the typical broad weak reversed wings, and shows the exponential attenuation of the signal with thickness of the sample.[7]

We believe this technique may aid in resolving some of the remaining questions concerning the relaxation of conduction electron resonance in bulk lithium and sodium, particularly through the elimination of impurities included in the surface regions and as a result of dispersing the metal. It is possible that the greater sensitivity may aid in the study of spin resonance in other metals on which little relaxation data exists, and in the observation of conduction spin resonance in a few additional metals in which it has not yet been observed. This work will be continued.

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[1]M. Ya. Azbel', V. I. Gerasimenko, and I. M. Lifshitz, Zh. Eksperim. i. Teor. Fiz. 32, 1212 (1957) [translation: Soviet Phys.—JETP 5, 986 (1957)].

[2]M. Ya. Azbel' and I. M. Lifshitz, Progress in Low-Temperature Physics, edited by J. C. Gorter (North-Holland Publishing Company, Amsterdam, 1961), Vol. 3, Chapter VII.

[3]F. J. Dyson, Phys. Rev. 98, 349 (1955).

[4]G. Feher and A. F. Kip, Phys. Rev. 98, 337 (1955).

[5]I. Kaplan, Phys. Rev. 115, 575 (1959).

[6]Table of Integral Transforms (McGraw-Hill Book Company, Inc., New York, 1954), Vol. 1.

[7]N. S. VanderVen and R. T. Schumacher, following Letter [Phys. Rev. Letters 12, 695 (1964)].

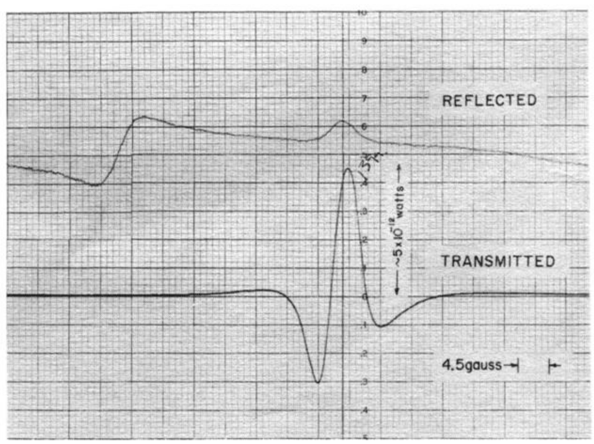

FIG. 2. Reflected and transmitted signals.