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Abstract

Full Text

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OBSERVATION OF SPIN INDUCTION IN ELECTRON PARAMAGNETIC RESONANCE

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As is known, nuclear magnetic resonance can be observed in two ways: by direct recording of power losses in the oscillator circuit, whose inductance coil contains the sample under investigation (^1), or by recording the induced e.m.f. generated in an auxiliary coil as a result of the precession of nuclear spins in the constant field $\mathbf{H}_0$ and the simultaneous action on them of a radio-frequency field $\mathbf{H}_v$, perpendicular to $\mathbf{H}_0$ (^2). The second method has received the not entirely fortunate name of the nuclear-induction method. The theory of nuclear induction is described with sufficient completeness by the phenomenological Bloch equations, which are a consequence of the classical description of the behavior of nuclear moments in the fields $\mathbf{H}_0$ and $\mathbf{H}_v$, with allowance for relaxation processes. From the solutions of the Bloch equations it follows that, when the field $\mathbf{H}_0$ is directed along the Oz axis, the variable component of the magnetic moment is induced not only along Ox, in the direction of the field $\mathbf{H}_v$, but also along Oy, i.e., perpendicular to the fields $\mathbf{H}_0$ and $\mathbf{H}_v$.

Fig. 1. Block diagram of the apparatus. 1 —klystron oscillator, 2 —ferrite isolator, 3 —variable attenuator, 4 —hybrid ring, 5 —microwave detector, 6 —electromagnet, 7 —bimodal resonator, 8 —microwave detector, 9 —low-frequency amplifier, 10 —oscilloscope.

It is easy to see that exactly the same situation should also occur in the case of electron spins under the action of fields $\mathbf{H}_0$ and $\mathbf{H}_v$: in the direction perpendicular to $\mathbf{H}_0$ and $\mathbf{H}_v$, there should appear a variable component of the magnetic moment of the electron spin, capable of inducing an e.m.f.

We attempted to observe electron paramagnetic resonance by recording the spin induction of electrons, similarly to how this is done in Bloch' s nuclear-induction method.

The block diagram of the apparatus is shown in Fig. 1. The power generated by a klystron at a frequency of 9500 MHz passes through a ferrite isolator and

Fig. 2. Design of the bimodal resonator

Figure 2: Fig. 2. Design of the bimodal resonator

Fig. 3. A—reflected signal from yttrium ferrite; B—induction signal from yttrium ferrite

Figure 3: Fig. 3. A—reflected signal from yttrium ferrite; B—induction signal from yttrium ferrite

a variable attenuator into a hybrid ring. Part of the power ($\sim 1/2$) enters

to arm I and then to a bimodal cylindrical resonator (Fig. 2) operating on an H_{111}-type wave. The input and output waveguides are arranged at an angle of 90° with respect to one another. The resonator is coupled to them through an aperture 4.5 mm in diameter. Tuning screws are used for adjustment: two opposite the coupling apertures and one in the end face of the resonator.

Fig. 2. Design of the bimodal resonator

The sample under study is placed on the other end face of the resonator, where the field strength $\mathbf{H}_\nu$ is maximal. The resonator is installed in the gap of an electromagnet so that the condition $\mathbf{H}_\nu \perp \mathbf{H}_0$ is satisfied. The use of a hybrid ring makes it possible to observe the EPR signal by the ordinary method of reflection from the resonator.

When there is no resonant absorption, arms I and II are decoupled and no signal appears in arm II. At resonance, owing to spin induction, a high-frequency emf appears in the volume of the resonator; it creates a second mode of type H_{111}, polarized perpendicular to the fundamental mode produced by the oscillations entering the resonator through the input waveguide. Then an EPR signal appears in arm II.

The possibility of observing EPR by the method described was tested by us on diphenylpicrylhydrazyl and on a single crystal of yttrium ferrite (a sphere 0.36 mm in diameter, with a resonance line about 1 oersted wide). Figure 3 shows oscillograms of the absorption lines in the ferrite, recorded with ordinary and induction observation.

Experimentally it was found that, in the absence of resonance, the power from the generator practically does not pass into arm II of the system. The decoupling between the arms was measured by comparing the EPR signals under ordinary and induction observation with the signal leaking into arm II in the absence of resonance. With precise tuning of the system the decoupling reached several tens of decibels (not less than 30). This figure can be considerably increased by more careful construction of the resonator (absence of ellipticity of the resonant volume, strict perpendicularity of the input and output waveguides).

Fig. 3. *A*—reflected signal from yttrium ferrite; *B*—induction signal from

yttrium ferrite

Investigation of the frequency dependence of the decoupling showed that the bimodal resonator transmits only the frequencies covered by the resonance line of the sample under study. The rest of the frequency spectrum is cut off, which leads to a substantial increase in sensitivity, especially in the case

narrow EPR lines. A second, very useful feature of the method under discussion is the high stability of the balance of the microwave circuits of the setup. This makes it possible to substantially reduce the requirements on the frequency stability of the microwave generator.

Observation of EPR by the spin-induction method can be successfully carried out in a radiospectroscope with superheterodyne detection. Such a spectroscope will have a number of important advantages: 1) the possibility of avoiding the use of a hybrid ring or circulator; 2) the possibility of using high microwave power, which will lead to an increase in the sensitivity of the instrument; 3) considerably greater stability in the operation of the circuit and the associated ease of operation. Observation of electron spin induction may also prove useful for measuring relaxation times when pulsed methods are used.

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Note: Figure translations are in progress. See original paper for figures.