Quantum-electrodynamic effects in solid-state EPR spectroscopy

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Introduction:

The phenomenon of the electron paramagnetic resonance (EPR) is accompanied by effects that usually are poorly manifested and not taken into account in the standard conditions of EPR measurenments. One of such effects, the strong coupling between electron spins and the standing electromagnetic field in the resonator, can be observed at low microwave power, the high number of spins and a narrow EPR signal. This quantum-electrodynamic phenomenon is the solid-state analog of the vacuum Rabi splitting, whose essence is the strong interaction between an atom and a photon trapped in the cavity. The value of Rabi splitting characterizes the strength of atom-photon coupling and is described by cavity quantum electrodynamics.

At the initial studies, this phenomenon was observed mainly for atoms in the optical cavity. However, as spin coherence times in solid-state systems is significantly longer than those in atom-light interactions, nowadays, there are more and more studies of a strong coupling between solid-state spin systems and microwave photons in the resonator.

In the case of solid state EPR, the strength of a single spin coupling to the magnetic component of the electromagnetic field is small, but it is amplified in the case of a spin system, since the collective coupling is proportional to the root of the number of spins. Presently, the strong coupling between an electron spin ensemble and a microwave resonator is intensively studied due to its possible applications in quantum computing technologies. Our preliminary results and their analysis indicate that the use of electrically conductive carbon materials can enhance the ability to control coupling of spins with the resonator.

The scientific objective of the work and the proposed research methods:

The aim of the work is to determine the properties of the strongly coupled spin-resonator systems, taking into account the effects of interactions, which are present in solids, particularly in carbonaceous materials.

Experimental studies will be performed using the modified EPR method allowing the measurement of the resonant frequencies of the coupled spin-resonator system. Additionally, the use of a temperature variation system makes it possible to change the value of the coupling constant by the order of magnitude.

Analysis of the results requires knowledge of the theory of EPR and cavity quantum electrodynamics as well as the theory of spin systems in conductive materials.