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THE INFLUENCE OF RARE EARTH IONS ON FERRIMAGNETIC RESONANCE

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Abstract

By utilizing the method of correlation function (theory of Kubo), the ferrimagnetic resonance behaviour of the tight exchange coupled system was discussed. The general formulae of the magnetic susceptibility tensor were given, from which the resonance field H_0 (or resonance frequency) and the line width $2\Delta\omega$ of the ferromagnetic branch and that of the exchange branch were determined. The results obtained show that the so-called fast relaxation and slow relaxation mechanisms are nothing but two branches (the transverse branch and the longitudinal branch) of the ferromagnetic resonance. The transverse branch corresponds to the coupled motion between the transverse components of $\vec{\mathbf{J}}$ and $\vec{\mathbf{S}}$ ($\vec{\mathbf{J}}$ and $\vec{\mathbf{S}}$ are the magnetic moments of rare earth ion and iron ion respectively), while the longitudinal branch corresponds to the coupled motion between the longitudinal component of $\vec{\mathbf{J}}$ and the transverse component of $\vec{\mathbf{S}}$.

Owing to the action of crystal field and anisotropic exchange field, the direction of quantization of $\vec{\mathbf{J}}$ deviates from that of $\vec{\mathbf{S}}$ by an angle ϕ. Besides, owing to the anisotropy of exchange interaction, the nondiagonal elements of the tensor $\overleftrightarrow{\lambda}$ in the Hamiltonian of exchange interaction $\vec{\mathbf{J}}\cdot\overleftrightarrow{\lambda}\cdot\vec{\mathbf{S}}$ may be quite large. It was shown that the contribution of the longitudinal branch to $2\Delta\omega$ is approximately proportional to ϕ^2 and $\lambda_{i3} (i=1,\ 2)$.

According to the general formula for $2\Delta\omega$, the latter is determined mainly by the transverse branch at very low temperatures (below 4.2°K). Along certain crystal directions θ_a, when the two lowest energy levels of rare earth ion nearly cross over, anomalous peaks of H_0 and $2\Delta\omega$ should appear, as it was verified experimentally. As the temperature increases, the longitudinal branch shall gradually dominate over the transverse branch. When the longitudinal relaxation frequency reaches the value of the frequency ω of the high frequency field, the line width possesses a maximum, which is the one ordinarily observed in experiments. As the temperature is increased further, the transverse branch shall play the dominant role again. When the transverse relaxation frequency approaches the frequency ω_{21}, corresponding to the energy difference of the two lowest energy levels of the rare earth ion, the line width possesses a second maximum. Experimentally it is possible to observe the second maximum only in those directions θ_a, along which the two lowest levels have a near cross-over. When ω is high enough so that the condition $|\omega_{21}(\theta_a)-\omega|\ll\omega$ is satisfied, at very low temperatures there

shall be a very sharp maximum of line width determined by the transverse branch.

With the theoretical results obtained, in addition to the phenomena mentioned above, the following experimental facts observed in rare earth garnets can also be satisfactorily explained: the strong dependence of effective gyromagnetic ratio on temperature; the abrupt increase of line width near the compensation point; the abrupt increase of H_0 for YbIG at the temperature where the line width reaches its maximum; etc.

The limitation of classical equations of motion of magnetic moment was pointed out. For ferrites, in which the crystal field is comparable with the exchange field, it was shown that the results obtained by solving the classical equations of motion can qualitatively explain only those experimental facts, which are not concerned with the concrete spectrum of the energy levels of rare earth ions.