Contribution to the theory of magnetoelectric resonance

V. A. Kolganov

(Submitted March 11, 1974)
ZhETF Pis. Red. **19**, 508–509 (April 20, 1974)

The onset of carrier drift in the ferromagnetic resonance regime under the influence of crossed alternating fields due to magnetization precession is investigated.

In a ferromagnet placed in mutually perpendicular constant magnetic field **H** and an alternating field $\mathbf{h}(t)$ that is the component of electromagnetic radiation of frequency ω incident on the sample, a surface distribution of the charges was observed, and the density of these charges increased appreciably under conditions of absorption ferromagnetic resonance.[1]

We use a classical analysis, neglecting the interaction of the electron system of the ferromagnets with the electric component of the radiation at $\omega_c\tau \ll 1$ (ω_c is the cyclotron frequency and τ is the carrier relaxation time). Omitting for simplicity the terms quadratic in B, we write down the equation of motion for the current density produced by a definite type of carrier in the following form:*

$$\tau \frac{d\mathbf{j}}{dt} + \mathbf{j} = \sigma \mathbf{E} + \frac{\omega_c \tau}{B}[\mathbf{j}\mathbf{B}], \tag{1}$$

where σ is the specific conductivity; $\omega_c = eB/m^*c$, and m^* is the effective carrier mass.

The stationary solution of the equation for the current is the time-independent part of the formal expression

$$\mathbf{j} = \sigma \frac{\mathbf{E} + \frac{\omega_c \tau}{B}[\mathbf{E}\mathbf{B}] + \left(\frac{\omega_c \tau}{B}\right)^2 \mathbf{B}(\mathbf{E}\mathbf{B})}{1 + (\omega_c \tau)^2}. \tag{2}$$

Using the solution of Maxwell's equation relative to **E** and **B**

$$\mathbf{E}(\mathbf{r}, t) = \frac{1}{c} \nabla \times \int_V \frac{d\rho}{|\mathbf{r} - \vec{\rho}|} \left(\hat{N}(\vec{\rho}) - 1\right) \frac{\partial \mathbf{M}(\rho, t)}{\partial t}, \tag{3}$$

$$\mathbf{B}(\mathbf{r}, t) = \mathbf{H}(\mathbf{r}) + 4\pi \mathbf{M}(\mathbf{r}, t),$$

where $N(\mathbf{r})$ is the tensor of the demagnetizing coefficients, we obtain the stationary value of the current in the case of a ferromagnetic ellipsoid of revolution relative to $\mathbf{H} \parallel \mathbf{n}_z$, placed in the homogeneous fields **H** and $\mathbf{h}(t)$

$$\mathbf{j}(\vec{\rho}, z) = j_{\parallel}(z)\mathbf{n}_z + j_{\perp}(\rho)\mathbf{n}_\rho,$$

where $\mathbf{n}_z$ and $\mathbf{n}_\rho$ are unit vectors of the cylindrical coordinate system (ρ, φ, z),

$$j_{\parallel}(z) \approx -\sigma z \omega \frac{(4\pi M_\perp)^2 (1 - N_\perp)^2}{cB} \frac{N_{\parallel}(\omega_c \tau)^2}{1 + (\omega_c \tau)^2},$$

$$j_\perp(\rho) \approx \frac{\rho}{2z} |j_{\parallel}| N_\perp / N_{\parallel}, \tag{4}$$

$$M_\perp^2 \sim \frac{(\gamma M h)^2}{(\omega_{\text{res}} - \omega)^2 + (\gamma \Delta H_0)^2}, \quad h(t) = h_\phi(t).$$

The appearance of direct current is due to the complex action of the magnetization oscillations on the carriers, and correspond, to the third term of (2), which is usually responsible for the appearance of longitudinal magnetoresistance (in the model in which nonsphericity of the Fermi surface is taken into account).

Let us estimate the resonant radial potential difference for the case of a transversely demagnetized ferromagnetic disk [$\rho_0 \gg z_0$, $\omega_{\text{res}} = \gamma(H - 4\pi M)$]

$$\frac{U_\perp}{P} \sim \frac{8\pi}{c^2} \left(\frac{4\pi M}{\Delta H_0} \rho_0 \omega_c \tau\right)^2 \gamma \left(1 - \frac{4\pi M}{H}\right) \frac{\pi z_0}{4\rho_0} \sim 10^{-3} \text{ V/W},$$

where $4\pi M \approx 3\times 10^3$ Oe, $\Delta H_0 \sim 30$ Oe, $\omega_c\tau \sim 8\times 10^{-2}$, $z_0 \sim 2\times 10^{-2}$ cm, and $\rho_0 \sim 0.15$ cm.[1] The influence of the longitudinal current at $\rho_0 > z_0$ can be neglected. The positive charge is then situated at the center and the negative on the edge of the disk.

The sign and magnitude of the emf are in satisfactory agreement with the results of the experiments,[1] if allowance is made for the approximate character of the estimate of the sample parameters (private communication from the authors).

The nontrivial character of the dependence of the current density on the coordinates explains the anomalies of the potential difference picked off a spherical sample at an arbitrary geometry of the contacts.[2]

---

*$[\mathbf{j}\mathbf{B}] \equiv \mathbf{j} \times \mathbf{B}$.

[1]V. I. Salyganov, Yu. M. Yakovlev, and Yu. R. Shal'nikov, ZhETF Pis. Red. **18**, 366 (1973) [JETP Lett. **18**, 215 (1973)].
[2]M. Toda, Appl. Phys. Lett. **17**, 1 (1970).

