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Electron Iso-Energetic Surface Openness and Helicon Type Wave in Metal

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Abstract

The possibility of existence of the electromagnetic wave similar to the helicon type wave is analysed for metal anisotropy single crystal media having an openness of Fermi surface in the transverse direction to an external magnetic field. Usually helicon waves takes place due to specific conductivity tensor having off-diagonal Hall components being of much higher than diagonal these. However for open Fermi surface the only one transverse tensor component along the opennes is small before Hall that. On this reason the existence of spiral waves in metal single crystal conductor (for instance copper) is hardly possible when crystallografic direction [111] is strictly orthogonal to wave vector direction being oriented along [110].

Introduction

The tasks of electromagnetic wave propagation via different media are based on the macroscopic phenomenological Maxswell field equations being supplied with material equations. Material equations are determined with the type of electric conductivity for given frequency range. For metal media the only term should be taken into account is conductivity current. So the magnetostimulated anisotropy of conductivity is an important factor that determines the particle movement. The conductivity behaviour under steady magnetic field action during electromagnetic field excitation in surface layers should be determined from differential kinetic Boltzman equation. Here the phenomenological task of transverse electromagnetic wave excitation in metal single crystal sample is analyzed on the base of tensor connections between electric field component and current density in the approximation of weak spatial dispersion for electron probability distribution function. This approximation is valid for microwave range and also for optical range too.

Analytical results and discussion

The total base equations for formulated problem are phenomenological these for conducting media having free charges.

$$rotH = \frac{4\pi}{c}j; rotE = -\frac{1}{c}\frac{\partial B}{\partial t} \tag{1}$$

Here H, E and B — vectors of electromagnetic field. From the (1) it follows usual expression for presentation of electromagnetic field properties in metal media

$$graddivE - \nabla^2 E = -\frac{4\pi}{c^2}\frac{\partial j}{\partial t} \tag{2}$$

here j — vector of conductivity current density. It is connected with components of electric field vector E. In linear approximation it is admitted to seek the decision in the form of $\exp{(ikr - i\omega t)}$, here k — wave vector, r — radius vector of any point in material, kr — scalar multuplication.

For this problem the matter equations are followed from kinetic equation for electron probability distribution function.[1 — 3]. Kinetic equation is to be represented as

$$\left(\frac{1}{\tau} - i\omega\right)\psi + \Omega\psi + ikv = evE \tag{3}$$

here τ — time of electron-impurities scattering, Ω - Larmor frequency, e — electron charge, ψ — non-equilibrium addition to electron function, v — Fermi velocity. A weak spatial dispersion denotes that a respective last term in the left part of (4) is rather small in comparison with others. Respectively the parameter $kr_L < 1$, (r_L — Larmor radius). Beneath we concretize this approximative conditions and the range of validity for given analysis. For the case of strong external magnetic field the maximal parameter of frequency is Larmor frequency

$$\left|\frac{1}{\tau} - i\omega\right| \langle\langle \Omega \tag{4}$$

The decision of (3) under conditions of (4) is well known and conductivity tensor is to be expressed as a function of parameter $\gamma = (\tau^{-1} - i\omega)\,\Omega^{-1}$[4]:

$$\sigma_{ik} = \sigma_0 \begin{pmatrix} \gamma^2 & \gamma & \gamma \\ -\gamma & 1 & 1 \\ -\gamma & 1 & 1 \end{pmatrix} \tag{5}$$

here σ_0 — static conductivity in zero magnetic field. Following to (2) it is possible to determine characteristic equation system, that represents frequency field in the sample

$$\begin{pmatrix} \left(k_z^2 - \dfrac{4\pi i\omega\sigma_0}{c^2\gamma 2}\right) E_x - \dfrac{4\pi i\omega\sigma_0\gamma}{c^2} E_y - \dfrac{4\pi i\omega\sigma_0\gamma}{c^2} E_z = 0 \\ \dfrac{4\pi i\omega\sigma_0\gamma}{c^2} E_x + \left(k_z^2 - \dfrac{4\pi i\omega\sigma_0}{c^2\gamma 2}\right) E_y - \dfrac{4\pi i\omega\sigma_0}{c^2} E_z = 0 \\ \dfrac{4\pi i\omega\sigma_0\gamma}{c^2} E_x - \dfrac{4\pi i\omega\sigma_0}{c^2} E_y - \dfrac{4\pi i\omega\sigma_0}{c^2} E_z = 0 \end{pmatrix} \tag{6}$$

As a result the wave vector can be represented

$$k_z^2 = \left(\frac{\tau^{-1} - i\omega}{\Omega}\right)^2 \frac{4\pi i\omega\sigma_0}{c^2} \tag{7}$$

For the most simple case the reversal relaxation time is higher of microwave field frequency. This takes place at helium temperatures in materials of large purity. For metals the value τ is of the order of $10^{-10}s$. It corresponds to resistivity of the order of $10^{-10} Ohm \cdot cm$ as the v is of the order of $10^{8} cm \cdot s^{-1}$. For microwave region ($\omega \sim 10^{9} s^{-1}$) it is possible to neglect the influence of the wave frequency on electron properties and the responsibility of matter. The wave vector can be represented as

$$k_z = \frac{1+i}{\sqrt{2}\Omega\tau c}\sqrt{4\pi\omega\sigma_0} \tag{8}$$

Respectively a complex refraction index N and reflectivity coefficient R may be written

$$N = \frac{1+i}{\sqrt{2}}\frac{\omega_p}{\Omega\sqrt{\omega\tau}} \tag{9}$$

$$R \simeq 1 - \frac{2\sqrt{2\omega\tau}\Omega}{\omega_p} \tag{10}$$

What is the frequency range being valid for (8), (9), (10). The primary condition of weak spatial dispersion corresponds to the next frequency range which is a microwave that

$$\omega \prec \frac{\Omega^4}{\omega_p^2}\frac{c^2\tau}{v^2} \cong 10^{10}s^{-1} \tag{11}$$

So spiral wave of helicon type can not be excited in cubic single crystal metal sample along crystallographic direction [110] on the reason of the existence of isoenergetic surface openness in direction [111].

Another case of frequency range belongs to ($\omega \sim 10^{11}s^{-1}$) and wave vector k_z for this range of spectrum corresponds to

$$k_z^2 = -\frac{\omega^2}{\Omega^2}\frac{4\pi i\omega\sigma_0}{c^2} \tag{12}$$

For this case the restriction of weak spatial dispersion defines frequency limit as

$$\omega^3 \prec \frac{\Omega^4 c^2}{\omega_p^2\tau v^2} \cong 10^{31}s^{-3} \tag{13}$$

here ω_p — plasmas frequency. The condition (13) determines the similar frequency range as for (11). This condition contradicts a bet to mentioned above frequency. However the approximation of effective small spatial dispersion may be applied for this case because the difference is of the one order in magnitude. Respectively wave vector, refraction index and reflectivity coefficient are to be established as

$$k_z = \frac{(1-i)\,\omega}{\sqrt{2}\Omega}\frac{\omega_p\sqrt{\omega\tau}}{c} \tag{14}$$

$$N = \frac{(1-i)\,\omega_p\sqrt{\omega\tau}}{\sqrt{2}\Omega} \tag{15}$$

$$R \cong 1 - \frac{2\sqrt{2}\Omega}{\omega_p\sqrt{\omega\tau}} \tag{16}$$

Conclusion

The analysis has shown that the spiral electromagnetic waves of helicon type can not be excited in uncompensated metals (for instance copper) along crystallographic direction [110]. Copper has an open Fermi surface along crystallographic direction [111]. On this reason the movement of particle in the plane being orthoganal to an external magnetic field is infinite . Infinite movement of electrons stimulates an anisotropy of conductivity tensor transverse diagonal components and negativity of dielectric penetrability. An incline of direction of wave vector to Fermi surface opennes does not exclude the probability of existence of electromagnetic wave in sample volume due to an existence of elongated closed electron orbits . The degree of inclination and the range of necessary magnetic field magnitude demand an additional analysis.

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