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Spatial Inversion of Gyrotropy Parameter in Conductivity Tensor and Charge Transport Peculiarities

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Abstract

Charge transfer is discussed for the case when gyrotropy parameter (Hall coefficient) varies along transport x-direction and inverses its sign. This situation takes place in contacts of the serially joined materials having electron and hole types of conductivity. Spatial inhomogeneity of conductivity and inversion of Hall coefficient sign are analyzed in terms of electric potential and current density distribution. It is shown that under inhomogeneous magnetic field the steady current skinning takes place in plate sample.

1. Introduction

Metal heterocontact between the conductors having electron and hole types of conductivity (for example contact similar to conjunction of Al and Cu plate sample) is an example of bianisotropic medium especially under the action of an external magnetic field. Bianisotropy is a result of opposite signs of Hall coefficients in Al and Cu. As a result such a contact has a transformation of conducting properties from the electron type to the hole that along transport direction and may be represented as an inhomogeneous medium having gradient type of conductivity. The inhomogeneity is not determined with only the electron structure via contact. The magnetic field itself is a reason of magnetostimulated inhomogeneity of conductivity and respective the potential picture rearrangement. As a result the current density redistribution through cross section of sample takes place [1, 2]. So the excessive resistance connected with current line redistribution is a result of conductivity inhomogeneity stimulated with magnetic field and heterogeneous electron conducting properties in such a conjunction. In this paper the double type of electric conductivity inhomogeneity stimulated by bianysotropy and by magnetic field is investigated. In other words the processes taking place in metal heterocontacts placed in inhomogeneous magnetic field are modeled and analysed.

2. Experimental and Theoretical Approach

The procedure of modeling of magnetic field inhomogeneity is based on the method of curving of current lines so that the normal local component of magnetic field has a variation along the transport direction in accordance with definite law. For simplicity the heterocontact under the investigation have been chosen as a symmetric one consisted of materials not Al-Cu but Al^+-Al^- type. Here Al^+ is an usual widely used aluminum of hole type of conductivity and Al^- is an farfetched electron analogue of Al^+ which has an electron type of conductivity in magnetic field. That is Al^- has an electron type of conductivity so that its Hall coefficient R is equal $-|R|$ instead of R for usual aluminum. So Al^+ and Al^- type components used in experimental modeling process have the same electric resistivity tensors excluding the sign of Hall coefficient. Both components are realized on the base of usual aluminum.

3. Results and Analysis

In experiment two types of magnetic field inhomogeneity in bianisotropy contact medium are modeled. The first type of magnetic field structure is represented in Fig. 1-a) and the second type of magnetic field spatial structure is represented in Fig. 1-b).

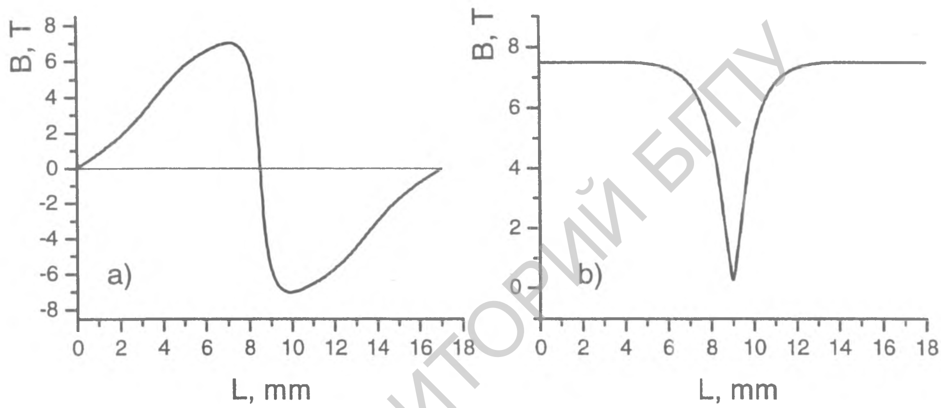

Fig. 1 The topology of magnetic field: a) The inversion type of inhomogeneity; b) The symmetric type of inhomogeneity.

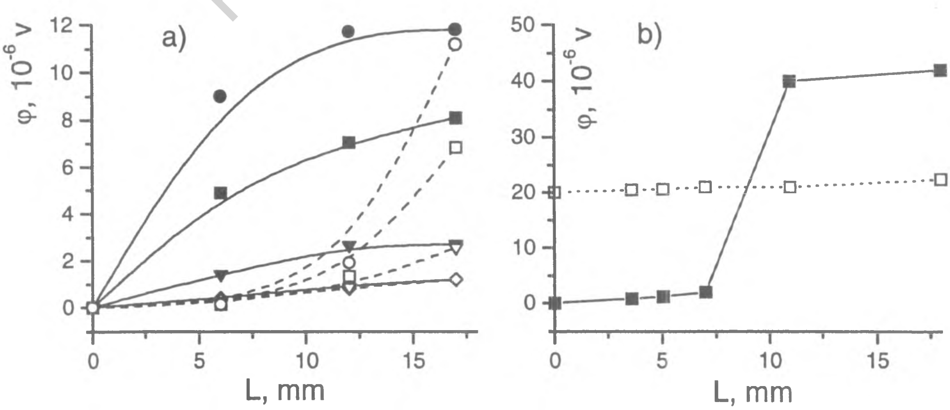

Fig. 2 The potential picture along sample length on opposite sides (solid and dashed lines) in inhomogeneous magnetic field: a) Field topology Fig. 1-a) where the maximal field B, T: 0.14 (diamonds), 1.4 (triangles), 4.3 (squares), 7.1 (circles); b) Field topology Fig. 1-b) where the maximal field is 7.5 T.

Here the potential distribution has been measured on opposite sides of sample in accordance with scheme of potential probes arrangement. Electric field potential picture is represented in Fig. 2 where the potential distribution on opposite Hall sides is shown along sample length L in contact region and close to it. It is interesting that for inversion type of inhomogeneity of magnetic field the potential picture is symmetric respectively zero field point. The strong and weak spatial dependence of potential on L takes place. For symmetric type of magnetic field inhomogeneity the potential dependence on opposite sides is different on behavior. One side has abrupt jump of potential in contact region but another side shows very weak dependence on coordinate along transport direction including the contact region. To analyze this behavior the discontinuity conditions for current density have been used to write the equation for electric potential φ. Taking into account that the thickness of samples directed along the magnetic field is rather small in comparison with other dimensions the approximation had been used that the current flow picture does not influence on potential distribution along z-direction. The carrier motion along magnetic field is neglected and the electric potential is not a function of z-coordinate. So for the two-dimensional geometry the potential equation is

$$\left(\frac{1}{\beta^2}+\frac{\alpha}{\beta}\right)'_x \varphi'_x + \left(\frac{1}{\beta^2}+\frac{\alpha}{\beta}\right)\varphi''_{xx} - \frac{\beta'}{\beta^2}\varphi'_y + \left(\frac{1}{\beta^2}+\frac{\alpha}{\beta}\right)\varphi''_{yy} = 0 \qquad (1)$$

Here φ'_x , φ''_x , $(\ldots)'_x$ and so on are the derivatives of respective order, $\beta' = \partial\beta/\partial x$; $\beta = \omega\tau$, ω is Larmor frequency, τ is a relaxation time. The next type of electric conductivity tensor is used

$$\sigma = \sigma_0 \begin{pmatrix} \frac{\alpha}{\beta}+\frac{1}{\beta^2} & \frac{1}{\beta} & \frac{1}{\beta} \\ -\frac{1}{\beta} & \frac{\alpha}{\beta}+\frac{1}{\beta^2} & \frac{\alpha}{\beta}+\frac{1}{\beta} \\ \frac{1}{\beta} & \frac{\alpha}{\beta}-\frac{1}{\beta} & 1 \end{pmatrix} \qquad (2)$$

Here σ_0 is the conductivity in zero magnetic field. The component $\sigma_{xx} = 1/\beta^2 + \alpha/\beta$ has such view after taking into account of the existence of a layer of open electron orbits. The term responsible for this layer is α/β which must be accepted in modulo. Following such a presentation the magnetoresistance of aluminum $\rho_{xx}=1/\sigma_0(1+\alpha\beta)$ that is has not very strong slope in linear dependence on magnetic field because the parameter α/β describing the quantity of open electron trajectory is rather small. Respectively the magnetoresistance ρ_{xx} for copper may be represented as the same expression where the linear Kapitza law takes place because the same parameter describing the width of open electron trajectories is closed to unit. The separation of variables allows to get the total decision of equation for some particular cases:

$$\varphi = C_1\left(\int \frac{\beta^2}{1+\alpha\beta}dx\right)\exp\left(\beta' \frac{1}{1+\alpha\beta} y\right) + C_2 \qquad (3)$$

Here this expression is valid when $\beta'/(1+\alpha\beta)$ = const. So for the limit case $\alpha \to 0$ one can obtain the potential distribution in approximation of free electron gas and at nonzero α the potential picture for aluminum and copper separately and for the contact of these materials can be obtained. Following Eq.(3) the potential dependence on sides of sample placed in inhomogeneous magnetic field has strong (at $y = b$, where b is the sample width) and weak (at $y = 0$) dependence on coordinate along transport direction. The direction of magnetic field gradient plays very important role in the potential distribution on the reason that magnetic gradient participates in the governing of transport process via strong exponential dependence on transverse y-coordinate. The transverse dependence of potential on

y-coordinate is much higher of that along transport x-coordinate. Here under inhomogeneity the correspondence between transport electric field and Hall field is similar to homogeneous situation. So for particular case of aluminum type conductor having very small width of elongated trajectories the potential picture and respective current density distribution along transport direction are:

$$\varphi = C_1 \int \beta^2 dx \exp(\beta' y) + C_2\,; \quad j_x = C\beta' \exp(\beta' y); \quad \beta' = const \tag{4}$$

Following this expression the potential dependence on coordinate in transverse magnetic field is rather complicated than that belonging to the homogeneous magnetic field actions which is $\varphi = C(x+\beta y)$. Respectively the steady current skinning takes place. Namely near one of side the current density is large and near opposite side the current density is small. Magnetic field gradient inversion transforms the potential picture and the current skinning center to opposite side. This type of dependence takes place in Fig.2a where the effective inversion of magnetic field gradient sign occurs near zero point because the conductivity is opposite on Hall effect. For Fig.2b the dependence of φ is governed with the effective magnetic field gradient which has the same sign via total sample. The opposite type of conductivity near zero point transforms the effective magnetic actions and the abrupt increase of potential corresponds to an action of exponent in Eq.(4) whereas the weak potential growth on opposite side is a result of decrease of exponential include. As to copper type conductor in heterocontact (experimental results we have no yet), the analysis of Eq.(3) allows to conclude that the potential picture redistribution due to double inhomogeneity also can be estimated. So for copper type conductor the width of layer of open trajectories is to be taken into account and the expressions for the potential dependence is:

$$\varphi = C_1 \int \frac{\beta}{\alpha} dx \exp\left(\frac{\beta'}{\alpha\beta} y\right) + C_2\,; \quad \frac{\beta'}{\alpha\beta} = const \tag{5}$$

The analysis shows that for copper type conductor the potential redistribution due to inhomogeneity is not so high as in aluminum type conductor. The reason of this is the large number of elongated orbits on isoenergetic surface. The carriers of these orbits are not so free to drift in gradient magnetic field and as a result more complicated movement of carriers leads to more weak degree of electric potential and current skinning.

4. Conclusion

The method of modeling of magnetic field inhomogeneity via curving of current lines allowed to create a physical picture of current flow through the aluminum based heterocontact. Aluminum based heterocontact consists of pure aluminum sample have been bent in such manner that an effective magnetic field action is equal to the presence of two heterocomponents having opposite Hall coefficient. Double type of inhomogeneity due to heteroconductivity in magnetic field and due to magnetic field action itself generates current density redistribution via contact region. This redistribution depends strongly on the topology of magnetic field and the excessive heat generation due to current skinning can be taken into account on the base of data have been analyzed here.

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