KRISTALLARDA GALVANO- VA TERMOMAGNIT HODISALAR

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Annotatsiya: Yarimo’tkazgichlarda kechadigan galvano- va termomagnit hodisalar namunaning tashqi elektr, magnit, deformatsiya va issiqlik maydonlari ta’sirida xossalarining o’zgarishi bilan tavsiflanadi.

Аннотация: Гальвано- и термомагнитные явления, происходящие в полупроводниках, характеризуются изменением свойств образца под воздействием внешних электрических, магнитных, деформационных и тепловых полей.

Abstract: Galvano- and thermomagnetic phenomena occurring in semiconductors are characterized by changes in the sample's properties under the influence of external electric, magnetic, deformation and thermal fields.

Bunday tur kinetik hodisalarning amaliy ahamiyati sezilarli, chunki ularning yordamida tok tashuvchilar konsentratsiyasi va harakatlanuvchanligi, sochilish mexanizmlarini tavsiflovchi fizikaviy kattaliklar, yarimo’tkazgichlar zonaviy strukturasining parametrlari, masalan, ta’qiqlangan zona kengligi, tok tashuvchilar effektiv massalari miqdoran aniqlanadi [1-3].

Galvano- va termomagnit samaralar texnikada ham keng qo’llaniladi. Magnit maydoni kuchlanganligini aniqlash imkonini beruvchi Xoll datchiklari, Xoll va magnitoqarshilik samarasiga asoslanib ishlaydigan elektr signallarini o’zgartirgichlar, Nernst-Ettingsgauzen samarasiga asoslanib ishlaydigan issiqlik energiyasini elektr energiyasiga aylantiruvchi datchiklar hamda Ettingsgauzen samarasiga asoslanib ishlaydigan sovutgichlar va termostatikaviy qurilmalarning hayotimizning qator sohalarida qo’llanilishi yuqridagi fikrimizning asosi bo’la oladi [4-6].

Shunday qilib, galvano va termomagnit va bunday tur kinetik hodisalarni keng qamrovda o’zrganish, ularning mexanizmlarini qaralayotgan hollarga, masalana kvantlashgan o’ralarda yokri anizatropiyani e’tiborga olgan holda, tekshirish o’z mazmunini yo’qotganicha yo’q. Shu sababdan bunday tur hodisalarni, dastlab, fenomenologiviy, so'ngra, hech bo'lmasa, kvaziklassik yaqinlashishda tadqiq etamiz [7-10].

Tashqi magnit maydon ta'siri

Yarimo'tkazgichlarning qator xossalari tashqi magnit maydon ta'sirida o'zgartiradi, uning ta'sirida yangi tabiatli hodisalar, masalan, Xoll samarasi, sodir bo'lishi mumkin.

Umuman olganda, $\vec{\varepsilon}=(\varepsilon_x,\varepsilon_y,\varepsilon_z)$ kuchlanganlikli elektr va $\vec{B}=(B_x,B_y,B_z)$ induksiyali tashqi magnit maydonlari zaryadli zarralarga

$$\vec{F}=-|e|\cdot\vec{\varepsilon}-\frac{|e|}{c}\left(\vec{V}\times\vec{B}\right)$$

Lorens kuch bilan ta'sir etadi Bu ifodada e-elektron zaryadi, c-elektromagnit to'lqinlar vakuumda tarqalish tezligi, $\vec{V}$-zaryadli zarraning tezligi.

Izotrop nomagnit muhitlarda $\vec{B}$ induksiya vektori $\vec{H}=(H_x,H_y,H_z)$ tashqi magnit maydon kuchlanganligiga miqdoran teng bo'ladi. Magnit xossasi sezilarli muhitlarda esa, $\vec{B}=\vec{H}+4\pi\vec{M}$ munosabat o'rinli bo'ladi. Bunda $\vec{M}$-muhitning spontan (o'z-o'zidan) magnitlanish vektoridir.

Quyida, agar alohida qayd qilingan bo'lmasa, u holda muhitni izotrop nomagnit muhit deb hisoblaymiz. Agar tashqi elektr maydoni ta'siri bo'lmasa, ya'ni $\vec{\varepsilon}=0$ bo'lsa, u holda Lorens kuchi ta'sirida zaryadli zarra $\omega_c={|e|B}/{(m_0c)}$ siklik chastota bilan magnit maydoni induksiya vektori atrofida aylanadi. Bunday holda, ma'lum bir yo'nalishlarda, elektron energiyasi, tabiatan o'zgarmasa-da, biroq ayrim yo'nalishlarda, $\vec{B}$ yo'nalishiga tik bo'lgan tekislikda elektron energiyasi kvantlashib qoladi, ya'ni elektronlar Landau sathlariga taqsimlanadi. Har ikki qo'shni Landau sathlari orasida ekvidistans energiyaviy oraliklar bo'ladi va bu oralik miqdoran $\hbar\omega_c$ kattalikka teng bo'ladi. Natijada bunday elektronlar sistemasida qator fizikaviy kattaliklar, miqdoran, magnit maydoni induksiya vektorining son qiymatiga qarab ostsillyatsiyalanib qoladi. Jumladan muhit diamagnit kirituvchanligining ostsillyatsiyalanishi de Gaaz-van Alfen samarasi deb yuritilsa, o'tkazuchanligining ostsillyatsiyalanishi Shubnikov-de Gaaz effekti, qo'ndalang magnitoqarshiligining ostsillyatsiyalanishi magnit teshilish samarasi deb yuritiladi. Bunday ostsillyatsiyalanuvchi samaralara yordamida yarimo'tkazgichlarning qator miqdoran noma'lum fizikaviy kattaliklari hisoblanadi. Xususan metallarda Fermi sirtlarning fizikaviy tabiati shunday samaralar hisobiga aniqlanadi [11-15].

Elektr o'tkazuvchanlikka magnit maydoni ta'sirining klassik nazariyasi

Masalani oydinlashtirish maqsadida magnit maydoniga o'rnatilgan metalldagi erkin elektronlarning elektr o'tkazuvchanlikka beradigan ulushini, elektronlarning elektr o'tkazuvchanligini impuslar relaksatsiyasi vaqti yaqinlashishida tadqiq etaylik. Lorens kuchi ta'sir etayotgan erkin elektronlarning harakat tenglamasi quyidagicha yoziladi

Bu yerda $\ddot{\vec{r}} = \dfrac{d^2\vec{r}}{dt^2}$, $\dot{\vec{r}} = \dfrac{d\vec{r}}{dt}$ belgilanlar kiritilgan, τ-elektronlar impulsi relaksatsiya vaqti. Masalani to'la hal qilish maqsadida oxirgi tenglamaning vektor kattaliklarning tashkil etuvchilariga nisbatan qayd qilamiz, ya'ni

$$m_0\ddot{x} + \frac{m_0}{\tau}\dot{x} = -|e|\varepsilon_x - m_0\omega_c\dot{y},$$

$$m_0\ddot{y} + \frac{m_0}{\tau}\dot{y} = -|e|\varepsilon_y - m_0\omega_c\dot{x},$$

$$m_0\ddot{z} + \frac{m_0}{\tau}\dot{z} = -|e|\varepsilon_z.$$

Bu holda magnit induksiya vektori z o'qi bo'ylab yo'nalgan, ya'ni $\vec{B} = (0, 0, B)$ deb hisobladik.

Aytaylik tashqi elektr maydoni ω chastotali garmonik o'zgaruvchan tabiatli, ya'ni $\vec{\varepsilon} = \vec{\varepsilon}_0 \exp(i\omega t)$ ko'rinishda olinsin. U holda (12.3) tenglamadan

$$m_0\left(i\omega + \frac{1}{\tau}\right)\dot{z} = -|e|\varepsilon_z$$

kelib chiqadi. Tok zichligining z tashkil etuvchisiga nisbatan qayd qilingan

$$j_z = -|e|n\dot{z}$$

munosabatda (12.4) ifodani e'tiborga olsak, u holda

$$j_z = \frac{ne^2}{m_0\left(i\omega + \frac{1}{\tau}\right)}\varepsilon_z = \frac{ne^2\tau}{m_0(1+i\omega\tau)}\varepsilon_z = \frac{1+i\omega\tau}{1+\omega^2\tau^2}\frac{ne^2\tau}{m_0}\varepsilon_z,$$

bu yerda n-elektronlar konsentratsiyasi.

Agar Om qonunini

$$j_\alpha = \sum_{\beta=x,y,z}\sigma_{\alpha\beta}\varepsilon_\beta$$

ko'rinishda tanlasak, u holda

$$\sigma_{zz} = \frac{1+i\omega\tau}{1+\omega^2\tau^2}\frac{ne^2\tau}{m_0} = \frac{1+i\omega\tau}{1+\omega^2\tau^2}\sigma_0$$

va $\sigma_0 = \dfrac{ne^2\tau}{m_0}$.

(12.3) tenglamalar sistemasining dastlabki ikki tenglamalarini xOy tekisligiga nisbatan echamiz. Buning uchun $r_\perp = x+iy$ $(\dot{r}_\perp = \dot{x}+i\dot{y})$ shakl almashtirishlar qilamiz. Natijada quyidagi munosabatga ega bo'lamiz

$$m_0\ddot{r}_\perp + \frac{m_0}{\tau}\dot{r}_\perp = -|e|\varepsilon_\perp + im_0\omega_c\dot{r}_\perp,$$

bu holda $\varepsilon_\perp = \varepsilon_x + i\varepsilon_y$. Yuqoridagidek, elektr maydonni garmonik o'zgaruvchan deb hisoblasak, u holda

$$m_0\left(i(\omega-\omega_c)+\frac{1}{\tau}\right)\dot{r}_\perp = -|e|\varepsilon_\perp$$

va oxirgi munosabatdan

$$\dot{r}_\perp = -\frac{1}{1+i(\omega-\omega_c)\tau}\frac{|e|\tau}{m_0}\varepsilon_\perp$$

U holda

$$j_\perp = \frac{1-i(\omega-\omega_c)\tau}{1+(\omega-\omega_c)^2\tau^2}\sigma_0\varepsilon_\perp$$

foydali munosabatni olamiz. Bundan tok zichligining tashkil etuvchilari uchun

$$j_y = \frac{\sigma_0}{1+(\omega-\omega_c)^2\tau^2}\left[\varepsilon_y - (\omega-\omega_c)\tau\varepsilon_x\right]$$

ifodalarni olamiz.

Agar tok zichligini

$$\begin{bmatrix} j_x \\ j_y \\ j_z \end{bmatrix} = \begin{bmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{bmatrix}\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \end{bmatrix}$$

ko'rinishda ifodalasak, u holda (12.7), (12.8), (12.12.3) va (12.14) munosabatlardan

$$\begin{bmatrix} j_x \\ j_y \\ j_z \end{bmatrix} = \frac{\sigma_0}{1+(\omega-\omega_c)^2\tau^2}\begin{bmatrix} 1 & -(\omega-\omega_c)\tau & 0 \\ (\omega-\omega_c)\tau & 1 & 0 \\ 0 & 0 & \dfrac{1+(\omega-\omega_c)^2\tau^2}{1+\omega^2\tau^2} \end{bmatrix}\begin{bmatrix} \varepsilon \\ \varepsilon \\ \varepsilon \end{bmatrix}$$

natijaga kelamiz.

Shuni qayd qilish o'rinliki, $\sigma_{\alpha\beta}$ elektr o'tkazuvchanlik tenzorining xOy tekislikdagi tashkil etuvchilari

$$\sigma_\perp = \frac{1}{1+i(\omega-\omega_c)\tau}\sigma_0 = \frac{1-i(\omega-\omega_c)\tau}{1+(\omega-\omega_c)^2\tau^2}\sigma_0$$

ko'rinishda bo'lib, oqibatda

$$\begin{bmatrix} j_x \\ j_y \end{bmatrix} = \begin{bmatrix} \sigma_{xx} & \sigma_{xy} \\ \sigma_{yx} & \sigma_{yy} \end{bmatrix}\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \end{bmatrix}$$

yoki

$$\begin{bmatrix} j_x \\ j_y \end{bmatrix} = \frac{\sigma_0}{1+(\omega-\omega_c)^2\tau^2}\begin{bmatrix} 1 & -(\omega-\omega_c)\tau \\ (\omega-\omega_c)\tau & 1 \end{bmatrix}\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \end{bmatrix}$$

xOy tekislikdagi Om qonunini ifodalaydi.

Oxirgi ifodadan $\sigma_\perp$ kattalikning haqiqiy qiymati, ya'ni $\mathrm{Re}(\sigma_\perp)$ kattalik $\omega=\omega_c$ shartda maksimal qimatga erishadi, mavhum qiymati, ya'ni $\mathrm{Im}(\sigma_\perp)$ kattalik esa nolga aylanadi. Bu holda siklotronli rezonas hodisasi deb yuritiladi [15-18].

Shuni ham qayd qilmoq zarurki, (12.15) ifoda Drude natijasi bo'lib, statik maydon yaqinlashishida, ya'ni $\omega=0$ shartda yangi tabiatli hodisa Xoll samarasini tavsiflovchi kattaliklarni olamiz.

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