

LETTER TO THE EDITOR

ON THE FIELD EMISSION FROM BISMUTH IN THE PRESENCE OF
A QUANTIZING MAGNETIC FIELD

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An attempt is made to study the influence of the energy band models on the magneto-field emission from Bi by using the latest models of Cankurtaran and Abrikosov by incorporating the electron spin and the broadening of Landau levels, respectively. The field emission current density increases both with the electron concentration and the electric field in an oscillatory way for various temperatures. The quantum oscillations in the Abrikosov model show up much less significantly as compared to the model of Cankurtaran et al.

In recent years there has been considerable interest in studying the different electronic properties of Bi by using the various band models¹⁻⁸⁾. Among these dispersion laws, the models of Abrikosov⁵⁾ and Cankurtaran et al.⁶⁾ are being widely used since they give very good fits to a large number of magneto-oscillatory and resonance experiments. In this paper we shall study the doping and electric field dependences of the magneto-field emission from Bi in accordance with the

aforementioned models by including the combined influences of electron spin and broadening of Landau levels which seriously affect the measurement of any electronic property of Bi under magnetic quantization.

Following the method as given elsewhere⁹⁾, the net field emitted current density from Bi in the presence of a quantizing magnetic field H can be written, by including spin and broadening effects, as

$$T = [|e|^2 H k_B T g_v] [8\pi^2 \hbar^2]^{-1} \sum_{n=0}^{n_{max}} [\ln |f_{1A,c}|] \exp(-f_{2A,c}) \quad (1)$$

where e is the carrier charge, g_v is the valley degeneracy,

$$f_{1A,c} \equiv [1 + \exp(2\eta_{A,c}) + 2(\cos \lambda_0) \exp(\eta_{A,c})],$$

$$\lambda_0 \equiv \Gamma / k_B T, \quad \eta_{A,c} \equiv (k_B T)^{-1} [E_{FH A,c} - E_{nA,c}],$$

E_{FH} is the Fermi energy in the presence of magnetic field as measured from the edge of the conduction band when $H = 0$, E_{nA} and E_{nc} can, respectively, be expressed through the equations⁴⁾

$$E_{nA} (1 + \alpha E_{nA}) = \left(n + \frac{1}{2} \right) \hbar \omega_0 \pm \frac{1}{2} g_0 \mu_0 H + \beta (E_{nA,n}) \quad (2)$$

and

$$E_{nc} (1 + \alpha E_{nc}) = A_3 \quad (3)$$

$\alpha \equiv 1/E_g$, $\omega_0 \equiv eH [m_1 m_2]^{-1/2}$, g_0 is the magnitude of the band edge g factor, μ_0 is Bohr magneton,

$$\beta(E, n) \equiv [\{ A(E) - 1 \} \cdot \left(n + \frac{1}{2} \right) \hbar \omega_0 + (3\alpha/8) \left(n^2 + n + \frac{1}{2} \right) \cdot \hbar^2 \omega^2 A^2(E)],$$

$$A(E) \equiv [1 + E a_0]^{1/2}, \quad a_0 \equiv (1 - \mu) \alpha,$$

$$f_{2A,c} \equiv [\{ 4 \sqrt{2m_3} / 3\hbar |e| F_s \} \zeta_{1,A,c}^{3/2}(\bar{E}_{A,c}) / \zeta_{2A,c}(\bar{E}_{A,c})],$$

$$\zeta_{1A}(\bar{E}_A) \equiv [\bar{E}_A (1 + \alpha \bar{E}_A) - \left(n + \frac{1}{2} \right) \hbar \omega_0 \pm \frac{1}{2} g_0 \mu_0 H - \beta(\bar{E}_A, n)],$$

$$\bar{E}_A \equiv [\Phi_0 + E_{FH A} - E_{nA}],$$

Φ_0 is the work function,

$$\zeta_{1c}(\bar{E}_c) \equiv \Theta_1 \{-A_2 + [A_3^2 - 4A_1A_3 + 4A_1\bar{E}_c(1 + \alpha\bar{E}_c)]^{1/2}\},$$

$$\Theta_1 \equiv (4A_1m_3)^{-1}, \quad \bar{E}_c \equiv [\Phi_0 + E_{FHe} - E_{nc}],$$

$$\zeta_{2A}(\bar{E}_A) \equiv \left[1 + 2\alpha\bar{E}_A - a\hbar\omega_0(1 - \mu) \left\{ \left(n + \frac{1}{2} \right) \cdot \right. \right. \\ \left. \left. \cdot (2\sqrt{A(\bar{E}_n)})^{-1} + (3a_0\hbar^2\omega_0^2/8) \left(n^2 + n + \frac{1}{2} \right) \right\} \right]$$

and the other notations are defined elsewhere⁴⁾.

It appears that for the purpose of evaluation of the doping dependence of J_s , we have to determine the electron statistics which has been derived elsewhere in accordance with both the models⁴⁾. Finally we wish to note that under the conditions $H = 0$, $m_1 = m_3 = m'_2 = m_2 = m^*$ and $T = 0$, the equation (1) assume the form of equation (10) of Ref. 9.

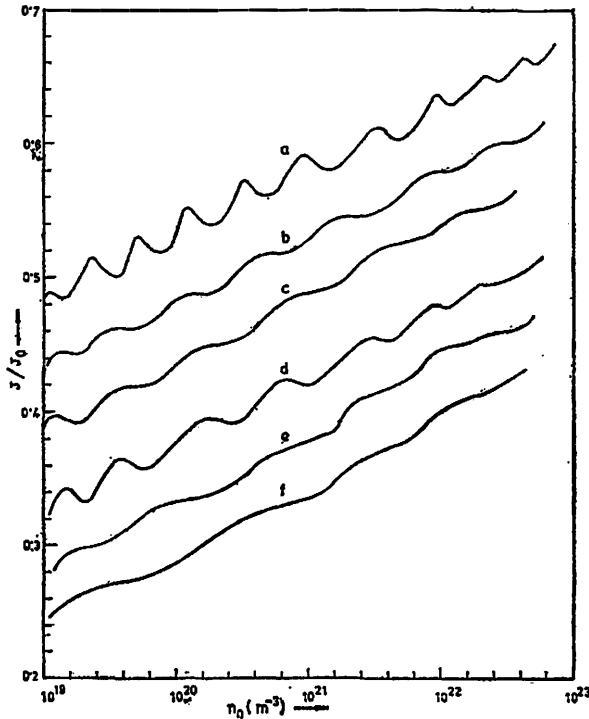


Fig. 1. The plots a, b and c exhibit the variation of J/J_0 versus n_0 in accordance with Cankurtaran type energy bands in Bi for $T = 4.2$ K, 8 K and 11 K, respectively. The plots d, e and f exhibit the same dependence for Abrikosov model.

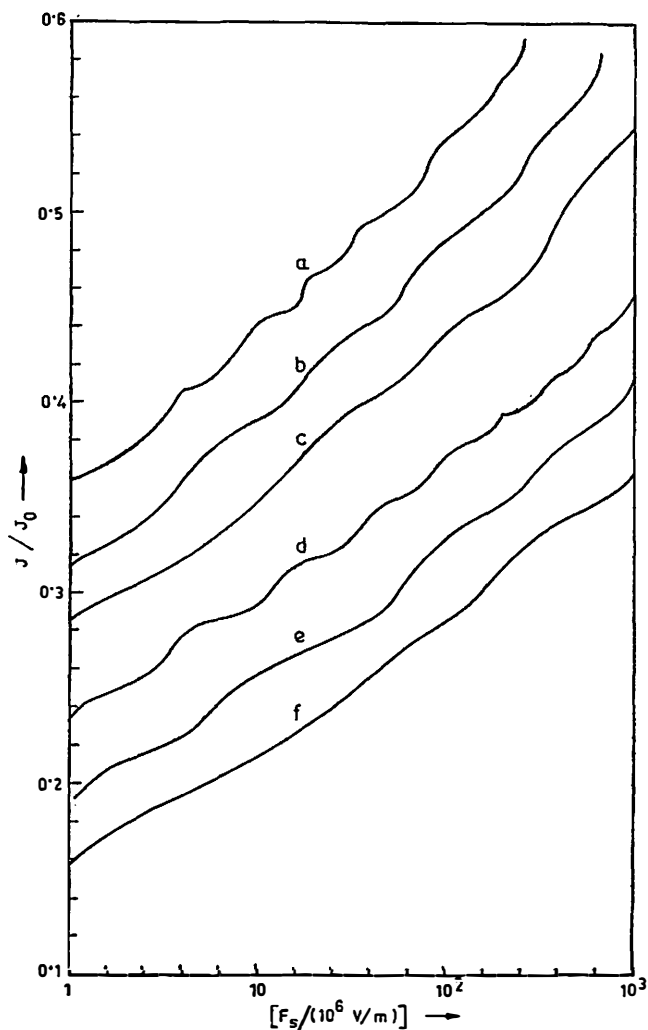


Fig. 2. The plots exhibit the variation of J/J_0 versus F_s for the above cases ($n_0 = 2 \times 10^{21} \text{ m}^{-3}$).

Using the appropriate equations together with the parameters⁴⁾ $m_1 = m_0/172$, $u = 2$, $m_3 = m_0/88.5$, $\Phi_0 = 3.5 \text{ eV}$, $m_2 = m_0/0.8 = m'_2$, $E_g = 0.0153 \text{ eV}$, $T_D = 2 \text{ K}$, $g_v = 3$, $\theta = 0^\circ$, $F_s = 10^7 \text{ V/m}$ and $H = 1.4 \text{ T}$ we have plotted J/J_0 versus n_0 in Bi in accordance with both the models for three values of T as shown in Fig. 1. In Fig. 2 we have plotted J/J_0 versus F_s for the above cases. It appears from both the figures that the magneto-field emission increases both with n_0 and F_s in an oscillatory way, respectively. The appearance of the humps are due to the redistribution of the electrons among the quantized energy levels when the magnetic quantum number corresponding to the highest occupied level changes from one fixed value to another. The oscillations are due to SdH effect. The quantum oscil-

lations in accordance with the model of Cankurtaran et al.⁶⁾ show up much more significantly as compared to Abrikosov model. The influence of temperature on J is also apparent from the figures.

The carrier energy spectra of Bi could be described by ellipsoidal parabolic, Lax, Cohen, Hybrid, Abrikosov and Cankurtaran models as often used by various authors to investigate the carrier properties in Bi. In this paper we have studied the magneto-field emission from Bi by including spin and broadening in accordance with the latest models of Abrikosov and Cankurtaran though we can not compare between the said models with respect to magneto-field emission since the experimental results of the same emission are not available in the literature to the best of our knowledge. The Abrikosov model which is a generalization of Cohen model can be used to describe the electron energy spectrum of lead chalcogenides. The semimetals are best described by Cankurtaran type energy bands. Thus the present analysis is valid for all types of chalcogenides semimetals and wide-gap materials, respectively. The influence of the energy band models in the magneto-field emission from Bi has also been studied in this paper. Finally, we wish to note that our analysis is also valid for holes of Bi with the proper change of the band parameters.

References

- 1) R. J. Dinger and A. W. Lawson Phys. Rev. **B1(6)** (1970) 2418; **B3** (1971) 253; **B7** (1973) 5215;
- 2) C. C. Wu and C. J. Lin, J. Low Temp. Phys. **57** (1984) 469; **59** (1985) 83; **64** (1986) 65;
- 3) M. H. Cohen, Phys. Rev. **121** (1961) 387; S. Takoka, H. Kawamura, K. Murase and S. Takano, Phys. Rev. **B13** (1976) 1428; M. Meltz and M. S. Dresselhaus, Phys. Rev. **B2** (1970) 2887;
- 4) K. P. Ghatak, B. Mitra and S. N. Biswas, Fizika **21** (1989) 395; K. P. Ghatak, N. Chattopadhyay and S. N. Biswas, Fizika **19** (1987) 387;
- 5) A. A. Abrikosov, J. Low Temp. Phys. **8** (1972) 315; N. B. Mustafaev and M. G. Shakhtakh-tinskii, Phys. Stat. Sol. **124** (1984) K151; **120** (1983) K63;
- 6) M. Cankurtaran, H. Celik and T. Alper, J. Phys. F.: Met. Phys. **16** (1986) 853;
- 7) J. W. McClure and K. H. Choi, Solid State Commun. **21** (1977) 1015;
- 8) A. E. Dorafeev and L. A. Fabkovskii, Sov. Phys. JETP **60** (1984) 1273;
- 9) K. P. Ghatak, Fizika **21** (1989) 17.

O EMISIJI POLJEM U PRISUSTVU KVANTIZIRAJUĆEG
MAGNETSKOG POLJA

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Razmatran je utjecaj modela energetske vrpce na emisiju poljem iz Bi koristeći novije modele Cankurtarana i Abrikosova uvođenjem spina i uzimanjem u obzir širenja Landauovih nivoa. Nađeno je da gustoća struje raste i s iznosom električnog polja i koncentracijom elektrona na oscilatorni način za razne temperature. Pojava kvantnih oscilacija manje je značajna u modelu Abrikosova nego u modelu Cankurtarana i dr.