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ARTICLE ODYSSEY

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QC176.A1 P5 PART B
Location: Compact Stacks

Journal Title: Physica status solidi. B,
Basic research.

Volume: 130 **Issue:** 2
Month/Year: 1985 **Pages:** K149-K152

Article Author:

Article Title: kasamanyan z. et al;
Oscillatory Current along a Tunnel-Thin
Potential Barrier in a Magnetic Fieldbe
applied to slow light.

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Investigations of the electron energy spectrum near the surface in the presence of a homogeneous magnetic field parallel to the surface are usually carried out assuming boundary conditions for the wave function on the surface to be zero, which is equivalent to the electron wave total reflection condition at the surface. In heterostructures when a potential barrier at the border is present, or in a homogeneous semiconductor system when a tunnel-thin dielectric is present, the electron reflection amplitude (r) can vary within a broad range in the interval $0 \leq |r| \leq 1$ and r can be essentially depending on energy. Let us direct the magnetic field along the z axis, lying in the barrier plane (z and y parallel to the barrier, x perpendicular to the barrier) and choose the vector potential in the form $\vec{A} = (0, xH, 0)$. It is also interesting to observe how the Landau levels degenerated with respect to the impulse component P_y transfer into surface magnetic states, when degeneracy with respect to P_y vanishes and all states between Landau levels are filled (at a fixed value of the impulse component along the magnetic field) as the barrier penetrability decreases. As we shall show, forbidden and allowed narrow bands, so-called mini-bands, appear in the electron energy spectrum in the presence of a semi-penetrable barrier in a magnetic field parallel to the barrier.

We shall consider the case when in the system there is a thin potential barrier, for instance, a tunnel-thin dielectric in a homogeneous semiconducting system. If the thickness of the dielectric layer is smaller than the magnetic length, one can pass to the approximation of a δ -like potential. Then the Schrödinger equation (for simplicity we neglect here spin splitting of the levels in the magnetic field) may be written in the form

1) Mravian Str., Erevan-49, USSR.

phys. stat. sol. (b) 130, K149 (1985)
 Subject classification: 13.3 and 14
 Faculty of Radiophysics (a) and Faculty of Physics (b),
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 Oscillatory Current along a Tunnel-Thin Potential Barrier
 in a Magnetic Field
 By
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 and E. S. YUZBASHYAN (b)

status solidi (b) 130
 3, 390 (1976).
 March 29, 1985)

$$(1) \left[\frac{1}{2m} \left(\vec{p} - \frac{e}{c} \vec{A} \right)^2 + V \phi(x) \right] \psi(\vec{r}) = E \psi(\vec{r}) .$$

The solution of (1) may be presented in the form 1/

$$(2) \psi(\vec{r}) = C \exp \left\{ i k_x y + i k_z z \right\} G(\vec{k}, \vec{k}_0; \nu) ,$$

where

$$\vec{k} = \sqrt{m\omega/h(x-x_0)} , \quad x_0 = P_y/m\omega , \quad \omega = eH/mc ,$$

$$E' = E - (P_z^2/2m) = \hbar\omega \left(\nu + \frac{1}{2} \right) ,$$

G(\vec{k}, \vec{k}_0; \nu) is the electron Green function (GF) in the magnetic field (the potential barrier being absent).

The electron energy spectrum in the presence of the barrier is determined by the equation (see 1/)

$$(3) G(\vec{k}_0, \vec{k}_0; \nu) = V^{-1} .$$

Thus the problem is brought to the finding of the GF in explicit form.

The calculation of the explicit form of the electron GF in the magnetic field has become subject of many studies in various forms. It is necessary for us to determine the explicit form of this function in one-dimensional coordinate and energy representations. It is simpler to calculate it from the formula

$$(4) G(\vec{k}, \vec{k}_0; \nu) = C \left[\psi_1^I(\vec{k}) \psi_2^I(\vec{k}_0) + \psi_1^I(\vec{k}_0) \psi_2^I(\vec{k}) \right] \Theta(\vec{k}, \vec{k}_0) ,$$

where \Theta is the step function, \psi_1^I and \psi_2^I are the two solutions of the corresponding one-dimensional Schrödinger equation satisfying the conditions

$$\psi_1^I(\vec{k} \rightarrow \infty) \rightarrow 0 \text{ and } \psi_2^I(\vec{k} \rightarrow -\infty) \rightarrow 0 , \quad C \text{ is the normalizing coefficient determined by the condition}$$

$$C = \left[\psi_1^I \psi_2^I - \psi_2^I \psi_1^I \right]_{\vec{k} = \vec{k}_0} .$$

The functions \psi_1^I and \psi_2^I are of the form

$$(5) \psi_{1,2}^I(\vec{k}) = e^{-\vec{k}_2/2} \Gamma^{-1} \left[\Gamma^{-1} \left(\frac{\vec{z}}{1-\nu} \right) \Phi \left(-\frac{\vec{z}}{\nu} ; \frac{\vec{z}}{2} ; \frac{\vec{z}}{2} ; \frac{\vec{z}}{2} \right) + \Gamma^{-1} \left(\frac{\vec{z}}{1-\nu} \right) 2 \vec{k} \Phi \left(\frac{\vec{z}}{1-\nu} ; \frac{\vec{z}}{2} ; \frac{\vec{z}}{2} \right) \right] ,$$

(5)

where \Gamma is the Gamma function, \Phi is the degenerated hypergeometric function. The final expression for the GF is of the form (4), with functions (5), where

$$C = \frac{1}{\Gamma} \Gamma \left(\frac{1}{1-\nu} \right) \Gamma \left(\frac{1}{2} \right) .$$

In quasi-classical approximation

$$G(\vec{k}, \vec{k}_0; \nu) = - \frac{\hbar}{2} \dots$$

Taking into account

$$(\lambda = \sqrt{\hbar/m\omega})$$

$$\sin \pi \nu - \frac{\hbar^2 \sqrt{2\nu + 1}}{m V \lambda}$$

From this it is easy

we have \nu = 0, 1, 2, \dots

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The analysis of (7)

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$$\left[\frac{2\pi}{\hbar} \Phi \left(\frac{2}{1-\nu}, \frac{2}{3}, \frac{2}{2}, \frac{2}{2} \right) \right],$$

In quasi-classical approximation $\nu \gg 1$, at $\epsilon, \epsilon' \ll \sqrt{2\nu + 1}$ we have the

simple formula

$$G(\epsilon, \epsilon'; \nu) = - \frac{m \lambda}{2 \sqrt{2\nu + 1} \sin \pi \nu} \left[\cos(\pi \nu - |\epsilon - \epsilon'| \sqrt{2\nu + 1}) + \cos(\epsilon + \epsilon') \sqrt{2\nu + 1} \right]. \quad (6)$$

Taking into account (6), equation (3) will be written in the form

$$(\lambda = \sqrt{\hbar/m\omega}) \sin \pi \nu - \frac{m V \lambda}{2 \sqrt{2\nu + 1}} (1 + \cos \pi \nu) = - \frac{2m V \lambda}{2 \sqrt{2\nu + 1}} \sin^2 \frac{\lambda}{2} \sqrt{2\nu + 1}. \quad (7)$$

From this it is easy to get the known results in asymptotic cases: at $V \rightarrow 0$,

we have $\nu = 0, 1, 2, \dots$ (Landau levels); at $V \rightarrow \infty$ and $x_0 \rightarrow 0$, we have

$$\nu = 1, 3, \dots$$

The analysis of (7) at $0 < V < \infty$ shows that the energy spectrum of the

electron depending on F_y gets band character - allowed and forbidden mini-bands

appear. The energy, considered in quasi-classical approximation, is periodical-

ly dependent on F_y , the period $2\pi \lambda m \omega (2\nu + 1)^{-1/2}$ itself depends on the level

number of volume quantization $\nu = n; n = 0, 1, 2, \dots$

In a sufficiently thin barrier case $2 m V \lambda \hbar^{-2} \gg \sqrt{2\nu + 1}$ narrow ($|\nu - n| \ll 1$)

allowed and relatively wide forbidden mini-bands appear. The dispersion law in

this case has the form

$$\nu = n + \frac{\hbar^2 \pi^2 \lambda^2}{m V \lambda} \left[1 + \cos \left(\pi n + \frac{\lambda}{x_0} \sqrt{2n + 1} \right) \right]. \quad (8)$$

Naturally the obtained simple analytical formulas for the GF (6) and dis-

persion law (8) are true, when the above-mentioned assumptions are made.

Nevertheless the conclusion about the formation of allowed and forbidden mini-

bands is always true, if only $0 < V < \infty$, of which one may be convinced by

graphical solution of (3) with the exact form of the GF (4).

In conclusion let us note that the formation of a mini-band structure of the

electron energy spectrum may appear, influencing, for instance, the current

along the barrier and perpendicular to the magnetic field direction, when there

is an additional electric field $\epsilon = \epsilon_y$. By analogy with the case considered in

$\hbar/2$ for a superlattice, here the current depending on ϵ_y will be of oscillatory

character. For experimental tests, the required conditions (at low temperature,

$T > 5$ K, strong magnetic field of $B \approx 10$ T) are available and are used in in-

vestigations of the quantum Hall effect.

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(Received June 6, 1985)

phys. stat. sol. (b)

Subject classification

Institute of Materials

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3d-Impurity Level

By

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The effect of 3d impurities

has been extensively studied

in various semiconductors

of these levels remains un-

known. In the present note the

molecular cluster method

is used. When A_{II} B_{III}

atoms substitute the A_{III}

atoms in a 17-atom cluster

model. Boundary conditions

are chosen so that the

energy of the cluster is

justified for semiconductors

with dangling bond electrons

on the surface. Energy

levels are calculated by the

method including only σ

orbitals of the central atom

and the nearest neighbors.

where C_{ν} are the coefficients

of the cluster. $G_{\mu\nu}$ are the

matrix elements of $H_{\mu\nu}$ and

$H_{\mu\nu}$ are the matrix elements

of the semi-empirical M

method. $H_{\mu\nu}$ can be

calculated by the

method of Zhovtneva ¹

1) Zhovtneva S, 2740