Oscillations of Magnetoconductance in semiconductor-superconductor junctions with a laterally potential barrier isolator inside semiconductor region

Tzong-Jer Yang [a], Young-Chung Hsue [a], Ben-Yuan Gu [b]

[a] *Department of Electrophysics, National Chiao-Tung University, Hsinchu, Taiwan*

[b] *Institute of physics, Academia Sinica, P.O.Box 603, Beijing 100080, China*

Abstract

Magnetoconductance(MC) in junctions of a superconductor and a semiconductor(Sm) consisting of two parallel quantum waveguides (QW) coupled through a potential barrier under a perpendicular applied magnetic field in the semiconductor region is studied theoretically. The results of MC showing a series of oscillations with stepwise platform and spikes may be understood well within the phenomenological argument similar to Y. Asano (Phys. Rev. B 61, 1732 (2000)) proposed. The oscillatory peaks of the MC in the dual QW are found essentially due to the variation of the number of the propagation modes.

Key words: Magnetoconductance, Semiconductor-superconductor junction, Quantum waveguide

1. Introduction

In recent years, the Magnetoconductance oscillations (MCO) in Sm-S junctions has attracted much attention. The condition of the appearance of MCO is the coexistence of both the normal and the Andreev reflections[1] at the interface, leading to interference between the wave functions of quasi-particles (QP). The interplay between the classical cyclotron motion of a QP and the phase shift caused by the magnetic field is the source of the MCO. The question would be raised while an isolator is set in the semiconductor region to form dual waveguides. Do there any new structures appear in the MCO? This short paper wants to dig out results using model of the semiclassical phenomenology (similar to the paper by Asano[2]).

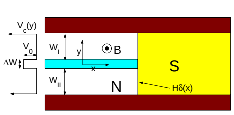

Fig. 1. Schematic view of a Sm-S junction

2. Method

The system we are considering is a junction of a dual channel quantum waveguide (DQW) connected to a semi-infinite superconductor (S) of width W in two-dimensional (2D) case shown in Fig. 1. One much thin scattered layer with the δ-function potential of strength H is placed at the interface ($x = 0$) of Sm-S junction to simulate the scattering effect. Two parallel semi-infinite long quantum waveguides are coupled through a thin layer of potential barrier with square profile of height V_0 and width ΔW. Total width of the QW is W. The DQW are subjected to magnetic field B along the z-direction. In order to simplify the analysis of MCO in our system, the applied magnetic field is limited only in normal region. The current flows along the x-direction. The hard-wall confinement potentials for the lateral boundaries of the junction is assumed. The potential inside the QW is set to be zero. In order to calculate the differential conductance, $G(V)$ of our system at $T = 0K$ by using the Takane-Eibsawa formula[3]

$G(V) = \frac{2e^2}{h} \sum'_{l.n} (\delta_{l,n} - R_{ee,ln} + R_{he,ln})$. Where l and n label the propagation channels in 2DEG (two dimensional electron gas) under magnetic field and the summation $\sum'_l = N_c$ runs over the all propagation channels. $R_{ee,ln}$ and $R_{eh,ln}$ represents the reflection probabilities for electronlike and holelike QPs, respectively. The current conservation law is also required to impose in $G(V)$. We first need to solve Bogliubov- de Gennes (BdeG) equations. For simplicity, the pairing potential is uniform in the superconductor region and zero in the semiconductor region. We follow Blonder-Tinkham-Klapwijk (BTK)[4] and neglect the phase of the pairing potential. The effective masses of electrons in the two materials are m_N^* (Sm region) and m_0 (S region), respectively. The Landau gauge of the vector potential of the magnetic field is employed as

$$\mathbf{A} = \begin{cases} (0, Bx) = (-By, 0) + \nabla(Bxy) & x < 0 \\ (0, 0) & x \geq 0 \end{cases}$$

After the solutions of BdeG equations, $R_{ee,ln}$ and $R_{eh,ln}$ can be gotten. Then, $G(V)$ correspondingly is gotten.

3. Results and Discussion

In order to reveal the characteristic nature of $G(V)$ due to the isolator barrier in the heterogenous semiconductor, we present the results of MCO with and without isolator barrier in QW for a particular set of parameters. The detail results of MCO in DQW for other set of parameters will be published elsewhere. The results of MCO is shown in Fig.2.

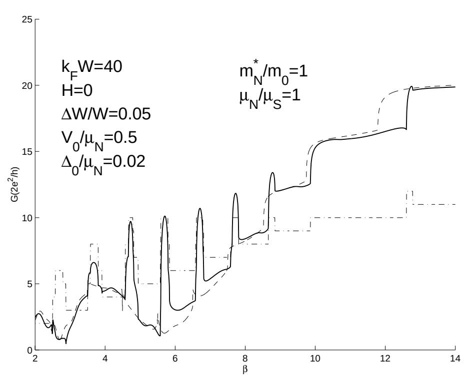

Fig. 2. dot-dashed line indicates the N_c, solid line indicates the G and the dashed line indicates the G with $\Delta W/W = 0$

The parameter $\beta \equiv \frac{\mu_N}{\hbar\omega_c}$, where ω_c is the cyclotron frequency. In order to keep the simple treatment and no lossing our purpose, the strength for the scattering potential barrier at the interface H is set to be zero. The broken line in this figure denotes the conductance curve of the QW without the isolating barrier. This result is essentially the same as Asano[2] got. In the weak field ($14 > \beta > 9$), QPs are almost perfectly Andreev reflected from the Sm-S interface for $\mu_S = \mu_N$. The rounded corner of every plateau is attributed to the electron reflection at the interface. At near every threshold of the magnetically depopulation, the longitudinal momentum of electrons is small enough, thus, the electron scattering effect becomes observable, it is the electron reflection that leads to the rounded corner in the every plateau. In the intermediate field ($8 > \beta > 4.5$), G drops below N_c curve because the electron reflection increases and the AR becomes imperfect; therefore, the behavior of $G(V)$ departs away from that of N_c. Here, N_c is the number of the propagating channels in the 2DEG under the magnetic field. In the uniform QW ($\mu_S = \mu_N$ and $m_N^* = m_0$), only the holelike QPs are excited from the AR, and they move in skipping orbits along the interface and boundary wall. The holelike QPs are major current carriers. The quantum interference effect deceases. The variation of MC with magnetic fields in the DQW with isolating barrier (solid-line in this figure) is much different from that of the QW. The dispersion relation of electrons almost dominates the profile of G. The behavior of G seems to be the dashed line curve superimposed upon a series of square wave peaks, which are attributed to the oscillations of Nc. The position of the peaks is perfectly aligned with that of the peaks of N_c. Hence, the whole tendency of G is essentially dominated by the variation of N_c. These oscillatory peaks are not caused by the quantum interference of wave functions of QPs undergoing multiple AR at the interface alone.

4. Conclusion

The oscillatory peaks of the MCO in the DQW is exploited and found essentially to be due to the variation of N_c.

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