Spin-transistor action in waveguides with periodically modulated strength of the spin-orbit interaction

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Spin-polarized electron transport through waveguides, in which the strength of the spin-orbit interaction (SOI) α is varied periodically, is studied using the transfer-matrix technique. It is shown that the transmission T exhibits a *spin-transistor* action, as a function of the strength or of the length of one of the two subunits of the unit cell, provided only one mode is allowed to propagate in the waveguide. A similar but not periodic behavior is shown by T as a function of the incident electron energy E. In a waveguide with only in **one** segment, of strength α_2 and length l_2, comprised between two segments of strength α_1, the *total* transmission, obtained as $T = 1/[\cos^2(\Delta_2 l_2) + r\sin^2(\Delta_2 l_2)]$, with r a function of Δ_1, Δ_2 and $\Delta_j = [m^{*2}\alpha_j^2 + 2m^*(E - E_1)]^{1/2}$, shows an explicit sinusoidal dependence. The corresponding *spin-up* (T^+) and *spin-down* (T^-) transmissions are given by $T^+ = T\cos^2\phi$ and $T^- = T\sin^2\phi$, where ϕ is a measure of the spin precession. The total phase acquired by electrons in different branches during propagation is $\phi = 2[\delta_1(L - l_2) + \delta_2 l_2]$ with[1] $\delta_i = 2m^*\alpha_i/\hbar^2$ and L the waveguide length. The transmission through a superlattice, with alternating segments of lengths l_1, l_2, and corresponding SOI strengths α_1, α_2, is also a *periodic* function of α_j and $l_j, j = 1, 2$. As the strength α can be well controlled by applying gates or adjusted with the help of band engineering[2], the structure considered is a good candidate for the establishment of a realistic spin transistor. The recently developed spin-detection technique[3] could be used to observe this transistor action also reported for periodically stubbed waveguides of constant[4] strength α.

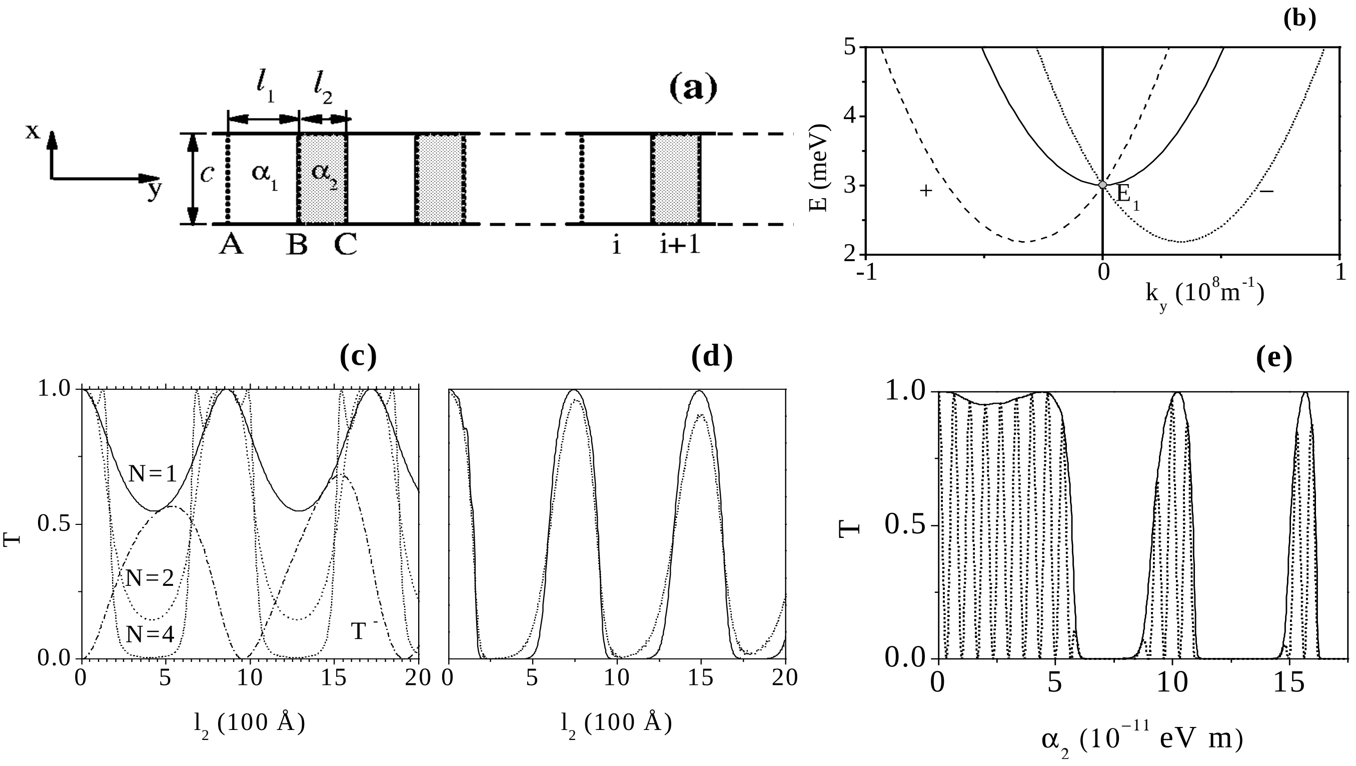
[1] S. Datta and B. Das, Appl. Phys. Lett. **56**, 665 (1990)

[2] T. Koga *et al.*, Phys. Rev. Lett. **89**, 046801 (2002).

[3] R. M. Potok *et al.*, Phys. Rev. Lett. **89**, 266602 (2002).

[4] X. F. Wang, P. Vasilopoulos, and F. M. Peeters, Appl. Phys. Lett. **80**, 1400 (2002).

SUPPORTING MATERIAL



DESCRIPTION

(a) Schematics of a waveguide, of width c, with periodically modulated strength of the SOI. Within one unit, l_1, l_2 and α_1, α_2 are the lengths and SOI strengths of the subunits AB and BC, respectively.

(b) Dispersion relation for a waveguide. Neglecting subband mixing the energy levels are given by

$$E^{\pm}(k_y) = E_n + \hbar^2 k_y^2 / 2m^* \pm \alpha k_y, \qquad (1)$$

and E_n is the energy of the nth subband due to the confinement along the x axis. The dashed and dotted curves show the + and - branches for finite strength α, the solid curve is for α=0.

(c) Transmission versus length l_2. N is the number of units, l_1=1050 Å, α_2=5x10^{-11} eV m, and E=3.2 meV. The dash-dotted curve shows the *spin-down* transmission T^- for N=1, the other curves show the *total* transmission. The incident carriers are assumed to be spin-up polarized. For only **one** waveguide segment, of strength α_2 and length l_2, comprised between two segments of strength α_1=0, the *total* transmission at zero temperature is given by ($\Delta_j = [m^{*2}\alpha_j^2 + 2m^*(E - E_1)]^{1/2}$, j=1,2)

$$T = \frac{1}{\cos^2(\Delta_2 l_2) + r \sin^2(\Delta_2 l_2)}, \qquad (2)$$

where $r = (\Delta_1^2 + \Delta_2^2)^2 / 4\Delta_1^2\Delta_2^2$. The periodicity of T with l_2 or Δ_2 is evident. As shown, T is also periodic for N>1. Its approximate *square-wave* form, pertinent to a *spin transistor*, is rounded off with increasing temperature. The spin-up (+) (spin-down) (-) transmission is $T^+ = T\cos^2\phi$, $T^- = T\sin^2\phi$. The phase difference is $\phi = 2[\delta_1(L - l_2) + \delta_2 l_2]$ with L the waveguide length and $\delta_i = 2m^*\alpha/\hbar^2 = k_y^- - k_y^+$.

(d) As in **(c)** for l_1=100Å, N=8, α_2=6x10^{-11} eV m, and E_F=3.2 meV. The solid curve is for temperature T=0.2 K, the dotted one for T=0.5 K.

(e) Transmission as a function of the strength α_2 for l_1=l_2=900Å, α_1=0, N=8, and E_F=3.3 meV, at temperature T=0.2 K. The solid (dotted) curve is the *total* (spin-up) transmission.