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EFFECT OF A PARALLEL MAGNETIC FIELD ON RESONANT TUNNELING IN GAAS/AL$_X$GA$_{1-X}$AS DOUBLE-BARRIER HETEROSTRUCTURES

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ABSTRACT

We have studied resonant tunneling in GaAs/Al$_x$Ga$_{1-x}$As double-barrier heterostructures (DBH) in the presence of magnetic field parallel to the current. We adopt a simple one-band tight-binding Hamiltonian to describe the system and follow the formalism of Green`s function(GF) to calculate local electronic properties. Diagrammatic techniques for nonequilibrium processes proposed by Keldysh, were used to investigate resonant tunneling transport properties through the structure. In particular, we discuss the effects of the applied magnetic field on the characteristic curves of current versus voltage. We also study the effects of isoelectronic impurity-planes, localized at the well region on the I-V characteristics of the system.

INTRODUCTION

Since the first experimental observation of resonant tunneling [1], there has been a great deal of interest in the physics of this phenomenon and its potential application to high speed electronics and optoelectronics [2]. Resonant tunneling through impurity states in DBH has been reported in experimental works [3,4], in which shallow donor impurities are incorporated into the quantum well. The effects of a defect layer located in the barrier regions of DBH, on the tunneling currents have been analyzed theoretically[5] using the nonequilibrium GF obtained by Keldysh formalism[6]. An enhancement of the peak current intensity and the peak to valley ratio were found for certain positions of the defect layer. Recently there has been great interest in magnetotunneling studies of GaAs-Ga$_{1-x}$Al$_x$As double-barrier diode [7,8]. Shulz and Tejedor [8] have been studied the effect of scattering processes on resonant transmission. The effect of the scattering processes on the current becomes even more important in the off-resonant regimen, as evidenced by magnetotunneling analysis of the valley current[9,10]. In the present work we report on results for the I-V characteristic of resonant tunneling in presence of parallel electric and magnetic fields in double-barriers constituted by GaAs-Ga$_{1-x}$Al$_x$As. Also study the effects isoelectronic impurity-planes localized into en center plane of the quanntum well. We find a good behavior of the I-V characteristics as a function of the applied magnetic field in the comparison with reference [8].

THEORY

DBH can be described by a simple one-band tight-binding Hamiltonian with only nearest-neighbor interactions. In the presence of a magnetic field (**B**=B**z**) parallel to the heterostructure growth direction. Three-dimensional problem for each Landau-level index n, and Hamiltonian can be written as

$$H = \sum_i \varepsilon_i c_i^+ c_i + \sum_{<i,j>} V_{ij} c_i^+ c_j \qquad [1]$$

where V_{ij} is the hopping between neighboring sites i and j and $\varepsilon_i = \varepsilon_i^s + \varepsilon_i^{//}$ where ε_i^s is the site energy and $\varepsilon_i^{//} = (n + \frac{1}{2})\hbar\omega_i$ (w_i is the cyclotron frequency), which contains the contribution of the applied electric and magnetic fields, respectively. In order to treat the GF in this nonequilibrium situation (two different chemical potentials) we made use of the Keldysh method. The system is divided in two regions and described by Hamiltonian

$$H = H_L + H_R + T \qquad [2]$$

$H_L (H_R)$ contains the terms in H to the left (right) of an arbitrary point of the system and T is the term that connects the two sides.

$$T = V_{ab} c_a^+ c_b + h.c \qquad [3]$$

Following Ref. 11 we introduce the following Dyson`s equations for the advanced GF, with T playing the role of the self energy ($V_{ba} = V_{ab} = V$)

$$G_{pq}^a(\omega) = g_{pq}^a(\omega) + g_{pa}^a V G_{bq}^a(\omega) + (a \leftrightarrow b) \qquad [4]$$

(a similar equation for the retarded GF G^r

$$F_{pq}(\omega) = f_{pq}(\omega) + g_{pb}^r(\omega) V F_{aq}(\omega) + f_{pb}(\omega) V G_{aq}^a(\omega) + (a \leftrightarrow b) \qquad [5]$$

In a stationary state, the current may be calculated at any point in the system, say between a and b. The expression in terms of the GF is:

$$J = {}^{eV}\!/_{\hbar} \left[G_{ba}^c(t, t_+) - G_{ab}^c(t, t_+) \right] \qquad [6]$$

where $G_{pq}^c(t, t') = (G^a + G^r + F)/2$.

Taking the Fourier transform and using Dyson`s equations we arrive at an expression of J in terms of equilibrium GF,

$$J = \frac{4\pi^2 e V^2}{\hbar l_m^2} \sum_n^N \int_{(n+\frac{1}{2})\hbar\omega_c}^{E_F} \frac{\rho_b(\omega)\rho_a(\omega) d\omega}{|\Lambda(\omega)|^2} \qquad [7]$$

where $\rho_i(\omega)$ is the density of states at site i and l_m is the magnetic length:

$$\rho_i(\omega) = -\tfrac{1}{\pi}(\mathrm{Im}\, g_{ii}^{r}(\omega) \quad and \quad \left|\Lambda(\omega)\right|^2 = \left|1 - g_{aa}^{a}(\omega) V^2 g_{bb}^{a}(\omega)\right|^2 \qquad [8]$$

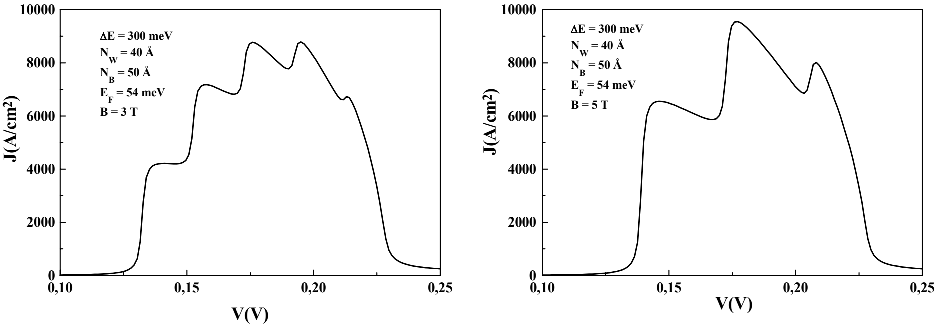

Fig 1. I-V characteristics for DBH with the different magnetic fields applied in the current direction. The barriers are 50Å wide and 0.3 eV high and the well width is 40Å.

RESULTS

In this model we have used the GaAs electronic effective mass $m^* = 0.067m_o$, m_o being the free electron mass, and a lattice constant a = 2.82Å. The electronic concentration at the injector is determined by assuming a three-dimensional free-electron gas. In the present discussion,we consider small doping of the order of $10^{18}cm^{-3}$ considering Fermi energy equal to 54meV. Characteristic curves of current versus voltage are presented in Fig 1. corresponding to a one-dimensional modeled $GaAs/Al_xGa_{1-x}As$ DBH with barriers 50Å wide and 0.3 eV high, while the well has a width of 40Å. We can see that the I-V characteristic modifies continuously and the number of jumps reduces with increasing magnetic field at the same time that the height of these jumps increases. We find a good agreement with the theoretical work in Ref [8]. Considering an impurity-plane in the center of the quantum well region we see that the I-V characteristic is shifted to higher (lower) energies corresponding to a repulsive potential (attractive potential) as shown in Fig 2.

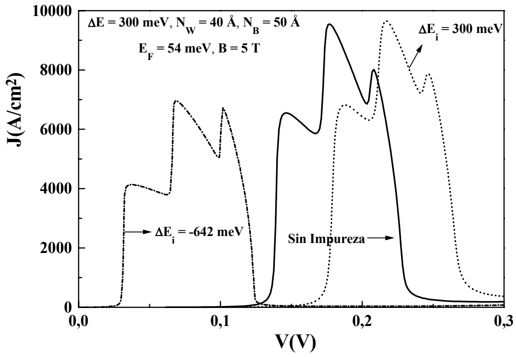

Fig 2. I-V characteristics for DBH with an isoelectronic impurity $\Delta E_i = -642$meV and 300mev corresponding a attractive and repulsive potential, located at the center of the quantum well region.

CONCLUSIONS

We have presented a study of resonant tunneling in DBH in the presence of magnetic field parallel to the current and also the effects of isoelectronic impurity-planes, localized at the well region on the I-V characteristics of the system. We have followed a theoretical description based on Keldysh´s nonequilibrium Green functions, which are adequate to describe transport properties. We find a good agreement with the theoretical work in Ref [8].

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