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RESONANT MAGNETOTUNNELING IN DOUBLE-BARRIER STRUCTURES

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In this paper we consider the influence of "mass barrier" and elastic scattering processes on the shape of $j(V)$ and $j(B)$ characteristics. Two scattering mechanisms, i.e. Coulombic on ionized impurities and on potential fluctuations in double-barrier structures are considered. The "mass barrier" shifts the whole $j(V)$ characteristic slightly towards lower voltage and makes the resonant energy E_{R} dependent on magnetic field. On the other hand, both considered scattering mechanisms change the shape of $j(V)$ and $j(B)$ characteristics by shifting the oscillation maxima towards lower applied voltage.

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Resonant magnetotunneling through double-barrier structures (DBS) is an important investigation tool providing information on how scattering processes influence the resonant tunneling process. For DBS with degenerate emitter in the resonant tunneling regime, when a magnetic field B is applied parallel to the current j, oscillations are expected in both, $j(V)$ and $j(B)$, characteristics [1]. These oscillations are a result of complete quantization of the electron energy in the DBS well. In an idealized picture, where we take the resonant level E_{R} in the DBS well and the Landau levels as delta functions, the $j(V)$ characteristic, for a given B, would be a series of steepy rises followed by flat regions. Each jump of the current corresponds to an opening of a new tunneling channel when a successive Landau level E_n in the well crosses the Fermi level E_{F} in the emitter. On the other hand, for a fixed bias, due to an increase in the magnetic field, successive Landau levels are pushed out to energies above the emitter Fermi energy, causing sudden falls in the $j(B)$ characteristic. The resonant tunneling conditions for each Landau level, as a function of applied bias and magnetic field, are usually summarized in the fan chart. In the idealized picture, maxima of $j(V)$ for various B and maxima of $j(B)$ for various applied bias V are lying on straight lines, given by the condition $E_{\mathrm{R}} - V + E_n - E_{\mathrm{F}} = 0$. The two factors, the inherent Landau level broadening and the finite width of the resonant level in the DBS well, would tend to smooth the oscillations. Indeed, the features due to the magnetic quantization are usually seen in the conductance only [1–3]. Moreover, deviations from linearity in the fan chart are also observed for high magnetic fields [3, 4].

There are several models of smoothing the magnetooscillations. Schulz and Tejedor [5], basing on phenomenological Stone and Lee's [6] one-dimensional model of resonant tunneling, have considered the influence of the resonant level width Γ_R on the shape of $j(V)$ and $j(B)$ characteristics. The width Γ_R was changed either by changing of the width of the DBS barriers, determining the so-called elastic decay half-width Γ_e, or by adding the small imaginary part Γ_i to the energy of tunneling electron, interpreted as the inelastic scattering decay half-width. Nogaret et al. [7] have approximated the resonant current by considering the Lorentzian shape of the transmission coefficient with the constant half-width Γ_R. In order to include an ionized impurity scattering in the calculation of the magnetotunneling current the authors have taken a Gaussian form of the in-plane density of states. Both these approaches elucidate the magnetooscillations broadening qualitatively, but the more subtle effect — the deviations of the fan chart from linearity — remains unexplained.

The last effect can have its origin in the coupling between in-plane and longitudinal motion caused by "mass barrier", i.e. the difference of effective masses in barrier and well regions, and also by the scattering processes always perturbing the resonant tunneling [7]. In this paper we consider the influence of both these factors on the shape of $j(V, B)$ characteristics. The starting point of our calculation is the expression for the resonant transmission coefficient T_G derived by Kane [8] and rederived for biased DBS in our earlier paper [9]. This approach has the advantage that it accounts for the changes of elastic decay half-width Γ_R and of magnitude of the transmission coefficient T_G at resonance with an applied bias. Both these quantities influence positions of magnetotunneling current maxima. The two scattering mechanisms are considered: Coulombic scattering on ionized impurities in the emitter and DBS regions and scattering on potential fluctuations in the DBS region only. In order to include scattering in the calculation the Gaussian form of the in-plane density of states is assumed. For both scattering mechanisms the level broadening is dependent on the strength of magnetic field, and for scattering on potential fluctuations it depends also on the Landau level number [10]. The relaxation time τ_f for $B = 0$ is the only free parameter of the calculation.

The calculated characteristics are shown in Figs. 1 and 2 for a double-barrier structure with 4 nm $Ga_{0.6}Al_{0.4}As$ barriers ($m_b^* = 0.1m_0$) surrounding 4 nm GaAs well ($m_w^* = 0.067m_0$). Figure 1 presents the $j(V)$ characteristic calculated for $B = 10$ T assuming that the scattering of the tunneling electron is on potential fluctuations in the DBS well. The scattering is characterized by the relaxation time $\tau_f = 3 \times 10^{-13}$ s comparable with the lifetime of the resonant level for the considered DBS well. The $j(B)$ characteristic calculated for applied voltage V close to the maximum of the $j(V)$ characteristic is plotted in Fig. 2. The characteristics calculated when assuming the sharp Landau levels are also shown for comparison.

Let us first discuss briefly how the "mass barrier" influences the magnetotunneling current. The "mass barrier" shifts the whole $j(V)$ characteristic slightly towards lower voltage and makes the resonant energy E_R dependent on magnetic field, namely decreasing linearly with the increase in the in-plane energy E_n. The

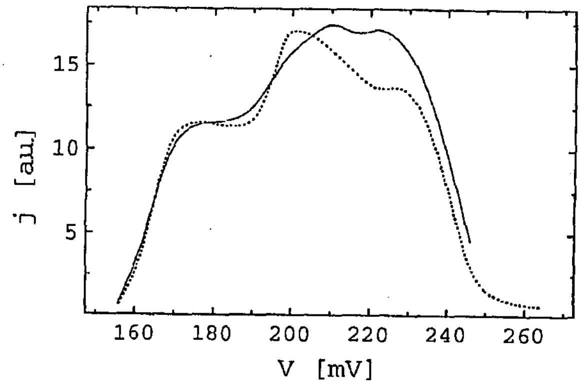

Fig. 1. The $j(V)$ characteristics calculated for $B = 10$ T assuming scattering on potential fluctuations in the DBS well (solid line) and the sharp Landau levels (dotted line).

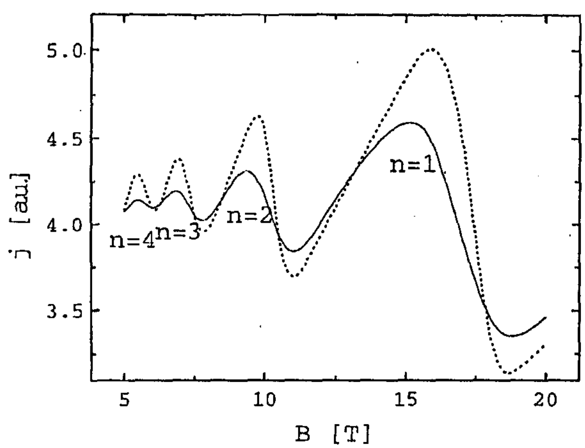

Fig. 2. The $j(B)$ characteristics calculated for applied voltage $V = 230$ mV assuming scattering on ionized impurities (solid line) and the sharp Landau levels (dotted line).

last effect is more pronounced for the narrow DBS well. However, the change of $E_{\rm R}$ with B is generally small and does not alter the fan chart significantly. The broadening of the Landau levels changes the shape of the $j(V)$ characteristics in similar way for both considered scattering mechanisms. Besides smoothing it causes a shift of magnetooscillation maxima towards lower applied voltage. This is a result of a competition of the two tendencies: the current increase due to an opening of a new tunneling channel and the current decrease caused by a decrease in the transmission coefficient with applied voltage. The positions of the conductance maxima remain unchanged. Therefore, the elastic scattering increases strongly the resonant level width $\Gamma_{\rm R}$ and it does not change the resonant energy $E_{\rm R}$.

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