REVISTA MEXICANA DE FÍSICA 44 SUPLEMENTO 3, 247–253 DICIEMBRE 1998

Tunneling in quantum wells in the presence of an electric field

G. González de la Cruz, A. Calderón, and L. Villegas
Departamento de Física, Centro de Investigación de Estudios Avanzados del Instituto Politécnico Nacional
Apartado postal 14-740, México, D.F., Mexico

Recibido el 12 de marzo de 1998; aceptado el 24 de mayo de 1998

The effect of an electric field on the electron energy and resonant width in a quantum well have been investigated theoretically. By considering the tunneling of electrons under the influence of an electric field in the quantum well, we obtain a shifted and broadened energy level spectrum from the tunneling of electrons. The lifetime broadening due to the rapid tunneling escape of electrons is related to the energy width of the resonant level by the uncertainty principle. Such lifetime decreases when the electric field increases.

Keywords: Quantum well; tunnel effect; lifetime

En este trabajo se estudia el efecto del campo eléctrico en el espectro de energía y el ancho de cada nivel electrónico en un pozo cuántico. Se calcula el corrimiento y el ancho de cada nivel de energía como función del campo eléctrico. El ancho de cada nivel de energía es debido al efecto tunel del electrón en el pozo cuántico. Por el principio de incertidumbre de Heisenberg es posible calcular el tiempo de vida del electrón en el pozo cuántico. Dicho tiempo de vida disminuye cuando el campo eléctrico aumenta.

Descriptores: Pozo cuántico; efecto tunel; tiempo de vida

PACS: 78.90.+i; 79.80.+w

1. Introduction

The quantum well stark and intersuband optical properties have attracted a great deal of interest because of their potential applications in optical devices [1, 2]. By engineering the well width and barrier height, quantum well devices with desirable properties may be fabricated. Recently, very high frecuency infrared photodetectors were experimentally demonstrated based on the intersuband transition and the subsequant tunneling effect of the photoexcited electron in the quantum well [3]. additional work has shown, that the responsivity spectrum in this process has significant spectral broadening and line asymmetry as compared to the zero-bias absorption spectrum. Both features are produced by the rapid tunneling escape of the photoexcited electrons in an electric field.

Resonant tunneling is a quantum phenomenon in which wave-like properties of an electron are notable and has been a subject matter of great interest. Resonant tunneling in quantum wells in an electric field may be understood in terms of the transmission coefficient through the potential barrier. Hence, an isolated resonance is characterized by two quantities that depend on the parameters of the profile potential, a position ϵ_n and a decay width Γ_n. These quantities are the main ingredients in the analytical expression for the transmission coefficient close to the resonance energy, and the have played a relevant role in the discussion of tunneling lifetime broadening of the quantum well intersubband photoconductivity spectrum [4]. On the other hand, the decay widths are most important quantities in relation to the time characteristics of these structures [5]. The usual procedure to determine the resonance energy ϵ_n is to define it as the energy corresponding to the maxium value of the transmission coefficient as function of the energy. In a similar fashion the decay width may be obtained using the rule of the full width at half maximum which follows from the approximate Lorentzian form of the transmission coefficient near the resonance energy.

We believe that it is important to have a theoretical framework to discuss resonant processes in quantum wells in an electric field which may provide a consistent calculation of resonance parameters. In a recent work [6] the effect of an electric field on the energy ϵ_n and the resonant width Γ_n of quantum well levels with surface states at the adges were found through an exact numerical solution of the Schrödinger equation with a complex energy $\epsilon = \epsilon_n - i\Gamma_n/2$.

In the present paper, we take a different approach than previous investigations to calculate the shifted energy level and the life-time broadening due to the tunneling of electrons in a quantum well in the presence of an electric field. We restrict our analysis to the solution of the Schrödinger equation only considering the asymptotic approximation of the Airy functions, which is valid in the regimen on the electric field of the experimental conditions. The shift of the energy level $\Delta\epsilon_n$ is compared with previous theories.

Let us consider a particle, of charge e and effective mass m^*, in a finite quantum well of width $2a$ in the presence of an electric field F along the direction of the well, z (in semiconductor heterostructures, this direction is perpendicular to the material layers). The origin of the distance and electrostatic potential are chosen at the center of the top of the well without applied electric field. The Hamiltonian of the problem is therefore,

$$-\frac{h^2}{2m}\frac{d^2}{dz^2}\phi(z) - [\epsilon - V(z) + eFz]\varphi(z) = 0, \qquad (1)$$