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RESONANT TRANSMISSION IN EFFECTIVE-MASS "DOUBLE-BARRIER" SYSTEM

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The transmission characteristic of barrierless ABABA multilayer system, where A and B are materials with differing effective masses, is analyzed. The system shows resonant transmission similarly to a conventional double-barrier system, but shows unique features: unity transmission at zero energy, a more structured nature of the transmission versus energy curve and a non-decreasing peak-to-valley ratio with increasing energy.

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Resonant tunneling through double barriers is of great interest from the point of view of fundamental research as well as potential high-speed applications [1]. Such a system consists of two potential barriers with a potential well between them. Resonant transmission occurs when the incoming energy matches the quasi-bound state level of the well.

There is, on the other hand, an interest towards effective-mass superlattices, in which the effective mass, rather than the potential is modulated periodically [2]. These systems exhibit interesting properties which are important for possible device applications. As an analogy to the conventional double-barrier structure, an effective-mass system can be constructed. It is the aim of this paper to analyze the transmission coefficient versus energy, $T(E)$, of such a structure and compare it with that of conventional double-barrier systems. We use the transfer matrix method for the calculation of $T(E)$ within the framework of the envelope wave function approximation. For simplicity, we assume a one-dimensional problem; band non-parabolicity, scattering and bias effects are also neglected.

The transfer matrix method is a simple but powerful method for solving the Schrödinger equation for arbitrary potential profiles [3]. In its simplest form, the potential profile is piecewise-approximated, and in each step, the solution is written as a sum of foregoing and reflected waves. Then the (envelope) wave function and its first derivative weighed by the reciprocal effective mass are matched at each interface; the transmission is then calculated as a squared ratio of transmitted and forward wave amplitudes.

For a conventional double-barrier system, $T(E)$ was calculated, for example, by Yamamoto [4]. His results can be written as

$$T = \frac{1}{1 + (MB)^2}, \tag{1a}$$

where

$$M = \frac{(m_a/m_b)k^2 + (m_b/m_a)\beta^2}{k\beta}\sinh\beta b \tag{1b}$$

and

$$B = \cosh\beta b \cos ka - \frac{(m_a/m_b)k^2 - (m_b/m_a)\beta^2}{2k\beta}\sin\beta b \sin ka. \tag{1c}$$

Here k and β are the wave vectors in the well and in the barriers, respectively, that is, $k = \sqrt{2m_a E}/\hbar$ and $\beta = \sqrt{2m_b(V - E)}/\hbar$, where m_a and m_b are the effective masses in the well and in the barrier, respectively. The corresponding layer thicknesses are a and b. E is the electron energy and V is the barrier height.

Now consider a barrierless ABABA system where A and B denote materials with the effective masses: m_a and m_b, respectively. Simply substituting $V = 0$ in Eq. (1) and introducing $R = m_b/m_a$, after straightforward but laborious algebra, we get

$$M = \frac{1/R - R^2}{\sqrt{R}}\sin\sqrt{R}kb \tag{2a}$$

and

$$B = \cos\sqrt{R}kb \cos ka - \frac{1/R + R^2}{2\sqrt{R}}\sin\sqrt{R}kb \sin ka. \tag{2b}$$

The plot of $T(E)$ for a conventional and an effective-mass double barrier system is shown in Fig. 1. The pertinent material and structure properties are summarized in Table. We note that although the envelope approximation and thus the concept of

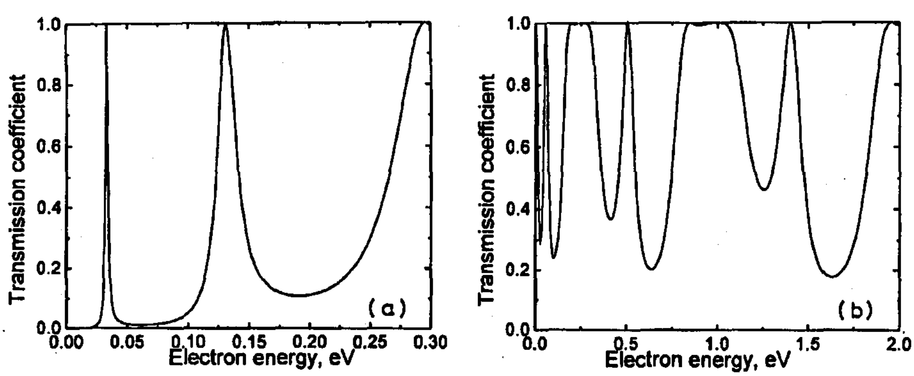

Fig. 1. Resonant transmission characteristics of a conventional AlAs/GaAs (a) and an effective-mass $Al_{0.23}Ga_{0.3}In_{0.47}P$/GaAs (b) double-barrier system. The pertinent material and structure parameters are shown in Table.

TABLE
The material and structure properties of the conventional and effective-mass double-barrier structures (Fig. 1).

	Conventional structure		Effective-mass structure (after Sasaki [2])	
	Barrier	Well	Barrier	Well
Material	AlAs	GaAs	$Al_{0.23}Ga_{0.3}In_{0.47}P$	GaAs
Width nm	2	10	2	10
Effective mass (in the units of free electron mass)	0.067	0.067	0.3819	0.067
	Barrier height $V = 0.3$ eV		Effective mass ratio $R = 5.7$	

the effective mass may be questionable in the case of such thin (few nm) layers, the success of the envelope approximation in conventional resonant tunneling diodes [1] and quantum well structures indicates that this approximation is valid in our case as well.

Some interesting observations can be made on the differences between conventional and effective-mass systems. First, $T(E = 0) = 0$ for the conventional system, while $T(E = 0) = 1$ for the effective-mass system. This follows simply from the analytical formulae and is also seen in Fig. 1. Also, $T(E)$ is more structured for the effective-mass structure, since the expression of both M and B consists of periodical (sine and cosine) functions of the wave vectors, opposing to the conventional structure where monotonic (hyperbolic) functions also occur. This is, in turn, a consequence of the fact that the wave vectors are always real in the effective-mass case. This also leads to a non-decreasing peak-to-valley ratio with increasing energy in the effective-mass case, while in the conventional structure, this ratio decreases with increasing E.

In conclusion, we analyzed the transmission properties of an effective-mass double-barrier structure. The similarities and differences between conventional and effective-mass systems were discussed. An extension of the theory would involve the inclusion of bias and scattering effects and computation of the current–voltage curve of such a device.

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