Dependence of tunneling transparency of the disordered superlattice on the parameters of impurity centers located inside the barriers

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Tunneling spectra of the disordered superlattice with impurities in the potential barriers are calculated. Disorder is due to random distribution of quantum-well widths along the superlattice chain. The dependence of the transmission coefficient on the parameters of impurity centers is analyzed.

Impurity centers located in the potential barriers affect significantly the energy spectra of various resonant tunneling structures (RTS's), such as periodical superlattices (SL's),[1] double barrier RTS's,[2] quasiperiodical Fibonacci chains,[3] hierarchical SL's.[4] It has also been shown in our previous work[5] that the interaction of impurity states in the barriers both with each other and with the states in quantum wells resulted in considerable enhancement of the transmission coefficient of the disordered SL's with quantum-well widths distributed randomly along the SL chain. In this Brief Report, we calculate the transmission coefficient T for the model of SL determined in Ref. 5 and analyze the dependence of T on the parameters describing the impurity centers.

Consider the SL constructed by a finite number of rectangular potential barriers of equal heights. The widths of quantum wells are distributed randomly along the chain of the SL, which is parallel to the x axis directed from left to right. There is a flux of electrons incident from the left with energies E and an effective mass m, which we assume to be independent of x. Following Ref. 1 we analyze the one-dimensional SL that models the real SL where impurity centers create the planes normal to the direction of the electrons flow—"impurity planes of deep levels" (IPDL).[1,2] As in Ref. 1, the scatterers potential is modeled by the δ function $U(x)=\Omega\,\delta(x-x_j)$, where Ω is the potential power and $-x_j$ its coordinate. The transmission coefficient may be expressed as follows:

$$T(E)=\left|\left(\prod_{n=1}^{r} R_n'\right)_{11}\right|^{-2} \tag{1}$$

where r is the number of interfaces, $R_n'=R_{2s-1}M_s$ for n odd and $R_n=R_{2s}, s=1,2,3,\ldots,$ for n even, R is the matrix transferring the solution of the corresponding Schrödinger equation through the interface, M is the matrix transferring the solution through the IPDL.[5]

The dependence of the ensemble averaged maximum values of the transmission coefficient $\langle[T(E)]_{\max}\rangle=T_m$ on the potential power $\beta=2m\Omega$ is presented in Fig. 1 for the parameters corresponding to a Si-SiC SL: $V=0.015$ a.u., $m=0.2m_0$; the number of SL periods $l=20$, the barrier width $b=100$ a.u. for the 1.1 curve and $b=50$ a.u. for the 1.2 curve. The quantum-well width distribution is assumed Gaussian with a large spread, sufficient to make the width distribution random for all practical purposes. 300 independent sets of quantum-well widths were taken into consideration while calculating the ensemble average transmission coefficient (the smoothed curves are presented here). We see in Fig. 1 that there is a range of values of β for which the transmission coefficient is practically equal to unity. It is easy to check that this is the same interval of β for which resonant energies in single barrier RTS's (SBRTS's) exist for

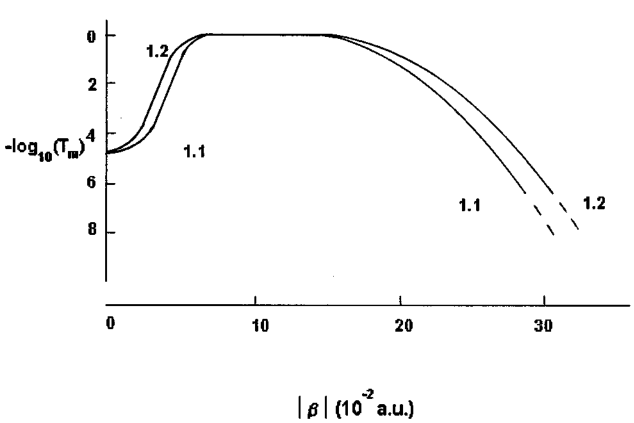

FIG. 1. The dependence of T_m vs $|\beta|$; $l=20$, $b=100$ a.u. for the 1.1 curve, and $b=50$ a.u. for the 1.2 curve.

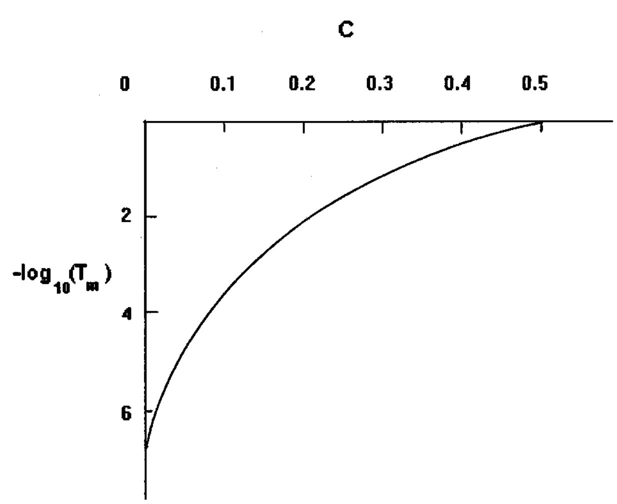

FIG. 2. The dependence of T_m on the ratio $C=x_c/b$, x_c being the distance from the impurities to the interface inside the barrier.

the parameters taken (whereas when $|\beta|$ increases ($|\beta|\gtrsim 0.15$ a.u.) resonant energies ''disappear'' into the subbarrier region). This means that tunneling spectra of the disordered SL considered are determined by resonances of SBRTS's to a large extent: calculations demonstrate that if there are resonances in SBRTS's (in the barrier region of energies $[0, V]$), the tunneling transparency of the disordered SL is close to unity for energies that are equal to resonant energies of SBRTS's. We would like to emphasize that even in the case where there are no resonances in SBRTS's (in an interval $[0,V]$) the effect of scattering on $T_m(E)$ for the SL considered is strong. It is seen in Fig. 1 that T_m for the SL with scatterers becomes equal to the transmission coefficient of the SL without scatterers ($T_m \approx 10^{-5}$ for given values of the parameters $b=100$ a.u., $l=20$) for $\beta \approx -0.27$ a.u. Note that further increase of $|\beta|$ leads to values of T_m lesser than that for the SL without impurities. Denote now the distance from IPDL to the left interface by x_c; Fig. 2 allows us to see that even little shift of the IPDL from the value $x_c=0.5b$ results in a strong decrease of T_m, e.g., T_m is reduced approximately by 10 times for $x_c=0.3b$ ($b=100$ a.u., $l=20$). When impurity centers are located close to interfaces the additional scattering on the IPDL leads to a decrease of T_m in comparison with the SL without impurities.

The following fact, which attracts our attention, refers to the SL with thin barriers ($b<200$ a.u.). In these SL's, the value of an energy E_r, for which the tunneling transparency becomes close to unity, depends on the barrier thickness b– the 1.2 curve illustrates this in Fig. 1, the value of b being equal to 50 a.u. ($l=20$, $x_c=0.5b$). We would like to note that with increasing b the value of E_r is shifted to larger E for small $|\beta|$ but E_r is shifted to smaller E for larger $|\beta|$; this means that E_r is independent of b for a certain value β_c ($\beta_c \approx -0.085$ a.u. for the parameters taken). This results in a broader range of β values over which high transmission occurs through the disordered superlattice.

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