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The Dependence of the Width and the Height of Barriers in a Step-like Single Barrier Resonant Tunneling Device

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ABSTRACT

Transmission coefficient was calculated by a transfer matrix method in the case of a step-like single barrier structure. The resonant energy is mainly determined by the width and the height of the thicker (main) barrier. The height of the thinner (additional) barrier does not affect the resonant energy, but strongly influenced the peak valley ratio instead.

KEY WORDS: resonant tunneling, transfer matrix, step-like barrier, transmission coefficient

１．Introduction

The study of resonant tunneling busted out since Tsu et al. reported the I-V characteristics of a finite superlattice obtained by a numerical calculation[1)]. The resonant tunneling is characterized by the existence of a resonant peak in the relationship between transmission coefficient and incident electron energy. It follows a differential negative resistance at room temperature[2)] that can be realized in various devices such as oscillators. The resonant tunneling is at the same time a genuine quantum phenomenon and so operates at high frequencies in THz region[3)].

The resonant tunneling effect has been usually realized in a double barrier structure. The barriers have mostly the rectangular form but the form makes little sense in the effect. The well width determines the resonant energy and the sharpness of the resonance depends on the barrier width. The barrier height slightly affects the resonance. These features have been systematically studied in the transmission coefficient spectra[4-6)].

Recently, a step-like single barrier structure was reported to show resonance as well as the double barrier structure[7)]. The step-like single barrier is depicted in Fig. 1 (b) with a conventional double barrier (a). The advantage of the structure is that only three heterointerfaces are needed while the double barrier structure requires four. We report, in this article, the dependence of the width and the height of the two barriers on the resonant characteristics.

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２．Calculation method and parameters

Transmission coefficient was calculated based on a one-dimensional time-independent Schrödinger equation where the effective mass was assumed to be 0.05 m_o through the system (m_o: electron mass in vacuum). The negligible difference in the effective mass in the two barriers was ignored to simplify the problem. Since there are three boundaries in the system, six boundary conditions are obtained which are expressed with matrices. The transfer matrix formalism was in accordance with the literature[1)]. Since the step-like single barrier structure includes fewer boundaries than a double barrier structure, the calculation was less complicated.

３．Results and discussion

We studied first the width dependence of the first barrier on the transmission coefficient. The barrier heights of the first and the second barrier were 0.3 and 0.5 eV, respectively. The width of the first barrier was varied from 10 to 50Å while that of the second barrier fixed to 10 Å. Figure 2 shows the results

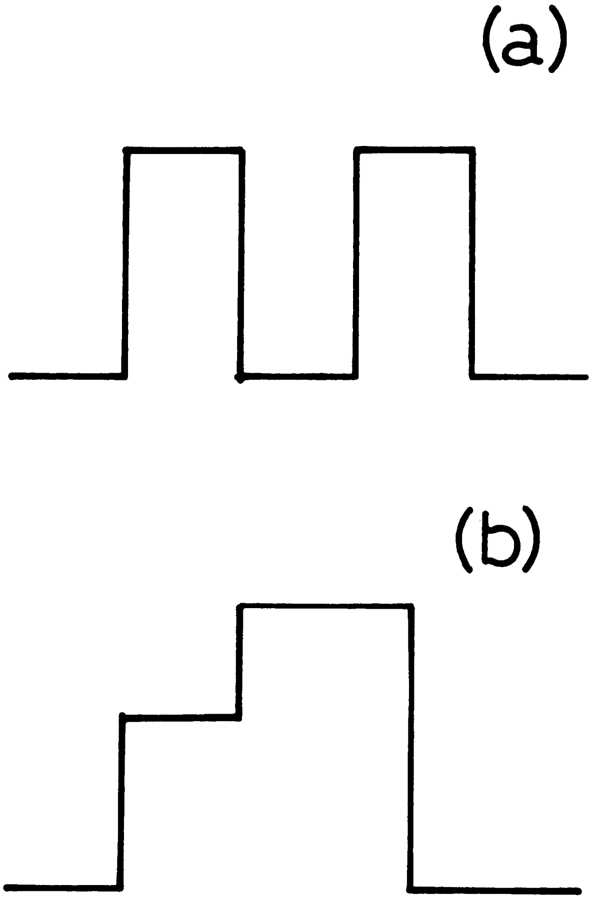

Fig. 1. A conventional double barrier structure (a) and a step-like single barrier structure (b).

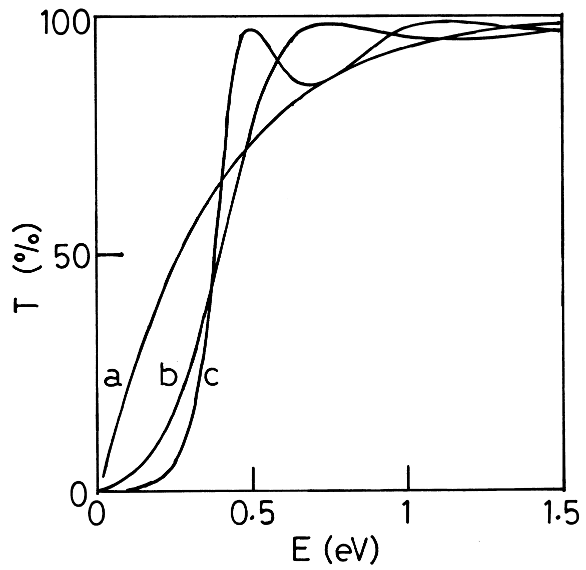

Fig. 2. The dependence of the width of the first barrier on the transmission coefficient T. The second barrier has a fixed width and a height of 10 Å and 0.5 eV respectively. The first barrier has a height of 0.3 eV. The widths of the first barriers are 10 Å (a), 30 Å (b), and 50 Å (c).

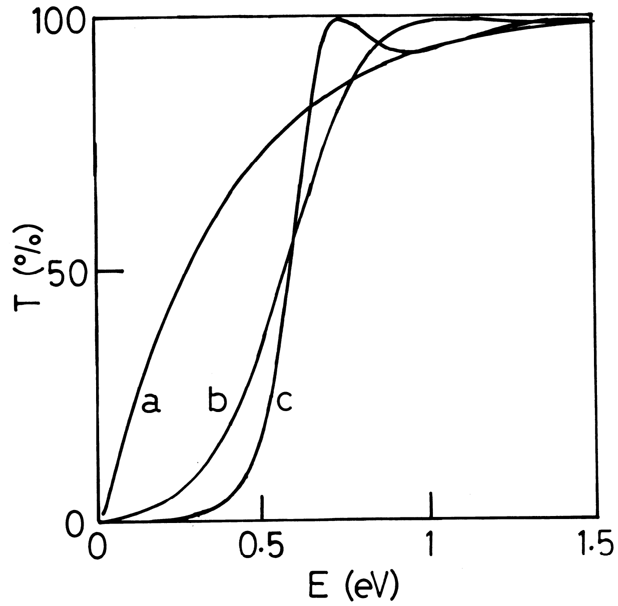

Fig. 3. The dependence of the width of the second barrier on the transmission coefficient T. The first barrier has a fixed width and height of 10 Å and 0.3 eV respectively. The width of the second barrier was varied 10 Å (a), 30 Å (b) and 50 Å (c) where the height was fixed to 0.5 eV.

of the transmission coefficient as a function of the incident electron energy. When the width of the first barrier was 10 Å, no resonance exists less than 1.5 eV. As the width becomes thicker, the sharper resonance peak appeared at the lower energy. The first resonant energy was 0.74 and 0.50 eV when the width of the barrier was 30 and 50 Å, respectively. In the latter case, the second resonance was also seen at 1.13 eV. The resonant energy depends on the width of the first barrier.

On the other hand, the width of the second barrier was varied in Fig. 3 from 10 to 50Å. The first barrier width was fixed to 10 Å. When the second barrier width was 10 Å, the identical result was obtained as shown in Fig. 2. As the width of the second barrier becomes thicker, the sharper resonant peak appeared at the lower energy in the same way as Fig. 2. However, the resonance occurs in the higher energy compared with the results shown in Fig. 2. The first resonant energy was 1.07 and 0.74 eV when the width was 30 and 50 Å, respectively. In this case, the resonant energy depends on the width of the second barrier. However, the resonant energy is different between Fig. 2 and Fig. 3 even if the total width of the barrier is the same.

In both cases, the resonance occurs at the lower energy, as the width of a barrier becomes the larger. It should be pointed out here that the transmission coefficient is not changed if the potential barrier is inverted from the right side to the left. It means that the concept of the first and the second barriers is nonsense. It can be said from these results that the thicker barrier determines the resonant energy. The feature should be discussed in terms of the main (the thicker) and the additional (the thinner) barriers.

We describe next the interesting results shown in Fig. 4. The effect of the additional barrier was investigated as a function of the potential height. The width of the first and the second barrier is 10 and 50 Å, respectively. The potential height of the first barrier was varied from 0.1 to 1.0 eV while that of the second barrier was fixed to 0.5 eV. It is important to note that the resonant energy is independent of the barrier height. The first resonant energy is 0.71 eV when the height is 0.6 and 1.0 eV. Even when the height is 0.1eV, the first resonant energy is no more than 0.79 eV. When the height is 0.6 and 1.0 eV, the second resonant peak is also seen at 1.32 and 1.35 eV, respectively. The second resonant energy is also mostly independent of the height of the first barrier.

As the first barrier becomes high, the resonant peak grows distinct accompanied by the reduction of the valley transmission coefficient. The valley energy is not affected so much by the height of the first barrier when the height is between 0.6 and 1.0 eV.

From the facts described above, the resonant energy is mainly determined by the width and the potential height of the main barrier. The height of the additional barrier contributes to the transmission coefficient at the valley and to how distinct the resonance is. The same tendency is obtained in the case when the height of the main barrier is 0.3 eV, as is shown in Fig. 5.

In a conventional double barrier structure, the resonant energy is determined mainly by the well width.[5] The barrier height slightly affects the resonant energy.[6] The sharpness of the resonance can be controlled by the barrier width. The structure has been well studied because the physical meaning of the parameters is definite.

As for the step-like single barrier structures, the principal parameters of the resonant energy and the sharpness of the resonance (the peak-valley ratio in other words) are possibly controlled separately as we have shown. The disadvantage of the step-like single barrier structure is the less peak-valley ratio that directly influences the performance of the resonant tunneling devices.

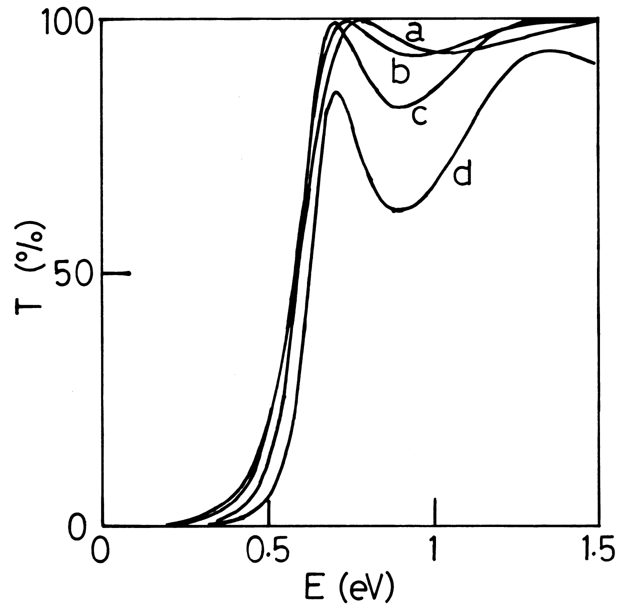

Fig. 4. The dependence of the height of the additional (the first) barrier on the transmission coefficient T. The height was taken to be 0.1 eV (a), 0.3 eV (b), 0.6 eV (c) and 1.0 eV (d) where the width was fixed to 10 Å. The width and the height of the main (the second) barrier were fixed to 50 Å and 0.5 eV respectively.

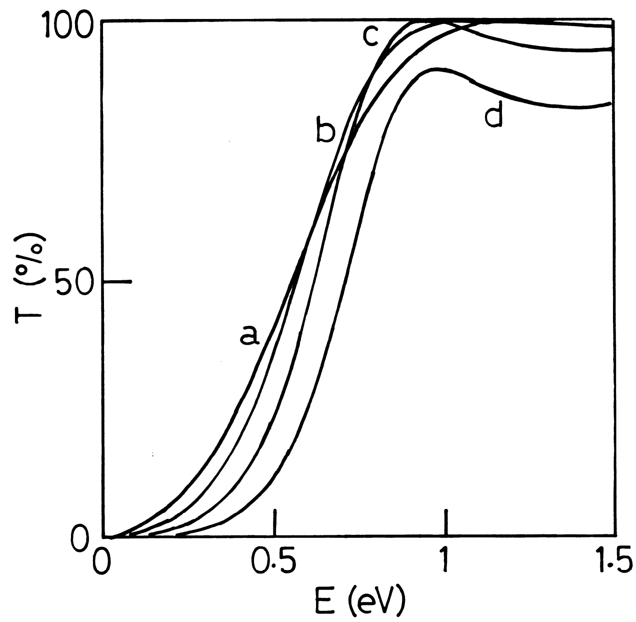

Fig. 5. The dependence of the height of the additional barrier on the transmission coefficient T. The conditions are the same as those in Fig. 4 except for the width of the main barrier; 30 Å.

Further investigation is expected to confirm the effect of the width of the additional barrier and the quantitative relationship between the resonant energy and the two parameters of the main barrier. The width of the additional barrier may make less contribution to the resonant energy because the width is small. If the I-V characteristic is investigated, the potential barrier should include the effect of the externally applied voltage. Since the applied voltage breaks the invariance in inversion of the input and output, the effect is of interest. The step-like single barrier structure can be more attractive than a double barrier structure if the inherent properties are unveiled.

４．Conclusion

We studied a step-like single barrier structure without externally applied voltages in the view of the dependence of parameters on resonant characteristics. The transmission coefficient spectra as a function of incident electron energy were calculated by means of a transfer matrix method based on a one-dimension time-independent Schrödinger equation. It was found that the width and the potential height of the main (thicker) barrier determine the resonant energy. The additional (thinner) barrier is insensitive to the resonant energy but the height affects the peak valley ratio. The step-like single barrier structure has the advantage to include fewer heterointerfaces than the conventional double barrier structure and expected to be studied more closely in the future.

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