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Phase Breaking Effect Appearing in I-V Characteristics of Double-Barrier Resonant-Tunneling Diodes —Theoretical Fitting Over Four Orders of Magnitude—

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1. Introduction

Experimental I-V characteristics of double-barrier resonant tunneling diodes (DBRTDs) are explained well by a theory without phase breaking as far as seen in linear scale. However, for the study of the electron coherence, if we look the second derivative characteristics of I-V curve [1], experimental data cannot be explained anymore by the theory. As one of methods to incorporate the phase breaking, a decaying-wave-function method explains a broadening of the second derivative peak, but fails to express the peak current density, less than the measured one by three orders of magnitude. It is required to fit the experimental data by a theory in the whole range of the current density for the study of the electron coherence using DBRTDs.

In this paper, we have achieved fitting of the experimental I-V curves over four orders of magnitude by the theory with the phase correlation function [2] for the phase breaking effect. Based on the theory, it is revealed that the phase breaking effect appears remarkably in the region of the current less than one-hundredth of the peak. The roughness of the heterointerface influences on the second derivative characteristics of I-V curve [3].

2. Theoretical I-V characteristics using phase correlation function

The transmission through the double barrier structure is described using multiple waves which make various numbers of round trip between the two barriers. The phase correlation among the waves is given as exp(-dL/Lc) where dL and Lc are a path length difference and a coherent length, respectively. Using Esaki-Tsu formula [4], the current density is derived as;

$$J(V)=\frac{qm^*}{2\pi^2\hbar^3}\int_0^\infty \ln\left[\frac{1+\exp\left(\frac{E_f-E_z}{k_BT}\right)}{1+\exp\left(\frac{E_f-E_z-qV}{k_BT}\right)}\right] \times \frac{|t_1|^2|t_2|^2\left(1-|r_1|^2|r_2|^2\exp(-\frac{4w}{L_c})\right)}{(1-|r_1|^2|r_2|^2)\left|1-r_1r_2\exp(-\frac{2w}{L_c})\right|^2}dE_z \tag{1}$$

where T and E_f are temperature and Fermi level, w is the well width and $t_1(r_1)$ and $t_2(r_2)$ are the transmission (reflection) coefficients denoted in Fig.1, which are precisely calculated by the transfer-matrix and self-consistent potential analysis.

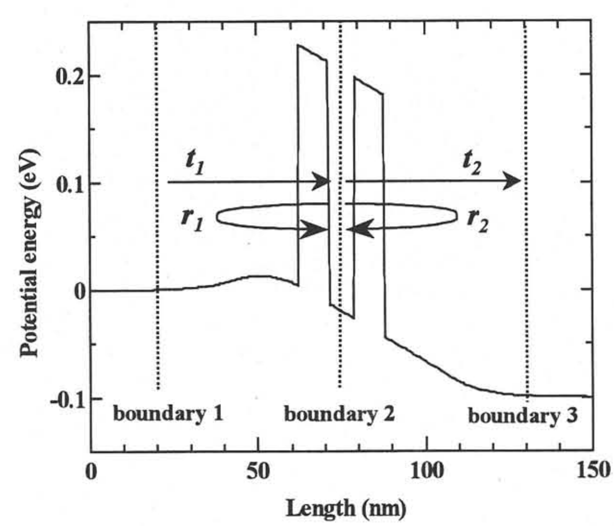

Fig. 1 Potential distribution of DBRTD designed.

3. Phase breaking effect

Theoretical I-V characteristics for GaInAs/InP DBRTD are calculated. As shown in Fig. 2, when the current is less than one-hundredth of the peak, it depends on Lc, that is, phase breaking effect appears while it does not depend on Lc around the peak. In contrast with this, curves obtained by the decaying-wave-function method depends on Lc around the peak and does not when the current is low.

4. Theoretical fitting of experimental data

DBRTDs were grown by OMVPE to measure I-V curves at 4K as shown in Fig. 2. Measured curve is fitted by the theoretical one (thick solid line) corresponding to the phase coherent length of 500 nm from the current density of $5A/m^2$ to $200kA/m^2$. As clearly shown, the dacaying-wave-function method does not fit in the whole current range.

To obtain this fitting we adjust the barrier thickness by -1nm, the well thickness by 0.5nm. Furthermore, to fit in the range of the current density from 100 to $100kA/m^2$, the fluctuation of the well width is taken into account by superposing I-V curves of various well width. Best fitting is obtained when we assume the well width fluctuation Δw is 0.6nm. We can see that the influence of the well width fluctuation is remarkable in the region where the second derivative of I-V curve is large.

5. Summary

Experimental I-V characteristics is fitted by the phase-correlation-function theory over the entire range of the current density. Using this fitting, we estimated the phase coherent length is 500nm and the well width fluctuation is 0.6nm.

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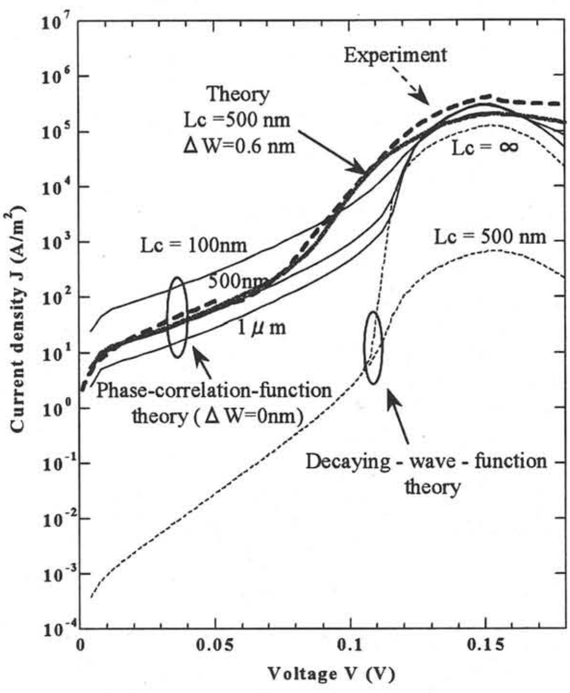

Fig.2 I-V characteristics of DBRTD at 4.2 K.