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Confinement Potential in an Asymmetrically Biased Quantum Point Contact

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Abstract

Conductances of a quantum point contact (QPC) were measured with asymmetrical bias conditions. While quantized conductances were observed with the asymmetrical conditions, the width of each quantized plateau was changed. The confinement potentials of the asymmetrically biased QPC were calculated self-consistently. It was concluded that asymmetrical bias affected not only the position of the electron path but also the confinement potential.

1 Introduction

Since the conductance quantization of a quantum point contact (QPC) was observed [1], the waveguide nature in electron transport has been attracting much attention of researchers. Therefore, transport properties of QPC's have been intensively studied worldwide.

The position of the path of electrons in a QPC can be controlled by asymmetrical bias conditions. The theoretical [2] and experimental [3, 4] demonstrations of such asymmetrically biased QPC's have already been reported. The bias condition is thought to affect not only the position of the electron path but also the shape of the confinement potential. However, the shape of the confinement potential in an asymmetrically biased QPC is not considered so far. In this present work, the shape of the confinement potential in an asymmetrically biased QPC is investigated experimentally and numerically.

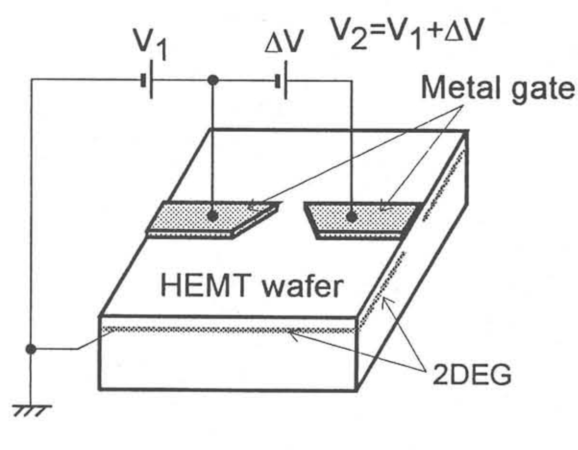

Fig. 1. Schematic view of the split-gate quantum point contact. V_1 and V_2 are the bias voltages for the left and right gate, respectively. ΔV is defined to be $V_2 - V_1$.

2 Experimental

Figure 1 shows schematically the sample structure with the bias-voltage condition. The starting wafer consists of 100-Å n-type GaAs, 500-Å n-type AlGaAs, 200-Å undoped AlGaAs and 8000-Å undoped GaAs grown on the semi-insulating GaAs substrate by molecular beam epitaxy. The electron concentration and mobility at 4.2 K after illumination is 4.5×10^{11} cm^{-2} and 4.4×10^5 cm^{2}V^{-1}s^{-1}, respectively. The 50-keV electron beam lithography, Au/Ti evapora-

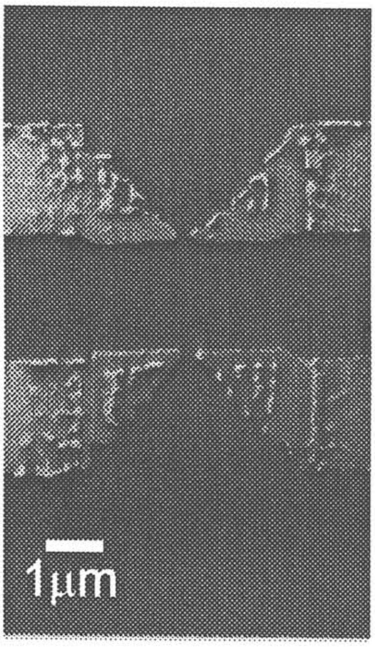

Fig. 2. SEM photograph of the split-gate quantum point contact.

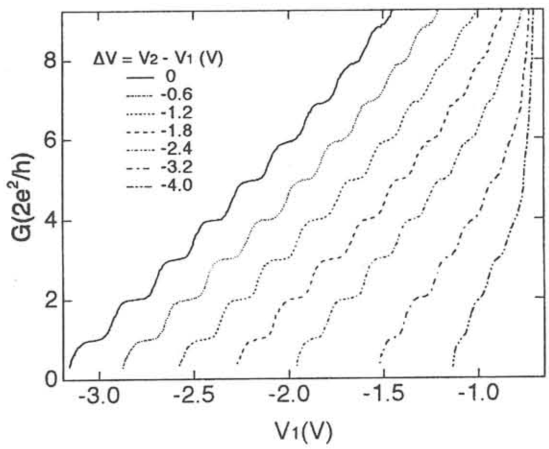

Fig. 3. Conductances of an asymmetrically biased quantum point contact with fixed ΔV as a function of V_1.

tion and lift-off technique were used for the fabrication of the split gates. The distance between the split gates D was 260 nm. Although there are two QPC's in series (Fig. 2), one of them was used for the present work. The resistance was measured at 1.4 K by an ac resistance bridge operating at 30 Hz.

3 Results and Discussion

Figure 3 shows the conductances of the asymmetrically biased QPC with the fixed ΔV as a function of V_1, where the conductances are obtained from the resistances which are revised by the background resistance. The lateral position of the potential minimum, $x_{\rm min}$, measured from the center of the QPC is estimated to be [3]

$$x_{\rm min} = \frac{D}{2}\frac{\Delta V}{V_1 + V_2}. \qquad (1)$$

According to this equation, the range of $x_{\rm min}$ varies 0 – 90 nm in the present experimental situation. In Fig. 3 the plateaus were clearly observed even when the ΔV became large. This means that there were no significant scattering centers in the width of about 180 nm in the QPC in contrast to the case of ref. 3.

It was observed that the widths of the plateaus became narrow when ΔV became large. This suggests that the asymmetrical gate bias change not only the path of the electron but also the confinement potential. The widths of the plateaus depend on the confinement potential in both the x and y direction [5]. However, the change of the shape of the potential in the y direction can be neglected compared to that in the x direction. In order to estimate the confinement potential in the x direction, we solved numerically the two-dimensional Schrödinger equation and the Poisson equation self-consistently. In the calculation, the temperature, electron effective mass and conduction band offset between AlGaAs and GaAs were assumed to be 0 K, $0.067m_e$ (m_e: electron rest mass) and 300 meV, respectively.

Some results of the calculations are shown in Fig. 4. The path of the electron is shifted to the negative x direction due to the asymmetrical bias. There are four eigenstates below the Fermi level in both the symmetrically and asymmetrically biased QPC. The calculated energy separation between the uppermost two eigenenergies in symmetrical and asymmetrical case were 1.36 and 1.21 meV, respectively. These values mean that asymmetrically bias condition gives the broad confine-

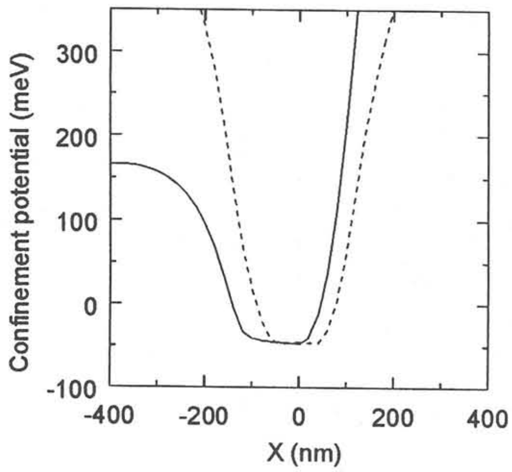

Fig. 4. Calculated confinement potentials in asymmetrically (solid) and symmetrically (dashed) biased quantum point contacts, where $V_1 = -1.0$ V and $V_2 = -2.0$ V in the asymmetrical case, and $V_1 = V_2 = -1.4$ V in the symmetrical case. Four eigenstates are occupied in both case.

ment potential, resulting in the small separation of the eigenenergies. Therefore the widths of the plateaus become narrow with large ΔV.

4 Conclusions

We measured the condactances of a QPC which was biased symmetrically or asymmetrically. The quantized conductances were observed even when the gates were biased asymmetrically, suggesting that there were no significant scattering centers in the QPC. In order to estimate the confinement potential, we solved numerically the Schrödinger equation and the Poisson equationthe self-consistently. It was concluded that asymmetrical bias affects not only the position of the electron path but also the confinement potential, resulting in the changes of the width of the plateaus of the quantized conductance.

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References

[1] B. J. van Wees, H. van Houten, C. W. J. Beenakker, J. G. Williamson, L. P. Kouwenhoven, D. van der Marel and C. T. Foxon: Phys. Rev. Lett. **60** (1988) 848.

[2] L. I. Glaman and I. A. Larkin: Semicond. Sci. Technol. **6** (1991) 32.

[3] J. G. Williamson, C. E. Timmering, C. J. P. M. Harmans, J. J. Harris and C. T. Foxon: Phys. Rev. B **42** (1990) 7675.

[4] T. Sakamoto, Y. Nakamura, S. W. Hwang and N. Nakamura: Ext. Abstr. 2nd International Workshop on Quantum Functional Devices, Matsue, Japan, May, 1995, p. 104.

[5] M. Reed: *Semiconductors and Semimetals,* ed. R. K. Williardson, A. C. Beer and E. R. Weber (Academic Press, Boston, 1992) Vol. 35, Chap. 4, p. 208.