Title	Gate Controlled Conductance Oscillations in GaAs Schottky Wrap-Gate Single Electron Transistors
Author(s)	Kasai, S.; Hasegawa, H.
Relation	Proceedings of the 25th International Conference on the Physics of Semiconductors Part I / Part II
Citation	Springer Proceedings in Physics, 87(2), 1817-1818
Issue Date	2001
Doc URL	https://hdl.handle.net/2115/8367
Rights	The original publication is available at www.springerlink.com
Type	conference paper
File Information	M279.pdf

Gate Controlled Conductance Oscillations in GaAs Schottky Wrap-Gate Single Electron Transistors

S. Kasai, H. Hasegawa

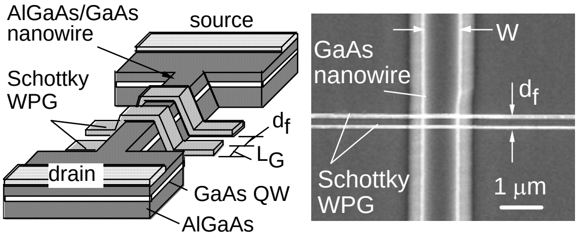
Research Center for Interface Quantum Electronics and Graduate School of Electronics and Information Engineering,
Hokkaido University, North 13, West 8, Kita-ku, Sapporo 060-8628, Japan e-mail: `kasai@rciqe.hokudaiac.jp`

Abstract Conductance oscillation characteristics of a Schottky wrap-gate controlled single electron transistor (WPG SET) were investigated. The device showed a small number of high conductance peaks and they were visible up to 30 K. These features were explained by a lateral single electron resonant tunneling. The line width of the resonant state was estimated to be 1.5 meV and indicated the strong coupling between dot and leads. In low temperatures where kT was much smaller than addition energy, the device showed an unusual temperature dependence of the peak width, whose behavior was different from that expected from the theory.

1 Introduction

III-V compound semiconductor single electron transistors (SETs) are promising candidates for next generation high-density, high-speed and low-power integrated logic circuits with rich functionality due to quantum effects. For this purpose, we proposed and have developed a GaAs Schottky wrap-gate (WPG) SET technology suited to high-density integration due to its simple planar structure[1]. Using this, single electron logic inverter circuits have been fabricated and a transfer gain larger than unity has been realized[2]. For further advance applications of the WPG SETs, understanding of the transport within the device is strongly required for device design.

The purpose of this paper is to clarify experimentally and theoretically the transport mechanism of the gate controlled conductance oscillation characteristic of the WPG SET.



(a) (b)

Fig.1 (a) Device structure of WPG SET and (b) SEM image of the fabricated device

2 Device Structure of WPGSET

The structure of the WPG SET is schematically shown in Fig.1(a). Two narrow Schottky gate electrodes wrapped around an AlGaAs/GaAs nanowire. The two WPGs, kept at the same gate bias, V_G, completely deplete electrons underneath and form two tunneling barriers and a quantum dot in between. They also control the size of the dot through the lateral extension of electric field lines.

The AlGaAs/GaAs nanowire was formed on a δ-doped MBE-grown AlGaAs/GaAs heterostructure by electron beam (EB) lithography and wet chemical etching. WPGs were formed by the EB lithography and a conventional Cr/Au deposition lift-off process. The SEM image of the fabricated device is shown in Fig.1(b).

3 Result and Discussion

The measured WPG SET conductance characteristics as a function of temperature are shown in Fig.2(a). Clear and high conductance peaks were observed and the height reached to e^2/h at a few K. The number of peaks was small. The peak height increased with the decrease of the temperature and it saturated at a few K. The peak was visible up to 30 K. These characteristics are quite different from those of metal-based SETs and also from

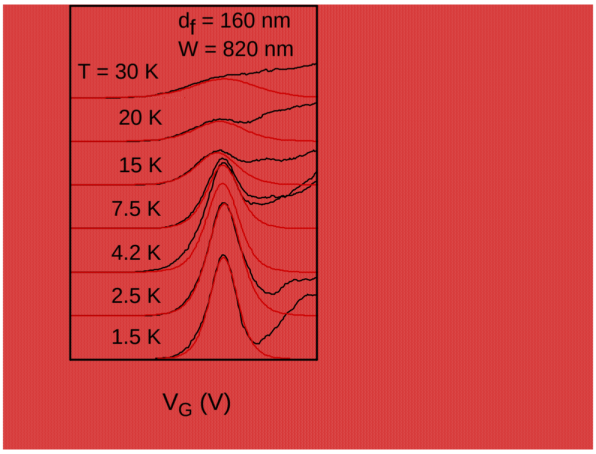


Fig.2 Conductance oscillations (a) experiment and (b) theory.

those of conventional split gate III-V semiconductor SETs[3,4]

In order to analyze the observed behavior, we evaluated the conductance peak theoretically by computing the following equation.

$$I = \frac{e^2}{h}\int |\,T(E)\,|^2 \,\{f(E) - f(E + qV_{DS})\}dE \qquad (1)$$

where f(E) is the Fermi-Dirac distribution function, $T(E)$ is the tunneling probability through the double tunnel barriers and V_{DS} is source-drain voltage. Here, the Breit-Wigner formula[5] was used for $T(E)$. Examples of the calculated conductance oscillations are shown in Fig.2(b), where Γ is the line width of the tunneling probability. In the case of T>5 K, the theory well reproduced the experimental results. However, when T<5 K, the width of calculated peaks seems to be narrower than that of experimental.

The temperature dependence of the conductance peak height, $G_{\max}$, is shown in Fig.3(a). Theoretical curves as a function of Γ are also shown in the figure. In low temperature limit, the theoretical curves approach to e^2/h. With the increase of Γ, the peak height becomes less dependent on temperature. From the comparison between theory and experiment, Γ is estimated to be 1.5 meV. This value is much higher than Γ = 0.005 - 0.1 meV of the split-gate SETs[4,6] and indicates much stronger coupling between the dot and the leads in the WPG SET. In the present WPG SET, the quantized energy, ΔE, given from the resonant peak intervals of $T(E)$ by the theoretical calculation is estimated to be 4 meV[7] and the charging energy, U, is estimated to be 4 meV from the potential simulation[8].

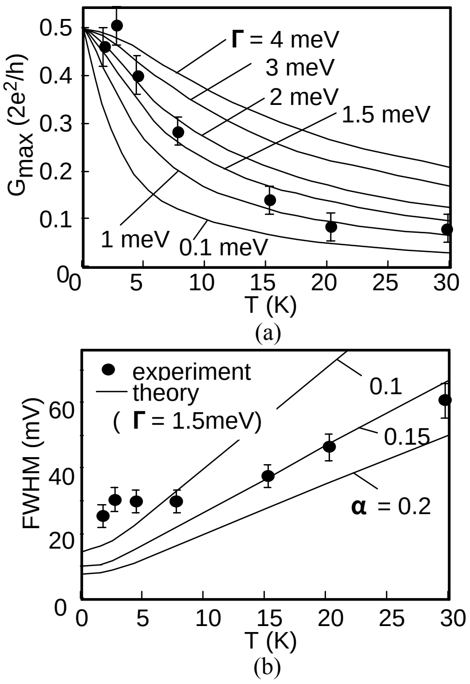


Fig.4 Temperature dependence of (a) conductance peak height and (b) FWHM.

The temperature dependence of the peak width, FWHM, is shown in Fig.3(b). The theoretical curves as a function of a scaling factor, α, relating energy, E, in the dot with the gate voltage, V_G, as $E = \alpha V_G$ are also shown of for Γ = 1.5 meV. The theory shows that the FWHM depends on T linearly and the slope is almost same as that of $1/\cosh^2(\alpha(V_G - V_{th})/2kT)$ [5] even when Γ nearly equals to kT. However, when $kT \ll \Gamma$, the FWHM hardly depends on T and approaches to Γ/α. Experimentally obtained FWHM also showed linear dependence of T for T >5 K. Thus, a much higher constant width appeared at a much higher temperature than the theoretical prediction. One possible mechanism for the observed unusual behavior is the Kondo effect, which takes place under a strong dot-lead coupling. This effect enhances and widens the conductance peak at low temperatures[6].

4 Conclusion

Conductance oscillation characteristics of Schottky wrap-gate single electron transistor (WPG SET) were investigated. The device showed small number of high peaks and it was visible up to 30 K. The features were explained by a lateral single electron resonant tunneling. The line width of 1.5 meV was estimated from the temperature dependence of the peak height and indicated the strong tunneling condition. An unusually wide and constant FWHM of the peak was seen at low temperatures.

References

1. S. Kasai, K. Jinushi, H. Tomozawa and H. Hasegawa, Jpn. J. Appl. Phys. **36** (1997) 1678.
2. S. Kasai and H. Hasegawa, Technical digest of 58th DRC, Denver, June 19-21, 2000.
3. L. P. Kouwenhoven et al., Phys. Rev. Lett. **67** (1991) 1626.
4. E. B. Foxman et al., Phys. Rev. B **47** (1993) 10020.
5. C. W. J. Beenakker, Phys. Rev. B 44 (1991) 1646.
6. D. Goldhaber-Gordon et al., Nature **39** (1998) 156.
7. S. Kasai, Y. Satoh and H. Hasegawa, Physica B **272** (1999) 88.
8. Y. Satoh, H. Okada, K. Jinushi, H. Fujikura and H. Hasegawa, Jpn. J. Appl. Phys. **38** (1999) 410.

Gate Controlled Conductance Oscillations in GaAs Schottky Wrap-Gate Single Electron Transistors
S. Kasai, H. Hasegawa .