Analysis of High-Frequency Rectifying Characteristics of Single-Electron Transistor

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1. Introduction

It has been reported experimentally that there seems no cutoff frequency in the rectifying operation of single-electron transistor (SET) [1]. In order to understand this, frequency dependence of the rectifying current is simulated, and theoretical explanation of the phenomena is attempted in this report.

2. Simulation

The simulation is based on the time-dependent master equation considering the four states of electron number n in the SET island. The rectifying current (average I_d) becomes negative and positive depending on V_g (Fig. 1), and is plotted against the frequency (Fig. 2) at V_g=0.15 V where it is minimum. The average I_d drops at around 1 MHz, but continues to assume a finite value up to 1 THz. Figs. 3 and 4 respectively show the drain voltage V_d dependences of the probability of states $p(n)$ and the drain-junction tunneling rate $G_{d,n,m}$ for transition from electron number n to m at representative low (7.4 kHz) and high (740 MHz) frequencies.

3. Result and discussion

At low frequency, $p(n)$ follows the change in V_d, and generate current I_d together with G_d, i.e. $I_d \sim e \times [p(1) \times G_{d,1,0} - p(0) \times G_{d,0,1}]$. Asymmetry in p(n) and G_d with respect to V_d causes the asymmetry in I_d, resulting in the rectification. At high frequency, p(n) cannot follow the rapid change in V_d, and becomes nearly constant. However, the asymmetry in G_d is kept the same, and the symmetry in I_d and the rectifying operation remains at high frequencies.

4. Conclusion

There is no cutoff frequency in the rectifying operation of SETs, and the asymmetry in the tunneling rate with respect to the drain voltage is responsible at high frequencies.

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Reference: [1] Y. Takahashi, et al. ECS Transactions, 58 (9) 73-80 (2013)

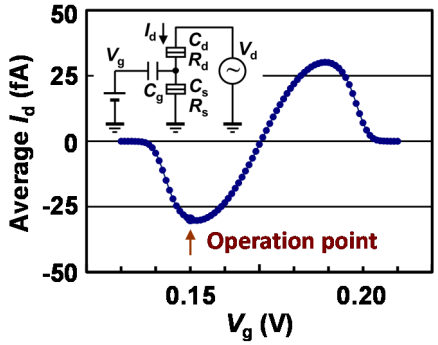


Fig. 1 Rectifying current vs. gate voltage V_g. C_g=0.47 aF, C_d=C_s=2.5 aF, R_d=R_s=2.5 GΩ, V_d=±5 $mV_{p\text{-}p}$, T=0.8 K

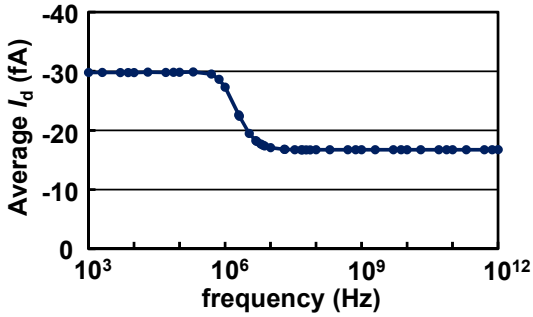
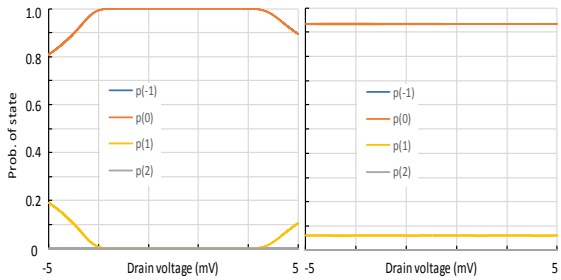
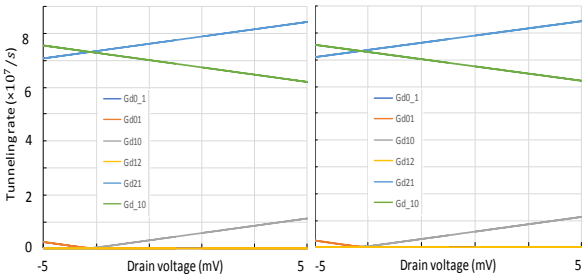


Fig. 2 Frequency response of the rectifying current.



(a) 7.4 kHz (b) 740 MHz

Fig. 3 Probabilities of state vs. drain voltage at low (a) and high (b) frequencies.



(a) 7.4 kHz (b) 740 MHz

Fig. 4 Tunneling rate vs. drain voltage.