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 \( V_g=0.15 \text{ V} \) 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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