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Room Temperature Coulomb Oscillation for Single Electron Transistor on Atomically Flat Ti/α-Al_2O_3 Substrate Made by Pulse-Mode AFM Nano-Oxidation Process

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1. Introduction

Clear Coulomb Oscillation was observed even at room temperature for a single electron transistor(SET) fabricated on the atomically flat titanium(Ti) metal /α-Al_2O_3 (1012) substrate using AFM nano-oxidation process. In order to get this results, new & improved process and measurement system are introduced, such as a pulse mode AFM nano-oxidation process, an ultra-high vacuum evaporation system, and a triaxial active feedback measurement system, etc.

2. Improved and new fabrication process on atomically flat substrate

We have proposed to use the atomically flat α-Al_2O_3 substrate for the AFM nano-oxidation process to improve the smoothness and reproducibility of the narrow oxidized Ti metal line[1]. In the present paper, three new and/or improved processes are introduced as described below:

1) As shown in Fig. 1, the $\pm 1.5 \sim \pm 2$V pulse bias was applied between the conductive AFM cantilever and the Ti metal to oxidized the surface of the Ti metal instead of a negative DC bias as in the previous work[1]. The negative pulse anodized the surface of the metal and the positive pulse removed the residual charge which had been formed during the anodization and prevented the penetration of electron during the anodization[2]. Therefore, using the pulse bias for the oxidation, the deeper oxidation becomes possible at the lower applied bias leading to the formation of the narrower oxidized Ti line.

2) The Ti metal was deposited onto the α-Al_2O_3 substrate at the ultra-low pressure of less than 2×10^{-8}Torr. So far, Ti was deposited at the pressure of 2×10^{-7}Torr, and the fabricated SET using this Ti film showed some degradation characteristics during the measurement owing to the residual oxygen inside the Ti film. On the other hand, the SET using the improved Ti metal shows no degradation characteristics at all during the measurement.

3) The width of the gate insulator for the side gate SET was increased up to 1μm to completely prevent the gate leakage current at room temperature (In the previous work, the width of the gate insulator was 300nm). The plain AFM image of the fabricated one island side gate SET[3,4] on the atomically flat substrate is shown in Fig. 2. The gate leakage current is less than 50fA at the applied bias of 10V at room temperature.

3. Electrical property of SET at room temperature

In order to reduce the noise and the leakage current from the measurement system, the triaxial cable and the active feedback system were introduced. Figure 3 shows the result of the current-voltage characteristics between opened two probes at room temperature. The noise level is less than 1fA(10^{-15}A), and the leakage current is 0A even at the applied bias of 10V. Using the conventional co-axial cable without the active feed back system, on the other hand, the noise level is as large as 20fA and the leakage current is as large as 80fA at the applied bias of 10V.

Figure 4 shows the gate bias dependence of the drain current of the SET at the drain bias of 0.25V and 0.3V at room temperature. The drain current oscillate with the period of 1.8V. Five peaks are clearly seen. The current modulation rate is from 20% to 30%. Even at the differnt drain bias, the drain current shows the oscillation peaks at the same gate bias points. The gate capacitance estimated from the periods of the Coulomb oscillation is 9×10^{-20}F which almost coincide with the roughly calcuratred value from the structural parameter.

4. Conclusions

We have succeeded in obtaining the clear Coulomb oscillation at room temperature. The new pulse-mode AFM nano-oxidation process, the ultra-high vacuum evaporation system, the triaxial cable and active feedback measurement system are used for this results.

References

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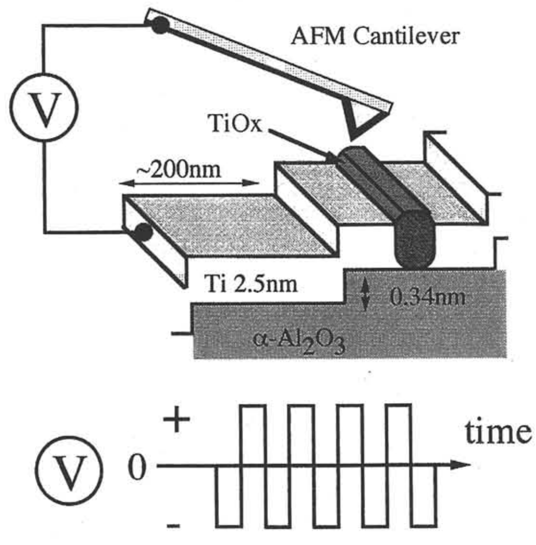

Fig. 1, Pulse-mode AFM nano-oxidation process on atomically flat Ti/α-Al_2O_3 substrate.

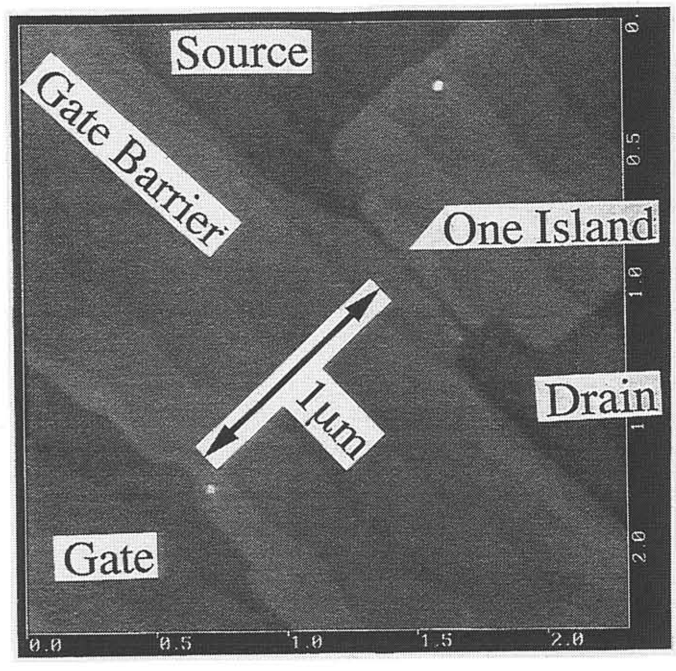

Fig. 2, Plain AFM image of the fabricated one island side gate SET on the atomically flat substrate.

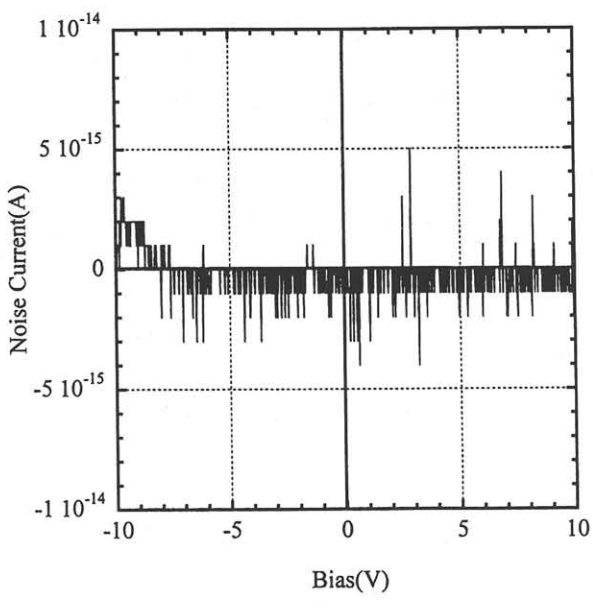

Fig. 3, Noise & leakage current-voltage characteristics between opened two probes at room temperature.

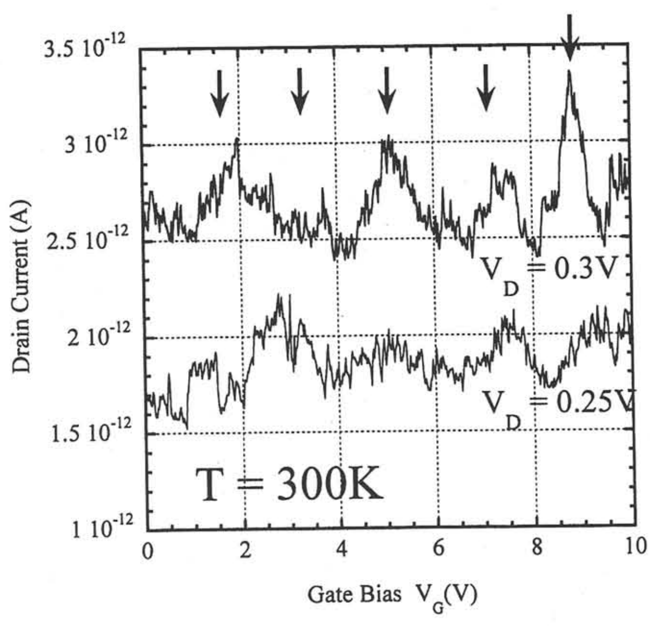

Fig. 4, Room temperature Coulomb oscillation characteristics at VD=0.25V and 0.3V