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Single Electron Transistor on Atomically Flat α-Al_2O_3 Substrate Made by AFM Nano-Oxidation Process

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1. Introduction

On the atomically flat niobium(Nb) metal surface that was on the atomically flat α-Al_2O_3 (10$\bar{1}$2) surface, the single electron transistor[3,4] was fabricated using the narrow oxidized Nb metal wires as tunneling junctions which were fabricated using the AFM cantilever as an ultra-fine cathode[1,2]. Owing to the atomically flat surface of the Nb metal, the uniformity and reproducibility of the line width and space, such as 10-15nm were greatly enhanced. The electrical characteristics of the single electron transistor on the atomecally flat substrate is shown.

2. Fabrication process on atomically flat substrate

By heating the α-Al_2O_3 substrate up to 1000C for 1 hour, the surface of the α-Al_2O_3 substrate becomes atomically flat due to the step migration. The Nb metal of 3nm thick was deposited by e-beam evaporator on to the α-Al_2O_3 substrate as shown in Fig. 1. Even after the deposition of the metal, the surface of Nb metal retains the atomically flat condition. The measured terrace size and step height are 280nm and 0.34nm, respectively, as shown in Fig. 2. The roughness of the Nb metal is less than 0.1nm. Therefore, the surface of Nb metal could be called as "atomically flat." The terrace size of 280nm is wide enough for the structure of the single electron transistor.

By scanning the AFM cantilever with the applied bias of 1.5-2V, the surface of the atomically flat Nb metal was oxidized to form the nano-meter wide oxidized Nb wire. Figure 3 shows the palin view of the atomically flat surface of the Nb metal with the narrow oxidized wire. The measured area is 1μmx1μm and the clear 4 terraces of about 250nm wide are observed. The width and the height of the Nb oxide wire fabricated in the center of the terrace parallel to the step is 15nm and 0.7nm, respectively, as is shown in Fig. 3. Owing to the atomically flat Nb surface, such a low height of 0.7nm of the oxide wire could be easily observed. Using the atomically flat Nb surface, more complicated structure was easily obtained. Figure 4 shows the six folded meander line of oxide wire and one folded one, which are both on the atomically flat terraces. The measured six folded meander line is also shown in Fig. 4, and the line width and height are uniform and is 25nm and 0.6nm, respectively, and the space between lines is 13nm. Owing to the atomically flat surface of Nb metal, the uniformity and the reproducibility of the oxide wire are improved.

3. Single electron transistor on atomically flat substrate

The single electron transistor was fabricated on the atomically flat Nb surface and the plain view of the fabricated device measured by AFM is shown in Fig. 5. The device has two islands with the same size of 15nm x 45nm, and the three tunneling junctions width is all 26nm. The gate insulator is made of wide Nb oxide barrier of 1μm wide and the source-drain barrier is the same width of 1μm. The three tunneling junctions are between these wide oxide barriers. In the figure, clear step of the substrate are observed. The critical area that includes the tunnel junctions and island regions is on the same terrace and the non-critical areas which include the gate region and the source-drain region are on the diffent terrace.

The drain current-voltage characteristics of the single electron transistor measured at 9K is shown in Fig. 6. The gate electrode was open in the measurement. The clear Coulomb gap of 200mV and the Coulomb staircases were observed.

4. Conclusions

We proposed to use the atomically flat substrate such as α-Al_2O_3 for the fabrication of the single electtron transistor. The fabricated single electtron transistor on the atomically flat α-Al_2O_3 substrate shows the Coulomb gap of 200mV . This process improved the uniformity and the reproducibility of the fine structure, drastically, and is expected to be profitable for the more complicated fine structure, such as a single electron memory.

References

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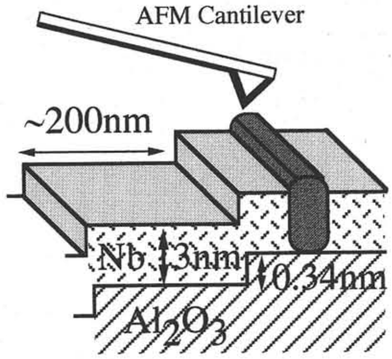

Fig. 1, Schematic illustration of AFM nano-oxidation process for Nb metal on atomically flat Al_2O_3 substrate.

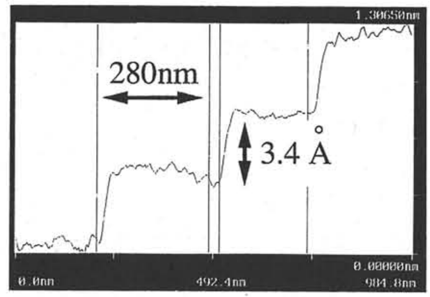

Fig. 2, Measured surface of Nb metal on atomically flat Al_2O_3 substrate. Terrace size is 280nm, and step height 0.34nm. Surface roughness of Nb metal is less than 0.1nm.

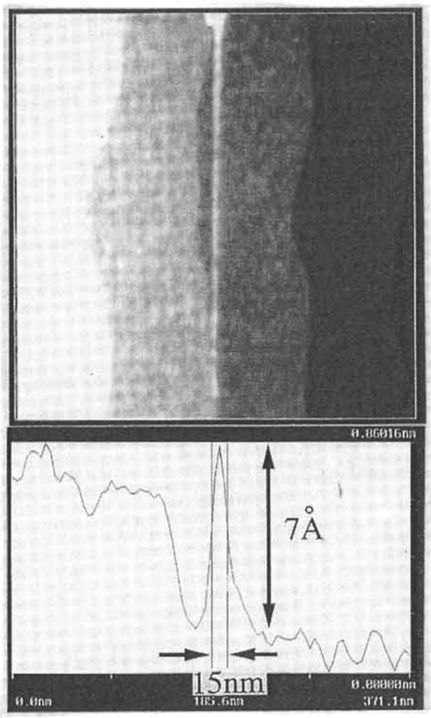

Fig. 3, Oxidized Nb wire formed by AFM nano-oxidation process on atomically flat Nb surface. Width and height of oxide wire is 15nm, and 0.7nm, respectively.

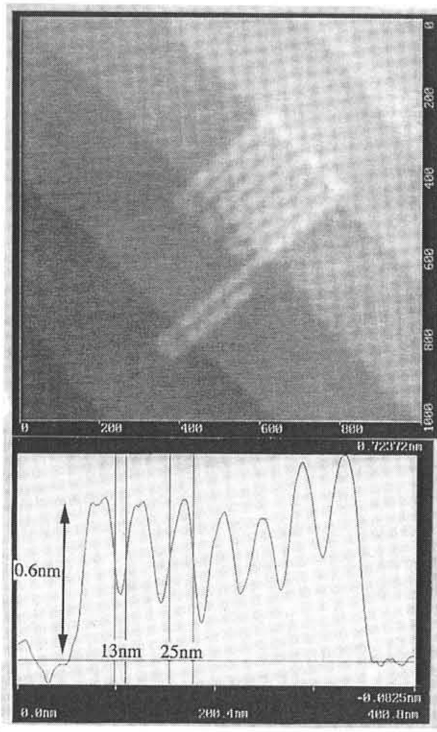

Fig. 4, Oxidized Nb Meander line on atomically flat Nb surface. Uniform line width of 25nm, height of 0.6nm, and spacing between lines of 13nm are obtained.

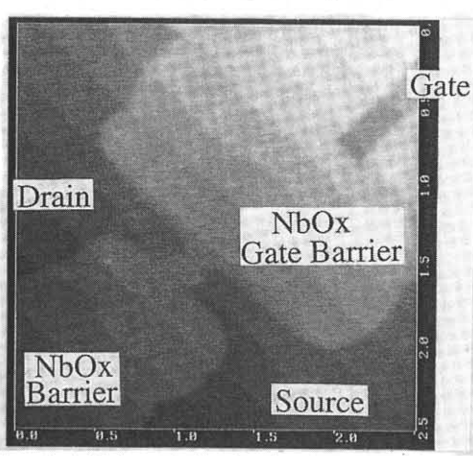

Fig. 5, Fabricated single electron transistor on atomically flat Nb surface. Transistor has two islands on the atomically flat terrace between large NbOx gate barrier and source-drain barrier.

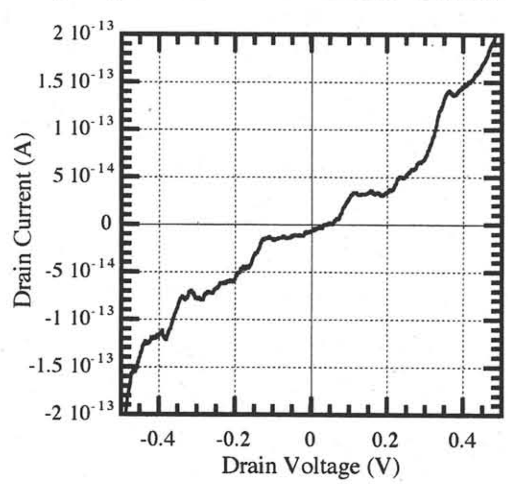

Fig. 6, The measured drain current-voltage characteristics at 9K. Clear Coulomb gap of 200mV is observed.