To be published in Physica B, 2006

All-chromium single electron transistor fabricated with plasma oxidation

T. Kubota and R. Yagi

Graduate School of Advanced Sciences of Matter (ADSM), Hiroshima University, Higashi-Hiroshima, Hiroshima 739-8530, Japan.

Abstract

We fabricated all-chromium single electron transistor using electron beam lithography and shadow evaporation, employing a plasma oxidation technique. This improved the controllability of the tunnel resistance determined in the oxidation process. We measured the device characteristics of the fabricated SET transistor at 90mK and found that Coulomb blockade with little leakage current, showing excellent quality of the tunnel barrier.

Key words: SET transistor, Plasma oxidation

Owing to the nano-fabrication technologies developed in these days, fabrication of small tunnel junction devices with capacitance of the order of femto farad has been realized. In these devices, charging energy of a single electron is not negligible and the Coulomb blockade phenomenon occurs at sufficiently low temperatures. The SET (single-electron tunneling) transistor, one of the typical device of the SET devices, is composed of a couple of tunnel junctions, an island electrode and a gate electrode controlling the flow of electrons by applying voltage. Most of the studies concerning metal-based SET transistor were performed using aluminum. This is because the oxide of aluminum could be formed easily and its quality as a tunnel barrier was excellent. However it would not be suitable for the SET transistor operating in normal states because of the superconductivity occurring at low temperatures. For this reason we examined chromium as a base material for normal electrodes. To date, the SET transistor of chromium has been studied in Refs.[2][3][4]. It was pointed out that the most difficulty one had to overcome was the process forming the tunnel barrier. Because chromium is oxidated much slower than aluminum, they have exposed the chromium surface to about 760 torr of air or oxygen for a considerably long time (typically one day). In this work, we report an improved method of fabrication of tunnel barrier with plasma technique.

We fabricated the device using electron beam lithography and shadow evaporation. Fig.1 is a scanning electron micrograph of the fabricated SET transistor. In order to form the tunnel barrier, we placed the substrate in the vacuum chamber that is capable of generating oxygen plasma with glow discharge. We could control the tunnel resistance to be between 30kOhm and 400kOhm varying the oxidation time between 30sec to a few minute, for a typical condition if oxygen pressure

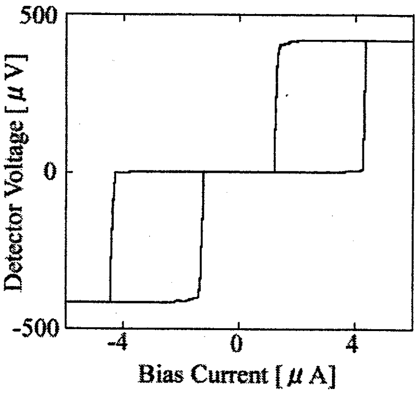

Fig. 2. *I-V* characteristic of a single Josephson junction.

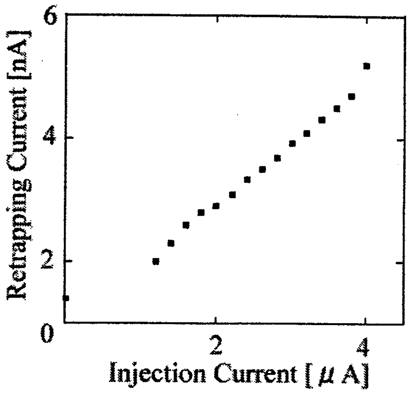

Fig. 3. Dependence of retrapping current of Josephson junction on quasi-particle injection

surements were performed at T=50mK using a dilution refrigerator.

The typical *I-V* characteristics of a single Josephson junction are displayed in Fig.2. *I-V* characteristics exhibited hysterisis. The critical current was about 4.5nA, which agreed with estimation from the Ambegaokar-Baratoff formula. The retrapping current reflects the energy dissipation directly. The retrapping current without quasi-particle injection was about 1.4nA. The retrappinig current could be varried by unjecting quasi-particle as shown Fig.3. With increasing injection current from 0μA to 4μA, the retrapping current increased from 1.4nA to 5.6nA. This could be interpreted in terms of the RSJ model and quasi-particle diffusion: injection current created quasi-particles, which diffused in the wire and contributed the quasi-particle tunnel resistance at the target junction. Quantitative study of relation between the quasi-particle tunnel resistance and the magnitude of retrapping current could reproduce the theoretical prediction for McCumber-Stewart parameter if we assuming the capacitance of the junction to be 0.015fF.

We could observe non-local response of the injected current at a detector junction located away from the injector. Since the injected quasi-particles are in disequilibulium, they are inevitably subject to the recombination. Recombination length estimated from the experiment were about 9μm (not shown) are consistent with the experimental setups.

Finally we would like to comment on the heating effect. The injection of quasi-particles might cause heating of the system. We could estimate the variation of the system temperature using theory of phase diffusion branch [3] to be of the order of 50mK even for the maximum injection current and at the lowest temperature. This might indicate that heating would not seriously affect the measurements of macroscopic quantum phenomenon and that the method described here would be helpful for further studies of quantum phenomena and frictions.

Acknowledgements

This work was supported by Grant-in-Aid from the Ministry of Education, Science, Culture, Sports and Technology of Japan.

References

[1] A. O. Caldeira and A. J. Leggett, Phys. Rev. Lett. 46, 26 (1981).

[2] R. Yagi, S. Kobayashi, J. Phys. Soc. Jpn. 66, 3722 (1997).

[3] M. Tinkham, "Introduction to Superconductivity", Dover Publications, Inc., Mineola, N.Y. (2004).