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Fabrication of Single Electron Transistors on Hydrogen-Terminated Diamond Surface Using Atomic Force Microscope

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Recently, nanofabrication technology using a scanning probe microscope (SPM) has attracted special interest. The fabrication of several nanoscale devices has been reported based on this technique, including single electron transistors (SETs), which have been fabricated by the local anodization [1].

Hydrogen terminated (H-terminated) diamond is attractive for electrical applications because it induces p-type surface conduction even in undoped diamond. The thickness of this surface conductive layer was estimated to be less than 10 nm, and the surface hole density to be $\sim 10^{13}$ cm^{-2}. On the other hand, an oxygen-terminated (O-terminated) diamond surface is insulating. This means that diamond has an advantage over other semiconductor materials in the fabrication of a surface nanostructure using a SPM-based processing technology. Since undoped diamond is basically an insulating material, we can conclude that H-terminated diamond has a semiconductor-on-insulator structure. In the case of Si, special techniques such as separation by implanted oxygen (SIMOX) etc. are needed to fabricate the electrically isolated thin conducting layer. In diamond, an electrically isolated surface conductive layer is easily obtained by eliminating the surface H-termination. Recently, local anodization on H-terminated diamond surface was performed using a metal (Au, Rh, etc.) coated conductive atomic force microscope (AFM) cantilever by applying voltage bias to the sample surface [2]. Up to the present, local insulation (30-60 nm in line width) has been successfully achieved using AFM. The nm scale separation of H-terminated surface and O-terminated surface will produce new types of nanoscale surface quantum devices such as single charge tunneling devices.

In the present study, the fabrication and operation of the side-gated diamond metal-insulator-semiconductor FETs (MISFETs) are demonstrated using anodized surface as a gate insulator. Using the locally anodized double tunneling barrier and aforementioned side-gated FET structure, fabrication and operation of single electron transistor is also demonstrated.

Figure 1 shows the schematic and the I_{DS}-V_{DS} characteristics of a side-gated diamond FET fabricated by AFM local anodization. Source-drain channel is separated from the gate surface conductive area by anodized region. Current saturation is observed in the statistic characteristics, and channel current is well modified by the field effect, though slight short channel effect occurs at higher drain bias. Channel is depleted even at 0 V gate bias.

Single electron transistor is also fabricated using AFM-anodized area as a gate insulator and tunneling barriers. Figure 2 shows the AFM image and measured characteristic of the fabricated single electron transistor. A conductive island (100 X 120 nm^2) is separated from source and drain by the anodized tunneling barriers (40 nm in width). In the V_{GS}-I_{DS} characteristic under −100 mV drain bias condition measured at liquid nitrogen temperature (77 K), clear current oscillation is observed. This oscillation can be attributed to the coulomb blockade oscillation. However, the area of the island deduced from the period of this oscillation (ΔV_{GS} ~0.4 V) is in the order of nm. This value is smaller than aforementioned island area. If we consider the carrier depletion in the island, many smaller conductive regions appear in the isolated island. Sub-peaks besides the main oscillation peaks in the current oscillation also suggests this multiple island model.

References

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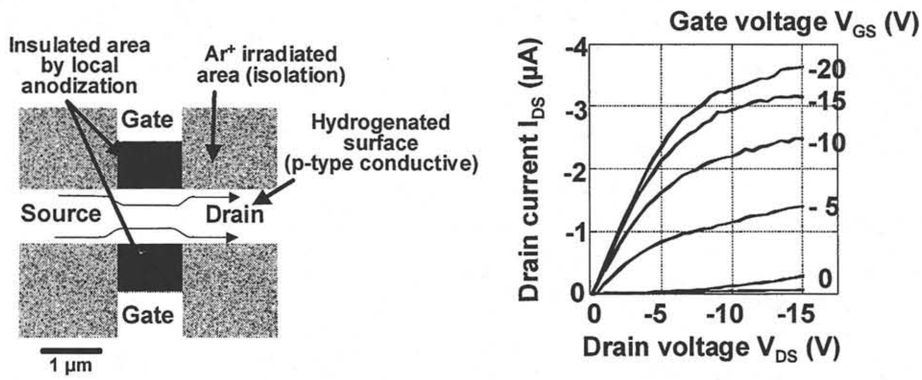

Fig.1 Schematic and statistic characteristics of side-gated FET (gate length: 1 μm) using local anodization by AFM.

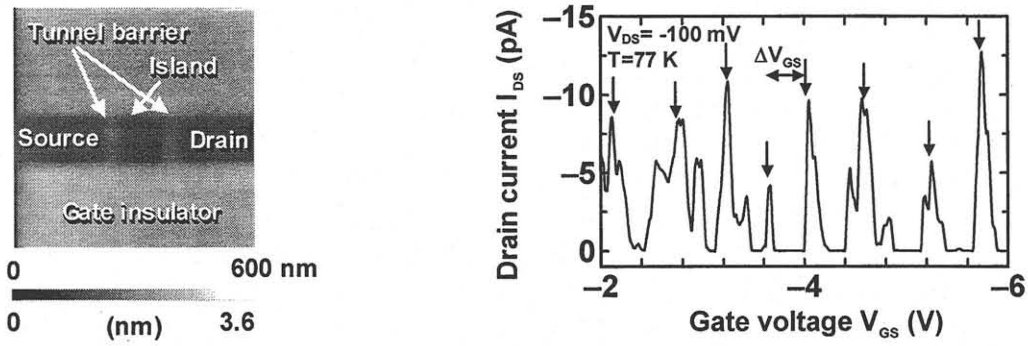

Fig.2 AFM image and VGS-IDS characteristic of diamond single electron transistor fabricated by AFM nano anodization.