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First Application of STM Nano-Meter Size Oxidation Process to Planar-Type MIM Diode

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Ultra-fine oxidized titanium (Ti) line of 18nm wide and 3nm high was formed on the surface of 10nm Ti layer on the SiO_2 / Si substrate using the STM tip as a selective anodization electrode. The dependence of the size of the oxidized titanium line on the parameter was investigated. The formed oxidized titanium line has the resistivity of 2×10^4 ohm cm, which is seven orders of magnitude higher value than that of the deposited Ti layer. The oxidized Ti line was used in the planar type MIM diode, and worked as an energy barrier for the electron. The energy barrier height of the oxidized Ti line was found to be dEg = 0.25 eV. This is the first application of STM process to the electron device.

Ultra-fine oxidized titanium (Ti) line of 18nm wide and 3nm high was formed on the surface of Ti layer on a SiO_2/Si substrate using the STM tip as a selective anodization electrode. This STM nano-meter size oxidation process[1,2] was first applied to the fabrication of the electron device such as a planar-type MIM diode.

The pattern formation procedure is shown in Fig. 1. After the deposition of the thin Ti layer of 4 nm at the pressure of low 10^{-7} Torr, the sample was set in an air ambient STM. The Ti surface was biased positively to the Pt STM tip. When setting the STM tip just near the Ti surface, not only the tunneling current but also the Faraday current flow between them through the water which is in the atmosphere. Then the Ti surface was oxidized to form the TiO_x. By scanning the STM tip, fine TiO_x line was formed. When the bias polarity was inverted, no pattern was formed at all, which indicates that the pattern was formed electrochemically. Figure 2 shows the three oxidized Ti line on the Ti surface formed by STM using the sample bias V_t of 5V, the sample current I_t of 1nA, and the scanning speed of 0.01m /sec. The line width and the height are 80nm and 4nm, respectively. The dependence of the line size on the scanning speed of the STM tip is shown in Fig. 3. By increasing the scanning speed from 0.01μm/sec to 3μm/sec at V_t=5V, I_t=1nA, the line width and the line height decrease drastically from 45nm to 18nm, and from 3.5nm to 2.5nm, respectively. This result means that, by increasing the scanning speed of the STM tip, the Faraday current that flows between the tip and the Ti surface per unit length decreases. Therefore, the formed oxidized Ti line width and height decreases. The finest line obtained was 18nm wide and 3nm high.

The structure of the planar-type MIM diode fabricated using the STM oxidation method mentioned above is shown in Fig.4. The Ti layer, which is deposited on the 10nm insulating SiO_2 layer, is 4μm in length, 2μm

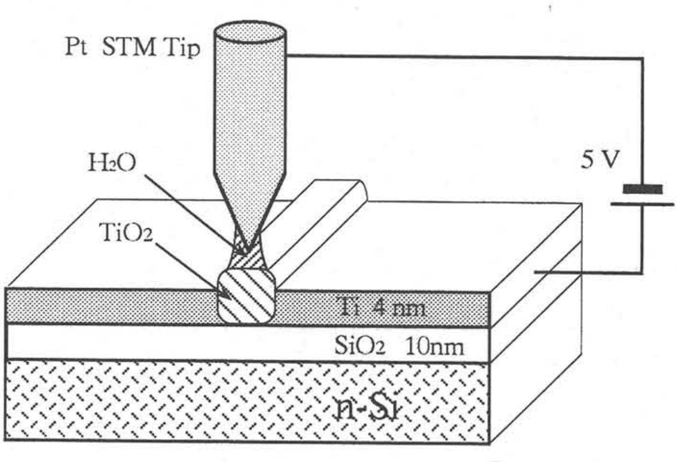

Fig.1, Principle of Ti oxidation process using STM tip as anodization electrode. Substrate is SiO_2/Si.

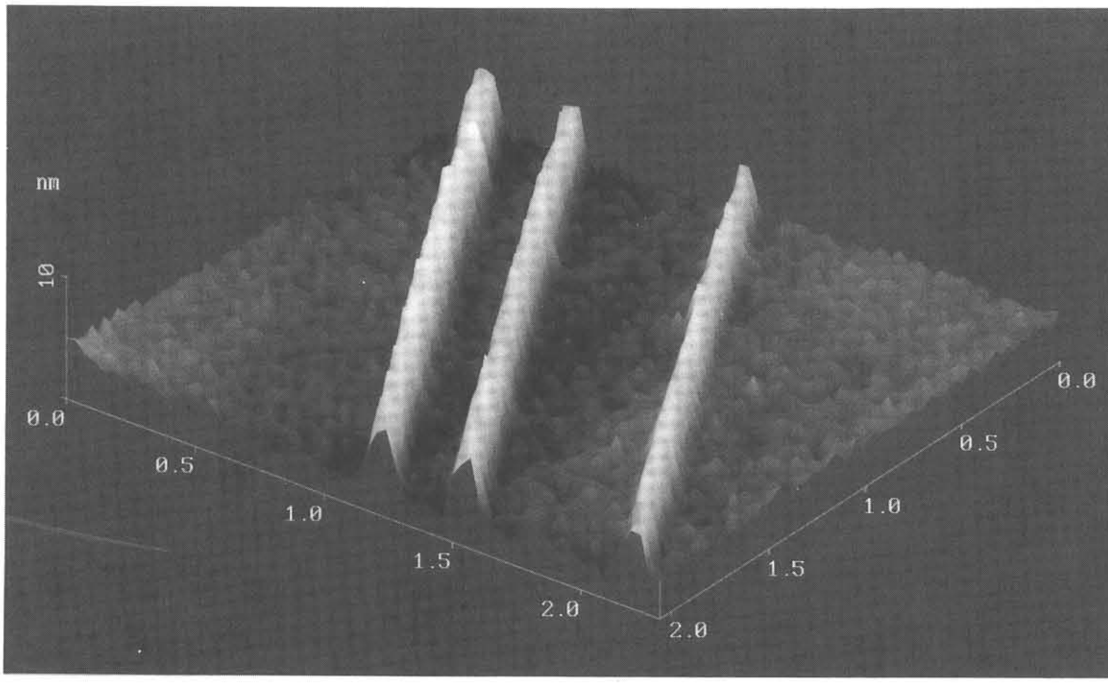

Fig.2, Three oxidized Ti lines formed by STM anodization method. Line width is 80 nm, line height is 4 nm. Scanning speed of 0.01μm/sec., sample bias V_t=5V, sample current I_t=1nA.

in width, 4nm in thickness. At the both ends of the Ti layer, the source and drain ohmic contacts made by Ti/Au were formed. In the center of the Ti layer, the oxidized Ti line of 80nm in width and 2 μm in length was formed by the STM oxidation method. Due to the thin Ti layer of 4nm, the oxidized Ti line reaches completely to the bottom of the Ti layer. The formed oxidized Ti line shows the high resistivity of ~10^3 ohm cm, which is seven orders of magnitude higher value than that of the deposited Ti layer.

Figure 5 shows the current-voltage characteristics and its conductance of the planar-type MIM diode at 77K. The current is completely suppressed at $|V| < 4V$ owing to the insulating oxidized Ti line which works as an energy barrier to the electron. At the higher bias of $|V| > 4V$, the current begins to flow through the oxidized Ti line by thermionic emission and/or tunneling, and shows the clear nonlinear characteristics.

Figure 6 shows the temperature dependence of the current of the planar-type MIM diode. The bias applied from V = 0.1V to 10V is used as a parameter. At the higher temperature region (1000/T = 3.5 ~ 6), the current shows the clear thermionic emission current. The energy barrier height of the oxidized Ti line obtained from the slope of the current is δE_g = 0.25 eV at V=1V. At the lower temperature region (1000/T = 6 ~ 9.5)

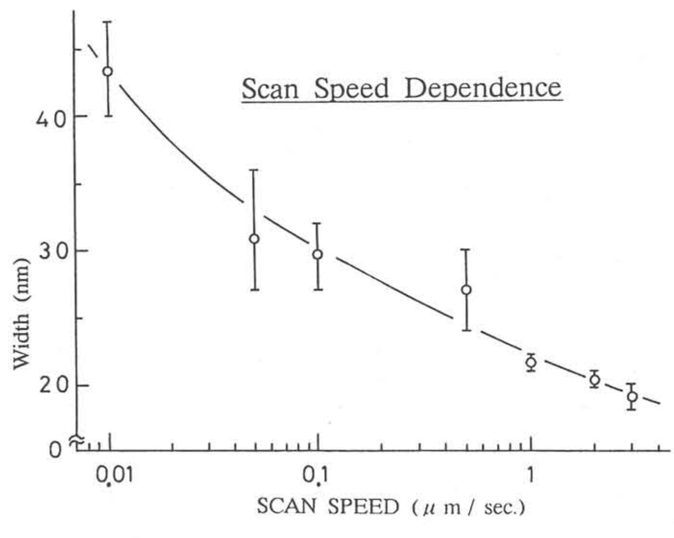

Fig.3, Dependence of oxidized Ti line width on scanning speed of STM tip. Sample bias V_t=5V. Sample current I_t=1nA.

and at the high applied bias of V = 4 ~ 10 V, the current shows the milder slope. This is because, owing to the high applied bias to the oxidized Ti barrier, the effective thickness of the tunneling barrier becomes thinner, and the contribution of the Fowler-Nordheim tunnel current that has no temperature dependence becomes increased.

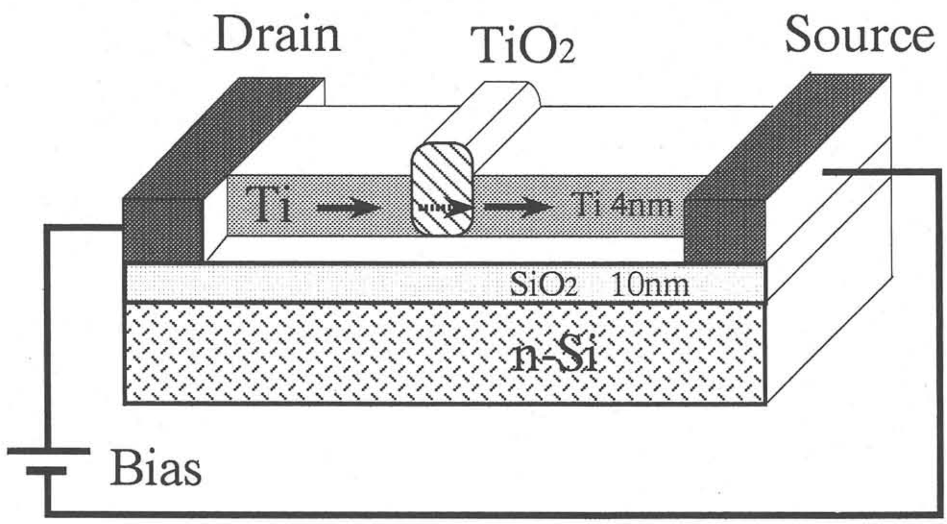

Fig.4, Structure of planar-type MIM diode. Ti layer is 4μm in length, 2μm in width, 4nm in thickness. Oxidized Ti line was formed in center of Ti layer by STM and is 80nm in width.

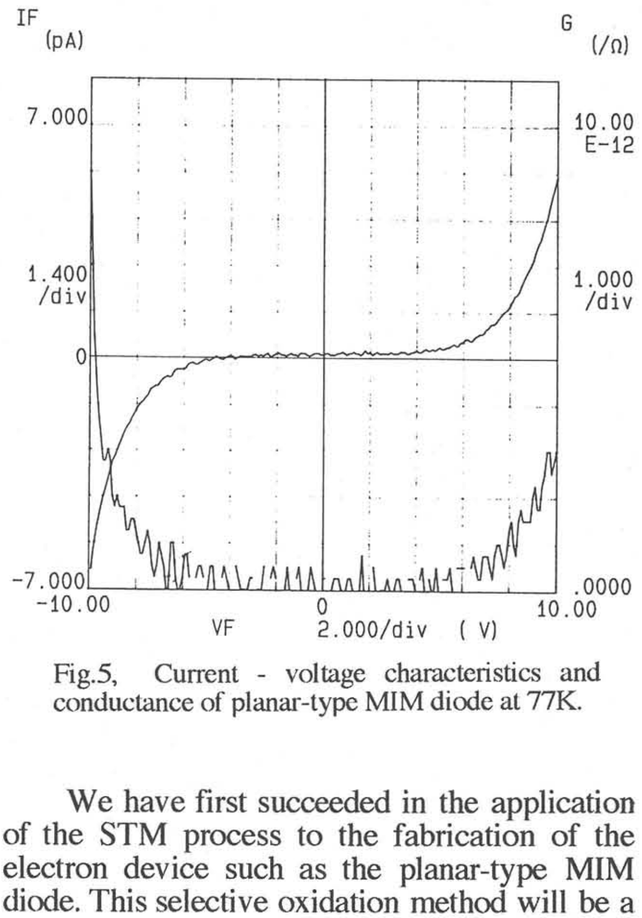

Fig.5, Current - voltage characteristics and conductance of planar-type MIM diode at 77K.

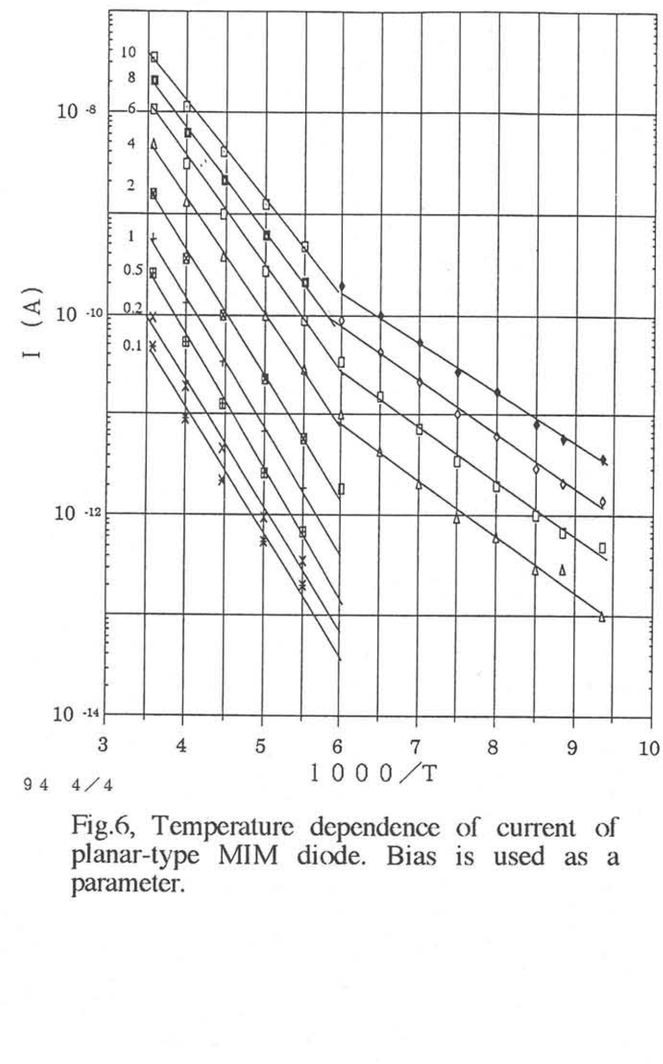

Fig.6, Temperature dependence of current of planar-type MIM diode. Bias is used as a parameter.

We have first succeeded in the application of the STM process to the fabrication of the electron device such as the planar-type MIM diode. This selective oxidation method will be a quite attractive method for the fabrication of future quantum effect electron devices.

References

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