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Control of Current in 2DEG Channel by Oxide Wire Formed with AFM

M. Ishii and K. Matsumoto
Electrotechnical Laboratory, MITI
Tsukuba 305 Japan

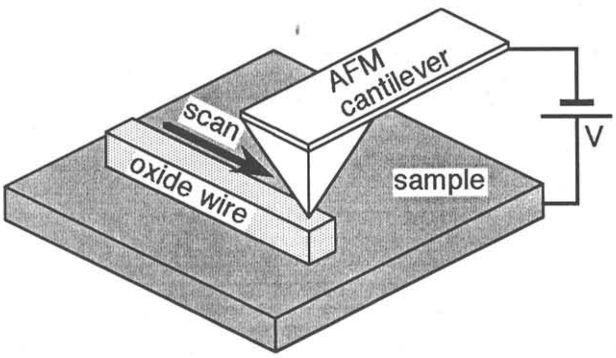
We have succeeded in depleting a two-dimensional electron gas (2DEG) channel by oxide wires formed with an atomic force microscope (AFM). Currents in the channel depended on the height of the oxide wire on a delta-doped HEMT structure. The current in the sample with the oxide wire of 25nm in height shows approximately one hundred times lower than that without wires.

1. Introduction

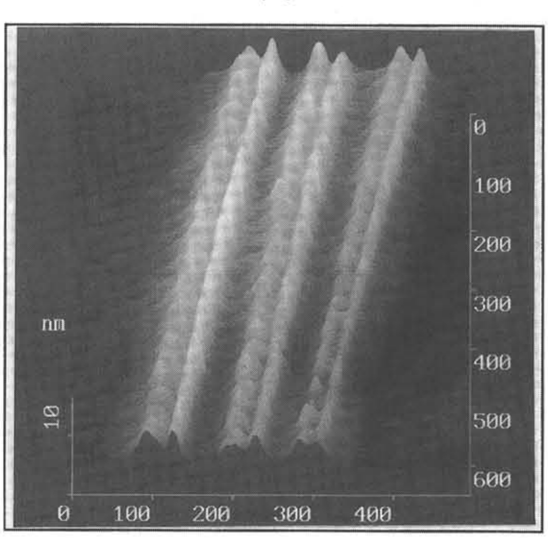
GaAs/AlGaAs quantum effect devices and single electron devices consist mainly of a two-dimensional electron gas (2DEG) channel and nano-scale depletion layers. Among many methods of fabricating those elements, we have selected the method similar to that reported by Ejiri *et al.*[1] who oxidized Si using an atomic force microscope (AFM), and that by Sugimura *et al.*[2] who oxidized Ti using a scanning tunneling microscope (STM). The oxidation of the surface of high-electron-mobility-transistor (HEMT) structures by further development of the AFM/STM technology bring us easy formation of the nano-scale depletion layers.

2. Experiments and discussion

Figure 1(a) shows the selective oxidation procedure using the AFM. The oxide wire was formed by moving the cantilever biased negatively to the sample. An AFM image of those three wires is shown in Fig.1(b). The sample is the delta-doped HEMT structure grown by an molecular-beam-epitaxial (MBE)



(a)



(b)

Fig.1 (a) Procedure and (b) AFM image of oxide wire on delta-doped HEMT structure method. That epitaxial layer consists of undoped AlGaAs (20nm in thick), delta-doped Si layer ($5 \times 10^{13} cm^{-2}$), undoped AlGaAs (4nm) and undoped GaAs (500nm) on a semi-insulating GaAs substrate. These wires were formed at the applied voltage (Vs) of 16V at the scanning speed of 100nm/sec. In spite of single scanning of the cantilever, a split wire was formed; the reason for this feature is still under consideration. The total width of a pair wire is 55nm, and that average height is 6nm.

We have fabricated the structure shown in Fig.2 in order to investigate whether those oxide wires really produce the depletion layer or not. The 2DEG channel region was fabricated by a chemical etching. The channel width and that length are 1μm and 7μm, respectively. Ohmic contacts, the source and the drain, were fabricated on both sides of channel. We have oxidized across the channel to control the currents from the source to the drain. If the depletion layers have been produced by those oxide wires, we will observe the current decrease.

Figure 3 shows an AFM image of that structure with three oxide wires formed at Vs=50V. Since we applied the higher voltage than the case Fig.1(b) in order to enhance the height of the oxide wire, the average height became 18nm, and the total width of a pair

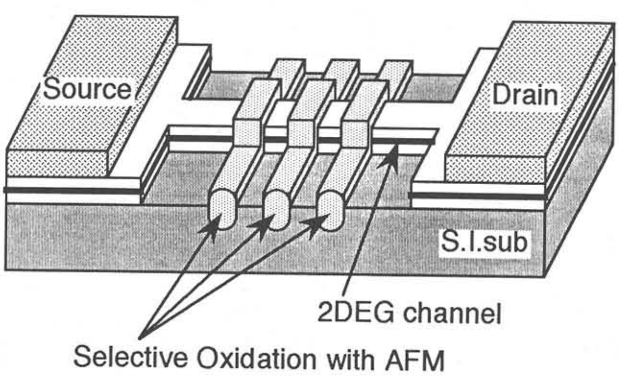


Fig.2 Fabricated structure to investigate whether oxide wires really produce depletion layer or not

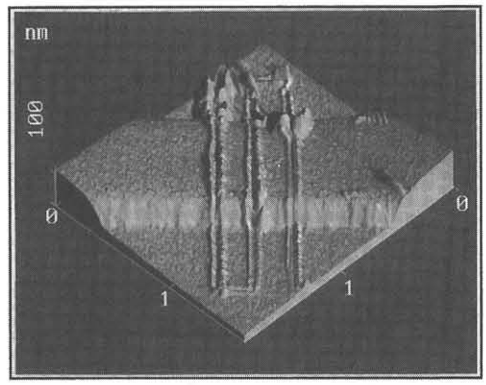


Fig.3 AFM image of oxide wire formed on 2DEG channel region

became 120nm as shown in Fig.3. That current-voltage characteristic was shown in Fig.4. The curve (a) is that before oxidizing; (b) is that for Fig.3; (c) is that for another sample with a pair wire of 25nm in height formed at Vs=70V. The decrease of current in the figure was evidently shows that the oxide wire produces the depletion layer in 2DEG channel. Moreover, Figure 4 shows that we can control the depth of those depletion layers by the wire height. In particular, the oxide wire of 25nm in height completely depletes the 2DEG channel; the current of that sample was decreased to 1μA,

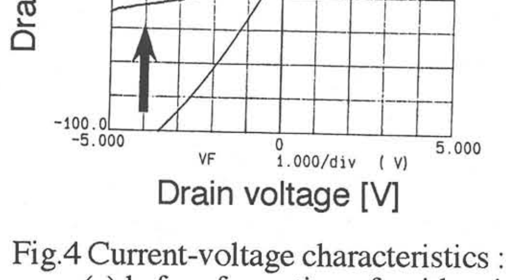


Fig.4 Current-voltage characteristics :
(a) before formation of oxide wire
(b) oxide wire of 18nm in height
(c) oxide wire of 25nm in height

which is approximately hundred times lower than that of the samples without wires.

3. Conclusion

Since we have succeeded oxidizing the delta-doped HEMT structure using the AFM, we can easily form the nano-scale depletion layers in the 2DEG channel. Those depths were controlled by the height depending on the applied voltage for the oxidation. Our experimental result will contribute to fabrication of GaAs/AlGaAs quantum effect devices and single electron devices.

Acknowledgments

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Reference

1) Y. Ejiri, M. Yasutake, and T. Hattori, Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, sponsored by The Japan Society of Applied Physics (Makuhari Messe, Chiba, 1993), pp. 606-608.

2) H. Sugimura, T. Uchida, N. Kitamura, and H. Matsuhara, Jpn. J. Appl. Phys. 32, L553 (1993); Appl. Phys. Lett. 63, 1288 (1993).