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Computer Simulation and Measurement of Capacitance Voltage Characteristics from Quantum Wire Devices of Trench-Oxide MOS Structure

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We have proposed Trench-Oxide MOS structure as a novel quantum wire devices. In this paper we present results of computer simulation based on a self-consistent system and calculated quantized electron distribution and capacitance-voltage characteristics. We have also fabricated quantum wire MOS structure by using electron beam lithography and electron cyclotron resonance reactive ion etching method and carried out measurements of C-V characteristics at 0.55K.

1. INTRODUCTION

Quantum effects due to nanostructured silicon are promising in the post ULSI era.[1,2] We have proposed Trench-Oxide MOS structure as a novel quantum wire devices and calculated quantized electron distribution and capacitance-voltage characteristics.[3] In this paper we present improved simulation based on self-consistent calculation. We have also fabricated quantum wire MOS structure by using e-beam lithography and ECR reactive ion etching method and carried out measurement of C-V characteristics at cryogenic temperatures.

2. COMPUTER SIMULATION

The simulated test structure was a trench-oxide structure, shown in Fig. 1, width 20nm and thickness 10nm. The thickness of field oxide was 50nm. The substrate was 10^{15}cm^{-3} B-doped (100)Si. The gate electrode was Al. The distribution of inversion electrons was obtained by the self-consistent calculation of the Poisson equation and the Schrodinger equation by using a supercomputer ETA^{10}. As shown in Fig. 2, the width of the ground state electrons was about

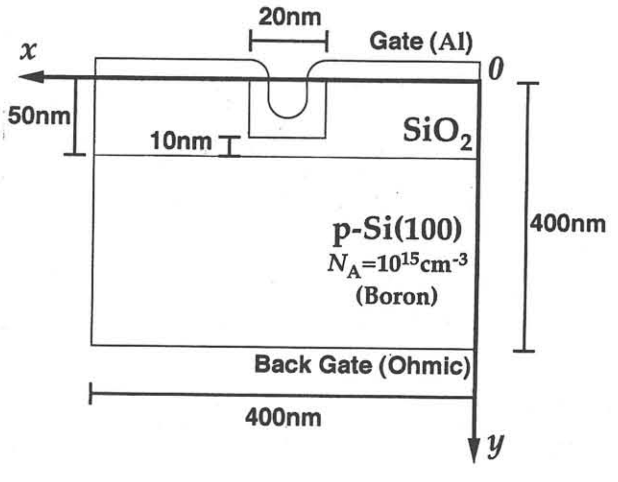

Fig. 1: Trench-oxide MOS structure tested by computer simulation.

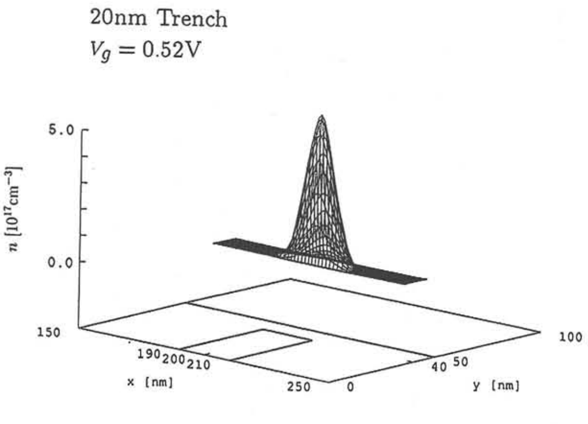

Fig. 2: Electron distribution of MOS quantum wire structure for a 20nm-wide trench.

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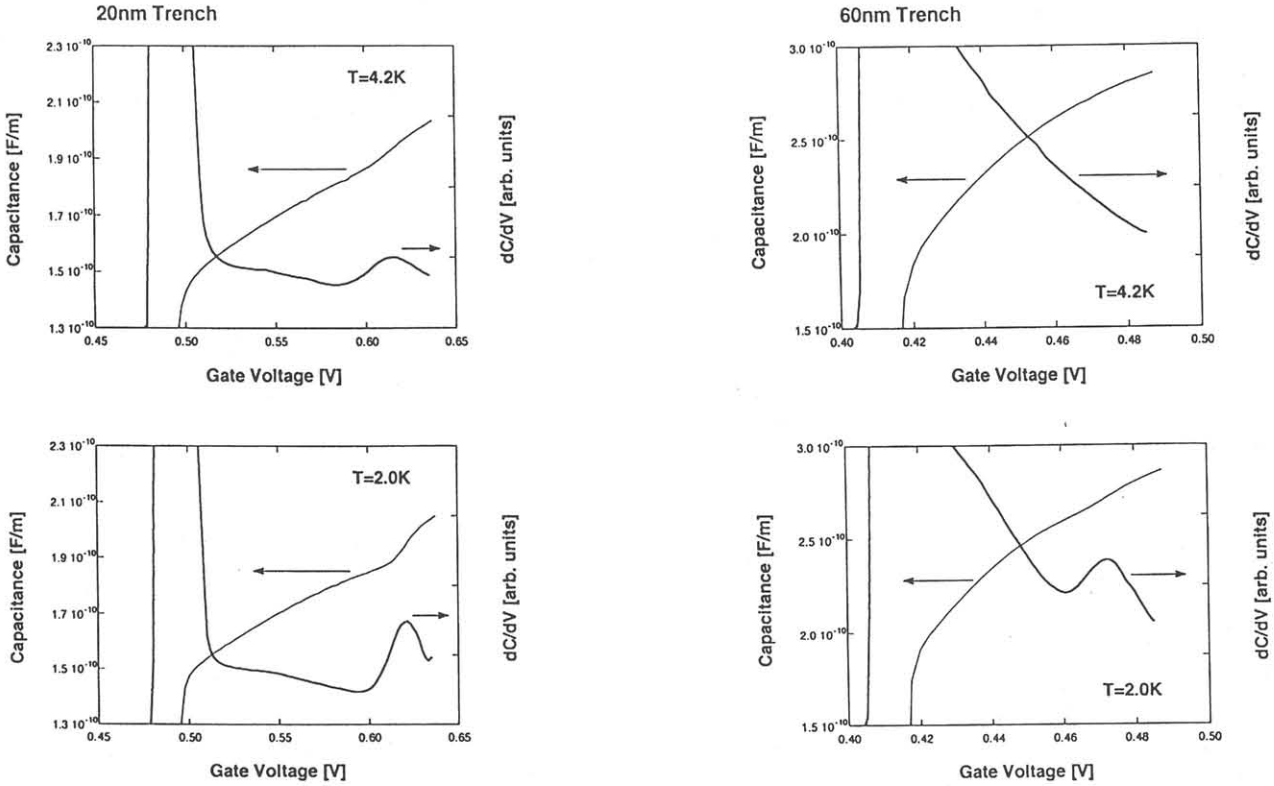

Fig. 3: Simulated capacitance-voltage characteristics and their derivatives for MOS structure of trench width 20nm and 60nm at 4.2K and 2.0K.

20nm, the same as the geometrical trench width.

The quantum state electrons can be evaluated by the capacitance-voltage characteristics.[4,5] Results of the simulation, shown in Fig. 3, reveal that structures are observed in the derivative of C-V characteristics when the trench width short enough at low temperatures.

3. FABRICATION PROCESS

Figure 4 shows the fabrication process of trench-oxide MOS structure. The spot size of 50KeV electron beam was 4nm. As an e-beam resist, we used ZEP-520, whose sensitivity to e-beam and resistivity to plasma were higher than PMMA. Anisotropic etching was carried out by using ECR plasma of CHF3 gas. The re-oxidation process determined the oxide thickness and annealed damages which might be caused by the plasma process. Minimum trench width of 16nm was observed by SEM.

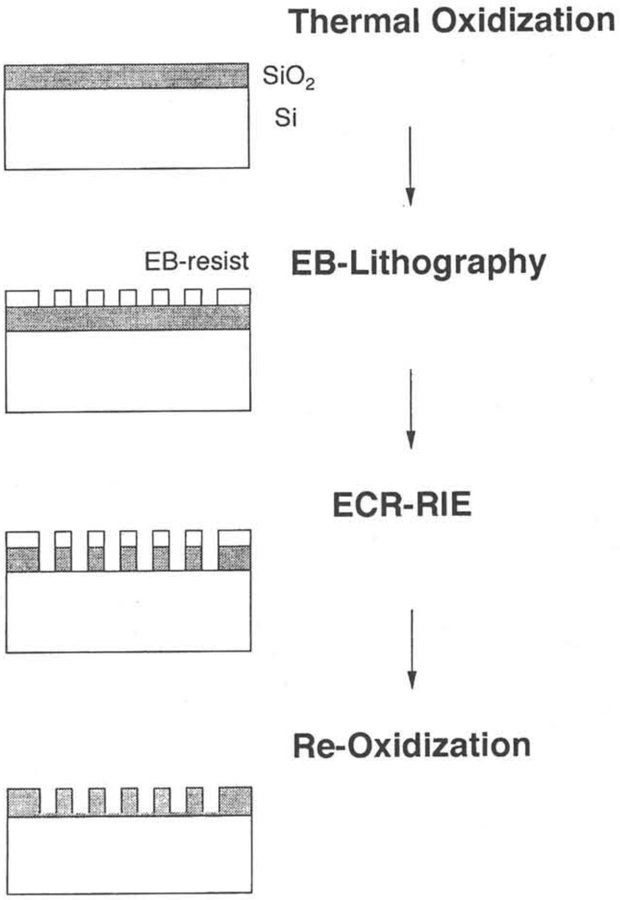

Fig. 4: Fabrication process of trench-oxide MOS structure.

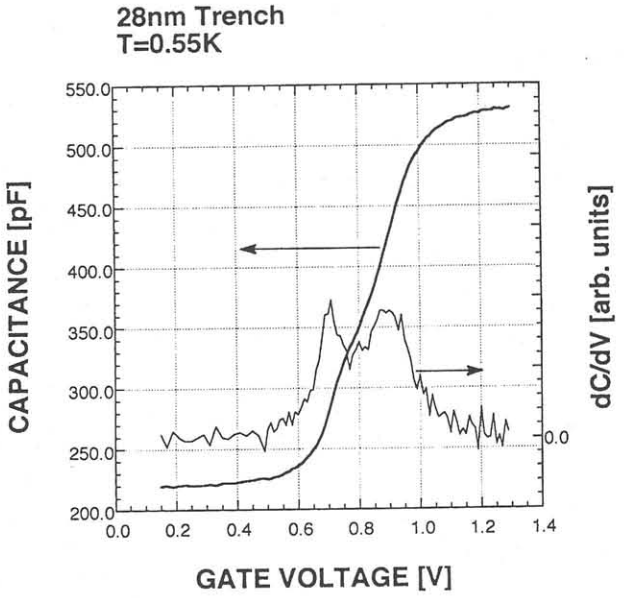

Fig. 5: A capacitance-voltage characteristic and its derivative from the array of 28nm-wide trench-oxide MOS structure measured at 0.55K, showing structure due to quantum size effect.

4. C-V MEASUREMENT

Measurements of C-V characteristics have been carried out using a 500Hz oscillator and a lock-in amplifier at temperatures lower than 4.2K using ^{3}He refrigerator. A problem of series resistance caused by the carrier freeze out was solved by employing planar MOSFET-like structure with heavily-doped contact region instead of ground contact from the substrate. Although C-V characteristics due to inversion electrons were obtained, the fine structure due to quantum effect was not observed from samples measured between 1.7 and 4.2K. Figure 5 shows a capacitance-voltage characteristic and its derivative from the array of 28nm-wide trench-oxide MOS structure measured at 0.55K. The number of lines was 1250 with 400nm apart. Two peaks were obtained in the derivative curve. Only the first peak, due to the threshold of the inversion electrons, was observed from a reference sample without trench structure. Therefore, the second peak in the trench-oxide MOS capacitor may be due to quantum size effect.

5. CONCLUSION

We have developed two-dimensional device simulator with self-consistent system for the estimation of performance of proposed trench-oxide MOS structure. The calculation has suggested that quantum effects can be evaluated by measuring C-V characteristics. Arrays of quantum wire structure with minimum width of 16nm were fabricated by using e-beam and ECR etching. A structure possibly due to quantum effect was observed in C-V characteristics of trench-oxide structure at 0.55K.

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