Mechanical property analysis and structural optimization for NEMS memory devices

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Introduction

Recent progress of silicon nanofabrication techniques has enabled not only to realize the MOSFETs with sizes of decananometer but also to explore a new field of silicon Nano Electro-Mechanical Systems (NEMS) research. Since the characteristic frequency of electromechanical systems, in principle, increases in inverse proportion to their sizes, the NEMS have a possibility of extremely high-speed operation [1]. We proposed a new non-volatile memory device concept based on mechanically-bistable operation of the floating gate in the cavity, combined with nanocrystalline Si (nc-Si) dots (Fig. 1) [2]. In this paper we analyze the switching power and speed of the floating gate by using the 3-D finite element simulation, in which the initial strain of the floating gate is taken into consideration for improving the accuracy.

Scaling law of the NEMS memory

We first analyzed the beam displacement when the static loading power was applied to the beam bent upward (see Fig.2). Figure 3 shows the resulting displacement as a function of applied force. Two stable points can be seen corresponding to the upward-bent and downward-bent states of the beam. In this curve, we define the switching power P_S as the power needed to change the beam from upward- to downward-bent and vice versa. In order to investigate the relationship between the floating gate dimensions and Ps, we calculated Ps with changing the length L, width W, thickness T and initial beam displacement Z_0 (seen Fig. 2). It was found that Ps is in proportion to L^{-4}, T and Z_0^3 and is not dependent on W. This means that Ps does not change when all the dimensions of the beam are scaled down proportionally as shown in Fig.4.

Reduction of switching voltage

Reduction of the switching voltage is one of key issues for realizing the NEMS memory. Apparently the switching voltage becomes lower if we make the initial displacement smaller. However, as the displacement of the floating gate is sensed via a change in the substrate surface potential, the change naturally decreases when the difference in beam displacement between the upward- and downward-bent states becomes small. We have to make the substrate surface in strong inversion at the ON state and that in depletion at the OFF state. As the initial displacement is smaller, the range of charge density, which enables both ON and OFF states becomes smaller and finally disappears (Fig.5). Possible ways to increase the range are to optimize the cavity height, the film thickness and the specific inductive capacity under the electrode. Figure 6 compares the operation range calculated for three alternative gate insulators with the original structure. For all the structures the cavity height and film thickness were optimized. The results show that we obtain a wider operation range by using a higher dielectric gate insulator. After all those structural optimization the switching voltage evaluated for those cases was found to be smaller than 20 V.

Switching speed

We finally analyzed the influences of the structural downsizing on the switching speed. In the dynamic simulation, we applied an instantaneous force to the beam, which is the minimum force to switch the initial beam state to another and monitored the transient motion of the beam. As no dumping mechanism was included in this simulation, the floating gate showed oscillations between bistable states (Fig.7). The oscillatory behavior differed depending on the initial beam displacement and showed a more sinusoidal nature as the initial displacement was smaller. The oscillation frequencies are shown as a function of the initial displacement in Fig.8. As the initial displacement is smaller, the oscillation frequency decreases. The results also show that the frequency increases in inverse proportion to the dimensions as far as the beam dimensions are reduced along the scaling law.

Summary

We demonstrated the scaling laws for the switching power and frequency of the NEMS memory in terms of the structural dimensions. We found that the switching power does not change while the switching frequency increases when we downsize the structure along with the scaling law. In addition, the switching voltage may be reduced by making the initial displacement smaller and optimizing the device structure except floating gate.

Acknowledgement

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References

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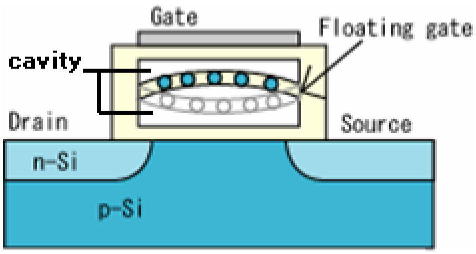

Fig.1: A schematic illustration of a NEMS memory device

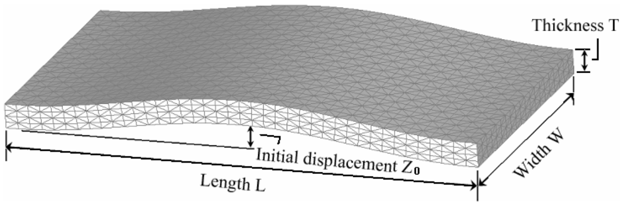

Fig.2: simulation model of SiO_2 floating gate

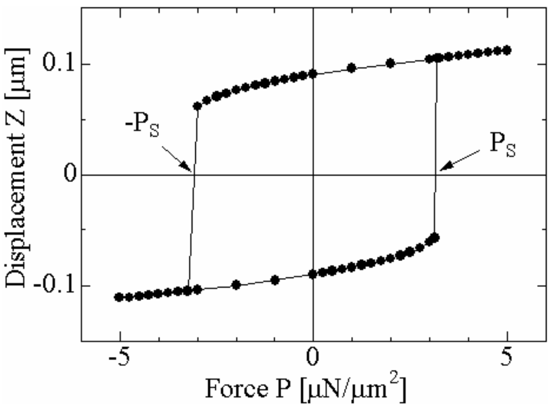

Fig.3: Displacement – force characteristic at L×W×T=2×1×0.1μm

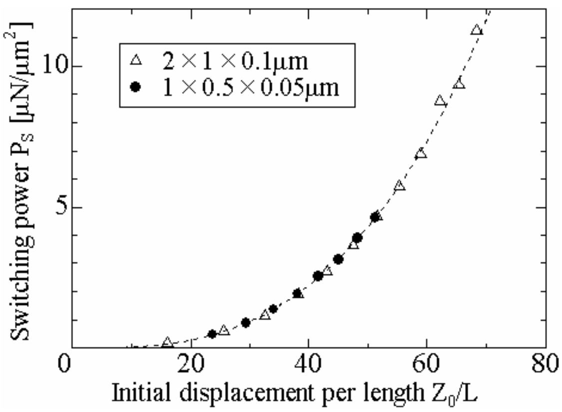

Fig.4: Scaling property

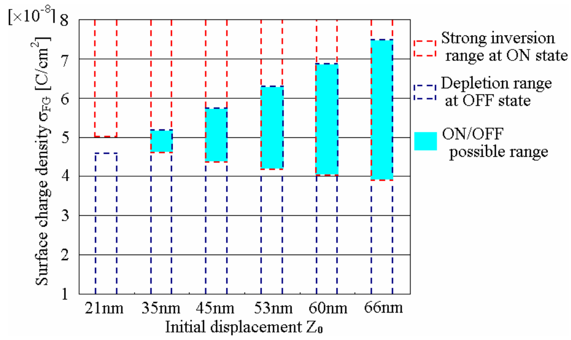

Fig.5: change of electric charge range which fills ON/OFF condition.

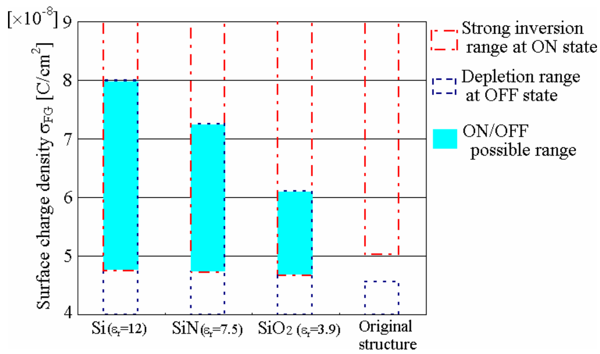

Fig.6: Improved electric charge range

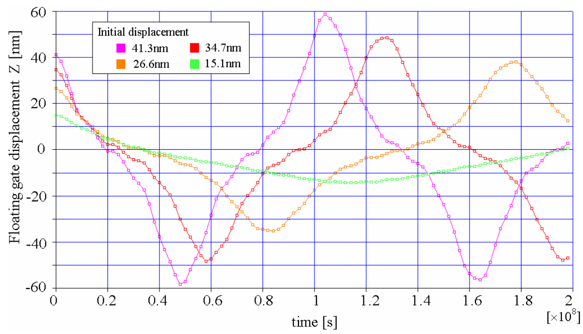

Fig.7: Time response of floating gate displacement

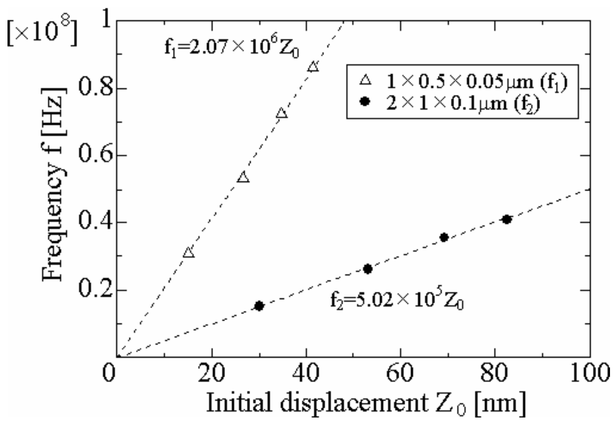

Fig.8: Relation between the frequency and initial displacement