IEEE Silicon Nanoelectronics Workshop,
Honolulu, June 2004

Nano Electromechanical Memory Device Using Nanocrystalline Si Dots

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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]. In this paper we propose a new non-volatile memory device concept based on bistable operation of the NEMS combined with nanocrystalline-Si (nc-Si) dots. Fundamental mechanical properties of a movable floating gate, which is a key building block of our NEMS memory, are studied theoretically and experimentally.

Device structure and fabrication

Our NEMS memory features a suspended floating gate beam in the cavity placed under the gate electrode, which contains the nc-Si dots as charge storage (see Fig. 1). The floating gate is bent naturally, either upward or downward, and its both ends are clamped at the cavity side walls. When the gate voltage is applied, the floating gate beam moves via electrostatic interactions between the gate electrode and the charge in the nc-Si dots. A positional displacement of the floating gate may be sensed with a change in the drain current of the MOSFET underneath. Mechanical bistablity of the beam is therefore essential for achieving our non-volatile NEMS memory, and a higher switching speed is expected with reducing their dimensions down to the nanometer regime. As the switching mechanism does not depend on any charge tunneling through the gate oxide, we may avoid the gate oxide degradation, which is one of the serious issues in the conventional flash memory.

For fabricating a prototype beam-in-cavity structure, we used an isotropic plasma dry etching using CF_4/O_2 chemistry, in which a Si/SiO_2 etching selectivity ratio of over 100 and 2 μm of undercut depth are possible. Details of the fabrication process are shown in Fig. 2. By etching a sacrifice layer of amorphous Si selectively, we obtain a double cavity structure divided by the suspended SiO_2 beam as shown in Figure 3.

Simulation of mechanical properties

Mechanical properties of the beam were analyzed by using a parallel three-dimensional (3D) finite element simulation [2]. A nc-Si beam structure, in which a two-dimensional array of nc-Si dots are embedded in a SiO_2 film (Fig. 4(a)), was compared with a simple poly-Si beam structure, in which a thin Si sheet are placed between SiO_2 layers (Fig. 4(b)). The Young's modulus and Poisson's ratio of 190 GPa and 0.27 for Si, and 70 GPa and 0.175 for SiO_2 were used for the present simulation. Calculated 3D images of the beam deformed under a constant homogeneous pressure parallel to Z-axis are shown in Fig. 5. Note that the maximum central displacement obtained for the nc-Si beam is larger than that for the poly-Si beam with the same pressure. This indicates that a larger displacement is achievable for the nc-Si beam structure under the same external electric filed and, therefore, the nc-Si beam has an advantage for low power operation.

Observation of beam bistability

In order to investigate the mechanical properties of beam structure experimentally, the nano-indentor type loading system [3] was used. For this experiment, a single layer SiO_2 beam structure was fabricated using a dry etching Si undercut technique (Fig. 6 (a)). The most of the fabricated samples showed convex-shaped beams as shown in Fig. 6(b), and this is considered as a result of release of mechanical stress stored in SiO_2 after removing a Si layer underneath. Figure 7 shows beam images before and after the beam was loaded with the tip of the nano-indentor around the center of the beam. A concave-shaped beam observed after the loading indicates that (1) a mechanically bistable SiO_2 beam can be formed by combining the conventional Si processes, and (2) the bistable states can be switched by applying an external force.

Summary

A new non-volatile NEMS memory device was proposed using the nc-Si dots embedded in a movable floating gate beam. Advantage of using the nc-Si dots array for the movable floating gate beam was shown for low power operation. The mechanical bistability of the fabricated SiO_2 beam was clearly observed.

Acknowledgement

This work has been supported by Core Research for Evolutional Science and Technology (CREST) program of the JST and Inter-Research Centers Cooperative Program (IRCP) of the JSPS.

References

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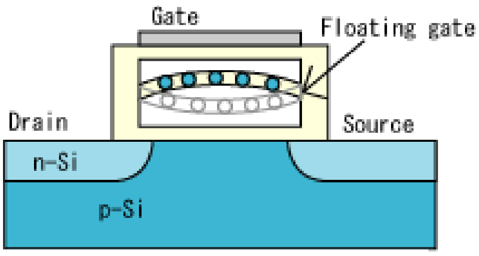

Fig.1: A schematic illustration of a NEMS memory device

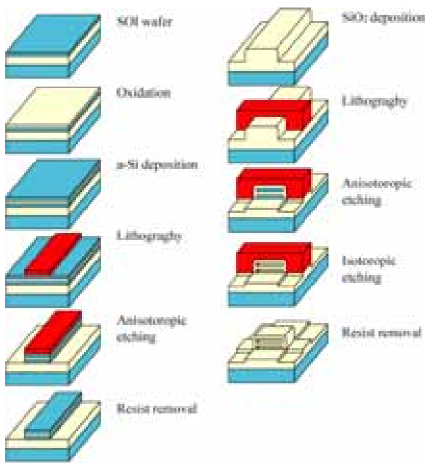

Fig. 2: A schematic diagram of prototype device fabrication process.

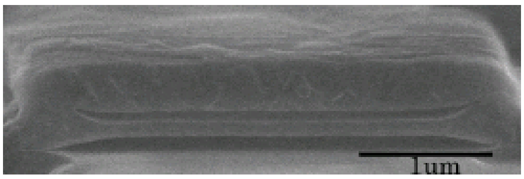

Fig. 3: SEM image of a double cavity structure divided by the suspended SiO_2 beam.

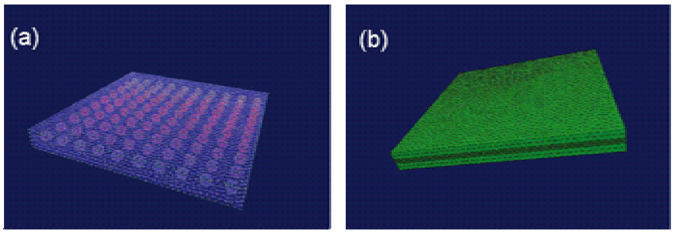

Fig. 4: (a) A nc-Si beam structure, in which a two-dimensional array of nc-Si dots are embedded in a SiO_2 film and (b) A poly-Si beam structure, in which a thin Si sheet are placed between SiO_2 layers;

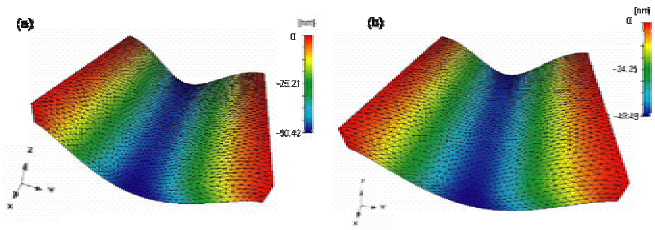

Fig.5: Calculated 3D images of the beam deformed under a constant homogeneous pressure parallel to Z-axis; (a) a nc-Si beam and (b) a poly-Si beam

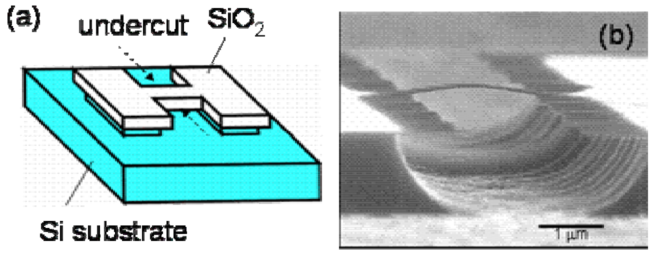

Fig.6: (a) A schematic illustration of a single layer SiO_2 beam structure; (b) SEM image of a convex-shaped beam after etching a Si layer underneath.

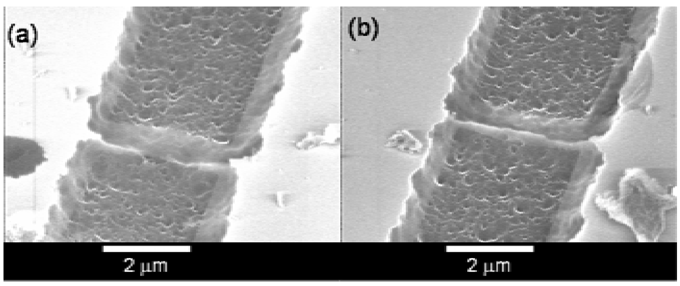

Fig. 7: SEM images of beams before ((a)) and after ((b)) the beam was loaded with the tip of the nano-indentor around the center of the beam. Switching from convex to concave was observed.