Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 696-697

P14-3

Vertically Buckled Bridges for Three-Dimensional SOI-MEMS

M. Sasaki[1], D. Briand[2], W. Noell[2] and N. de Rooij[2]

[1]Dept.of Machine Intelligence & Systems Eng., Tohoku University, Aramaki01 Aoba-ku, Sendai, 980-8579, Japan
Tel: +81-22-217-6965 Fax: +81-22-217-6963 E-mail: sasaki@hane.mech.tohoku.ac.jp
[2]Institute of microtechnology, University of Neuchatel, Switzerland

1. Introduction

SOI-MEMS is now well-recognized technique [1]. Microactuators generating the lateral movement can be included. On the other hand, some applications require the vertical movement that is relatively difficult to realize. In the field of the surface micromachining, the structural variation increases with the number of poly-Si structural layers [2]. According to the analogy to the surface micromachining, increasing the possible position of the device Si layer is attractive. In this study, by introducing the vertically buckled Si bridges, Si structures are lifted up and the new device layer position is created.

2. Principle

Figure 1 is the schematic drawing for explaining the principle. SOI wafer is thermally oxidized and patterned opening holes for the subsequent Si etching and sacrificial layer etching. The remained SiO_2 film is covered with thin poly-Si film. The following processes are same as those of the normal SOI-MEMS maintaining the process simplicity. When the bridge, which consists of Si and SiO_2 layers, is released, its center moves up due to the buckling generated by the compress stress in the SiO_2 film. Suspension bars are connected at ends of the buckling beam for allowing the minute rotation and the lateral displacement. When another Si structure (dashed rectangle in Fig. 1) is connected to the center of the buckling beam, it will be lifted up to its new position.

3. Results

Figure 2 shows one demonstrated structure, which has two buckled bridges for lifting the center part (a rotational mirror with holes) generating the vertical comb drive at sides. The center mirror is parallel to the substrate. Si and SiO_2 thickness is 14 and 2μm, respectively. In this design, the buckling beam length is 1500μm. The obtained vertical displacement is 27.0μm. Figure 3 is the magnified view at around the comb. The in-plane position between upper and lower combs is maintained. The lateral shift is less than 0.15μm, which is almost measurement error.

Figure 4 shows the vertical displacement as a function of the buckling beam length. The solid line is the theoretical estimation using a simple composite beam model of Si and SiO_2 layers. The used value of the compress stress is 0.285 GPa, supposing the average of the reported value of 0.27-0.3 GPa [3]. The circles and dots are obtained from buckled bridges suspended by I- and T-shaped bars as shown in Fig. 5, respectively. The vertical displacement reaches 52μm when the buckling beam length is 2100μm. The vertical displacement can be well-controlled by the design of the lateral dimension. The gray data in Fig. 4 show the difference between the experimental value and the theoretical estimation. Comparing I- and T-shaped suspension bars (width: 5μm, length: 145μm), T-shaped suspension bars give a little larger displacement. The experimental value especially for the longer buckling beam has a significant divergence. The thickness of the device Si layer of the used SOI wafer is 15 ± 0.5μm. This variation is the reason of the divergence. The sticking is not observed even for the 2100μm-long bridges. Bumps can be prepared as shown in Fig. 5.

Figure 6 shows the cross-section of buckled bridges having a simple thin structure as shown in the inset picture. Beam profiles have the almost same radius of curvature overlapping each other. Note that the 2100μm-long beam shows the relatively larger radius of curvature. This can be attributed to the stiffness of the suspension bar against the large buckling height.

Figures 7(a) and 7(b) are images when the driving voltages of 0 and 55V are applied to the vertical comb, respectively. The initial vertical displacement is 17.5μm. The typical rotation angle of the mirror is 3 degrees when 55 V is applied at one side of the vertical comb drive actuator. The resonant frequencies of the mirror and the buckled bridge are 6.9 and 20 kHz, respectively.

4. Conclusions

A method for realizing three-dimensional SOI-MEMS structures is developed using vertically buckled bridges as the structural elements. The buckling is obtained by the compress stress of the thermally grown SiO_2 film. The vertical displacement up to 50μm is confirmed. Using this technique, a vertical comb actuator is demonstrated.

References

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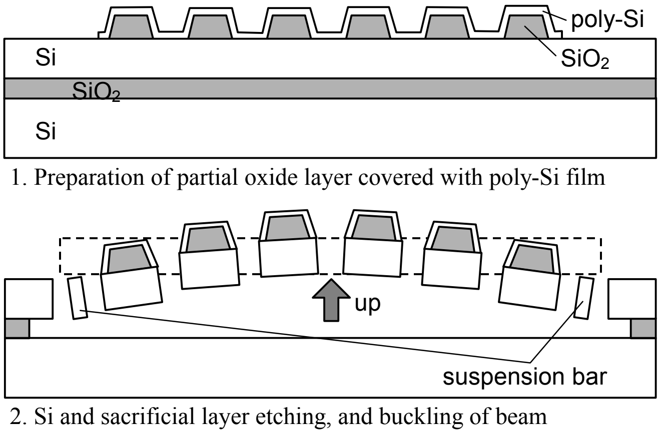

Fig. 1 Schematic drawing for explaining the principle.

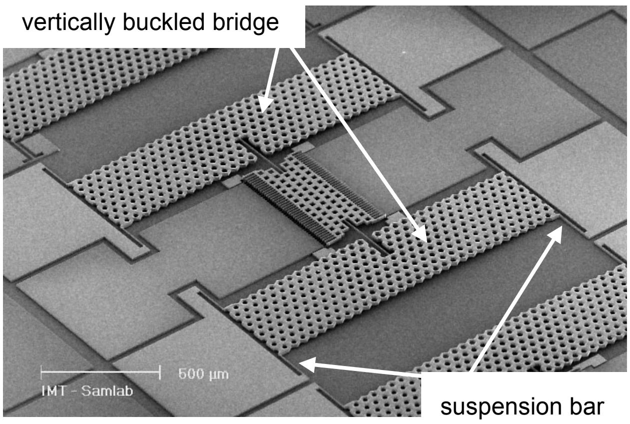

Fig. 2 One demonstrated structure.

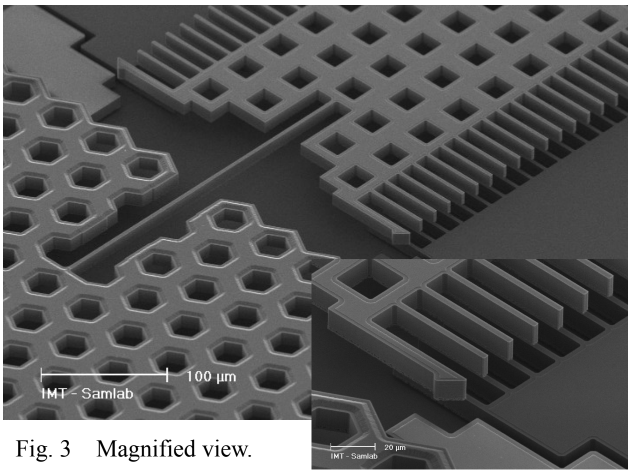

Fig. 3 Magnified view.

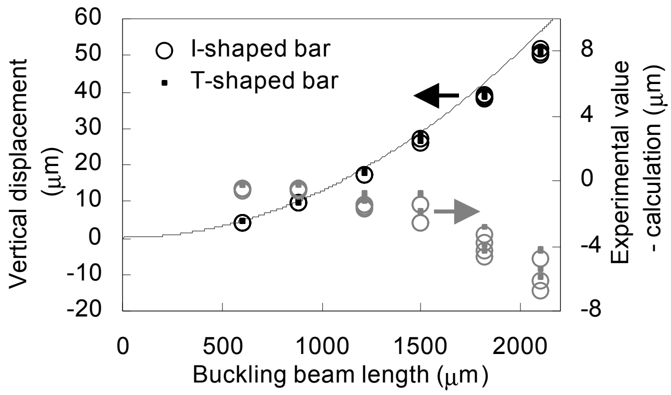

Fig. 4 Vertical displacement as a function of buckling beam length.

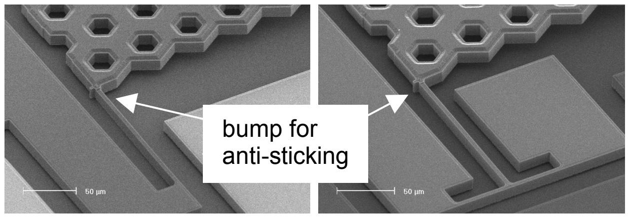

Fig. 5 I- and T-shaped suspension bars.

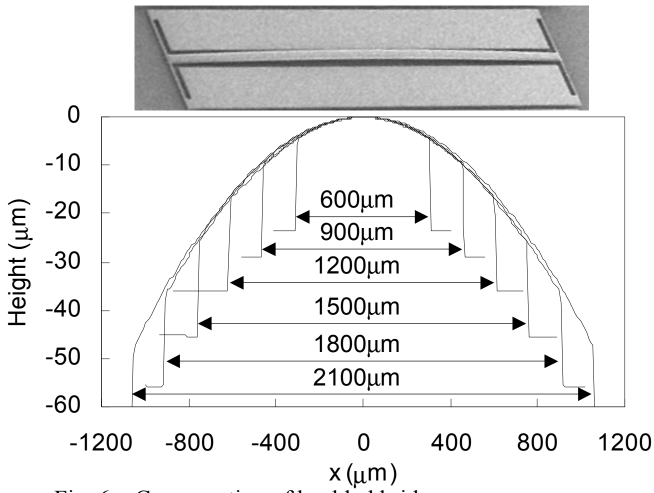

Fig. 6 Cross-section of buckled bridges.

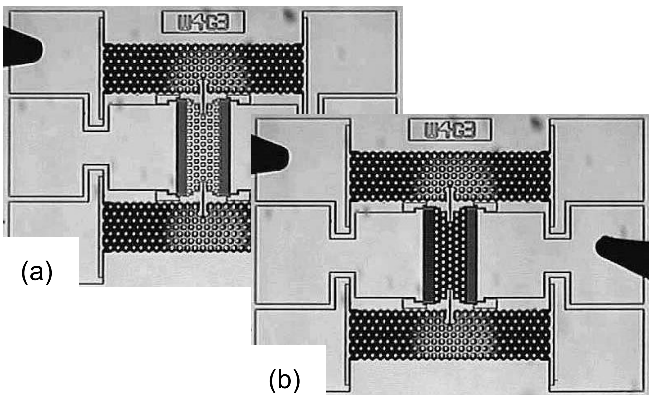

Fig. 7 Mirror rotation by applying the driving voltage of (a) 0 and (b) 55V.