J-5-04

Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp429-430

Development of Electret made of SiO_2 Thin Film with Micro Bump Array to Avoid Electrostatic Stiction and Enhance Its Surface Potential

Masato Suzuki[1], Yuki Onishi[2], Tomokazu Takahashi and Seiji Aoyagi[1]

[1] Kansai Univ.
3-3-35, Yamate-cho, Suita,
Osaka 564-8680, Japan
Phone: +81-6-6368-1115 E-mail: m.suzuki@kansai-u.ac.jp

Abstract

An electret made of SiO_2 thin film with micro scale bump array was developed to enhance power efficiency of vibration energy harvester. The bump array on SiO_2 surface was formed by lithography and etching process. The diameter of each bump is approximately 0.5 µm, 1 µm, and 2 µm. It was found that the smaller bump not only enhances surface potential, but also reduces sticking force between electret and movable electrode.

1. Introduction

Recently, vibrating energy harvesters (VEHs) which generate electrical power from environmental vibration have attracted considerable attention as one of the power supplies stable for wireless sensor networks [1] - [3].

We previously developed a VEH using electret, as shown in Fig. 1 [4], [5]. Electret is dielectric material in which electric charges are stored semi-permanently. Our developed This VEH is comprised of a fixed electrode with an electret and a movable electrode with insulating plate for prevention of electric discharge. Electrical power is generated when air gap distance between the electret and the insulating plate is changed by applying external acceleration.

Theoretical output of the VEH is proportional to square of surface potential of the electret. However, the insulating plate are stuck to the electret by Electrostatic attraction when the surface potential is exceeded a certain amount. This problem is generally called "stiction."

To overcome these problems, we tried to develop a novel electret using SiO_2 thin film, on which there is micro bump allay. In this paper, fabrication method and characteristics of the developed electret are described.

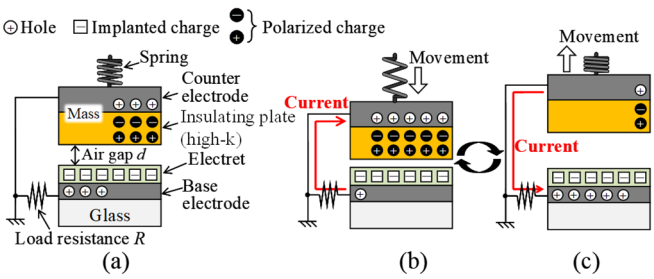

Fig. 1 (a) Schematic of developed VEH in previous study. (b) When the movable (upper) electrode approaches to the electret on the electret on the fixed (lower) electrode, electric current flows from the fixed electrode to the movable electrode. (c) When the movable electrode moves away from the electret, the current flows in the opposite direction.

2. Fabrication of SiO_2 electret with micro bump array

Fabricating method of the electret with micro bump is described as follows. At first, a silicon substrate was thermally oxidized to fabricate SiO_2 film (t1.6 µm). Then, an array of etching mask pattern for fabricating micro scale bump was formed by photolithography, followed by reactive ion (RIE) etching. The etching depth is approximately 0.6 µm. Total area of the bump array is approximately 225 mm^2 (15 mm × 15 mm). Finally, electrons were injected into a SiO_2 film with bump array by corona discharge method to functionalize the film as an electret. The setup for corona discharge is illustrated in Fig. 2.

In this study, four type of electret were fabricated. Three electrets have micro bump array on their own surface; and the remaining one is a control electret without bumps array. The side length of bumps on each electret are approximately 0.5 µm, 1 µm and 2 µm, respectively. Photographs of the SiO_2 electret with bump array taken by scanning electron microscopy (SEM) are shown in Fig. 3.

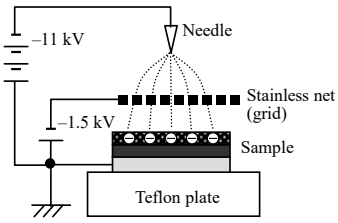

Fig. 2 Schematic of setup for corona discharge for implanting electron into the SiO_2 film.

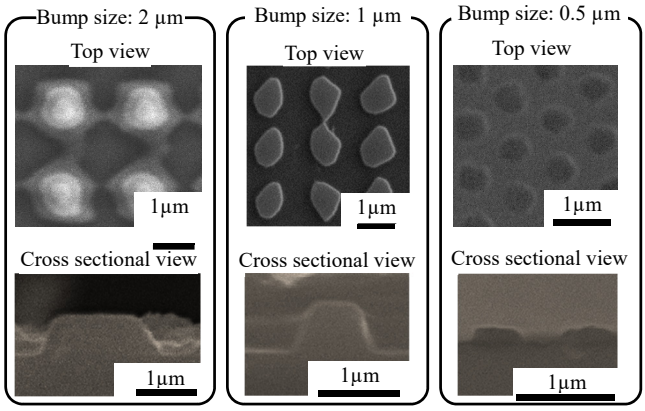

Fig. 3 SEM images of electret with micro bump array.

3. Measurement result of electrets and discussion

Surface potentials of electrets and those stabilities

The surface potential of fabricated electret was measured by a surface electrometer. Initial surface potential of the electrets and those time degradations are shown in Fig. 4. These results indicate that both initial value and its stability of the electret made of SiO_2 with bump array are better than that control electret made of plane SiO_2. It was also found that the smaller bump enhances these advantage.

Stiction force

The setup for measuring stiction force between the insulating plate under movable upper electrode and the electret on lower electrode is shown in Fig. 5. In this setup, the lower electrode was fixed to an electronic balance. In initial state, upper electrode with high-k plate was contacts to the lower electrode with electret. Then, the upper electrode lifting off from the lower electrode. The force applied to the electric balance at the moment when the two electrode were separated was measured as the stiction force of the electret. This measurement was repeated 50 times for each sample.

The measurement results are shown in Fig. 6. This graph shows that the stiction force of electret with bump array is smaller than that of control electret.

Discussion

From the results obtained in these investigations, we propose a model of SiO_2 electret with micro bump array, which is shown in Fig. 7. In this model, implanted charges are mainly trapped near electret surface. It is assumed that the amount of injected electrons into the electret with bump array is larger than that of control electret because volume of electret with bump array is larger than that of control electret. On the other hand, most electrons are trapped in the electret except the bumps. Thanks to the bump array, there is an air gap between most electrons trapped in the electret and upper electrode even when the two electrodes are touching each other. Therefore, it is presumed that the stiction force of electret with bump array smaller than that of electret without bump.

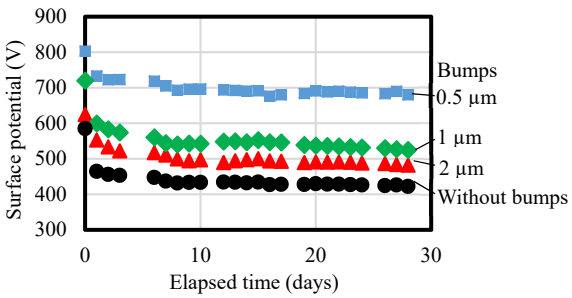

Fig. 4 Time degradation of surface potential of electret with micro bump array and control electret.

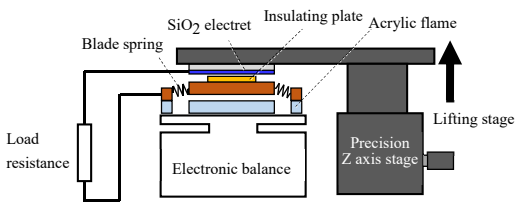

Fig. 5 Schematic of setup for stiction force measurement.

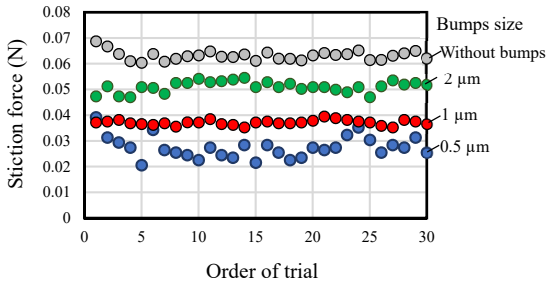

Fig. 6 Measured stiction force of each electret with bump array and control electret.

Table I Initial surface potential and averaged stiction force of each electret with bump array and control electret.

Bumps scale	Without bumps	2 µm	1 µm	0.5 µm
Initial surface potential (V)	431	499	540	770
Averaged stiction force (N)	0.037	0.051	0.027	0.063

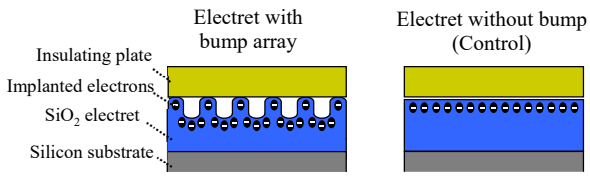

Fig. 7 Proposed mode of electret with bump array (left figure) and electret without bumps (right figure).

4. Conclusions

An electret made of SiO_2 thin film with micro scale bump array was develop for improving characteristics of VEH. The bump array on SiO_2 surface was formed by RIE etching. The size of the bumps on each electret are approximately 0.5 µm, 1 µm, and 2 µm. The surface potential and its stability of electret with bump array is larger than that of control electret. Additionally, stiction force of the electret with bump array is smaller than that of control one. Fabrication and characterization of harvesting device using electret with micro bump array is aim for the future work.

Acknowledgements

This work was supported in part by a grant of "Strategic Research Foundation Grant-aided Project for Private Universities": Matching Fund Subsidy of MEXT (Ministry of Education, Culture, Sport, Science, and Technology, Japan), 2015-2019. This work was supported in part by JSPS (Japan Society for the Promotion of Science) KAKENHI (26870728).

References

[1] S. P. Beeby, *et al.*, *Meas. Sci. Technol. 2011*, 17, pp.175-195

[2] K. Matsumoto, *et al.*, *Digest Tech. Power MEMS 2011*, pp.134-137

[3] T. Tsutsumino, *et al.*, *Digest Tech. IEEE MEMS 2006*, pp.98-101

[4] T. Takahashi, *et al.*, *Digest Tech. IEEE MEMS 2012*, pp.1265-1268

[5] T. Takahashi, *et al.*, *Digest Tech. IEEE MEMS 2013*, pp.877-880