Fabrication and Characterization of Nano/Micro Textured Electret to Avoid Electrostatic Stiction and Enhance Its Surface Potential

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Abstract. An SiO₂ electret with nano/micro scaled texture was developed to enhance generation power of our previously developed electrostatic vibration energy harvester. The texture on SiO₂ was formed by lithography and wet etching process. The width/pitch of the each texture is 0.2 µm /0.6 µm or 1.0 µm /2.0 µm, respectively. Both initial value and stability of surface potential of textured electret was better than that of control sample. It was also found that the smaller texture enhance these properties. On the other hand, the stiction force using textured electret was smaller than that using control electret.

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 [1-5]. Since frequency of environmental vibration is usually on the order of a few to several tens of hertz, electrical power generated by electrostatic VEH using an electret are generally higher than that generated by an electromagnetic VEH using a magnet [3]. Electret is dielectric material in which electric charges are stored semi-permanently.

We previously developed a VEH, as shown in Fig. 1 [4, 5]. This VHE consists of a fixed electret on bade electrode and an insulating plate which is suspended by vertically vibrated spring acts as a counter electrode. In this device, distance of air gap between the electret and the insulating plate is periodically changed according to vibration of the spring; and the output becomes maximum level when the insulating plate is closest to the electret. Surface potential of electret is most important characteristic for the VEH because the output power is theoretically proportional to square of it. However, the insulating plate are stuck to the electret by electrostatic force when the surface potential was exceeds a certain amount. This problem is generally called “stiction.” To overcome these problems, we tried to develop a novel electret via addition of nano/micro scald texture on its surface, which has both high-surface potential and low stiction force. In this paper, we present the fabrication method and characteristics of the developed electret. The output power of the VEH using developed electret is also shown.
Figure 1. (a) Schematic of developed VEH in which the counter (upper) electrode and insulating plate approach to the electret, the insulating plate was polarized by electric potential difference from the electret, and it attracts electric charge. (c) When the counter electrode and insulating plate move away from the electret, electric charge is attracted to the base (lower) electrode. The movement of the electric charge is changed to electric energy by the load resistance.

2. Fabrication of nano/micro textured electret

Process flow for fabricating nano/micro textured electret is shown in Fig. 2. At first, a low resistive silicon substrate (p-type, (100) orientation, resistivity < 0.01 Ω·cm, 500 µm in thickness) was thermally oxidized in vapour of deionized water at 1,000°C to fabricate SiO₂ film. SiO₂ is one of most famous electret material. In this study, two-types of SiO₂ film with different thickness were fabricated, one of which is 0.8 µm and the other of which is 1.6 µm. Then, arrays of square shaped electron beam (EB) resist were formed on the surface of SiO₂ (0.8 µm in thickness) by EB lithography, of which the width and pitch are 0.2 µm and 0.6 µm, respectively. As the same time, arrays of square shaped electron photoresist were formed on the surface of SiO₂ (1.6 µm in thickness) by photolithography, of which the width and pitch are 1.0 µm and 2.0 µm, respectively. Schematic of fabricated SiO₂ electret with nano/micro scaled texture. Since drawing speed of the EB lithography is much slower than that of photolithography, EB lithography was used only to form the nano scaled texture. Next, the SiO₂ films were etched using hydrofluoric acid diluted by DI water at 10%. The etching depth of SiO₂ is equal to the width of EB/photoresist. Next, EB/photoresist was removed, followed by wiring to the silicon substrate. Total area of the nano/micro texture is 225 mm² (15 mm × 15 mm), as shown in Fig. 3. Finally, electrons were implanted to the textured SiO₂ by corona discharge method to form electret. The setup for corona discharge is illustrated in Fig. 3. SEM images of textured SiO₂ are shown in Fig. 4. Control samples (non-textured SiO₂ electret, 0.8 µm in thickness) were also fabricated.

Figure 2. Fabrication flow of the nano/micro textured electret. (a) Cleaning of a low conductive silicon substrate. (b) Thermal oxidation of the silicon substrate to form SiO₂ film. (c) EB lithography or photolithography to form nano/micro scaled arrays. (d) SiO₂ etching by diluted HF acid, in which the arrays made of EB/photoresist was used as etching mask. (e) Removal of EB/photoresist. (f) Wiring to the silicon substrate using conductive resin.
3. Measurement result and discussion

3.1. Surface potentials and those stability

The surface potential of fabricated electret was measured by a surface electrometer. Initial surface potential of the electrets and those time degradation are shown in Fig. 6. These results indicate that both initial value and its stability of the textured electrets are better than those of control sample. It was also found that the smaller texture enhance these advantage.

3.2. Stiction force

The setup for measuring stiction force between the high-\(k\) insulating plate under counter electrode and electret on base electrode is shown in Fig. 7. In this setup, the electret is fixed to an electronic balance. First, \(\text{SiO}_2\) electret was contacted with high-\(k\) plate with counter electrode. Then the electret was lifted off. The electrostatic attractive force of the moment, in which the two parts leaved, was measured. This measurement was repeated 50 times for each sample. The measurement results are shown in Fig. 8. This graph shows that the stiction force between textured electret and the insulator is smaller than that between control electret and the insulator. Additionally, it was found that the surface potential of textured electret was hardly decreased by the measurement of stiction force (it means 50 times repetition of contact and release), as shown in Table 1.

3.1. Discussion

From the results obtained in these investigations, we propose a model of nano/micro textured electret shown in Fig. 9. In this model, implanted charges are mainly trapped near electret surface. Since surface area of the textured electret is larger than that of non-textured electret, the amount of electrical charge kept in the textured electret is larger than that kept in the non-textured electret.

![Figure 3. Schematic of fabricated SiO\(_2\) electret with nano/micro scaled texture.](image)

![Figure 4. Schematic of setup for corona discharge to implant electron to the nano/micro textured SiO\(_2\) film.](image)

![Figure 5. SEM images of surface of textured electrets, fabricated using (a) EB lithography or (b) photolithography.](image)

![Figure 6. Time degradation of surface potential of textured and control (non-textured) electrets made of SiO\(_2\).](image)
Figure 7. Schematic of setup for stiction force measurement.

Figure 8. Measured stiction force between electret and insulating plate with counter electrode.

Table 1. Summary of the measured stiction force between electret and insulating plate with counter electrode, and surface potential before and after testing.

|                      | Textured electret | Control electret |
|----------------------|-------------------|------------------|
| Side length / Pitch  | 2.0 µm / 1.0 µm   | NA               |
| Stiction force       | 22 mN             | 40 mN            |
| Surface potential before testing | -500 V | -330 V |
| Surface potential after testing | -420 V | -240 V |

Figure 9. Proposed mode of (a) textured electret which has both high surface potential and low stiction force, and (b) non-textured electret.

Next, we also consider stiction force of the textured electret using the proposed model. The textured electret contacts with the insulating plate with counter electrode only at its top, as shown in Fig. 9(a). Therefore, the stiction force becomes relatively smaller because the electric attraction is inversely proportional to square of distance between two objects. On the other hand, whole surface of control electret contacts with the counter electrode, as shown in Fig. 9(b). Therefore, electrostatic attraction between electret and the insulating is probably lowered by formation of texture to the electret.

4. Acknowledgments

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).

5. References

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