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A MICRO POWER GENERATOR USING PECVD SIO_2/SI_3N_4 DOUBLE-LAYER AS ELECTRET

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Abstract: This paper presented a micro power generator using PECVD SiO_2/Si_3N_4 double-layer as electret for harvesting vibration energy from the environment. This device was fabricated by bulk micromachining technology. The average surface potential of PECVD SiO_2/Si_3N_4 double-layer was about -409V. The measurement results of this electret micro power generator show that the peak to peak current and power outputs were 19.2nA and 46.14pW respectively at resonance frequency of 560Hz and 3g acceleration with 1MΩ resistive load. The power outputs per square centimeter of our device were 154pW.

Key words: Micro power generator, PECVD SiO_2/Si_3N_4 double layers electret, Vibration-to-electric energy conversion.

1. INTRODUCTION

Recent years, vibration energy harvesting devices have been widely studied for low-power consumption applications such as networks of mobile sensors and wireless components. These generators typically base on three main transduction mechanisms (piezoelectric, electromagnetic and electrostatic) used to extract mechanical energy from the surrounding. Much attention has been drawn towards electret power generators which employ electrostatic mechanism [1-3] because of their purely electric performance, long lifetime and high power-output in small scale.

Most of the published works of electret power generators were focused on organic electrets [4-6], which is difficult to be compatible with micromachining process. In all papers reached, at least one layer of the SiO_2/Si_3N_4 double layers electrets was deposited by thermal oxidation or APCVD/LPCVD on silicon substrate. The low deposition speed and high residual stress of these techniques lead to difficulties to prepare thick layers (>2μm). However, PECVD could be a better choice to prepare SiO_2/Si_3N_4 electret for its relatively high deposition speed, low residual stress and low deposition temperature. This paper proposed and fabricated a micro power generator with PECVD SiO_2/Si_3N_4 double-layer as electret, proved having high charge ability and stability [7]. Most of the published works about electrostatic generator were focused on only prototype. This paper reports an independent and practical device in harvesting vibration from the environment.

2. DEVICE DESIGN

The schematic graph of our electret micro power generator is shown in Fig. 1. The device is made of three parts: the electret, the movable and the shielding structures. The electret is 10μm/50nm SiO_2/Si_3N_4 double-layer prepared on glass substrate and has negative surface potential. It is a dielectric material that has been charged, in order to create a fixed and stable electric field.

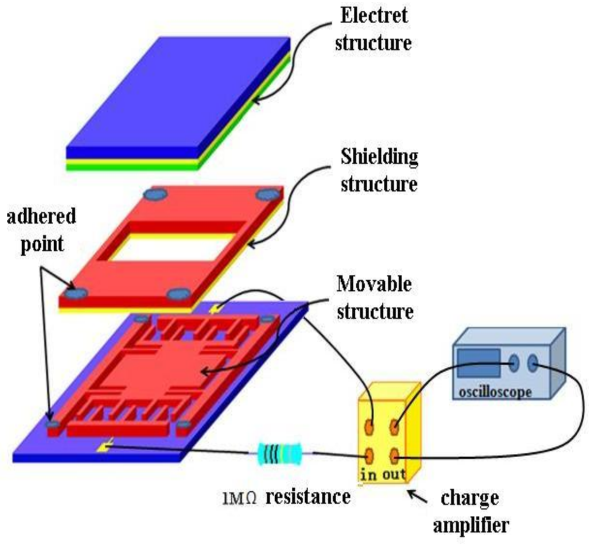

Fig. 1 Schematic graph of our new electret micro power generator

The silicon movable structure (Fig. 2) consists of a mass suspended by four beams and 510 pairs of interdigitated combs. A single comb finger has a width of 12 μm and a length of 195 μm at a structural thickness of 80 μm. The sizes of the initial finger overlapping are 95 μm and air gap widths are 5 μm, allowing comb finger to make the displacement of 100 μm.

The shielding structure is inserted between the electret and the movable structure. It is made of silicon with a rectangular via-hole in the center just over the mass for leading only the mass exposing to the electrical field of the electrets and shielding the interdigitated combs. The seismic mass is supported by silicon beams, by which it is oscillated at specific frequency. The capacitors are polarized by bonding an electret on top of the shielding structure. Due to the mass vibration with respect to the substrate, the overlapping areas of the combs vary accordingly, and so do the capacitance and the induced charge distribution, producing a current going through the load that is applied between two groups of fixed combs. Complementary groups of comb configuration can double the variation of the capacitance per unit area and so do the power output.

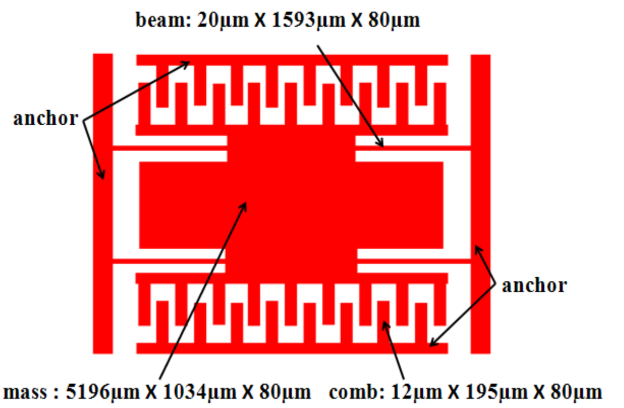

Fig.2 The schematic graph and the size of the movable structure

3. DEVICE FABRICATION

The electret structure started with Pyrex7740 glass wafer. First, Cr/Au (30nm/100nm) thin films were sputtered on the Pyrex7740 glass wafer as lower electrode. Then, SiO_2 and Si_3N_4 were deposited using PECVD with 300℃ substrate temperature on the Pyrex7740 glass wafer. After fabrication, it was charged by negative corona charging method with the conditions in table 1. The average surface potential of PECVD SiO_2/Si_3N_4 double-layer was about -409V.

Table 1 Table 1 Negative corona charging conditions

Needle height	10mm
Grid height	1.5mm
Needle voltage	-5000V
Grid voltage	-400V
Substrate temperature	80℃
Charging time	30mins

The shielding structure was made of silicon. The opening through whole wafer was obtained by KOH wet-etching. Then Cr/Au (20/120nm) was deposited on it. Fig. 3 shows the photograph of the shielding structure.

Fig.3 Photograph of the shielding structure

The movable structure was fabricated by bulk micromachining process (Fig. 4). Firstly, 15µm trench on silicon wafer was obtained by DRIE. Then, 20/120nm Cr/Au was sputtered on Pyrex wafer and patterned by liftoff. The silicon and glass wafers were anodically bonded together at 350°C and 1000V. Then, Silicon wafer was etched back till 95µm thick silicon left by KOH. Afterward, DRIE was performed to release suspension structures of the generators. Fig. 5 shows the photographs of the movable structure.

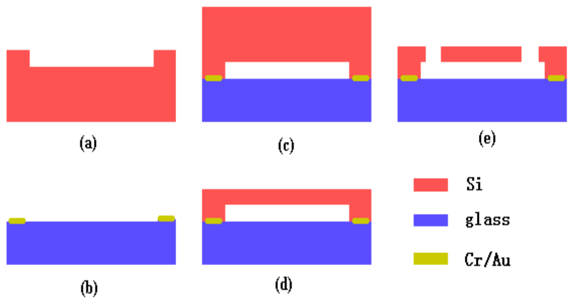

Fig. 4 The process flow for fabricating the movable structure

Finally, these above three parts were adhered together by epoxy orderly as shown in Fig. 1 forming our whole device.

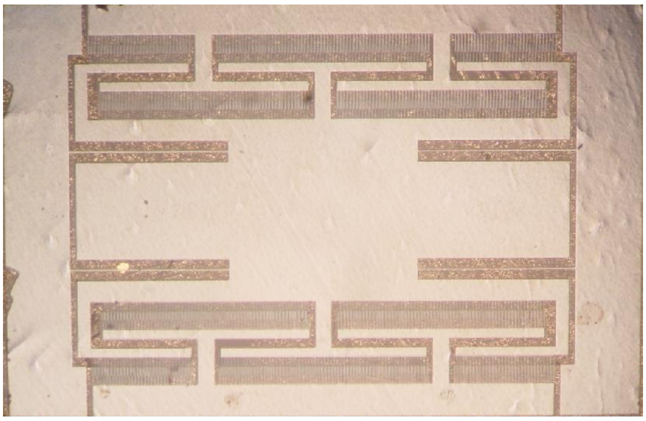

Fig. 5 Photograph of the movable structure

4. MEASUREMENTS AND RESULTS

The device was stick to a Printed Circuit Board and all necessary wires were soldered. The PCB was fixed in an aluminum box to suppress space electromagnetic interference. Afterward, the box was mounted to Dong Ling ES-025-S electrodynamic shaker driven sinusoidally by a HP 3562A dynamic signal analyzer through a DEITY PA1200 power amplifier. Acceleration was measured using a Da Shang CA-YD-103 accelerator. The shaking frequency can be varied from 5 to 2000Hz, and the acceleration can be varied from 0 to 200m/s^2. The output current of electret micro power generator with a load resistor was measured by Da Shang YE5852A charge amplifier. Both acceleration and charge amplifier voltage waveforms were displayed by a Tektronix TDS1032B oscilloscope. Fig. 6 shows the photographs of the whole test setup with packaged device.

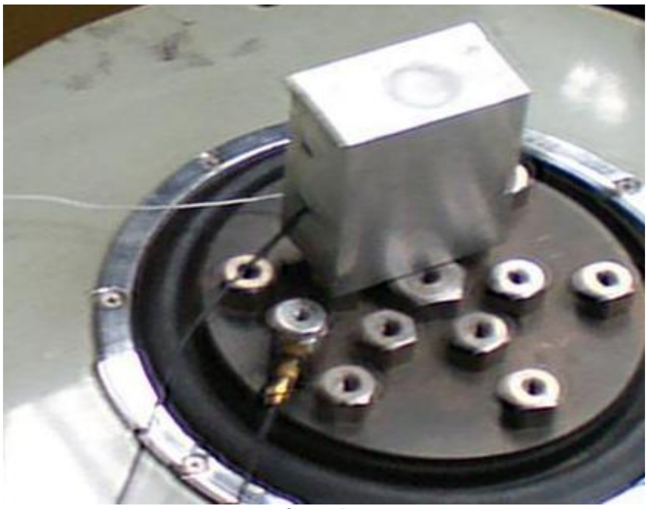

Figure 6 test setup for electrets power generator mounted on shaker

The current go through the resistance is given by:

$$i = \frac{\partial Q}{\partial t} \qquad (1)$$

The shaker is driven by a sinusoidal wave signal, so the charge wave is sinusoidal consequently. Therefore, the whole power output can be described by:

$$p = \left(\frac{i_{p-p}}{2\sqrt{2}}\right)^2 \times R \qquad (2)$$

Due to the cantilever nature of this device, there is an optimal frequency for the optimal power generation. Fig. 7 shows the power output at different driving frequencies with 1MΩ load resistance. It is shown that the optimal frequency is 560Hz, i.e. the resonance frequency of the cantilever.

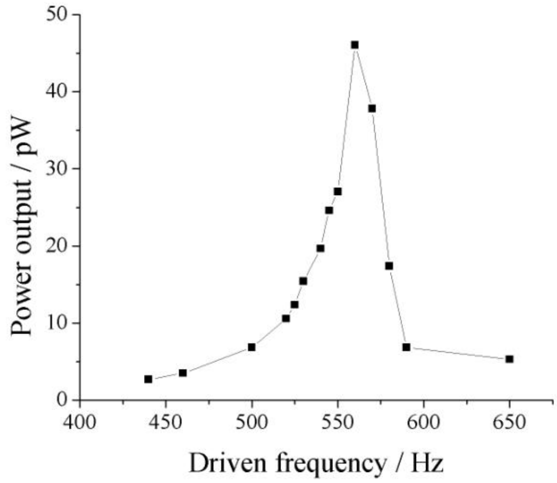

Fig. 7 Average power output at different frequencies with 1MΩ resistance

The time trace at 560Hz is shown in Fig. 8 where the peak to peak charge output is 5.46pC. Using equation (1) and (2), the peak to peak current output is 19.2nA and so the maximum power output of our device was calculated to 46.14pW at 560Hz with load resistance of 1MΩ. The area of our device is merely 0.30 square centimeter, the power output per cm^2 will be 154pW.

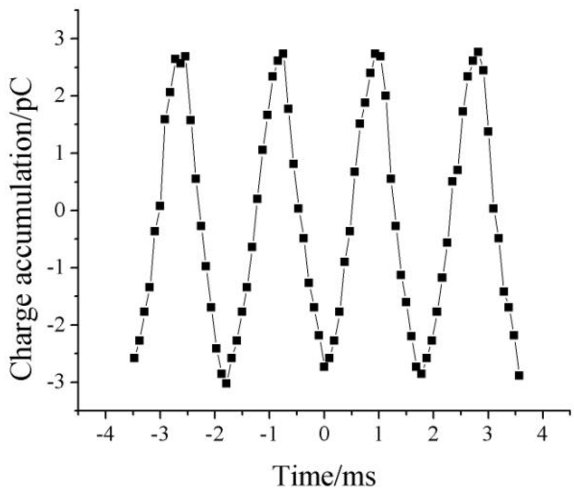

Fig. 8 Time trace at 560Hz

5. CONCLUSION

This paper presented a micro power generator using PECVD SiO_2/Si_3N_4 double-layer as electrets for harvesting vibration from the environment and fabricated a device by bulk micromachining technology. PECVD SiO_2/Si_3N_4 double-layer was charged by negative corona charging method and its average surface potential was about -409V. The peak to peak current and power outputs were 19.2nA and 46.14pW respectively at resonance frequency of 560Hz and 3g acceleration with 1MΩ resistive load. The power outputs per square centimeter of our device were 154pW. This device remains at the stage of prototype, but could apply to practice in the future.

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REFERENCES

[1] Hsi-wen Lo, Rus Whang, Yu-Chong Tai, A Simple Micro Electret Power Generator, Proc. 20th IEEE Int. Conf. MEMS, 2007, pp. 859-862.

[2] Takumi Tsutsumino, Yuji Suzuki, Nobuhide Kasagi, and Yoshihiko Sakane, Seismic Power Generator Using High-Performance Polymer Electret, Proc. 19th IEEE Int. Conf. MEMS, 2006, pp. 98-101.

[3] T. Sterken, P. Fiorinil, G. Altena, C. Van Hoof and R. Puers, Harvesting Energy from Vibrations by a Micromachined Electret Generator, Int. Conf. Solid-State Sensor, Actuator, and Microsystems Workshop, 2007, Transducer, 2007, pp. 129-132

[4] J. Boland, Y-H Chao, Y. Suzuki, Y.C. Tai, Micro Electret Power Generator, in MEMS 2003, Tyoto, Japan, 2003, pp.538-541.

[5] Y. Arakawa, Y. Suzuki, and N. Kasagi, Micro Seismic Power Generator Using Electret Polymer Film, in PowerMEMS 2004,Kyoto, Japan, 2004, pp187-190.

[6] T. Tsutsumino1, Y. Suzuki1, N. Kasagi1,and Y. Sakane, Seismic Power Generator Using High-performance Polymer Electret, in MEMS 2006, Istanbul, Turkey, 2006, pp.98-101.

[7] Zhiyu Chen, Zhiqiu Lv and Jinwen Zhang, PECVD SiO2/ Si3N4 double layers electrets on glass substrate, IEEE Transactions on Dielectrics and Electrical Insulation Vol.15, No.4, pp.915-919, 2008.