BIPOLAR ELECTRET CHARGING METHOD FOR ENERGY HARVESTER

T. Fujita[1,2], T. Onishi[1], K. Fujii[1], K. Sonoda[1,2] H. Katsuma[1], K. Kanda[1,2], K. Higuchi[2], and K. Maenaka[1,2]
[1]Department of EECS, Graduate School of Engineering, University of Hyogo, Himeji, Japan
[2]JST-ERATO Menaka Human-Sensing Fusion Project, Himeji, Japan

Abstract: This study proposes a novel electret charging method with bipolar potentials for vibratory type energy harvesters. The electret material of CYTOP is at first charged with negatively, and then the negative charged area is biased for preventing the following positive charging step. Then the electret is alternately charged with positive and negative polarity in fine patterned electret area. The bipolar charged electret makes a harvester with low electrostatic force and low electric field between the electrodes and electret for the same amplitude of the potential, because of the charged potential from the ground potential is half of the conventional one. The charging mechanism and experimental results for the novel bipolar electret charging method are described.

Keywords: electret, energy harvester, bipolar, CYTOP, corona discharge

INTRODUCTION

With the drastic advances of the MEMS (Micro electromechanical systems), the microcontroller and the RF devices, the high performance WSN (Wireless sensor network) and BAN (Body area network) systems for human application have almost come to realize [1]. Where the battery is the most important and the most difficult device to realize these systems. Now the energy harvesting devices that collect the electric energy from the ambient are drawing a lot of attentions as next generation power sources [2]. In order to generate a valuable energy from the human body, a thermoelectronic generator (TEG), a photovoltaic cell (PVC) and a vibratory energy harvester (VEH) are extensively studied.

Of these, the VEHs by using electrostatic mechanism (called as electret VEH) are reported as a good candidate for the low frequency energy sources i.e. human motions, because the electret VEH can generate a high voltage in spite of for the low frequency vibration [3]. The harvesting power from the electret VEH is proportional to the surface charge density, i.e. charged potential on the electret, vibration frequency and amplitude of the capacitance change. However it was difficult to obtain a large capacitance change from the in-plane movement structure of the typical MEMS electret VEHs [4]. Since it is difficult to avoid the fringe effect completely, we propose inversing the polarity of the electret potential.

In this paper, a novel charging method to obtain a bipolar charged electret is proposed. In our previous work, the fine patterned electret charging by applying the bias voltage to a buried grid electrode (BGE) method was established [5]. We apply this method to make a bipolar charged electret. The detailed mechanism and experimental results are described.

ELECTRET VEH

Figure 1 shows a schematic diagram of the typical in-plane MEMS electret VEH. The device consists of a counter electrode (CE), an electret and a base electrode (BE). A charge movement on the CE is caused by a capacitive induction from the charged electret. So that the harvesting current, *i,* is shown as

$$i = \frac{dQ}{dt} = \frac{dC}{dt} V_{\mathrm{electret}} . \tag{1}$$

In order to obtain the large harvesting power, the huge shift of the charge Q, i.e. large change of capacitance between the electret and the CE, C, is required. The high electret potential, V_{electret}, is also required as shown in Eq. (1). The V_{electret} depends on the electret material property. For example, the CYTOP (CTL-809M; Asahi glass Co., Ltd. Japan) is well known material that has a large dielectric strength of 110 kV/mm and has a very high theoretical limit of the surface charge density [6].

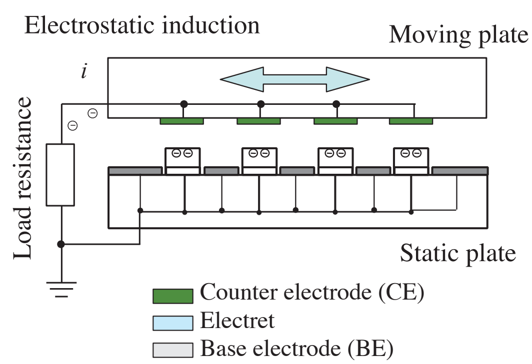

Fig 1: Schematic diagram of typical in-plane MEMS electret VEH.

However improving a capacitance change between the electret and the CE is not easy to obtain. Figure 2 shows a simplified schematic diagram of the typical MEMS electrostatic VEH. The capacitance change from the ideal calculation shows dashed-line in Fig. 2. Given the limitation on an actual device, the capacitance change from an actual one is depicted by solid line in Fig. 2. It is very low comparing to the ideal one. In the actual device, the electrode is divided finely in order to make a large capacitance change. The harvester with a narrower gap, finer line and space electrodes is not always obtained the large capacitance change, because of a fringe effect of the parallel plate capacitor. This unwanted effect obstructs miniaturization of the electret VEH and limits its harvesting power. Optimized design guide to improve the harvesting energy is studying [4].

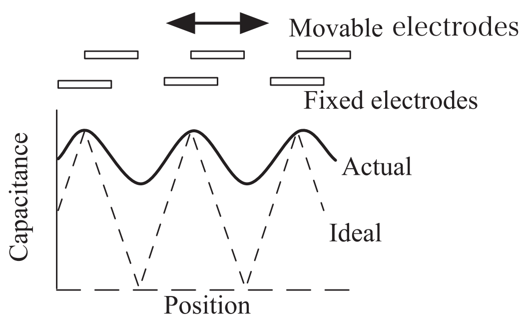

Fig 2: Ideal and actual capacitance of parallel plate capacitor.

BIPOLAR CHARGED ELECTRET

Figure 3(a) illustrates the estimated potential on the CE that is above the negatively charged electret film. The change of the induced opposite charge (positive) on the CE is as low as the capacitance change as explained earlier. In order to improve a harvesting energy, we propose a bipolar charging technique for stripe shaped electret, which is alternately charged with bipolar potentials. If the bipolar electret will be realized, induced potential on the CE is as shown in Fig. 3(b). The charge movement that induced by opposite polarity would be drastically increased in spite of the fringe effect still exists. Note that the harvesting power will be as same as a harvester with a double charged monopolar electret and a grounded electrode, however, our bipolar technique realizes a low electrostatic force and low electric field between the electrodes and electret for the same amplitude of the potential, because of the charged potential from the ground potential is half of the conventional one. And the CEs should be connected alternately for two-phase output because the potential on the CE shows two-phase AC waveform as shown by solid and dashed line in Fig. 3(b).

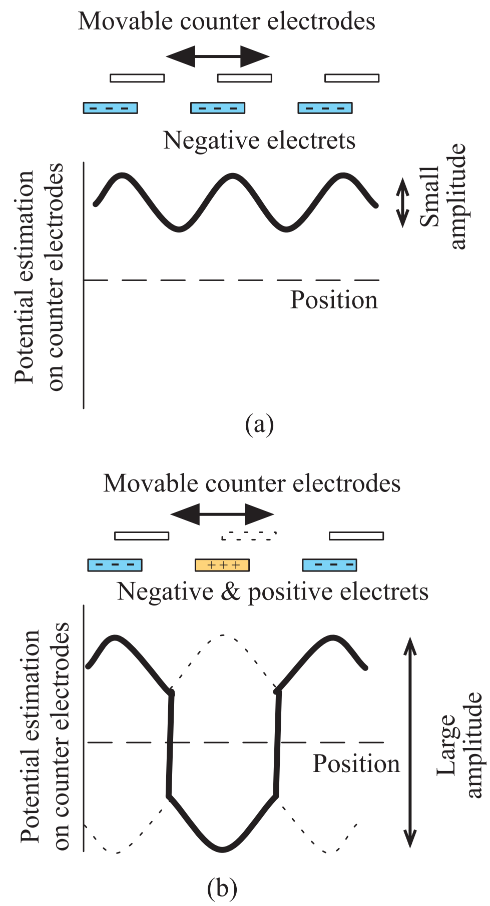

Fig. 3: Surface potential estimation of the counter electrodes, CE, above the electrets that charged with (a) only negative and (b) bipolar.

EXPERIMENTS

Before an experiment for charging the bipolar electret, we perform a charging test to evaluate positive and negative charging characteristics for the corona discharging on the CYTOP [7]. The charging apparatus and the test specimen are shown in Fig. 4. The central BE is surrounded by the BGE area, and both electrodes are made of 500 nm thickness aluminum deposited on the Pyrex glass substrate of

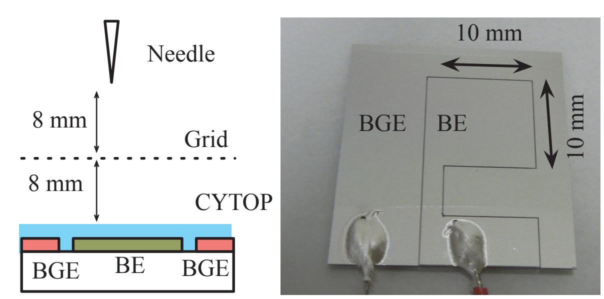

Fig. 4: Charging apparatus and photograph of sample specimen for charging by using corona discharging. The BE area of 10 ×10 mm^2 is surrounded by BGE

30×30×0.5 mm^3. The CYTOP (CTL-809M) with thickness of about 3 μm was coated on the both BE and BGE. The applied voltages of the needle, the grid electrode/BGE were set to –8 kV, –50 to –500 V in 50 V decrements for negative charging and +8 kV, +50 to +500 V in 50 V increments for positive charging, respectively. We also examined two types of BGE connections; one is biased with grid voltage and the other is grounded. The corona discharge was performed with same conditions; sample temperature of 80 ºC, charging time of 3 minutes and the gap between the needle, the grid and the electret of both 8 mm. Figure 5 shows the maximum surface potential versus applied grid voltages of the each samples. All data were measured by the contactless surface-electrostatic voltmeter (Model 279; Monroe Electronics Inc. USA) and normalized to surface charge density by each accurate thicknesses of CYTOP. While there are some slight differences, all charge densities are proportional to the grid voltage. Due to the bias effect from the BGE, both positive and negative charging with biased BGE shows highly surface charge density.

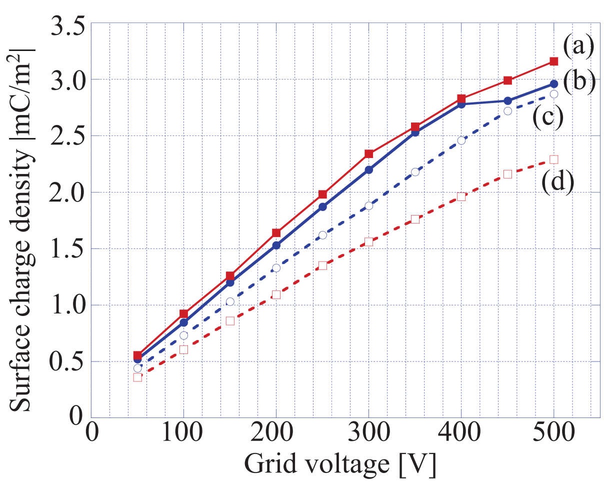

Fig. 5: Surface charge density versus applied grid voltage for (a) positive with biased BGE, (b) negative with biased BGE, (c) negative with grounded BGE, and (d) positive with grounded BGE.

We apply the biased BGE method to bipolar electret charging with small modification. Figure 6 shows the 2.5 μm CYTOP test specimen for striped bipolar charged electret, which was deposited on the patterned BGEs on a glass substrate. The BGEs have 1 mm line and 100 μm space. Each charging process was as same as previous test. Two BGEs that used for negative and positive charging are abbreviated as a BGE-N and a BGE-P, respectively. At first, the BGE-

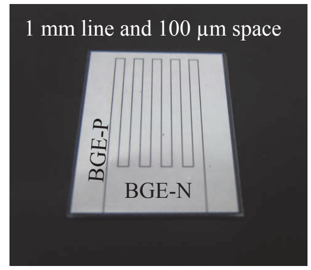

Fig. 6: Test specimen for bipolar charging. Beneath the 2.5 μm CYTOP layer, 1 mm BGE-N, 1 mm BGE-P and 100 μm space are deposited on glass substrate.

N connects to ground, the BGE-P and the grid are set to negative voltage of –400 V, and the needle voltage of –8 kV is applied. After the negative charging step, the electret upon the BGE-N is charged with about –400 V and the BGE-P is not charged as shown in Fig. 7(a). The measured surface potential profiles after the negative charging are shown as solid-line in Figs. 8(a) and 9(a). Both profiles have potential of about –300 V. The potential profile should be looked rectangular shape, but it looks sinusoidal curve because of a lack of spatial resolution of the electrostatic surface voltmeter about 2.5 mm at the 500 μm probe separation.

At the positive charging step, all voltage settings are inverted to the positive polarity. The BGE-P connects to ground and the grid is set to +400 V and the needle voltage of +8 kV is applied. If the BGE-N with negative charged electret keeps floating as shown in Fig. 7(b), the measured surface potential profiles after the positive charging is shown as dashed-line in Fig. 8(b). The electret above the BGE-P is charged with about +300 V as expected. However the electret above the BGE-N is neutralized and added the positive potential. It might be caused by parasitic capacitance between the BGE-N, the BGE-P and also a grounded substrate.

In order to prevent the neutralization of the negatively charged area, the BGE-N is biased with +800 V, BGE-P connects to ground, the grid is set to +400 V and the needle voltage of +8 kV is applied. By this voltage configuration, the surface potential of the negatively charged electret above the BGE-N appears +400 V (–400 V charged electret potential plus +800 V BGE-N bias equal +400 V surface potential). The measured surface potential profiles after the positive charging are shown as dashed-line in Fig. 9(b). The electric field on the negatively charged electret was negligible. Finally, after the positive charging step, the electret upon the BGE-N and the BGE-P are charged with about –300 V and about +300 V, respectively as shown in Fig. 9(b). The proposed bipolar charging method shows larger peak-to-peak surface potential change of about 600 V_{pp}, which is approximately 2.5 times larger than that using the only negative charged electret.

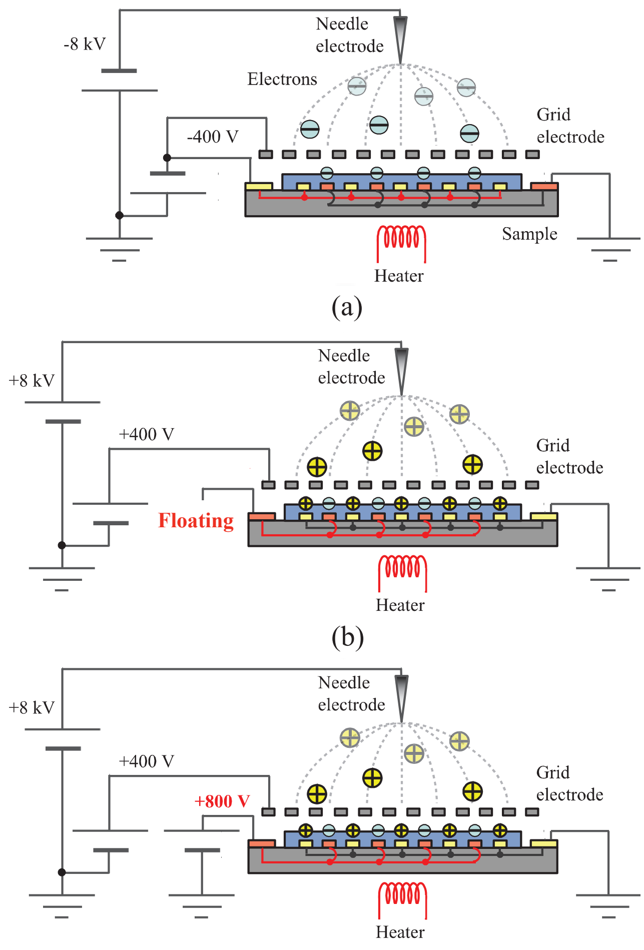

Fig. 7: Bipolar charging steps for (a) –400 V negative charging, and positive charging with (b) floated BGE, and with (c) +800 V positive biased BGE-N.

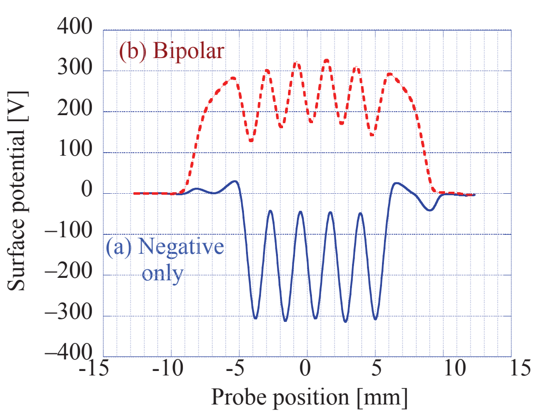

Fig. 8: Surface potential measurement of the electret that charged by (a) negative only and (b) bipolar with floated BGE-N.

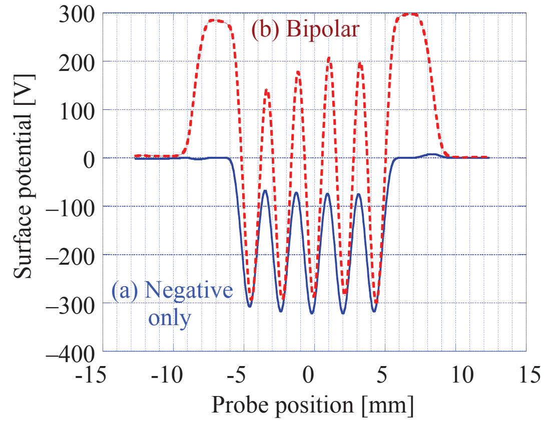

Fig. 9: Surface potential measurement of the electret that charged by (a) negative only and (b) bipolar with +800 V biased BGE-N.

CONCLUSION

We presented the novel bipolar charging method for electret type energy harvester by using biased electrode. The bipolar charged electret makes a harvester with low electrostatic force and low electric field between the electrodes and electret for the same amplitude of the potential, because of the charged potential from the ground potential is half of the conventional one. The biased electrode is used for preventing the neutralization of pre-charged electret area. This charging method can be applied to the arbitral electrode shapes and areas that are able to connect the biased voltage. It should be useful for realizing the high performance miniaturized electret harvester that has narrow gap and fine line and space electrodes.

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