Low Electrostatic Dumping Force Energy Harvester Using Bipolar Charged Electret

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Abstract In this paper, a bipolar charging method for electrostatic vibratory energy harvester and its analysis result of electrostatic force are described. To improve the harvesting power, higher voltage charged electret with large capacitance change structures are extensively studied. However, the higher voltage also shows a higher electrostatic force, which prevents the device movement for harvesting and causes pull-in behavior. From the result of FEM analysis on bipolar charged electret, the electrostatic force for vertical and horizontal directions were reduced by 15% and 10% from negative only charged device, respectively.

1. Introduction
Wireless sensor networks (WSNs) are attracted to many fields such as healthcare, infrastructure, and transportation to remotely monitor various parameters [1]. A power supply for WSNs is an issue in order to extend the lifetime and to reduce the maintenance cost. Utilization of WSNs are restricted by lifetime of the battery and installation place where the battery is hard to replace. Ambient energy harvesting technology is possible to overcome for these problems. There are several sources for energy harvesting such as mechanical vibration, thermal gradients, electromagnetic fields, and fluid flow. Mechanical vibration sources are ubiquitous and easy to use for conversion to electrical energy. In order to obtain large energy from the vibration by electret vibratory energy harvester (EVEH), higher charging voltage of electret with large capacitance change structures are typically used [2]. However, the higher electret charge causes some failures on EVEH’s operation by electrostatic force increasing or pull-in behavior especially on the MEMS EVEH with small and light weight mass structure [3].

In this paper, we present a novel EVEH with low electrostatic dumping force by using bipolar charged electret [4]. From a preliminary experiment and an FEM analysis, advantages of bipolar charged electret for reducing the electrostatic force are demonstrated.

2. Bipolar Charging Method
The bipolar charging method is carried out with two electrodes that buried under an electret material. Two buried grid electrodes (BGEs) for negative and positive charging are abbreviated as the BGE-N and the BGE-P, respectively. At first, the BGE-N is grounded, the BGE-P and grid electrode for corona discharging are set to –400 V, and a needle voltage of ~8 kV is applied. The electret material on the BGE-N is charged with –400 V after the first negative charging step. Then the BGE-N is set to +800 V and the BGE-P is grounded to prevent a neutralization of the negatively charged area. After that the grid is set to +400 V and the needle voltage of +8 kV is applied. The surface potential of the negatively charged electret is the subtraction of the charged electret potential with –400 V from the BGE-N biased with +800 V that is +400 V. Finally, the electrets on the BGE-N and the BGE-P are charged with –400 V and +400 V, respectively (figure 1).
Figure 2 shows the CYTOP (CTL-809M; Asahi glass Co., Ltd. Japan) test specimen with a thickness of 2.5 µm, which was deposited on the patterned 0.5 µm thickness aluminum BGEs on a 0.5 mm thickness glass substrate. The BGE-N and BGE-P have 1 mm line width and 100 µm spacing dimensions. Each charging process was performed for 3 minutes on a hotplate with 80 ºC. Figure 3 shows the surface potential profiles for (a) only the negative charged sample of –400 V and for (b) the bipolar charged sample of ±400 V. By using a counter electrode (CE) with 1 mm line width and 1.2 mm spacing and 50 µm air gap, a preliminary harvesting test was performed. Figure 4 shows the harvesting result with a load resistance of 1 MΩ for (a) the negative charged sample and (b) the bipolar charged sample with 30 Hz, 1 mm p-p sinusoidal vibration. The output voltages for negative and bipolar charged electrets were 248 mV p-p and 528 mV p-p, respectively. This result shows the harvested voltage is obviously proportional to the voltage difference of adjusting electrets.

Figure 1. Bipolar charging diagram. +400 V positive charging with +800 V biased BGE-N after -400 V negative charging step with -400 V biased BGE-N and grounded BGE-P.

Figure 2. 2.5 µm thickness CYTOP test specimen for bipolar charging method.

Figure 3. Surface potential measurement of the electret charged by (a) negative only and (b) bipolar.

Figure 4. Harvesting result of test specimen for (a) only negative and (b) bipolar charged electret at 30 Hz, 1 mm p-p excitation with gap of 50 µm.

3. Electrostatic Force Analysis

Electrostatic force is calculated by FEM analysis (ANSYS 14.0®). Figure 5 shows the analysis model consists of 50 pieces of CE with 10 mm in depth. The CEs are periodically located and move for X-axis direction. The BGE-P and BGE-N are set to the GND (0 V) and −600 V for negative only device, +300 V and −300 V for bipolar device, respectively. Figure 6 shows the vector plots of the electric field directions. The vector arrow direction depicts a electric field direction, length and color shows intensity. From the results in figure 5(a) and (d), (b) and (e), (c) and (f), electric fields between the CEs and the BGE-N are weak for bipolar device.

Figure 7 shows the electrostatic force between the BGEs and the CEs for (a) Y-axis and (b) X-axis. The 0 µm position on the horizontal axis depicts that the CE and the BGE-N are completely overlapped in the center. The electrostatic force for Y and X-axes are reduced by approximately 15% and 10%, respectively at maximum force point of the negative only result.
Figure 5. Dimension of the analysed device for the bipolar/negative only charged electrostatic force analysis. CEs move at on X-axis.

Figure 6. Vector graphics of the CE displacement of the bipolar and the negative only charged device (a), (b), and (c) are the bipolar of the displacement of 0, 50, and 100 µm, respectively. (d), (e), and (f) are the negative only of the displacement of 0, 50, and 100 µm, respectively.
Displacement [µm]
Bipolar
Negative-only
(a)

Displacement [µm]
Bipolar
Negative-only
(b)

Figure 7. Electrostatic force analysis results for (a) Y-axis and (b) X-axis between the BGEs and the CEs with an air gap of 40 µm. The bias voltages for negative only and bipolar electret are −600 V and ±300 V, respectively.

In previous work, the CE is designed for mono-polar (negative only) electret as shown in figure 8(a). In order to improve a space efficiency, we designed novel CEs for bipolar electret (figure 8(b)), which has separated electrodes of CE-P and CE-N for BGE-P and BGE-P, respectively. Figure 8(c) shows the 3-D diagram of the CE-N. The comb electrode like slits and two-step etching for air gap will be fabricated by DRIE. The CE-P and CE-N are isolated by dicing process after the wafer level bonding process.

Figure 9(a) shows conceptual diagram of wiring for the bipolar electret device. The harvested voltage from the CE-P and the CE-N are individually supplied to load resistances. Figure 9(b) shows the estimated output voltage with opposite phase waveforms for CE-P and CE-N.

CE
(a)

CE-N
CE-P
(b)

CE-N
(c)

Figure 8. CE structures (a) the conventional CE top surface, (b) the novel CE top surface, and (c) the novel CE-N structure. The slit between the CE-P and the CE-N is formed by dry etching. The both electrode are completely divided by dicing process.

Figure 9. (a) Connection diagram of CE-P and CE-N for bipolar charged device and (b) estimated output voltage waveforms on the load resistance R_P and R_N.
4. Conclusion
We present a bipolar charging method for electret energy harvester with low electrostatic force. From the result of FEM analysis, we also demonstrate the electrostatic dumping force could be drastically reduced by using the bipolar charged device than the negative only charged device. The electrostatic forces for Y and the X-axes are reduced by approximately 15% and 10%, respectively.

References
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