Impulse-Excited Energy Harvester based on Potassium-Ion-Electret

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Abstract. We have developed an energy harvester that is specifically desired for impulse acceleration of infrastructure vibrations such as sudden motion at railway bridges. The energy harvester based on potassium-ion-electret on the sidewalls of 1.8-µm-gap comb electrodes generated a 64 $\mu A_{p\text{-}p}$ current during low impulse acceleration, which was large enough to light a green LED.

1. Introduction

Trillion-sensor universe, where people annually consume more than a trillion sensors for comfortable life requires vast amount of energy wireless sensors operation and data transfer. Therefore, energy harvesting is a crucial component to avoid periodical change of battery as many as a trillion unit. Sensors for social infrastructures require all-day monitoring, which cannot be fulfilled by the solar cells, and hence it makes vibrational energy harvesters very attractive. There are three types of vibrational energy harvesters: piezoelectric, electromagnetic and electrostatic. Only the electrostatic type can efficiently harvest energy at low frequency vibrations (< 100 Hz) because the spring can be designed separately from the power generation regions.

Electret, a dielectric material storing semi-permanentl electric charges, has been attracting increasing attention for energy harvesters in recent years. High-performance electrostatic MEMS energy harvesters usually have a pair of opposing silicon electrodes with narrow gaps (< 2 µm) for high-output power. There are several methods to store electric charges in the electret films, such as corona discharge [1], ion implantation [2], electron beam injection [3], molecule ionization by X-ray radiation [4], and potassium ion-doping during thermal oxidation [5]. Amongst of these, electrets on the sidewall of narrow gaps can be made only by the potassium ion-doping Using this technique, we achieved high power generation during a low impulse acceleration due to extremely large force factor.

2. Concept and Device

2.1. Power generation method

The energy harvester device (illustrated in Figure 1) developed in this work has vertical comb-electrodes that were coated with potassium-ion-electrets. The harvester mechanism is consisted of

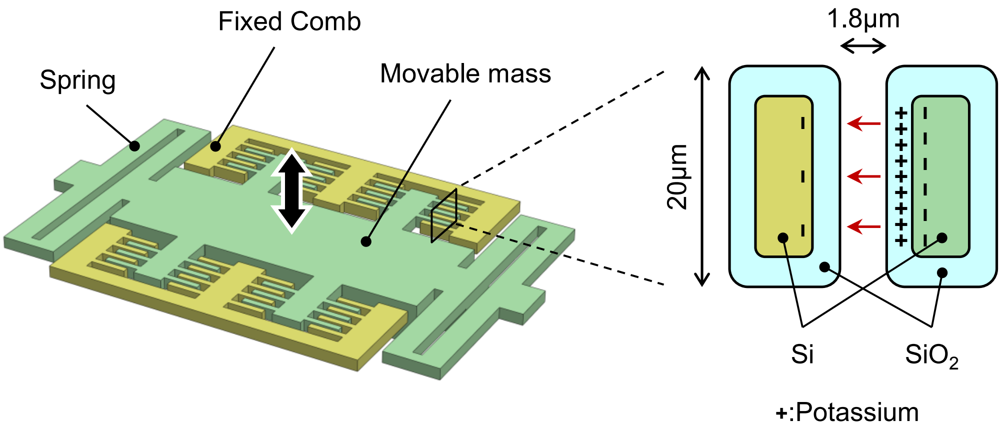

Figure 1. *Schematic of the electrostatic vibrational energy harvester.*

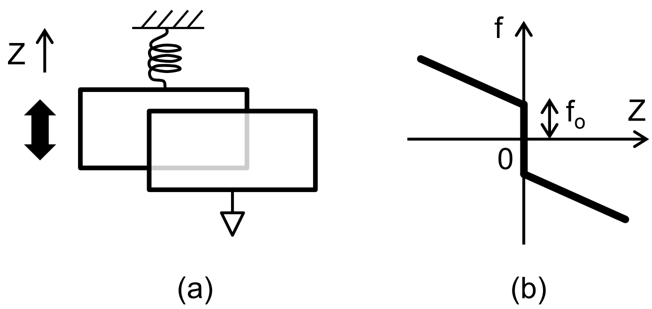

Figure 2. *Force (f) versus displacement of movable mass (Z).*

fixed combs and movable combs (with mass *m*) suspended springs on a silicon-on-insulator (SOI) wafer. The springs are made in the device layer, while the movable mass is in the handling layer to achieve relatively compliant springs and a large mass for efficient vertical motions at lower frequencies. A certain force level (f_o) is required to start the vertical motion (illustrated in Figure 2a) due to the strong electrostatic attraction that is built in between the electret combs at the initial position as schematically illustrated in the force curve in Figure 2b. Due to these characteristics, this device cannot use the mechanical resonance under small vibrations but it is more suitable for impulse acceleration.

In a case of power generation from a vibration source with stable frequency and phase, a resonance type energy harvester would have been more beneficial. However, we focused on the development of a impulse-type power generator because the environments surrounding the sensor network are rather rich in mechanical vibrations of random frequency and phase.

2.2. Fabrication and Device

The energy harvester was developed by by conventional photolithography and deep-RIE (DRIE) processes on an SOI wafer. Then, the whole device was thermally oxidized at 980°C in a wet environment by N_2-bubbling an aqueous solution of KOH to form a silicon oxide film resulted in a uniform inclusion of potassium ions in the silicon oxide film (Figure 3). During this process, the areas protected by the 100-nm-thick silicon-nitride (Si_3N_4) film by low-pressure chemical vapor deposition

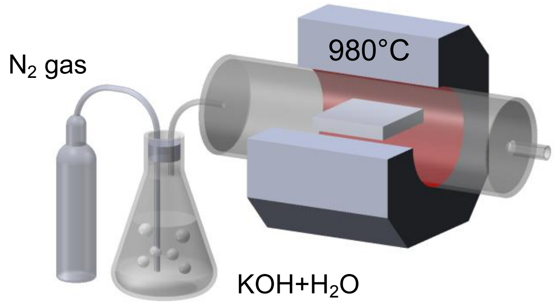

Figure 3. *Thermal oxidation.* by bubbling a stream of KOH solution.

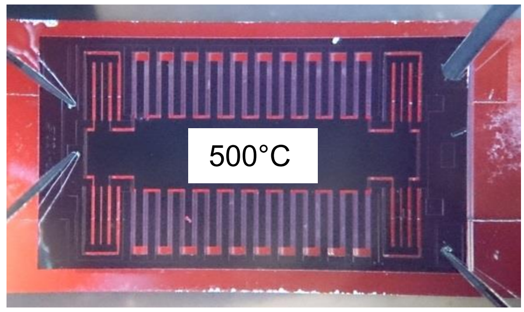

Figure 4. *Bias-temperature procedure.*

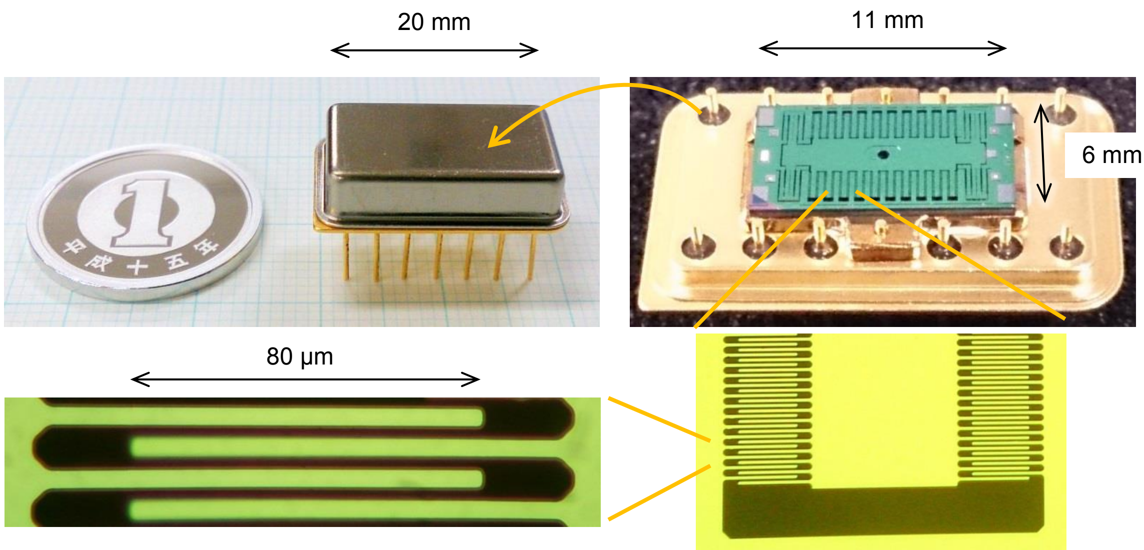

Figure 5. *Photographs of the developed energy harvester.*

(LPCVD) are free from the oxidation, and later used as electrical pads after stripping the nitride film. Finally, the included ions were electrically activated at approximately 500°C with 100-V-bias voltage to form 100-V- electret films between the comb electrodes (Figure. 4) [5]. The chip (11mm x 6mm) has 4000 pairs of 5-µm-width comb electrodes. The overlap between the coms is 80 µm with across a 1.8 µm gap.

3. Experimentals

For demonstration, the device was hermetically sealed in a nitrogen-filled package (12mm x 20mm, Figure 5). The packaged device was mechanically excited with consecutive impulses obtained by sliding a screw bolt on the package surface (Figure. 6). The output voltage at a 1-MΩ-load resistance and the short circuit current were 34.6 V_{p-p} and 64.2 μA_{p-p} respectively (Figure 7). The device provides considerably larger current than the previous devices reported elsewhere [6].

The output impedance was measured by the impulse acceleration using a voice coil. The output power peaked at a 0.6-MΩ-load resistance (Figure 9). Thanks to this very low output impedance and the large current, we could directly connect the harvester to a green LED and successfully light the diode brightly by sliding the bolt (Figure 8).

Journal of Physics: Conference Series **660** (2015) 012002 doi:10.1088/1742-6596/660/1/012002

Typically, a power obtained from an energy harvester is once charged, and it is intermittently discharged. So a large output current is more important than just large output power. Therefore, our energy harvester based on potassium ion electret is very superior in practice.

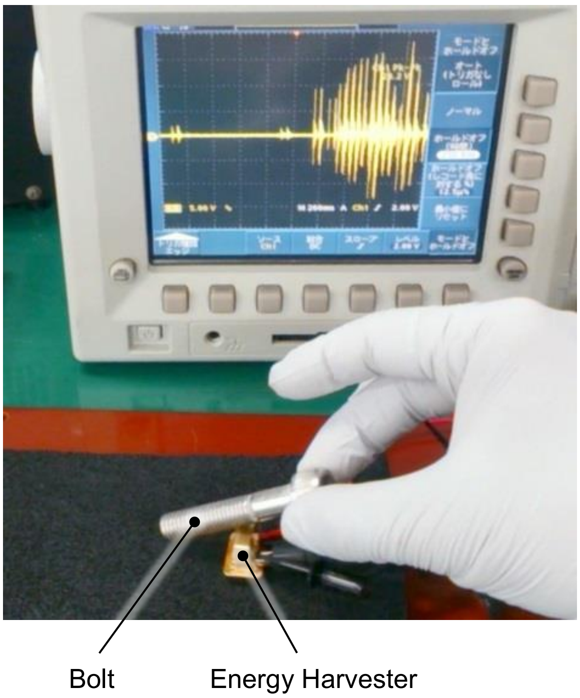

Figure 6. *Energy harvester device in operation.*

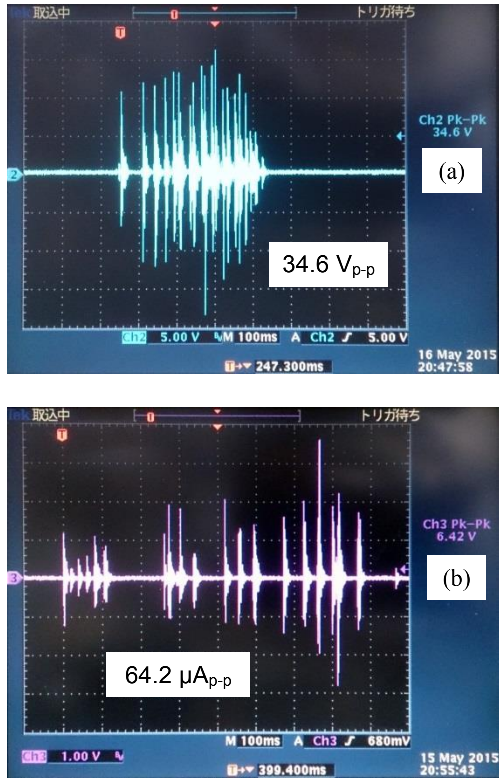

Figure 7. *Waveforms generated by impulses. (a) Output voltage of maximum 34.6 V_{p-p} for 1 MΩ load resistance. (b) Short current of 64.2 μA_{p-p}.*

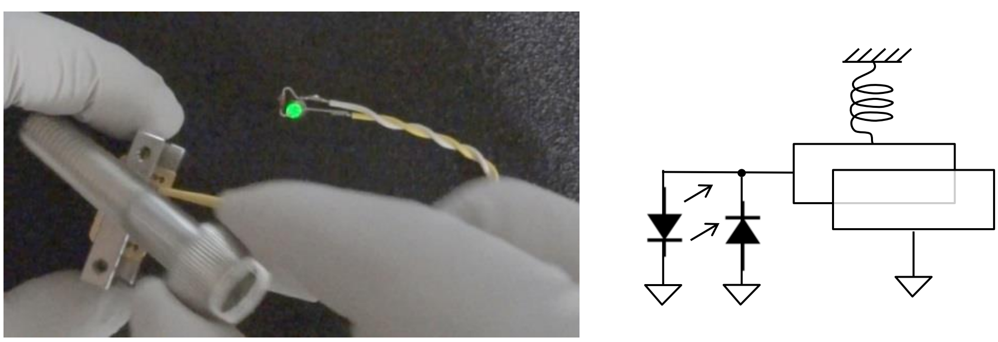

Figure 8. *A green LED directly driven by the energy harvester.*

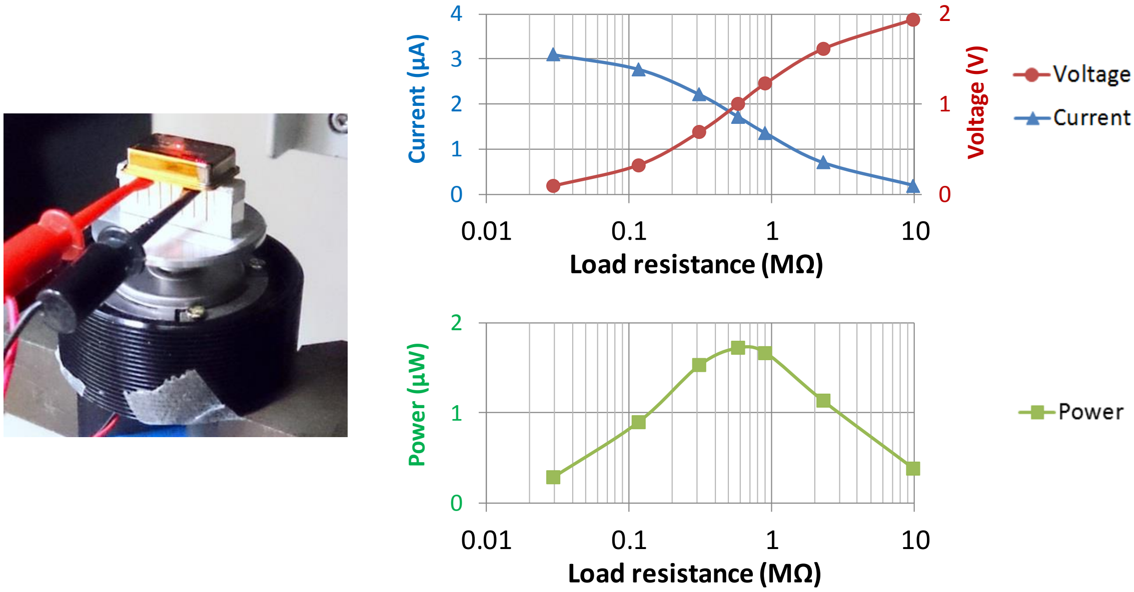

Figure 9. *Output voltage and current as a function of load-resistance (upper). Output power as a function of load-resistance (lower).*

4. Conclusion

In this study, we have developed an energy harvester based on potassium-ion-electret featuring (1) considerably large current (64.2 $\mu A_{p\text{-}p}$) and (2) very low output impedance (0.6 MΩ) owing to the superb performance of our potassium-ion-electret. The proposed technology allows us to develop independent energy source for sensor networks such as infrastructures that requires all-day monitoring.

5. Acknowledgments

This work is supported by the New Energy and Industrial Technology Development Organization (NEDO).

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