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MEMS Vibrational Energy Harvesters for Perpetual Electronics

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Abstract

We report on recent R&D results on MEMS (microelectromechanical systems) vibrational energy harvesters that convert environmental vibrations of 100 Hz or less and 0.1 G (1G = 9.8 m/s^{-2}) into electrical power of 100 µW or more by the electrostatic induction current generated by the mechanically modulated permanent charge "electrets."

1. Introduction

On the extension of further miniaturization of semiconductor electronics, we foresee a computer of a tiny grain size that has electronics functions equivalent to those of mobile electronics today, as schematically illustrated in **Fig. 1**. Having made electronics to such extreme small dimensions, we will encounter another technical problem: how are we going to supply power to such small electronics, for such electronics would have become smaller than a battery cell. Our R&D on energy harvesters has started to answer such a question. After several years now, we are good to provide MEMS (microelectromechanical systems) technology to supply 100 µW power from the environmental vibrations of 100 Hz or less and 0.1 G or less (1G = 9.8 m/s^2) with a 1-cm square chip footprint [1].

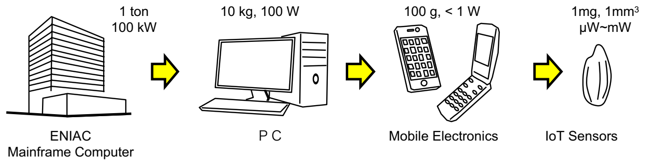

Fig. 1 How are we going to supply power to a grain-size small electronics?

2. MEMS Vibrational Energy Harvester

Environmental vibration is chosen as a redundant and ubiquitous power source that has not been used before. Amongst various power conversion mechanisms, we use the electrostatic induction current. **Figure 2** illustrates a part of the MEMS vibrational energy harvester electrodes that are coated with the permanent charge called the "electrets" [2]. At the rest position, the holes and electrons are coupled over the silicon/silicon-oxide interface. When the movable electrode is shaken by the mechanical vibration, then some of the electret charges alter the flux coupling to release the electrons, due to the mechanically modulated electrostatic capacitance. The released electrons are transferred to the counter electrode through an external resistance. Therefore, the incoming mechanical power to push the electrode is converted into electrical power. **Figure 3** is the overview of the MEMS vibrational energy harvester. Owing to the symmetric layout of electrodes, the electrostatic constraint force is suppressed such that vibrations in a small acceleration range could smoothly excite the mechanical resonance of the harvester.

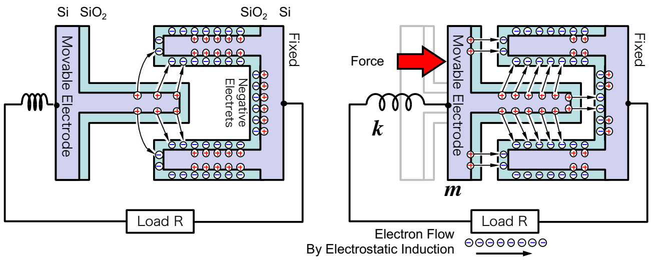

Fig. 2 Power conversion mechanism based on the electrostatic induction.

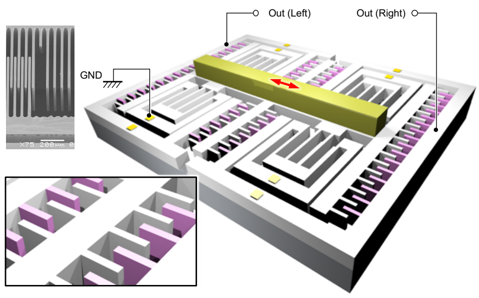

Fig. 3 Schematic illustration of MEMS vibrational energy harvester.

3. Fabrication Process of Electret Harvester

The electret on the surface of silicon oxide is produced by the bulk micromachining process shown in **Fig. 4**. We use an SOI wafer to produce the electrostatic electrodes on the top active layer, while mechanical mass on the bottom. After selectively removing the buried oxide, the entire surfaces are wet-oxidized through an aqueous bubbler of KOH solution, by which the oxide becomes impurity rich. The oxide film on the electrode surface is locally polarized and charged at a high temperature (650 ˚C) with a high voltage (over 500 V) to keep the permanent built-in potential. Note that this electret process takes place at the end of the CMOS post-process such that it would not diffuse impurities to the production line.

The SIMS profile shown in **Fig. 5** suggests that the impurities (K+ ions) have migrated through the silicon oxide film during the electret polarization process, leaving the lattice defects (SiO-) that are negatively charged, which is thought to be the source of the electrets [2].

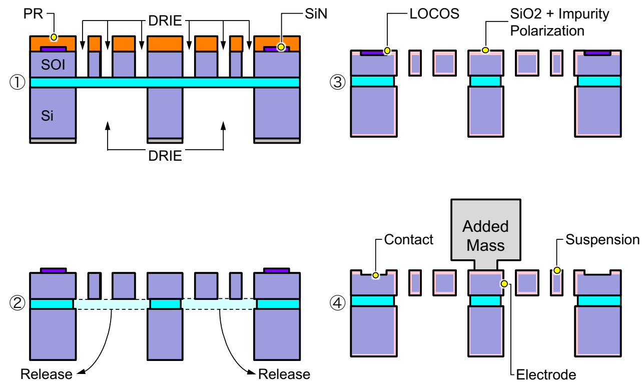

Fig. 4 Fabrication process.

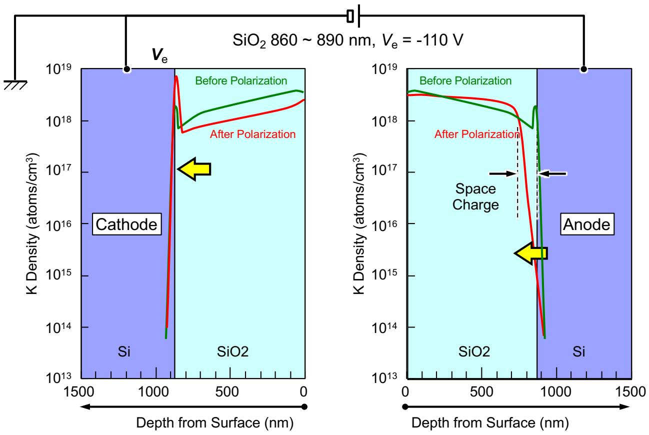

Fig. 5 SIMS profile of impurity in the silicon oxide layer.

4. MEMS Energy Harvester for Wireless Sensor Node

The developed energy harvester was found to be powerful enough to electrically charge a 470 μF capacitor in a few minutes by using weak vibrations of 0.6 G at 124 Hz, as shown in **Fig. 6**. Two curves compare the charge performances of two different electret potentials. The stored energy is intermittently used to drive a wireless sensor node (based on a ZigBee unit) to collect environmental information such as temperature and humidity as shown in **Fig. 7**.

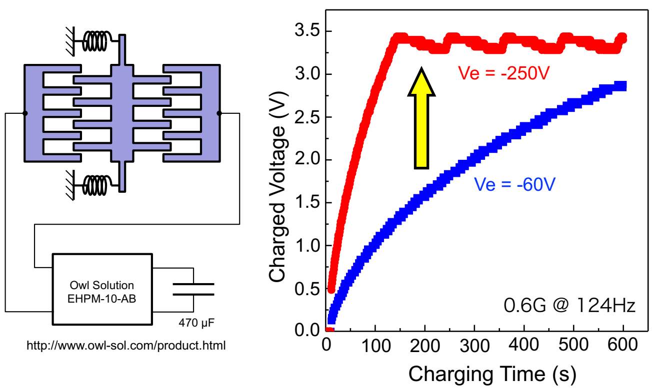

Fig. 6 Energy storage by MEMS vibrational energy harvester.

The protocol of ZigBee operation was limited to be intermittent (not continuous) due to the excess power demand for wireless transmission as listed in **Table 1**, and the harvested energy needs to be stored in a capacitor for a relatively long time compared with the short transmission period. Such an event-driven type operation is acceptable for monitoring system for social infrastructures such as bridges, tunnels and railroads. In contrast to this, there exist electronics of very low power consumption such as analog clock IC or time IC that are inevitable component for distributed IoT sensor nodes. Less than 100 nW power consumption is reported on a commercially available time IC chips, which could be continuously driven by the developed MEMS energy harvesters.

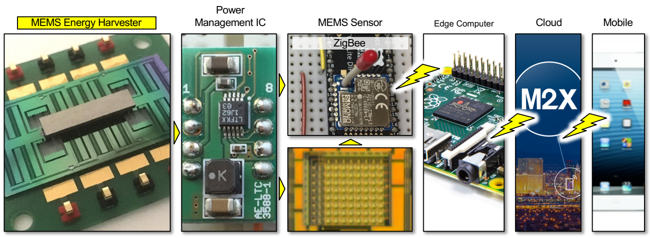

Fig. 7 Demonstration of wireless sensor node driven by the power generated by the MEMS vibrational energy harvester.

Table I Comparison of power consumption of mobile electronics

Device	Power	Current	Voltage
ZigBee	60 mW peak	20 mA	3.0 V
Apple Watch	52 mW avg	13.8 mA	3.76 V
Bluetooth 4.0 (BLE)	45 mW peak	15 mA	2.0 ~ 3.6 V
GPS Tracker (BLE)	↑ (intermittent)	↑ (intermittent)	3.0 V
Felica (readout)	~ 15 mW peak	~ 5 mA	3.0 V
Hearing Aid	~ 1 mW avg	0.67 mA	1.4 V
Heart Pace Maker	33 μW avg	13 μA	2.5 V
Analog Clock LSI (Wrist Watch)	2.8 μW avg	1.0 μA	2.8 V
	0.39 μW avg	0.25 μA	1.55 V
Timer IC	88 nW avg	35 nA	2.5 V

3. Conclusions

MEMS energy harvesters based on the permanent charge (electrets) are reported and demonstrated. The development was started to meet a 1 mW power demand [3] but we have found a lot of application in lower power range such as timer ICs. Autonomous time IC could be the first example of self-powered electronics with a built-in energy harvester in coming years.

Acknowledgements

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References

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