A micro-scale system that uses a new method of charging electrets can effectively convert 3D vibrational energy into electricity.

Wireless sensor nodes are used for a variety of applications from mobile phones to remote sensing. Currently, these devices use batteries that have a limited lifespan, requiring frequent replacement. An alternative is to power these sensor nodes by capturing renewable energy from their environment. To do this effectively, low-power, micro-scale energy harvesting devices are required. The preferred systems for this process, for reasons related to design complications and the scaling effect of output power (the energy coming out of the device changes with the size of the device), are the so-called electrostatic vibration micro-harvesters.

We report a new model for a low frequency (>150Hz) vibration harvester that uses electrets to provide the electrostatic effect. This device is capable of harvesting 3D vibrational energy in standard planar silicon-based microelectromechanical systems (MEMS). We also describe an innovative electret-charging technique for the harvester electrets.

M. Edamoto¹ and T. Tsutsumino² have previously presented low-frequency electret harvesters that can collect energy in a specific direction. In their systems, power losses are reported due to misaligned electrodes as a result of bonding and aligning movable and fixed electrodes of the harvester. Additionally, the pull-in effect (electrodes sticking onto each other due to the forces provided by the electrostatic effect) is a principle limitation for any energy harvester with capacitive comb-like surfaces. Although this can be avoided by using special bearings, these bearings are difficult to integrate into the micro-fabrication process. In our model, pull-in is avoided by mechanical stops, which are electrically isolated from the fixed electrodes to avoid discharge of the electrets in contact with counter electrodes (see Figure 1).

Our design is based on a SiO₂ electret³ defined only on the vertical sidewalls of fixed electrodes with capacitive comb-like fingers (see Figures 1 and 2). The fabrication process involves a
MEMS process compatible with a complementary metal-oxide semiconductor. It uses deep reactive-ion etching for anisotropic etching of silicon and local oxidation using Si$_3$N$_4$ as passivation. In addition, the SiO$_2$ electret is developed only on the sidewalls of the fixed opposite electrode (comb-like fingers), that is, the SiO$_2$ on the moving electrode must be etched away. Charging electrets developed on wafer surfaces can be done by corona charging$^4$ or ion-implantation.$^3$ However, to overcome limitations such as those related to pull-in (X- or Y-direction, indicated in Figure 1) and 3D-capable vibrations/harvesting, electrets can be created on vertical sidewalls of substrates to enable single-substrate MEMS processing.

We have also developed a new technique (see Figure 3) of charging electrets by simply using commercially available ionic hairdryers (e.g., Braun model 3549) or air ionizers. This method resulted in excellent long-term stability when charging 7.8μm-thick Cytop and 1.5μm-thick SiO$_2$ electret films placed perpendicularly to the air flow. In both cases a potential of more than −1000V was achieved.$^5$ In addition, we found that for single-electret surfaces placed in the same direction (almost parallel) as the flow of ionic air, the charge only has a slight dependence on the specific angle between the ionic flow and the surface of the electret film (see Figure 4).

Next, we proceeded to charge electrets defined on vertical sidewalls of comb-like electrodes. Because the air flow coming from an ionic hairdryer contains up to 65 million ions/cm$^3$, some of these charges can penetrate into the trenches present between the vertical sidewalls (see Figure 1). Figure 5 shows the charging of vertical sidewalls, for deep and narrow trenches, needed for the comb-like electrodes. It should be noted, however, that the surface potential is smaller than for the freely standing structures (see Figure 4).

The X-, Y- and Z-vibrational movement of the central seismic mass is achieved by suspending beams orientated at 45° with respect to the X- and Y-axes (indicated in Figure 1). The beams are attached to the four corners of the square seismic mass, equating the magnitude of movement from the so-called in-plane or in-gap and making out-of-plane movement possible. We have previously discussed details of design and technological realization of the basic structure of a 3D energy harvester.$^7$

In this paper, we presented a model for 3D micro-energy harvesting. It is based on a novel way of developing electrets on the sidewalls of fixed electrodes of the harvester and it achieves 3D vibrational movement by suspending diagonal beams attached to a mass lying at the center of the device. Within our method, the electrets are charged using a technique that employs commercially available ionic hairdryers. In the future, we intend to investigate the sidewall charging of micro-fingers (see Figure 5) with this charging approach. We anticipate that finger electrets on sidewalls with up to 10μm-deep trenches in-between them can be charged sufficiently (in range of −200V).

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Figure 5. Surface potential at sidewalls of six SiO$_2$-electret fingers after charging them with an ionic hairdryer for 30 min at a distance of 5 cm. Both sides are 0.5 $\mu$m thick, the distance between fingers is 500 $\mu$m and their height is 1 cm.

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