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A miniature and non-resonant vibration-based energy harvester structure

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Abstract

This paper presents a miniature and non-resonant vibration based electromagnetic (EM) energy harvester, which generates energy from low frequency and low amplitude vibrations. The structure combines a MEMS-based coil realized on a parylene cantilever, and a miniature NdFeB magnet, resulting in a small sized EM harvester prototype with a strong magnetic part. The magnet is attached to a moving platform, whereas the coil is fixed to a stationary base. The mechanical frequency up-conversion (mFupC) technique is utilized to increase the energy conversion efficiency. The fabricated prototype has a volume of 120 mm^3 and generates 1.44 mV RMS voltage and 24 nW RMS power from 10 Hz, 4 mm peak-to-peak (0.8 g) external vibrations. A power density of 200 nW/cm^3 has been realized with the prototype.

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1. Introduction

Vibrational energy harvesting from the environment at low frequency vibrations (1-20 Hz) has been proposed as a major renewable energy source for mobile platforms together with photovoltaic and thermoelectric sources [1]. The proposed energy harvesters for such applications utilize electrostatic, electromagnetic, or piezoelectric energy conversion principles, and are designed to be connected to a vibrating base through a spring-mass-damper (S-M-D) system. Hence, they rely on a mechanical resonance within a limited bandwidth [2]. Furthermore, in order to meet the low resonance frequency

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operation requirement, these devices are realized in large masses and volumes [3]. As an alternative method to the S-M-D system, different parts or edges of the energy harvester module may be attached to separate platforms in a system, which move with respect to each other [4]. This configuration enables energy generation through any kind of relative displacement of the platforms, regardless of the frequency and resonance of the motion.

In this work, we present a miniature vibration based electromagnetic energy harvester structure whose operation does not require a resonant vibration. The targeted vibrations are not necessarily resonant, but with low frequency (>20 Hz) and low amplitude (>10 mm peak-to-peak) characteristics. The mechanical frequency up conversion principle is also utilized for converting the vibration frequency to a higher value and hence, increasing the efficiency of the harvester [5].

2. Energy Harvester Structure and Operation Principle

Fig. 1 shows the energy harvester structure and its operation principle. It consists of one clamped-free support type cantilever beam, a pick-up coil attached on to the cantilever, a magnet placed on a vibrating platform, and a mechanical barrier arm, which is an extension from the side of the platform. With the moment of the platform, the barrier arm periodically touches, bends, and releases the cantilever. When the cantilever is released, it resonates at its resonant frequency, realizing the mFupC. The energy generation is independent from the frequency or periodicity of the vibration of the magnet as long as the magnet is displaced more than a certain threshold distance. The power is generated across the coil terminals via electromagnetic induction, resulting from the relative displacement of the coil and the magnet.

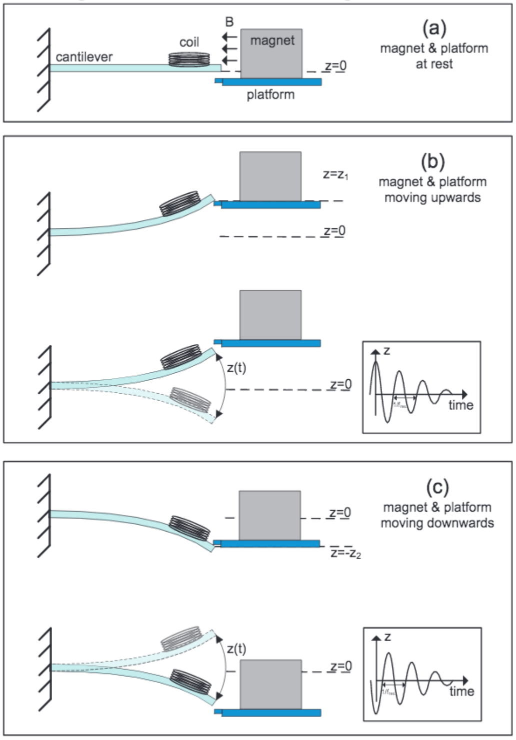

Fig. 1. Energy harvester structure and its operation principle.

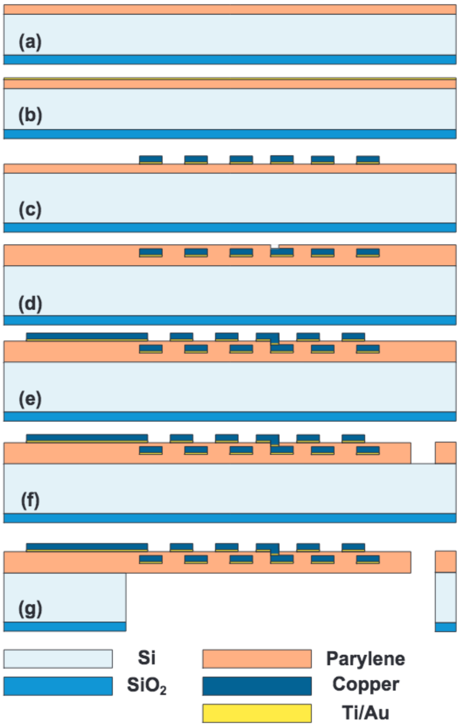

Fig. 2. The MEMS fabrication process of the cantilever/coil structure.

Fig. 2 shows the fabrication process flow of the cantilever/coil structure of the energy harvester. A MEMS fabrication process is utilized for miniaturization of the harvester. The structure is fabricated on a Si substrate, with a 0.5 µm SiO_2 at the back side. The first parylene layer with 10 µm thickness is deposited on the wafer, and the first coil level is formed with a 10 µm-thick Copper electroplating process on a Ti/Au seed layer. Then, 2^{nd} parylene layer (5 µm-thick) is deposited and patterned, 2^{nd} coil layer is formed by electroplating, the seed layer is stripped, and parylene is patterned forming the cantilevers. Fig. 3 shows the SEM images of the cantilever/coil structure at this stage. Finally, the cantilever is released by patterning the backside SiO_2 and etching the substrate with a Si DRIE process. The cantilever dimensions are 2 mm x 2 mm, and the 40-turn, 2-level coil has a 21.5 Ω resistance. Fig. 4 shows the photograph of the assembled prototype. For mFupC, a polystyrene film is shaped as the barrier arm and attached on a 2.5 x 2.5 x 0.5 mm^3 NdFeB magnet. The volume of the energy harvester is 120 mm^3, including the space needed for the movement of the magnet.

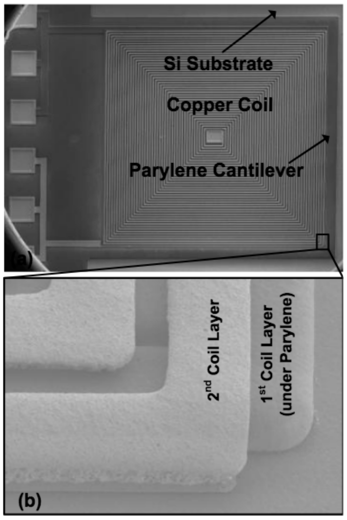

Fig. 3. SEM images of the MEMS coil/cantilever.

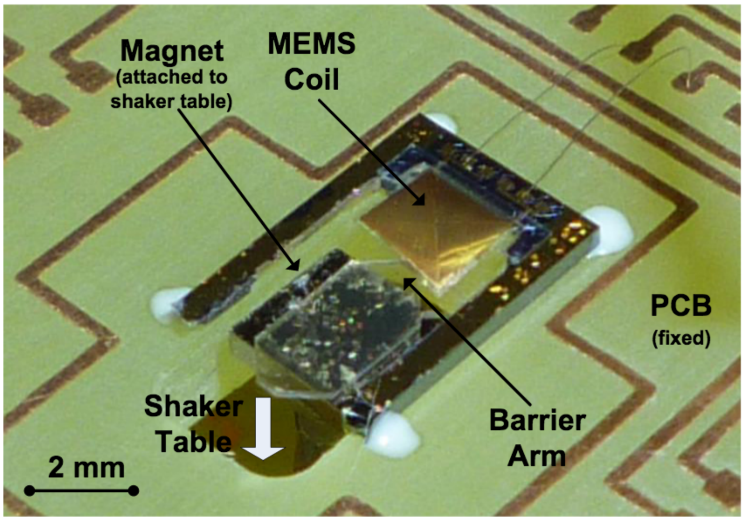

Fig. 4. The fabricated harvester prototype. The coil is attached to a fixed PCB, whereas the magnet is aligned to the coil and attached to a shaker table.

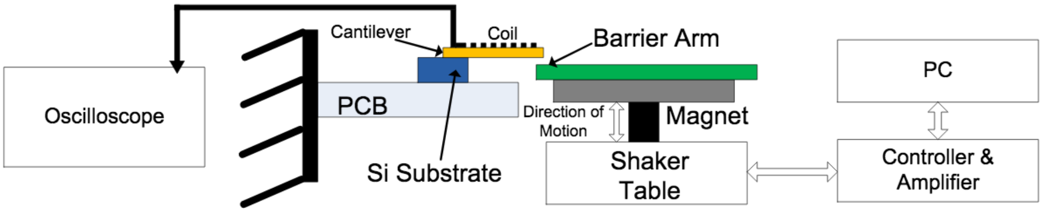

Fig. 5. The experimental test setup.

3. Experimental Results

Fig. 5 shows the sketch of the experimental test setup, where the PCB carrying the MEMS coil/cantilever is fixed to a stationary base, and the magnet is attached to a shaker table. The shaker table is PC controlled, and the coil voltage is observed trough an oscilloscope.

Figure 6 shows the generated voltage from the energy harvester with 10 Hz, 4 mm peak-to-peak vibrations (0.8 g peak acceleration). The resonance frequency of the cantilevers is measured as 170 Hz, and the mFupC, occurring twice in a single period is observed in the waveform. The RMS values of the generated voltage and power delivered to a matched resistive load are 1.44 mV and 24 nW, respectively. The resulting power density is 200 nW/cm^3 with the given vibration conditions. Figure 7 shows the test results of the prototype for different peak-to-peak vibration amplitude and corresponding peak acceleration values at 10 Hz. With this characterization, operation of the proposed device low frequency and low displacement vibration schemes is verified. Furthermore, the increase in the generated RMS voltage and RMS power with the increased vibration amplitude and acceleration is observed.

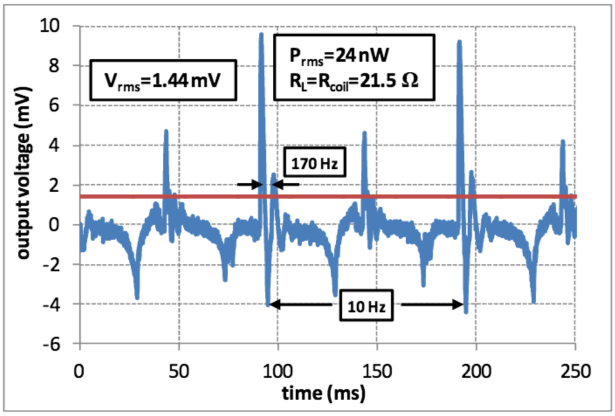

Fig. 6. The generated voltage from the micro energy harvester coil. The magnet movement is at 10 Hz with 4 mm p-p displacement, corresponding to 0.8 g peak acc.

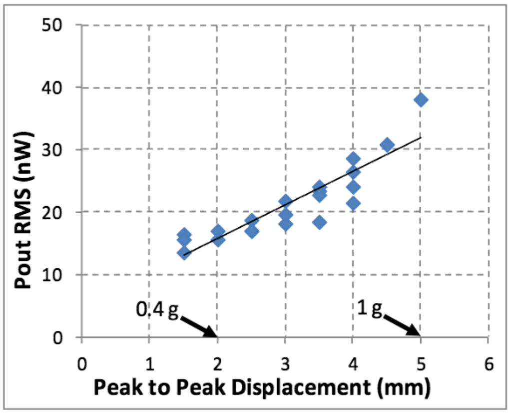

Fig. 7. The measured RMS power with the peak to peak displacement and acceleration of the magnet at 10 Hz.

4. Conclusion

In this paper a miniature vibration based electromagnetic (EM) energy harvester, which generates energy from non-resonant vibrations is presented. The structure combines a MEMS-based coil realized on a parylene cantilever, and a miniature NdFeB magnet. A mechanical barrier arm is employed to realize the mFupC technique. The magnet and the coil are attached to platforms moving independent from each other, eliminating the need for a resonant vibration for proper operation. The fabricated prototype has a volume of 120 mm^3 and generates 1.44 mV RMS voltage and 24 nW RMS power from 10 Hz, 4 mm peak-to-peak (0.8 g) external vibrations. A power density of 200 nW/cm^3 has been realized with the prototype. The prototype is a good candidate for energy harvesting applications with non-resonant vibration characteristics including human and vehicle motions.

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