ELECTROMAGNETIC ENERGY HARVESTER FABRICATED WITH ELECTRODEPOSITION PROCESS

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Abstract: A novel electromagnetic vibration MEMS energy harvester have been designed, simulated and microfabricated. The volume of the MEMS harvester was about 5mm×5mm×1mm. The highlight features of the harvester were the low frequency vibration energy harvesting and high property permanent magnet and copper electrodeposition technology which made the fabrication process IC compatible. It consists of fixed copper coils on the substrate and electrodeposited central CoNiMnP permanent magnets on the movable copper planar plate with six beams. The structure and magnetic field has been simulated and optimized with Finite Element Method software. The maximum output voltage was 3.8μV at 102Hz and the output power was in nano Watt scale.

Keywords: electromagnetic, energy harvester, electrodeposition magnet

INTRODUCTION

The development of microelectronic technology has scaled down the volume of the integrated MEMS system and reduced the system power consumption to micro and nano watt level, especially for the implant system, portable device and sensor network [1], meanwhile, they require the powering devices with smaller volume and high energy density. Unfortunately, the traditional power supply device, such as battery, couldn’t match these requirements. For example, the battery always too large to be integrated with IC circuit and the limited lifetime requires periodical replacement or recharge. The power supply became a crucial problem in micro integrated system.

The energy harvester was an alternative approach to powering the integrated system. It generates electrical power from ambient energy in the environment. Many energy sources are available in the nature, such as the solar, thermal and vibration, etc. The vibration power was the most common sources and easily to be harvested to electrical power with electromagnetic, piezoelectric and electrostatic energy transduction mechanisms. Moreover, the magnetic energy harvester poses more advantages compared to others such as it has not only the best energy density, but also the advantage of without operation voltages and control circuits [2]. However, the difficulty of fabricating magnet has been a big challenge for this device. Traditional high quality magnet fabrication process requires deposition or post-deposition annealing at very high temperature which are incompatible with IC fabrication. The magnets used in the fabricated electromagnetic harvester were in large size and assembled manually [3]. In [4], a simple cantilever beam was always utilized as vibration part, but its bad mechanical properties were limited its quality.

In this paper, a novel integrated MEMS electromagnetic energy harvester was designed and fabricated with compatible IC process. CoNiMnP permanent magnets were electrodeposited in the device with high performance [5]. The vibration plate with six symmetrical beams was designed to improved its performance. The coils and the beams were fabricated with copper electrodeposition process. The design of mechanical properities of the vibration structure and the magnetic field distribution was analyzed and optimized by Finite Element Method (FEM) software for low frequency energy harvesting. The fabrication process and testing results was fully investigated.

PRINCIPLE OF DEVICE

The magnetic harvester converts kinetic energy into electrical energy by electromagnetic transduction mechanisms. A general spring-mass model was built to describe the harvester system by C.B. Williams and R.B. Yates [6], as show in Figure 1, and it was discussed below.

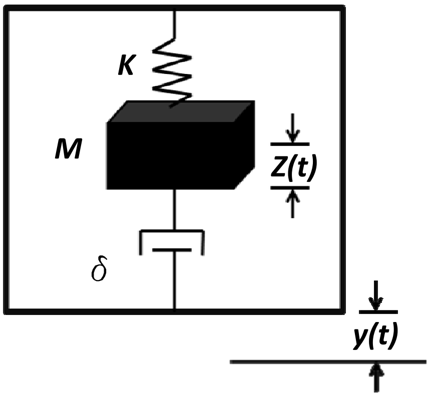


Fig 1 : Model of a spring-mass energy harvester

The vibration energy from excitation was transferred into the kinetic energy of the mass (M), the elastic potential energy in the spring (K) and the energy losses in the damper (δ) which consists of mechanical damping coefficients δ_d and electrical damping coefficients δ_e. The electrical energy exacted from the electric damper was harvester output power.

The differential equation of motion with a excitation $y(t)=y\cos wt$ was described as:

$$m\ddot{z}(t)+\delta\dot{z}(t)+kz(t)=my\omega^2\cos\omega t \quad (1)$$

Where k is the spring stiffness and δ is the damping coefficient. When the device was operated resonance at the input frequency, the maximum electrical power was:

$$|p|=\frac{m\delta_e\omega_n^{\ 3}y^2}{4\delta^2} \quad (2)$$

Where $\omega_n=\sqrt{k/m}$ is the system nature frequency [7]. It is shown that power is linearly proportional to mass and nature frequency decreased with more vibration mass.

SYSTEM DESIGN

The harvester was designed to convert vibration energy to electrical energy by electromagnetic transduction mechanisms, as shown in Figure 2, which consists of the coils, magnets and beams. The copper coils were fixed on the substrate and the center ring-shaped magnet was built on planar plate supported by six beam suspending in the center of the coils as vibration parts. Six side magnets were fixed around to enhance the magnetic field. When the vibration beams with the ring-shaped magnet were oscillating up and down above the coils with input excitation, the magnetic flux was cut by the coils and the vibration energy was converted to electrical energy.

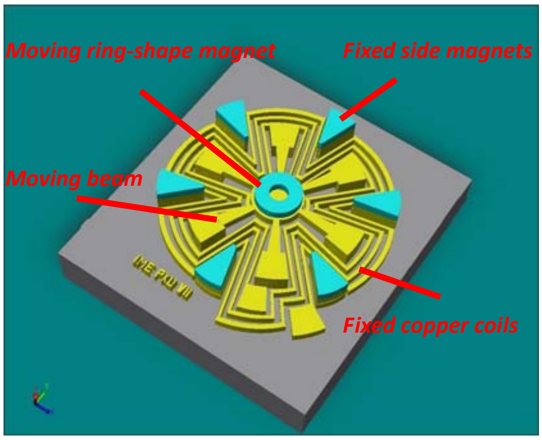
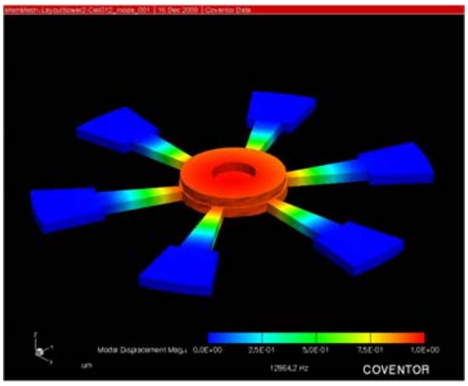


Fig 2 : Micro electromagnetic energy harvester

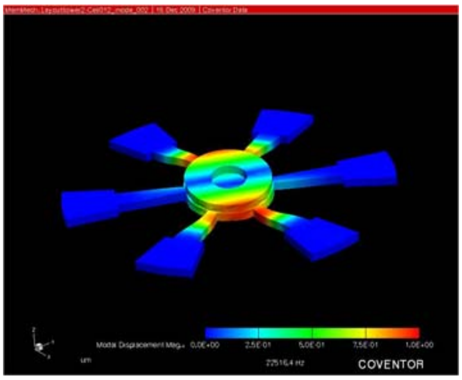
As discussed before, the power is linearly proportional to vibration mass. So the magnet was designed on the vibration plate to increase the vibration mass. The benefits was obvious, first, the increase mass will increase output power, then, the nature frequency of the beam will decreased and resonance with low frequency excitation, which was good for the low frequency vibration energy harvesting. What's more, the magnets can be electrodeposited on the copper vibration plate directly which simplified the fabrication process.

The vibration characteristics of six suspended copper beams with integrated magnet were studied by the Coventorware^{TM}. The displacement of modes was shown in Figure 3. In the first mode, the central plate oscillating up and down and reaches its maximum amplitude about 1μm. But in the second mode and third mode, the plate acts a rotational movement, which affects the power output.

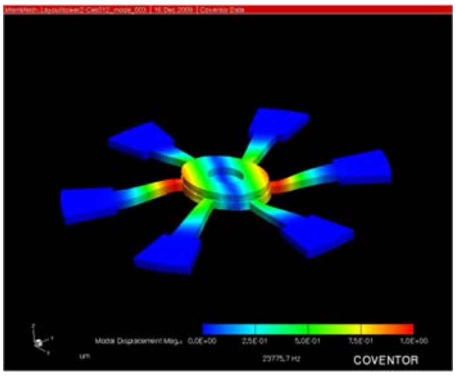
The CoNiMnP magnet has high coercivity and high energy density. But the arrangement of the magnets will great affect the magnet field distribution. It was simulated with Maxwell software, as shown in Figure 4. The magnetic flux density in the gap between the central and the side magnet was much higher than between side magnets. It is obviously that the magnetic field was sharply decreased from the surface and the



(a)



(b)



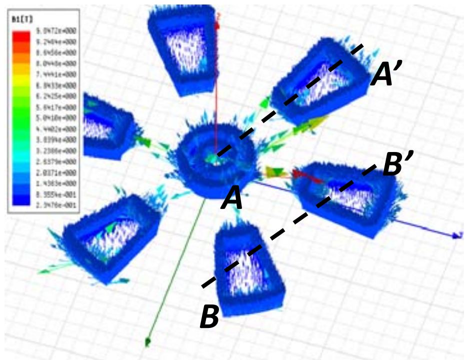
(c)

Fig 3 : Simulation results for (a) the first resonant vibration mode; (b) the second vibration mode; (c) the third vibration mode

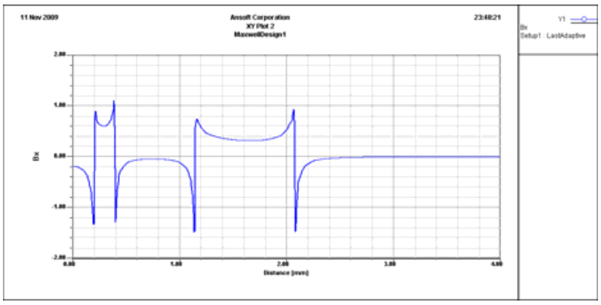
coils within 100μm from the magnet surface have higher magnetic flux density, which require the coils placed close to the magnets. Based on that, the path of coils was optimized as three turns and surrounding closely to the magnet. The magnets was arranged with movable central magnet and fixed six side magnets around. It is proved that this arrangement made the magnet field distribution more uniform in the space for performance improvement. .

FABRICATION PROCESS

The feature of the harvester was the integrated



(a)



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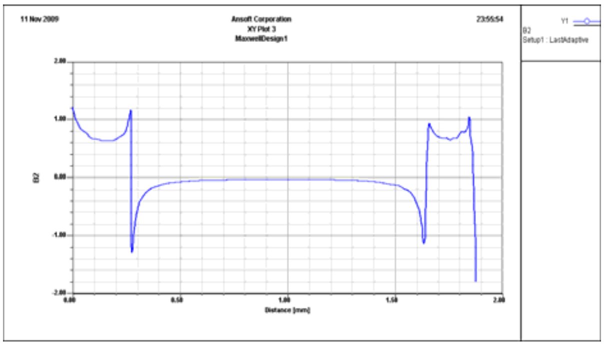

(c)

Fig 4 : (a)Simulation results of Magnetic field and (b) the magnetic field in AA' and (c) the magnetic field in BB'

magnets fabricated with electrodeposition process which was IC compatible. The fabrication process was shown in Figure 5. First, 30nm titanium and 300nm copper was deposited as the seed layer. Second, the 10μm photoresist was patterned on as a mask and copper coils were electrodeposited for 10μm. Third, titanium and copper was sputtered again and then the copper vibration planar plate with springs was electroplated with the thickness of 10μm using photoresist as the mask. Forth, the CoNiMnP permanent magnets with the thickness of 10μm were electroplated on copper vibration plate as well as the side magnets. At last, the device was finished after removing all the seed layers and photoresist. The fabricated micro harvester was shown in Figure 6.

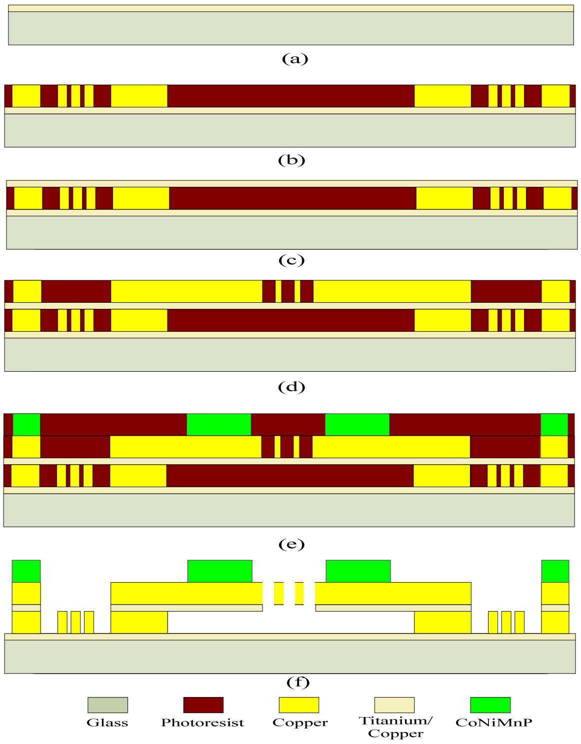

Fig 5 : Illustration of Fabrication process

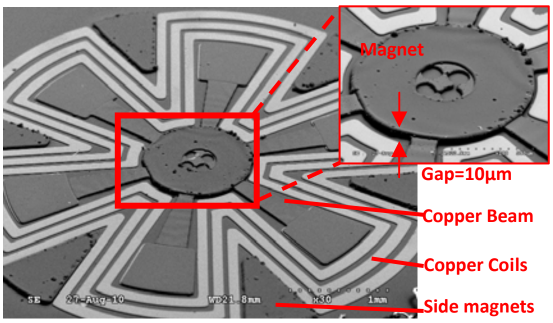

Fig 6 : SEM photo of the harvester

MEASUREMENT AND DISCUSSION

The harvester was tested with the instruments including a dynamic signal analyzer, a power amplifier and a shaker. The tested result was shown in Figure 7. The observed peak output voltage was 3.8μV at 102Hz with an acceleration of 2g and there were three peaks below 400Hz. The output power tested with optimum load resistance was in nanoWatt scale. Compared with other magnetic harvester, the vibration mass was the 10μm magnetic film in the center, which was much lighter than the bulk magnets. It greatly affects the maximum value of output power. For higher power output, thicker magnets should be electrodeposited to increase the weight by control fabrication time.

CONCLUSION

A microfabricated electromagnetic energy harvester was presented. The permanent magnets were electrodeposited for IC compatible fabrication process. The symmetrical vibration structure was studied and magnets arrangement was simulated for better performance. This device was favorable to integrated with micro system and suitable for low frequency powering applications.

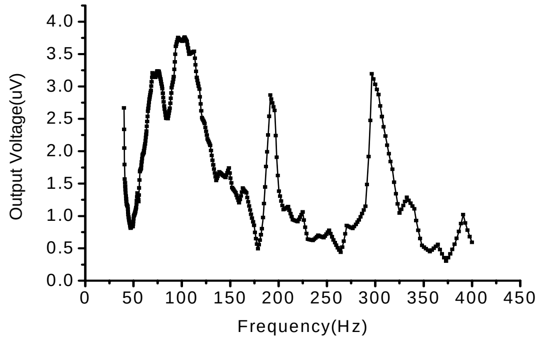

Fig 7 : Output voltage of the harvester

ACKNOWLEDGEMENTS

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