FABRICATION AND SIMULATION OF A NOVEL 3D FLEXIBLE ELECTROMAGNETIC ENERGY GENERATOR

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Abstract: This paper reports the design, fabrication, and simulation of a novel 3D flexible electromagnetic energy generator based on MEMS fabrication technology. This design is more effective than the ordinary ones, because it has six copper coils sides around the permanent-magnetic mass. The simulation results show that the resonant frequency of the PDMS cantilever is about 35Hz, and the max peak-to-peak voltage of one coil is about 1mV, at the acceleration of 0.5 g. The resonant frequency can be lowered by lengthening the PDMS cantilever or increasing the weight of the magnet. The energy generator is fabricated on two kinds of polymers, parylene and polydimethylsiloxane (PDMS), with the copper coils in the middle of them. This device is flexible and biocompatible, suitable for biomedicine applications.

Keywords: micro energy generator, fabrication, simulation, flexible, biocompatible

INTRODUCTION

With the growing demand of social production and the rapid development of micro-technology, the large number of new micro devices and systems are constantly developed and widely applied, especially the biocompatible micro-systems planted into living body to prevent and treat illnesses [1][2]. They require the powering device with smaller volume and high energy density. Unfortunately, the traditional power supply device, such as battery, has many drawbacks. The battery needs to be replaced constantly because of its short life. It is a complex operation for a micro-system, and may causes unnecessary damage. But if we can harvest ambient energy from the environment and convert it into electrical power, the supply of the micro-systems can be well solved. The energy generator is an alternative approach to powering the micro-system, for it generates electrical power from ambient energy in the environment.

Many energy sources, such as solar, wind, thermal, and vibration power, are available in the environment. The vibration power is general, constant and stable, and can be easily harvest by electromagnetic [3], piezoelectric [4], electrostatic [5] energy transduction equipment. But the internal resistance of the piezoelectric energy generator is too big to effectively output electric power，and the electrostatic energy generator is too complex and energy-consuming because of its external control circuit. So the electromagnetic energy generator based on vibration is more available than the other two kinds, and attracts universal attraction. Electromagnetic energy generators usually have tree parts, magnet mass, cantilever and coils. When the cantilever vibrates, relative motion occurs between magnetic mass and coils, and electricity will be generated according to Faraday's law of electromagnetic induction. The traditional generator usually has only one side of coils, so the space around the magnet can't be taken full advantage, and the energy density is very low [6][7]. Khan et al. [8] presented a new generator with two sides of coils beside the magnet mass, which yielded an open circuit voltage of 60.1mV, at the fundamental frequency of 371 Hz and base acceleration of 13.5 g. An electromagnetic micro energy harvester based on an array of parylene cantilevers was developed by Sari et al. [9]. A single cantilever of this device can generate a maximum voltage and power of 0.67 mV, respectively, at a vibration frequency of 3.4 kHz. But all of them are non-biocompatible and not suitable for low frequency applications, so it can't be planted into living body.

This paper discusses the design, fabrication, and simulation of a novel 3D flexible electromagnetic energy generator. The density of the generator is high, because it has six copper coils sides around the permanent-magnetic mass. And it is flexible and biocompatible, so it can work in special circumstances such as biomedicine and military affairs. The novel generator has a good simulation result and is suitable for low frequency applications.

SYSTEM DESIGN

The device is designed like a box, with copper coils on its six sides and a permanent-magnet (NdFeB) mass inside it, as shown in Fig. 1. It can work in special circumstances such as biomedicine and military affairs, because it is flexible and can deform in a certain range.

The generator is based on two kinds of polymers, parylene and polydimethylsiloxane (PDMS), with the copper coils in the middle of them. Parylene and PDMS are not only flexible but also biocompatible, so the device can be planted into living body e.g. supplying power for pacemakers and artificial retinas. It can convert efficiently the low level ambient vibration into electric energy because of its low resonant frequency.

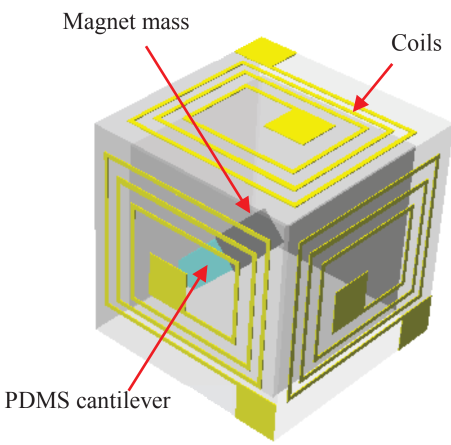


Fig. 1 Illustration of the 3D energy generator

According to Faraday's law of electromagnetic induction, all of the six copper coils can generate energy, as the permanent-magnet mass vibrates with the cantilever moving in it [10][11]. So it is very efficient within a certain volume.

The generator with moving magnet mass has several advantages. Firstly, using magnet mass as the moving parts will increase the mass of the tip of the cantilever, so the fundamental frequency will be low and suitable for low frequency applications. Secondly, moving magnet mass will simplify the fabrication process and strengthen the stability of the device comparing with copper coils as the moving parts.

FABRICATION

The copper coils were fabricated with electroplating process. In our previous work, the micro-fabrication of copper coils with electroplating technology was optimized for MEMS application [12]. The coils were electroplated in electrolyte with 10mA/cm2 current applied on at room temperature. 10μm thick copper coils were electroplated in one hour, and the width of the coils is 100μm, as show in Fig. 2.

The permanent-magnet (NdFeB) mass was used in this program because of its strong magnetism. It was coated in the PDMS layer in the suitable position, the top of the cantilever.

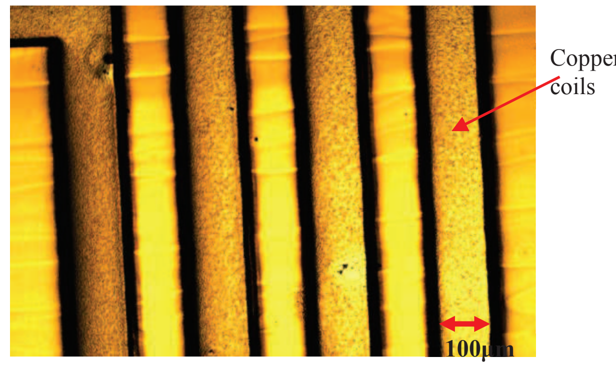


Fig. 2 The micrograph of the copper coils, the width is 100μm.

The fabrication process for the device is simple and requires only one mask, as shown in Fig. 3.

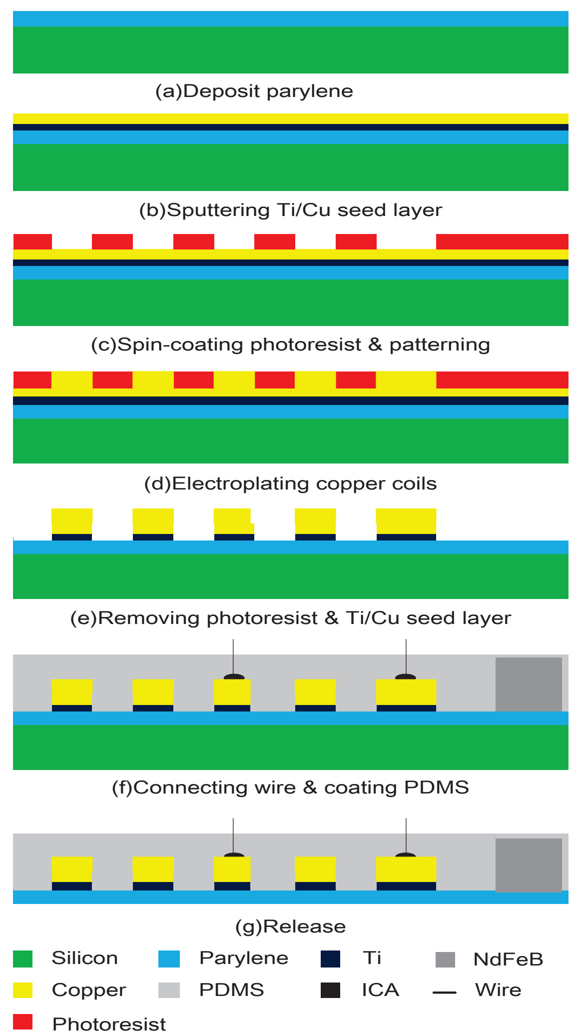


Fig. 3 Micro-fabrication process of the device

First, a 10μm thick parylene layer is deposited on the silicon substrate (Fig. 3(a)). Next, a 165nm thick seed layer is formed by sputtering Ti/Cu (Fig. 3(b)). Then, a 10μm thick photoresist (PZ-4620) is spin-coated and patterned by lithography as the masker layer (Fig. 3(c)). Afterwards, 10μm thick copper coils are formed by electroplating (Fig. 3(d)). Then, photoresist is removed by acetone, and the Ti/Cu seed layer is removed by wet chemical method (Fig. 3(e)). Next, wires are welded by Isotropic Conductive Adhesive (ICA). Then, a 1mm thick PDMS protective layer is coated, and at the same time the permanent-magnet mass is also coated inside the PDMS layer in the suitable location (Fig. 3(f)). Next, the structure layers are released from the silicon substrate (Fig. 3(g)). Finally, the device is formed through folding and bonding the structure layers, as shown in Fig. 4.

Parylene can't hold high temperature, so we welded wires by ICA. Firstly, mix well the two parts of ICA. Secondly, stick wires to copper coils by ICA. Finally, bake them in one hour at 65℃.

PDMS is a kind of polymer, flexible and biocompatible as parylene. There are several benefits to use PDMS. First, it can protect the copper coils and make the device stronger. Second, the magnet mass was fixed and the cantilever is fabricated by coating PDMS. Third, it is biocompatible, so it can be planted into living body. Finally, the Young's modulus of PDMS is very small, so the resonant frequency is very low and suitable for low frequency applications. The fabrication of PDMS is very simple, mixing well the two parts of PDMS and then baking it for one hour at 70℃ [13].

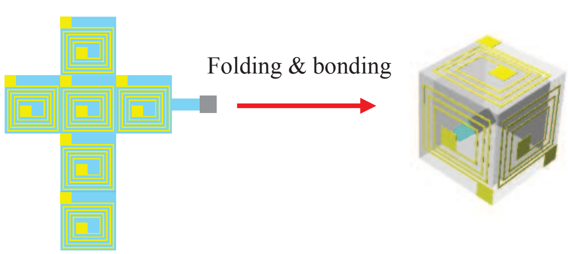


Fig. 4 Folding and bonding 2D structure to 3D energy generator

Bonding was not an easy process in the program. PDMS cannot be bonded to other materials, so we didn't use any binders and bonded two PDMS parts together directly. Firstly, preprocess the edges of PDMS parts by oxygen plasma. Then, put the two parts together and hold 30min, and them would be bonded firmly. After six times of the same process, the generator is formed, as show in Fig. 5.

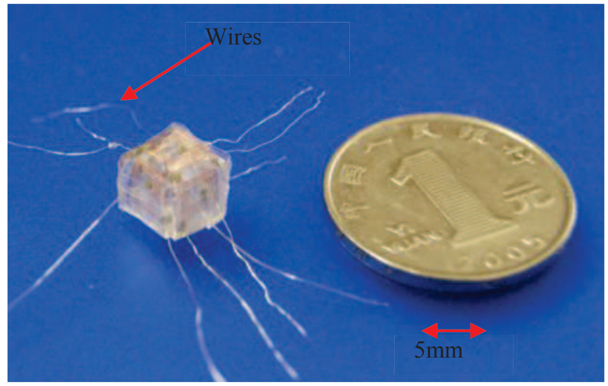
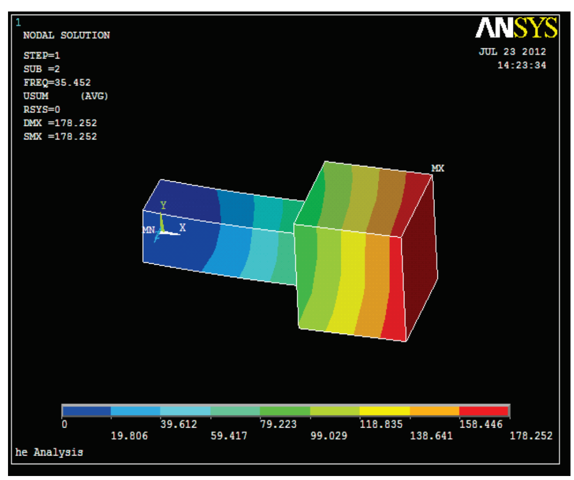


Fig. 5 The 3D flexible energy generator (5mm×5mm×5mm)

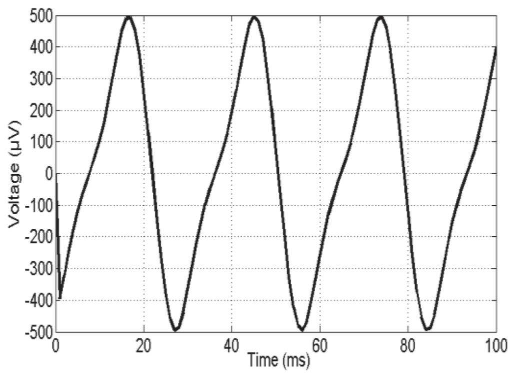
The generator is very small (5mm×5mm×5mm), and all of the six sides of copper coils can generate energy. If we connect them in parallel, we will get a big current output. And we will get a big voltage output in series connection.

SIMULATION AND DISCUSSION

The resonant frequency of the PDMS cantilever is about 35Hz simulated by ANSYS, as shown in Fig. 6(a). The resonant frequency is very low because of its small Young's modulus, and can be used in low-frequency vibration environment. The resonant frequency can be lowered by lengthening the PDMS cantilever or increasing the weight of the magnet. The simulation by Maxwell shows that the max open circuit peak-to-peak voltage of one coils side is about 1mV, at the acceleration of 0.5 g, as shown in Fig. 6(b). We can increase the output through increasing the turns of the copper coils or increasing the weight of the magnet.



(a)



(b)

Fig. 6 (a) Simulated resonant frequency of the cantilever is 35Hz, the size of the cantilever is 1mm ×1mm ×3mm, the size of the magnet mass is 2mm×2mm×2mm;(b) Simulated power output of one coils side is about 1mVpp.

CONCLUSIONS

The generator designed and fabricated in this paper is more effective than the ordinary ones, because it has six copper coils sides around the permanent-magnetic mass. The simulation results show that the resonant frequency of the PDMS cantilever is about 35Hz, and the max peak-to-peak voltage of one coil is about 1mV, at the acceleration of 0.5 g. The resonant frequency is so low that the generator can be used in low-frequency vibration environment. It is designed for the proof of concept, and the power and voltage levels can further be increased by increasing the coil turns or using a bigger magnet. The resonant frequency can be lowered by lengthening the PDMS cantilever or increasing the weight of the magnet.

ACKNOWLEDGEMENTS

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