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A shear-mode magnetoelectric heterostructure for harvesting external magnetic field energy

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Abstract. In this paper, a magnetoelectric (ME) energy harvester is presented for scavenging external magnetic field energy. The proposed heterostructure consists of a Terfenol-D plate, a piezoelectric PZT5H plate, a NdFeB magnet, and two concentrators. The external magnetic field is concentrated to the Terfenol-D plate and the PZT5H plate working in shear-mode, which can potentially increase the magnetoelectric response. Experiments have been performed to verify the feasibility of the harvester. Under the magnetic field of 0.6 Oe, the device produces a RMS voltage of 0.53 V at the resonant frequency of 32.6 kHz. The corresponding output power reaches 44.96 μW across a 3.1 kΩ matching resistor.

1. Introduction

There are a variety of energy sources in our living environment for power generation [1-5]. The external magnetic field has attracted much attention due to its abundance [6-8]. Recently, research has been conducted on magnetoelectric (ME) laminated composites for their potential applications in magnetic energy harvesters. The ME laminated composites typically work in L-T mode, where the piezoelectric constant d_{31} is used. However, the shear piezoelectric constant d_{15} can attain a larger value for the typical piezoelectric materials of PZT5H and PMN-PT [9], and the magnetoelectric response might be further improved.

In this paper, we develop a ME heterostructure for energy harvesting from external alternating magnetic field, which operates in shear-mode. The shear vibration is achieved as a result of the magnetostriction of the magnetostrictive material and the retaining plates. Meanwhile, concentrators are employed to enhance the response of the device. Experiments have been carried out, which validates the feasibility of the proposed device.

2. Structure of the energy harvester

Figure 1 illustrates the structure of the proposed device. Two permalloy concentrators are bonded at both ends of the Terfenol-D plate, which can concentrate the external magnetic field. The NdFeB magnet provides bias magnet field on the Terfenol-D plate. The PZT5H is polarized along 3-direction. Magnetostriction of the Terfenol-D is induced under the external alternating magnetic field. The stress is transmitted to the PZT5H plate which works in shear-mode due to the stiffness of the retaining plates. The PZT5H then generates voltage output. The output power can potentially improve due to the concentration effect and the larger piezoelectric constant d_{15}.

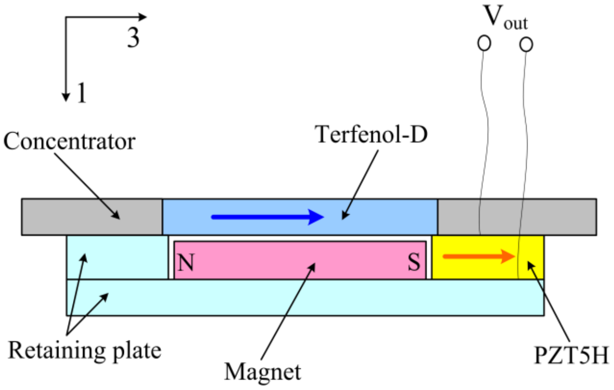

Figure 1. Structure of the proposed magnetic field energy harvester.

3. Analysis

The shear stress is transmitted to the PZT5H as a result of the magnetostriction of the Terfenol-D. At open-circuit condition, the piezoelectric constitutive equations are given by [10]

$$T_5 = c_{55}^D S_5,\ E_1 = -h_{15} S_5, \tag{1}$$

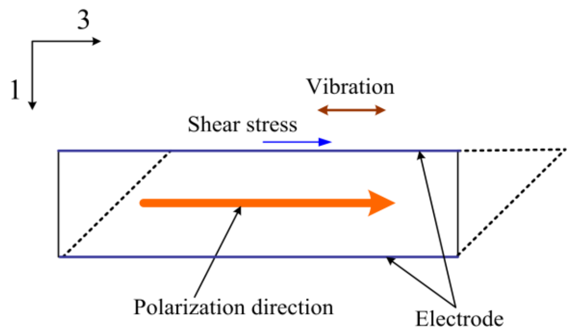

Figure 2. Shear vibration of the piezoelectric PZT5H.

where T_5 is the shear stress, c_{55}^D is the elastic stiffness coefficient (at constant D), S_5 is the shear stress, and h_{15} is the piezoelectric stiffness constant. According to equation (1), the electric field in 1-direction can be expressed as

$$E_1 = -h_{15} \frac{T_5}{c_{55}^D}. \tag{2}$$

The open-circuit voltage of the PZT5H can be given by

$$V_{open-circuit} = E_1 t = -h_{15} t \frac{T_5}{c_{55}^D}, \tag{3}$$

where t is the thickness of the PZT5H plate. Equation (3) indicates that the open-circuit voltage is proportional to the thickness of the PZT5H plate and the shear stress. For a given piezoelectric plate, the response of the device can be enhanced by selecting a suitable NdFeB magnet to attain optimal bias magnetic field.

4. Results and discussions

Figure 3 plots the output RMS voltage of the proposed device as a function of the frequency of the alternating magnetic field at H_{ac} = 0.6 Oe. It can be seen from figure 6 that the maximum output voltage attains 0.53 V at 32.6 kHz.

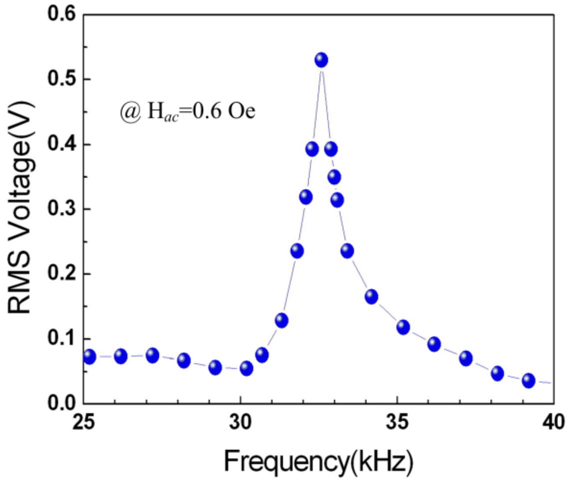

Figure 3. Output voltage as a function of the frequency of the external magnetic field at 0.6 Oe.

At the resonant frequency of 32.6 kHz, a resistance box is connected to the piezoelectric plate to investigate the output performance of the device. The results are shown in figure 4. It can be seen from figure 4 that, as the resistance increases, the output power increases first, and then reaches the maximum value. With the further increase of the load resistance, the power decreases. The maximum output power is 44.96 μW and the optimal load resistance is 3.1 kΩ.

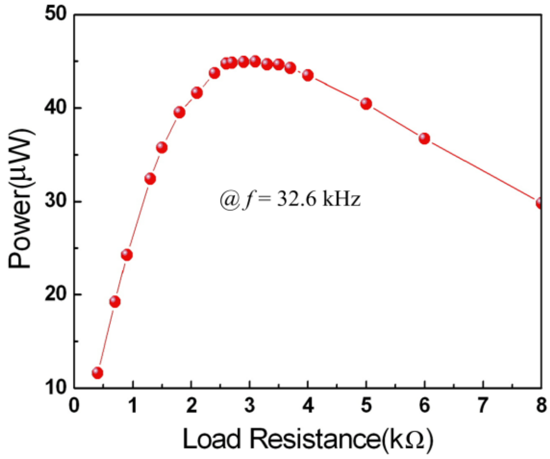

Figure 4. Output power versus load resistance at the resonant frequency of 32.6 kHz.

5. Conclusions

In conclusion, we have investigated a magnetoelectric energy harvester for scavenging external magnetic field energy. The proposed harvester uses permalloy concentrators to concentrate the alternating magnetic field and operates in shear-mode. Experimental results show that the device can feasibly work, with a maximum power of 44.96 μW on a 3.1 kΩ resistor.

Acknowledgments

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