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Piezoelectric Vibration Energy Harvesters with Stretched and Multi-stacked Organic Ferroelectric Films

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Abstract

We investigated the vibration energy harvesters with poly(vinylidene fluoride/trifluoroethylene) films and the improvement of power generation by using laminated and stretched ferroelectric films. The cantilever type harvesters were generated electricity at around 25 Hz of resonant frequency, which is lower than the ambient vibration. The output power of 10-layered harvesters was estimated to be 3.1 μW, and that of stretched harvesters had 3.6 times as compared to un-stretched. In addition, the resonant frequency of each harvesters were practically constant, even if the techniques of laminating and stretching were used because of the flexibility of organic ferroelectric films.

1. Introduction

Energy harvesting have attracted the significant attention in the recent years because it converts a wasted ambient energy into an electric power. The various ambient energy include the light, thermal, wind and vibration. The vibration energy widely exists in our living environment and includes the large energy source. The ambient vibration which has a low frequency (–100 Hz) mostly distributed, thus the resonant frequency of the vibration harvesters should be adjusted to the low frequency. The vibration harvesters using the inorganic piezoelectric materials have been investigated [1,2], however the resonant frequency of harvesters with inorganic materials was higher than that of environmental vibration.

Organic ferroelectric materials are attracting great attention as promising materials in the growing field of molecular electronics, especialy in the area of sensor applications. Poly(vinylidene fluoride/trifluoroethylene) [P(VDF/TrFE)] are well-known organic ferroelectric polymers and have been widely investigated because they show not only ferroelectric but also piezo-[3] and pyroelectric[4] properties. P(VDF/TrFE) polymers have a low Young's modulus and flexibility, and can be large deformation, therefore the energy harvesters with P(VDF/TrFE) have been expected to show the lower resonance frequency than the inorganic materials.

In this study, we investigated the performance of energy harvesters with P(VDF/TrFE) films. To improve the amount of power generation, we tried to increase the effective area of the energy harvesters by laminating of the multiple P(VDF/TrFE) films. The relationship between the vibration energy and piezoelectric properties of the stretched P(VDF/TrFE) films were evaluated for obtaining of high efficiency power generation.

2. Experimental

P(VDF/TrFE) was dissolved in 10 wt% methyl ethyl ketone. The solution was spin-coated onto the Al bottom electrode coated on polyethylene naphthalate films (25 μm). The P(VDF/TrFE) films were annealed at 125 °C for 2.0 h under nitrogen atmosphere. The thickness of P(VDF/TrFE) films were about 1.0 μm. The cantilever type energy harvesters were fabricated for measuring the piezoelectricity and power generation. The unimorph cantilever size for the power generation was 5×7 mm^2, and that for the piezoelectric measurement was 0.5×4 mm^2 (Fig. 1).

The electric power generation was measured under applying mechanical vibration to the cantilever, and the displacement of cantilever tip was read by a laser Doppler vibrometer. To observe the large displacement of energy harvester, the weight of 0.04 g was fixed to the tip of cantilever and the acceleration of excited vibration was 10 m/s^2. The piezoelectric properties were measured using a laser Doppler vibrometer. The piezoelectric vibration was generated by applying a sinusoidal voltage between the upper and bottom electrode, and the displacement of the cantilever tip was read by a laser Doppler vibrometer. The relationship between the molecular orientation and the vibration power generation characteristics of P(VDF/ TrFE) was evaluated by using the P(VDF/TrFE) stretched films. The P(VDF/TrFE) films were stretched at 150 %.

3. Results and Discussion

Figure 2 shows the output power and the displacement of P(VDF/TrFE) energy harvesters as a function of the vibration

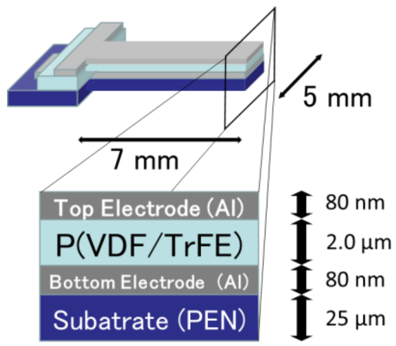


Fig. 1 Device structure of the cantilever type energy harvesters.

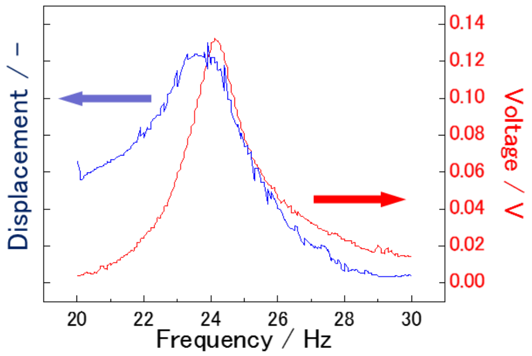


Fig. 2. The output power and the displacement of unimorph cantilevers as a function of the vibration frequency.

frequency. The resonant frequency of output voltage agree with that of tip displacement. This suggests that the output power of energy harvester was caused by the displacement of the cantilever, namely, the piezoelectric effects of P(VDF/TrFE) films. The frequency peak was observed at around 25 Hz, which was quietly lower than that of the inorganic hard harvesters. Therefore, the organic piezoelectric energy harvester indicated the possibility for the efficient power conversion of environmental vibrations widely present below 100 Hz.

Figure 3 shows the output power and the piezoelectric constant e_{31} of the unimorph cantilevers, as a function of the remnant polarization (P_r) of P(VDF/TrFE) films. Both output power and e_{31} increased with increasing of the P_r and they were saturated over the P_r of 60 mC/m^2. This means that the piezoelectric constants of P(VDF/TrFE) films need to increase for the high power generation. Subsequently, the number of stacked layers increased the output power of harvesters because the stacking of layers increased the effective electrode area. The generated power of the 10-layer laminated harvesters was measured to be 3.1 μW, however that of theoretical value was calculated to be about 6.5 μW. This difference of two value was probably caused the damages to the electrodes and films during the polling process.

The power generation and piezoelectric coefficients e_{31} of P(VDF/TrFE) un-stretched films were measured to be 61.2 nW and 8.24 mC/m^2, respectively, and those of the stretched films in the direction parallel to cantilever and perpendicular to cantilever are summarized in Table I. The piezoelectric

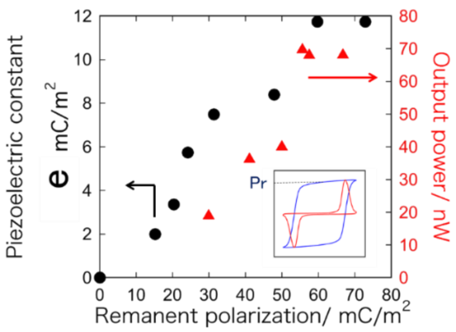
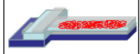
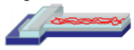
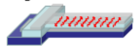


Fig. 3. The output power and the piezoelectric constants e_{31} of the unimorph cantilevers, as a function of the remanent polarization.

Table. I. Maximum output power and the piezoelectric constant.

	(1) Un-stretched 	(2) Molecular chain // longitudinal direction 	(3) Molecular chain ⊥ longitudinal direction 
Resonant Frequency: ω(Hz)	24	24.5	23
Effective Voltage: V_{rms}(mV)	400	700	300
Piezoelectric Coefficient: e (mC/m^2)	8.24	16.92	2.19
Output Power: $P(nW)$	61.2	222	22.4

constants depended on the orientation of P(VDF/TrFE) molecular chains, thus the vibration power generation characteristics were improved by using the stretched in the direction parallel to cantilever.

Conclusions

The energy harvesters of P(VDF/TrFE) films were fabricated, and the multiple laminating and stretching films were tried to improve their generated performance. The harvesters of single films were measured the power generation at 25 Hz, which was lower resonant frequency than that of inorganic materials. The power generation increased with increasing of the piezoelectric constant of P(VDF/TrFE) films. The generated power of the 10-layer laminated harvesters was measured to be 3.1 μW. The piezoelectric constants and generated performance depended on the orientation of P(VDF/TrFE) molecular chains. The vibration energy harvesters using both the laminating and stretching techniques are expected to become the efficiency harvesters under the ambient vibration.

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