# Development of a High-performance Fluorpolymer Electret Mixed with Nano-particles and Its Application to Vibration Energy Harvesting

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**Abstract.** We have been developing small power generation device of capacitance-type to be converted to electrical energy vibration energy using an electret. In this Study, dielectric nano-particles were mixed with an electret made of fluorocarbon polymer. As a result, implanted charge density of the electret was successfully enhanced thanks to the mixing of particles. A small sized vibration energy harvester (VEH) was fabricated using the fluorocarbon mixed with dielectric nano-particles. As a result of applying vibration (20 Hz, 0.65 G) to the fabricated VEH, The maximum generated power of approximately 50 μW was obtained.

## 1. Introduction

Recently, vibrating energy harvester (VEH) which generates electrical power from environmental vibration was widely developed [1-5], because it is prospective power supply for low-power electronic devices such as wireless sensor networks [1, 2]. Since frequency of environmental vibration is usually on the order of a few to several tens of hertz, electrical power generated by electrostatic VEH using an electret are generally higher than that generated by a electromagnetic VEH using a magnet [3]. Electret is dielectric material that keeps electric charge semi- permanently. Previously, many type of electrostatic VEH using electret were developed. We also developed a novel VEH consists of a fixed electret on bade electrode and a high dielectric constant plate such as barium titanate ($BaTiO_3$) which is suspended by vertically vibrated spring with counter electrode with, as shown in Fig. 1 [4, 5].
Surface charge density of electret is most impotent characteristic for VEHs because generated power from a VEH is theoretically proportional to square of it. Conventionally, fluorocarbon polymers [1-5] were frequently used as electret in VEHs because they keep higher concentration of electrical charge than other materials. CYTOP is famous fluorocarbon polymer as an electret, of which surface charge density and its time stability are better than other fluorocarbon polymer [6]. Additionally, it is reported that trapped charge density in a CYTOP can be enhanced when nano-clusters are added into the CYTOP because the nano-clusters are polarized by the electrical field applied during charge implantation, and they work as the charge trapping sites by their polarization [7]. Because of the above mentioned background, we propose a novel electret made of CYTOP in which many nano-dielectric-particles are added. It is expected that the charge density in CYTOP increases with dielectric constant of the nano-particles. Relationship between surface potential of CYTOP with nano-particles and consent ratio or dielectric constant of nano-particles are also evaluated.

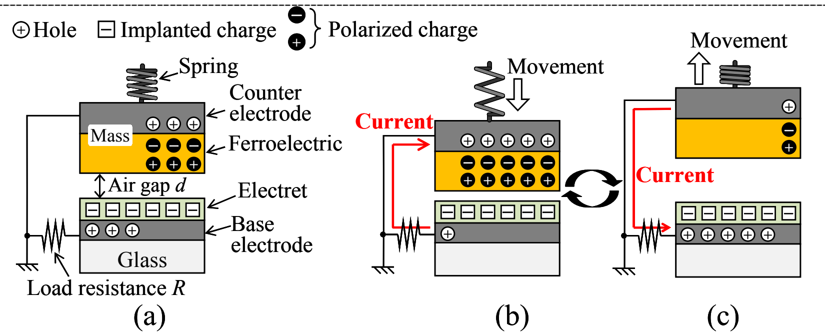


**Figure 1.** (a) Schematic diagram of developed Vibration energy harvester (VEH). (b) When the upper electret and dielectric plate supported approach the electret, dielectric plate was polarized by electric potential difference from the electret, and it attracts electric charge. (c) When the upper electret and dielectric plate move away from the electret, electric charge is attracted to the lower electrode and electret. The movement of the electric charge is changed to electric energy by the load resistance.

## 2. Experimental method

Fabrication process of the CYTOP with nano-particles is described as follows. At first, liquid CYTOP and nano-particles ($BaTiO_3$ or $CaF_2$) was mixed by a centrifugal mixer (THINKY CORPORATION, model:ARE310). Here, typical diameter of the $BaTiO_3$ and $CaF_2$ particles were 50 nm and 100 nm, respectively. Revolution speed of the mixer and mixing time were 2000 rpm and 60 sec, respectively. Next, mixed particles in CYTOP were dispersed using ultrasonic homogenizer (NIHONSEIKI KAISHA LTD., model:US-150T). Applied power and time of the ultrasonic were 150 W and 5 h. Then, the mixture was spin coated on a on the thermal oxidation ($SiO_2$) layer of a low-resistive silicon substrate, and dried by heating on an 80°C of hotplate. Then, it was baked using a clean oven. The baking temperature and baking time are 100°C and 1 h, respectively. Finally, negative electric charge was implanted to the fabricated electret by corona discharge method, as shown in Fig. 2.
The schematic diagram of the fabricated electret device is shown in Fig. 3. Thickness of CYTOP layer and $SiO_2$ layer are 5.4 μm and 1 μm, respectively. The low-resistive Si substrate acts as a lower electrode for the electret. Several kinds of samples were fabricated from which the mixture ratio differs, and these characteristic as an electret were compared.

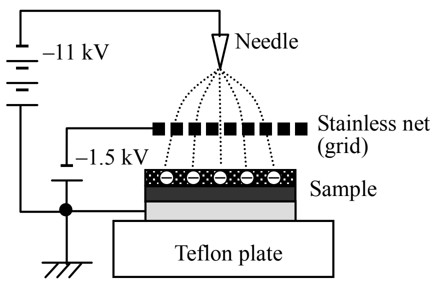


**Figure 2.** Schematic of setup for corona discharge to implant electron to the fluorpolymer film..

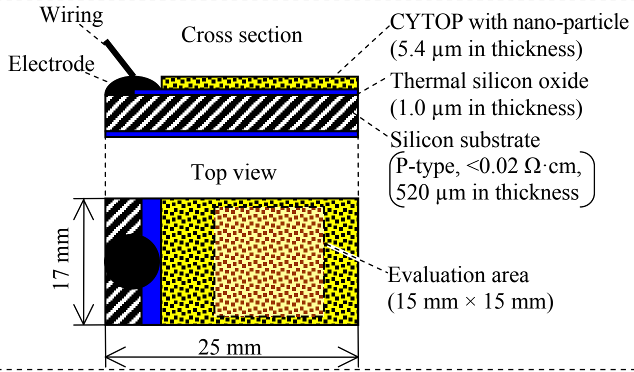


**Figure 3.** Schematic diagram of the fabricated electret device.

## 3. Results and discussion

### *3.1. Surface potential of CYTOP with nano-particles and its stability*

Time degradation of surface potential of electrets made of mixture of CYTOP and $BaTiO_3$ nano-particles is shown in Fig. 4. As compared with pure CYTOP, the initial surface potential of CYTOP which mixed the $BaTiO_3$ nanoparticle was also high, and the reduction speed was also slow. Surface potential monotonically increased with the mixed rate of a nanoparticle, when the mixed rate is 10% or lower. However, the surface potential of the electret rapidly decreased with time progress, in which the mixture ratio is 20%. As a result of observation of the sample using scanning electron microscopy (SEM), it is confirmed that there is many aggregate of the nano-particle. Therefore, it is presumed that the implanted electric charge discharged through the aggregate of nano-particles, as shown in Fig. 5. Time degradation of surface potential of electrets made of mixture of CYTOP and $CaF_2$ nano-particles is shown in Fig. 6. This result indicates that the surface potential of CYTOP also increases by mixing $CaF_2$ nano-particles. However, the amount of increase in the surface potential of CYTOP/$BaTiO_3$ is better than that CYOP/$CaF_2$. The reason why this result was obtained is discussed below. When nano-particles are mixed in a CYTOP, the particles are polarized by electrical filed of corona discharge. Additionally, degree of electrical polarization probably increases with dielectric constant of the particles. Therefore, that capability of the $BaTiO_3$ to capture negative electric charge maybe larger than that of the $CaF_2$ because dielectric constant of $BaTiO_3$ is larger than that of $CaF_2$.

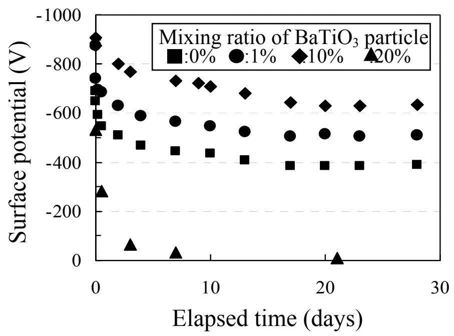


**Figure 4.** Time degradation of surface potential of electrets made of mixture of CYTOP and $BaTiO_3$ nano-particles.

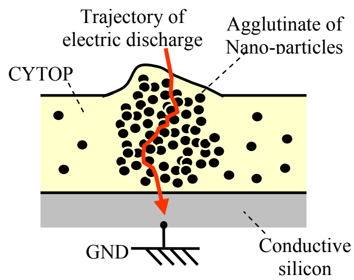


**Figure 5.** Schematic illustration describing how electric charge discharges through the aggregate of nano-particles.

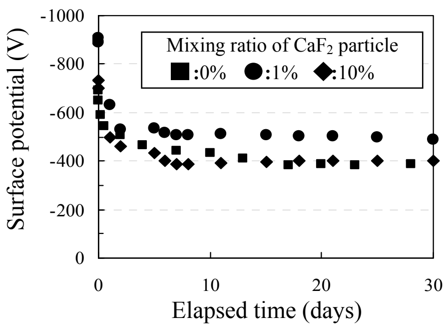


**Figure 6.** Time degradation of surface potential of electrets made of mixture of CYTOP and $CaF_2$ nano-particles.

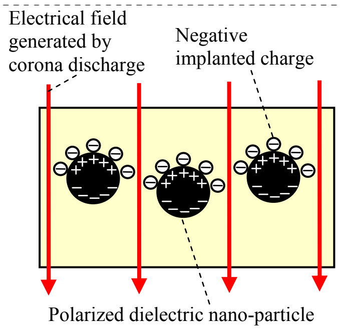


**Figure 7.** Schematic illustration describing how polarized nano-particle captures electric charge [4].

*3.2. Fabrication of VEHs using CYTOP with nano-particles electret and their characterization*

Five kinds of small VEHs were fabricated using CYTOP mixed with the particles. Schematic diagram and photographs of the fabricated VEH are shown in Fig. 8. Then electric power generated by the fabricated VEHs was characterized. The measurement system for the characterization is shown in Fig. 9. The result of characterization is shown in Fig, 10. This result shows that the maximum power of the approximately 50 μW was obtained when the VEH using CYTOP mixed with 1% of $BaTiO_3$ nano-particles as the electret. This generation power is about 10 times as large as the VHE using pure CYTOP. On the other hand, the generation power of VEH using CYTOP with 10% of $BaTiO_3$ becomes much smaller than that using pure CYTOP as the electret. This result indicates that the mixing of small amount (>10%) of dielectric particles into fluorpolymer electret is effective to increase the capability of power generation of VHE.

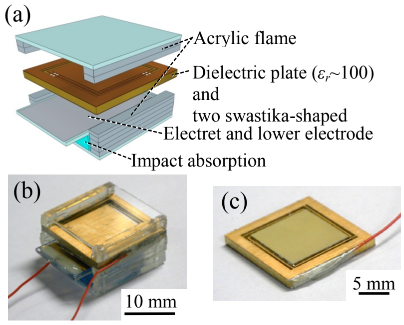


**Figure 8.** (a) Schematic illustration and (b) photograph of fabricated small vibration energy harvesting device, and (b)swastika-shaped flat spring used in the device.

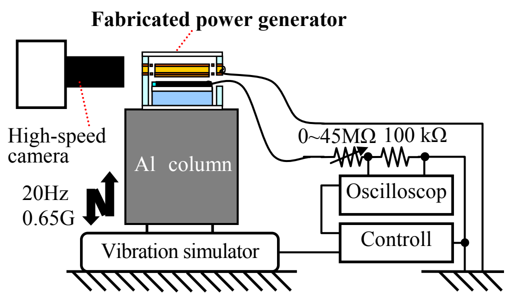


**Figure 9.** Setup for measuring generation power of the fabricated vibration energy harvesting device.

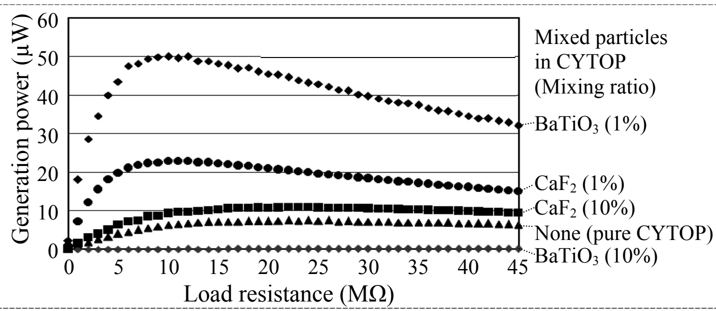


**Figure 10.** In this case simply justify the caption so that it is as the same width as the graphic.

## 4. Conclusion

In this study, we succeeded in raising the electric charge density of an electret made of one of fluorpolymer "CYTOP" by mixing dielectric particles. When the concentration of the particles in the CYTOP is smaller than several percent, the surface potential of the CYTOP with nano-particles after charge implantation monotonically increases with concentration of the nano-particles. However, the mixed nano-particles made an aggregate, and implanted charge discharged through it. This result indicates that the nano-particles should be mixed in the CYTOP with optimized concentration. We also developed an electrostatic vibration energy harvester (VEH) using CYTOP with nano-particles as an electret, which generated more electric power than the VEH using pure CYTOP.

## 5. References

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