

Energy conversion of electrostrictive poly(vinylidene fluoride-co-hexafluoropropylene)/Graphene composites

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Abstract. This study investigates energy-conversion properties of the electrostrictive polymer, poly(vinylidene fluoride-co-hexafluoropropylene), P(VDF-HFP), filled with graphene nanosheets (GNPs). The composites (i.e., P(VDF-HFP) and GNPs) were fabricated by using the solution casting method. The dielectric constant of these electrostrictive materials was measured to observe the energy conversion property with different frequencies using an LCR meter. Their mechanical properties were measured using a photonic sensor with varying various input vibrations and electric fields to calculate their electrostrictive coefficients. These characterized results revealed that dielectric constants and electrostrictive coefficients were significantly increased when GNPs fillers were filled higher. For the electrical property, the generating current, which was measured across these polymer films, increased proportionally with respect to the adding GNPs. In this obtained result, the main finding of P(VDF-HFP)/GNPs composites is a promising electrostrictive material for applications of electromechanical energy conversions in many smart-material systems.

1. Introduction

Energy harvesting is the process, which can converse small amounts of ambient energy into electrical energy for using suitable transducers in many smart systems. For portable and self-powered electronic devices, energy conversion using electrostrictive materials has the potential applications to be electromechanical transduction as a promising technique. In fact, electrostrictive is the property of materials that can compress itself that induced strain (S) in the regions of high electric field strength according to equation (1)

$$S = ME^2 \quad (1)$$

Where M is an electrostrictive coefficient [1-2]. Moreover, when this material is received stress (T) from vibration under an electric field, it can perform a pseudopiezoelectric property. Then, it can generate electricity from the stress (T), and this specific property of this promising material for energy-harvesting devices. In addition, the key factor to be developed for increasing the capability of electrostrictive material is a dielectric property. This factor relates directly to a polarization (P) [3]. The effective process to manipulate the dielectric permittivity is to add a filler into a polymer matrix. As this expected

result, the filler can lead to the increasing of charges between the boundary of the material matrix; furthermore, it can affect the increase of interfacial polarization as well as the dielectric constant to be increased too. In this work, Poly(vinylidene fluoride-co-hexafluoropropylene) polymer, P(VDF-HFP), is selected because it has unique properties, such as flexibility, low processing temperature, and low dielectric constant. P(VDF-HFP) can be enhanced its electrostrictive property by adding graphene nanoplatelets (GNPs). Its unique properties are high electrical conductivity, high modulus, and high specific surface area [4]. Thus, the composite P(VDF-HFP)/GNPs film is used to study the electrical, electrostrictive properties, and capability of energy conversions.

2. Experimental

2.1. Preparation of P(VDF-HFP) with GNPs composite films

The GNPs 0 (for PVDF-HFP pure), 1, 2, 3, and 4 wt% were added into the DMF and dispersed by using ultrasonic for 20 minutes. Then, the P(VDF-HFP) granules 20 g were added in solution and mixed continuously at 80 °C for 3 hours to gain a homogeneous solution. The final solution was cast onto a glass surface by a solution casting method and dried in the oven at 80 °C for 14 hours to remove the solvent.

2.2. Electrical properties and electrostrictive properties measurement

The electrical properties and electrostrictive properties of all samples were characterized. The electrical properties especially the dielectric constant was assessed across 1-10⁵ Hz by an LCR meter (Model IM 3533, HIOKI)[3]. Then, the electrostrictive behavior was assessed by measuring the electric field (E), induced strain (S) with a photonic displacement sensor (Model MTI-2100, Photonic sensor, sensitivity 0.0058 mm/mV) at a low frequency and low electric field strength ($f = 1$ Hz, $E \leq 2$ MV/m)[2]. The sample was placed between two electrodes, and the electric field (E) was applied to the sample across the thickness direction from high voltage (Model 610E, Trek). The Log-in amplifier (Model SR510, SRS) was applied to measure the induced strain in the following direction.

2.3. Energy conversion measurement using the energy-harvesting experiment setup

These samples were sputter-coated with gold electrodes (20×20 mm). They were then fixed with a mechanical shaker providing sinusoidal 20 Hz from a function generator and the signal amplified using a power amplifier. The dc-bias electric field was applied across both electrodes using a high-voltage power supply. The laser displacement sensor (Model IA030, KEYENCE) [1] was employed to observe the sample displacement. The induced output voltage from the polymer was amplified by a current preamplifier (sensitivity 1mA/V), then the signal was filtered to 20 Hz by a lock-in amplifier, and thus sending all output signals to the oscilloscope display. The measured voltage output can calculate the induced current of the electrostrictive material by varying the sensitivity of the current preamplifier.

3. Results and discussion

Figure 1 shows that the dielectric constant decreased while the frequency increased because of the effect of oriented polarization. It occurred when molecules of material, having a dipole moment, were induced to rotate under an AC-electric field. At the low frequency, dipole moment could follow the direction of the electric field, but it could not reorient at the high frequency. In addition, the dielectric constant also proportionally increased when the GNPs filler was more added because the GNPs filler conducted the interfacial polarization occurring from the induced charges in the boundary of the two-phase. The charge induced dipole moment between two boundaries. The increase of this specific interfacial surface area affected by the conductive filler (i.e., GNPs) was able to influence the dielectric constant to significantly increase as well. The electrostrictive coefficient (M), which could be calculated from the slope of the

graph between induced strain (S) and square magnitude of electric field (E^2) increased by adding the GNPs content, as shown in figure 2. In this case, the GNPs content was conducted to increase the total polarizations related to the dielectric constant. In addition, the electrostrictive coefficient (M) was proportional to the dielectric constant according to equation (2) [2].

$$M \propto \epsilon_0 (\epsilon_r - 1)^2 (Y \times \epsilon_r)^{-1} \quad (2)$$

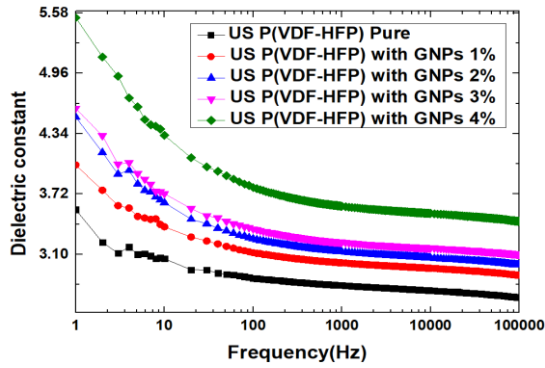


Figure 1. Dielectric constant as a function frequencies of all samples.

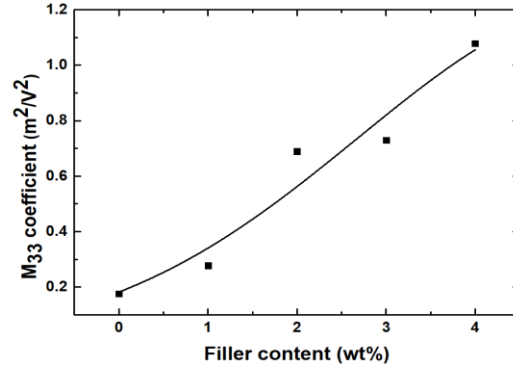


Figure 2. Electrostrictive coefficient versus the GNPs content.

The voltage calculated from the displacement on polymer using a photonic sensor is shown in figure 3. In the neat P(VDF-HFP) film, the voltage output at the operating frequency of 20 Hz was increased due to the increased displacement on the film from the mechanical shaker, as shown in figure 4. In addition, voltage output also increased with GNPs content, and the highest induced current from the sample was obtained with the maximum GNPs content, as shown in figure 5. In the theoretical modeling, the stress (T) on the samples could induce strain (S), by mechanical shaker under electric field, and electrical displacement (D) was also undergone, as shown in equation (3) and equation (4),

$$S_1 = s_{11}T_1 + M_{31}E_3^2 \quad (3)$$

$$D_3 = \epsilon_{33}E_3 + 2M_{31}E_3T_1 \quad (4)$$

Hence, these two parameters led to the polymer generating output current [1] according to equation (5),

$$I = 2M_{31}YE_{dc} \int \left(\frac{\partial s}{\partial t} \right) dA \quad (5)$$

The increase of electrostrictive coefficient (M) with GNPs content was also enhanced polymer abilities to compress itself, and led to the change of more strain under the same electric field. For this reason, the P(VDF-HFP) with more GNPs content adding could be induced more strain, led to the increase of the output voltage. Then the polymer composite could generate more output current under the stable dc-electric field, as shown in figure 6.

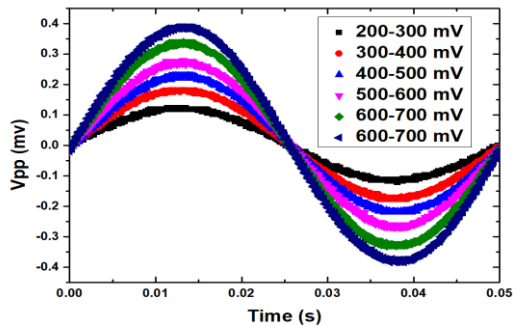


Figure 3. Input voltage signal as a function of time with various displacement.

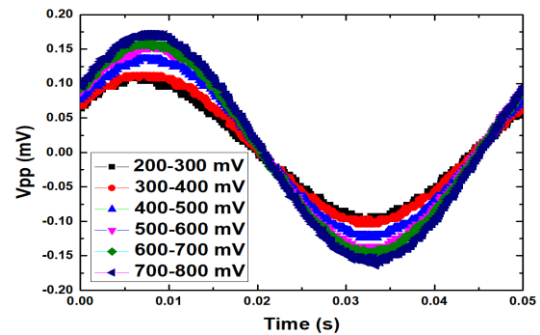


Figure 4. Output voltage from neat P(VDF-HFP) film measured as a function of time with various displacement.

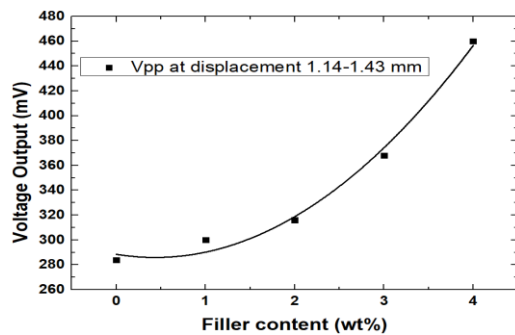


Figure 5. Voltage output versus GNPs contents.

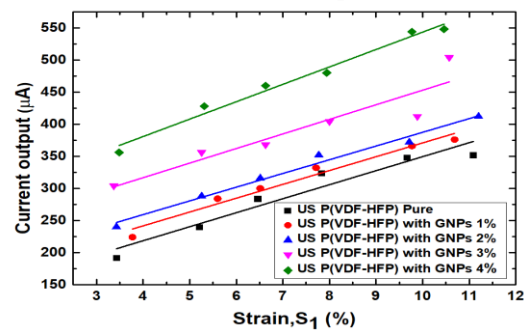


Figure 6. Induced current versus strain of all samples.

4. Conclusion

The P(VDF-HFP) filled with GNPs composites was fabricated to study energy conversions of electrostrictive polymers. The electromechanical conversions of these polymers were improved their electrostrictive properties by proportional increases of the GNPs. Their dielectric constants and electrostrictive coefficient (M) were also increased by the GNPs due to the increment of interfacial polarization at the boundary between GNPs particles and P(VDF-HFP) matrix. This experiment can enhance the electrostrictive property that was presented by measured results with various input vibrations and electric fields. Then, the polymers can provide a higher electrical-output voltage and current than neat polymers, depended on GNPs content adding. Hence, the potential applications of this electrostrictive material may be better smart actuators as well as energy harvester, based on energy-conversion capabilities of the electrostrictive materials.

Acknowledgements

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