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Investigation of electret devices using liquid crystal polymer

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Abstract

Development of electrets materials are required to improve performance in electronic devices such as sensors and vibration-driven microgenerators. In this study, we have investigated electret devices using liquid crystal polymer (LCP). LCP electret films were by a typical corona treatment with high voltage over -4 kV. The films exhibit surface charge density of approximately -3 mC/m^2 and piezoelectric property.

1. Introduction

In internet of things (IoT) society, many sensors work around us gather information regarding human life, security, and production. Toward the coming age of IoT society, power generation devices are requited in order to apply to the sensors. For the power source devices, we focus on a vibration power generation device. Three types of the devices have been reported; electrostatic induction type [1, 2], piezoelectric type [3], and electromagnetic induction type [4]. These devices have response frequencies of several tens Hz that are low-frequency ambient vibration around us. Thus, the power generation devices harvest the energy from the movement of the human body and minute vibrations by converting mechanical response to electricity [5, 6].

Among vibration power generation devices, we focus on electrostatic induction-type devices, because they have an advantage such as the usage of organic functional materials as charge accumulation layer. Organic materials-based device can attach anywhere regardless of their location owing to their flexibility and lightweight property. Additionally, maximum generated power (P_{max}) increases with lower dielectric constant. Typical dielectric constant of organic materials is ~ 3. Thus, P_{max} tends to improve the vibration power. For the electrostatics induction-type devices, charge-accumulated dielectrics, ‘‘*electrets*’’, are used as organic materials such as polyethylene and azobenzene polymers [7, 8]. In this study, we have investigated the electrets using random copolymer of 2,6-hydroxy naphthenic acid and parahydroxy benzoic acid (poly(HNA/HBA), Fig. 1) that is liquid crystal polymer. The polymer shows excellent electrical properties that are low dielectric constant of ~3 independent of frequency from 1 Hz to 1 MHz. This result is considered that poly(HNA/HBA)-based electrets can harvest the vibration energy in the wide range of frequency.

2. Experiments

A 6−8 µm thick poly(HNA/HBA) film was provided by POLYPLASTICS Co., Ltd. A 100 nm thickness of bottom Aluminum (Al) electrode was deposited on the poly(HNA/HBA) film under vacuum condition of 4×10^{-4} Pa. Then, we performed corona treatments with corona scanner apparatus at a high voltage. The electrets films were prepared by applying at -4 – -5 kV. The stage temperature kept at 30℃ during corona treatments. The surface potential of poly(HNA/HBA) films with bottom the electrode was measured with surface potential meter. After the corona treatments, the top Al electrode was deposited on the poly(HNA/HBA)/Al films. The piezoelectric characteristics of poly(HNA/HBA)-based electrets were measured with a laser doppler vibrometer and optical microscope [9]. The amplitude range of the input voltage was 40 – 200 V, and the frequency of the resonant vibration was 1.5 kHz.

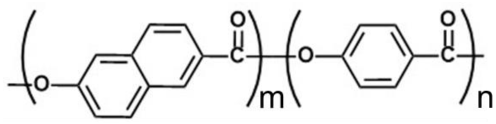


Fig. 1. A Chemical structure of poly(HNA/HBA).

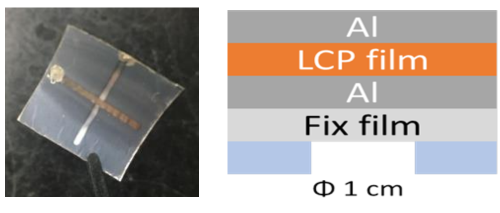


Fig. 2. (left) A photograph of poly(HNA/HBA) film with electrodes. (right) A moonie type device structure for inverse piezoelectric measurement.

3. Results and Discussions

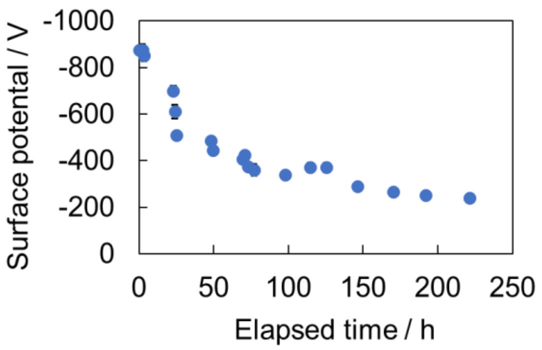
Figure 3 (a) shows the time-dependence of surface potential for poly(HNA/HBA) electrets. The surface potential gradually decreases from ~-900 V to ~-200 V when poly(HNA/HBA) electrets are stored in the atmosphere. The surface charge density, σ, that is the figure of merit for the electret were calculated using the following equation:

$$\sigma = \frac{\varepsilon\varepsilon_0}{d}V$$

, where V is the surface potential, d is the sample thickness, ε is dielectric constant, and ε_0 is dielectric constant of vacuum [10].

Figure 3 (b) shows the time decay of the σ. The σ was approximately -0.1 mC/m^2 without the corona treatment. Immediately after the corona treatments, the σ increased up to ~ -3 mC/m^2. The value decreased to ~ -1 mC/m^2 when the sample was stored in the atmosphere. This is because the accumulated charges in the poly(HNA/HBA) electrets released under the influence of moisture in the atmosphere [11, 12]. We have shown that LCP can be used as novel materials for electrostatic induction power generation.

(a)



(b)

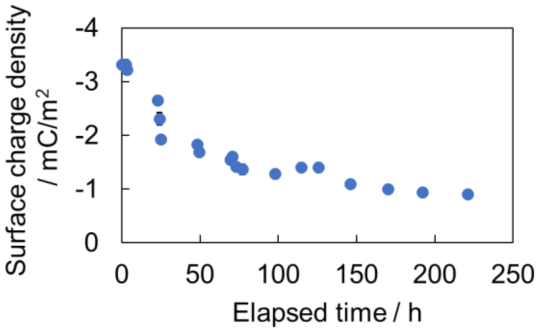


Fig. 3. Time-dependent of (a) surface potential and (b) surface charge density for poly(HNA/HBA) electrets used in this study.

To evaluate the piezoelectric properties of poly(HNA/HBA) electrets, we performed inverse piezoelectric measurements. As shown in Fig. 4, the displacement of corona treated poly(HNA/HBA) film increases according to the frequency of the AC voltage. Linear relationship between the piezoelectric displacement and the applied voltage is observed. This result indicates that the corona treated poly(HNA/HBA) films have piezoelectricity and expect to detect mechanical deformation modes of the film with electrical generation from vibrations. The piezoelectric constant (d_{33}) of the poly(HNA/HBA) films is still lower value of ~0.5 nm/V, comparing with polypropylene electrets (~0.6 nm/V)[13]. By further optimization of corona treatments, the performance of poly(HNA/HBA) electrets is expected to improve with increase of d_{33}.

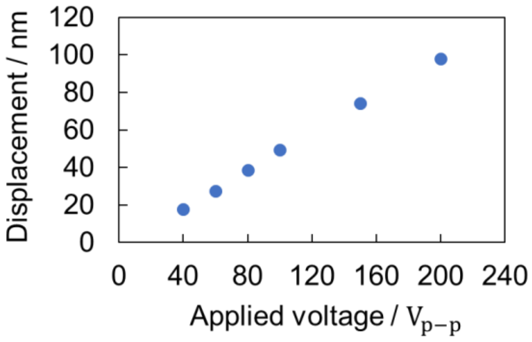


Fig. 4. AC applied voltage frequency dependence of piezoelectric displacement.

3. Conclusions

We prepared the liquid crystal polymer, poly(HNA/HBA), electrets by the typical corona treatment. The surface potential density was approximately -3 mC/m^2. The poly(HNA/HBA) films show piezoelectricity and work as sensors that detect the mechanical deformation. This study suggests the possibility that the liquid crystal polymer is one of the promising candidates for polymer electret materials.

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