C-4-1 (Invited)
Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp670-671

Development of new soft actuator using piezoelectric polymer film

Yoshiro Tajitsu

Department of Electrical and Electronic Engineering
Faculty of Engineering Science
Kansai University
3-3-35 Yamate, Suita, Osaka 564-8680, Japan
Phone: +81-6-6368-1121 E-mail: kenji_imoto@imonet.jp

Abstract

We designed a new film actuator whose driving force is generated by a surface wave. To realize the new film actuator, we fabricated a multilayer film laminated alternately with poly(L-lactic acid) (PLLA) and poly(D-lactic acid) (PDLA) films (PDLA/PLLA multilayer film). The PDLA/PLLA multilayer film of centimeter-order size with a large piezoelectric resonance has a piezoelectric performance equivalent to that of a piezoelectric ceramic. Then, using the PDLA/PLLA multilayer film, we developed a rotation actuation system with no complex mechanical parts. As a demonstration, a laptop personal computer (PC) with a weight of 2.1 kg was placed on the rotation actuation system. Under the application of an ac voltage of 150 Vpp with a frequency of 12.8 kHz, the laptop PC rotated with a rotation speed of 100 rpm.

1. Introduction

A human–machine interface (HMI) connects people with machines. At present, sensor systems, such as touch panels and touch-screen displays, are widely adopted as HMIs for smart phones and tablet personal computers (PCs). Combined with the development of smart actuators, the study of HMIs will be further promoted in future. Also, small soft and flexible actuators can be widely applied in the micromechanical, medical and biological fields [1,2]. In particular, the development of a light rotational actuator to achieve rotation in a minute space is required. The rotational actuators fabricated by practical piezoelectric material, lead zirconate titanate (PZT) ceramics, are a well-known application of the piezoelectricity of PZT. One of the weak points of PZT rotational actuators is their complicated fabrication process, which is very difficult to realize at the operation of both micromachines and large industrial equipment [1,2]. From the viewpoint of reducing environmental impact, an alternative piezoelectric lead-free product with the same specifications as PZT has been required in these years. In particular, lead-free bio-based polymers with piezoelectricity have attracted attention for the realization of new electronic parts and as an alternative of PZT [1-4].

In this study, we realized a new soft actuator by modifying the design of a new motor to use the properties of the PLLA film [3,4].

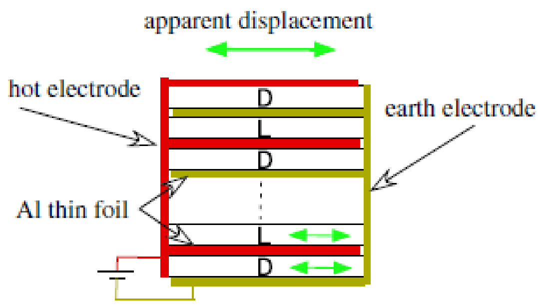

Fig. 1 PDLA/PLLA multilayer

2. Fabrication of PLA multilayer film device

As the first step to realizing a larger and more flexible polymer actuator with a very simple device structure compared with that of a PZT actuator, we attempted to improve a piezoelectric performance of the PLLA film. In particular, we fabricated a multilayer film with a laminated structure having more than 20 layers with a sandwich arrangement consisting of a PDLA film of 7 μm thickness with an evaporated Al electrode above it, and a PLLA film of 7 μm thickness with an evaporated Al electrode above it (PDLA/PLLA multilayer film), as shown in Fig. 1. The direction of the electric field is oriented in a line in alternating directions, as shown in Fig. 1, because the piezoelectric motion of a PLLA film is in the reverse direction to that od a PDLA film under the application of an electric field. Therefore, a simple device structure consisting of a PDLA/PLLA multilayer film was realized, as shown in Fig. 1. However, in this case, all the PLLA and PDLA films in the PDLA/PLLA multilayer film were required to be integrated to obtain a large piezoelectric resonance. In the following experiment, we proved that this requirement was satisfied. The damping of a single PLLA film is large and its *Q*-value is very small compared with that of PZT ceramic. Therefore, the piezoelectric resonance curve cannot be determined for a single PLLA film of 1 cm width and 5.5 cm length. In contrast, Fig. 2 shows the observed piezoelectric resonance curves for PDLA/PLLA multilayer films with different numbers of layers. In this case, a resonance frequency of approximately 13 kHz was pre-

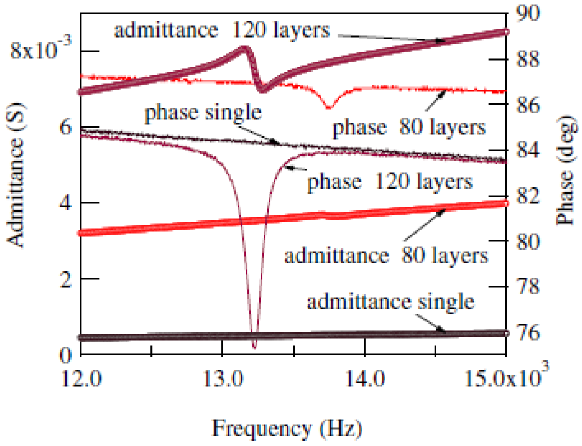

Fig. 2 Piezoelectric resonance curves.

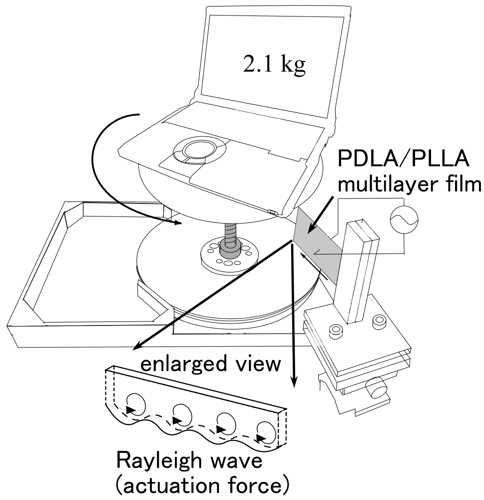

Fig. 3 Demonstration showing rotation of personal computer.

dicted. The actual resonance frequency was the predicted frequency (13 kHz) on the high-frequency side, as shown in Fig. 2. In particular, the experimental results for the PDLA/PLLA multilayer film having 120 layers (PDLA/PLLA (120)) strongly indicate the feasibility of its use as a new polymer actuator of centimeter order size. We speculate that the huge apparent piezoelectricity with the resonance of the PDLA/PLLA multilayer film was observed because the piezoelectric forces induced in each of the films are accumulated upon the application of a voltage.

3. Demonstration of PDLA/PLLA multilayer film as a piezoelectric actuator

The concept behind our new soft actuator is to use a PDLA/PLLA multilayer film, with a surface wave generated on the PDLA/PLLA multilayer film, such as a Rayleigh wave, applied as the actuation force of the new soft actuator. The necessary condition for generating a Rayleigh wave in the PDLA/PLLA multilayer film was thoroughly considered: if a large longitudinal wave with areas of compression and rarefaction in the resonance state and a shear displacement (a pseudo-Love wave) are generated simultaneously and combined in the PDLA/PLLA multilayer film, a surface acoustic wave (pseudo-Rayleigh wave) can be gener-ated on the end face of the PDLA/PLLA multilayer film.

Through our many experiments, we attempted to produce the most effective actuation system. We then developed an experimental system for demonstrating of the actuation of the PDLA/PLLA multilayer film, as shown in Fig. 3. The system includes a disc with a diameter of 15 cm without a primary torque, which can be swiveled through 360^o about a central axis. A demonstration was carried out. The following results were obtained. When an ac voltage with an amplitude of 150 Vpp and a frequency of 12.8 kHz was applied to the PDLA/PLLA (20) multilayer film, the rotation speed of the laptop PC increased with increasing time elapsed. Finally, the rotation speed of the laptop PC was settled to a constant value of 100 rpm within 10 s, which was maintained for over 2 h. Also, we found that the rotation speed is strongly dependent on the frequency and amplitude of the ac voltage applied. When the difference between the resonance frequency and the fre-quency of the applied ac voltage was over 1 kHz, the laptop PC could not be rotated. Also, when the amplitude of the applied ac voltage was less than 50 Vpp, the laptop PC could not be rotated. The experimental result was better than that predicted by calculation. From the experimental result, we anticipate the practical application of a new soft actuator using piezo-electric bio-based polymers such as PLLA. We are convinced that this actuator has greater functionality than those made of PZT.

4. Conclusions

We emphasize that no complex mechanical parts were required to induce the rotation of the laptop PC in our actuation system. Our experimental result indicates the strong possibility of realizing a new soft actuator for smart HMIs using PDLLA/PLLA multilayer films.

Acknowledgements

The experimental measurement system for this work was supported in part by a Grant-in-Aid for Scientific Research (Nos. 2528059 and 15K13714) from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

References

[1] E. Fukada, IEEE Transactions on Ferroelectrics, and Frequency Control **42** (2000) 1277.

[2] F. Carpi, and E. Smela (eds), *Biomedical Applications of Electroactive Polymer Actuators* (2009).

[3] Y. Tajitsu, IEEE Transactions on Dielectrics and Electrical Insulation **17** (2010) 1050.

[4] Y. Tajitsu, IEEE Transactions on Ferroelectrics, and Frequency Control **60** (2013) 1625.