International Journal of Advanced Technology in Engineering and Science
Vol. No.3, Issue 09, September 2015
www.ijates.com
ijates
ISSN 2348 - 7550

THE FULLY PLASTIC ACTUATORS BASED ON CNT/PVDF-CTFE COMPOSITES WITH CORRUGATED SURFACES

Jun-Hong Lin

Department of Mold and Die Engineering, National Kaohsiung University of Applied Sciences, Kaohsiung, Taiwan, Republic of China

ABSTRACT

The fully plastic ionic polymer actuators based on Poly (vinylidenefluoridetrifluoroethylene-chlorotrifluoroethylene) PVDF-CTFE polymer were investigated. The actuator consists of a high conductive electrolyte layer containing EMI-TF ionic liquid sandwiched between two CNT/polymer electrodes. To reduce the modulus of the CNT electrodes and hence enhance the actuation performance of the actuator, we hot embossing corrugate microstructures on these two electrode surfaces. The electroactive behaviors of the actuators are reported. Also an optimized ion content was found to have the fast strain speed and the highest strain up to 1.8% under 3.5V.

Key words: Ionic Liquid, PVDF, Actuators, Corrugated surface

I. INTRODUCTION

Electroactive polymer bending actuator is of great interesting due to its high strain (>1%) and low driving voltages (<4V)[1, 2]. Therefore, potentially it can be applied to many portable electronic devices as the transducer or even the artificial robots[3, 4]. The ionic polymer bending actuator consists of an ionic conductive membrane sandwiched between two electrodes with large surface area. The ionic conductive membrane contains ion resources and provides path ways for ions to transport from one electrode to the other while the large surface area of the two electrodes gives space for ions to accumulate. When applied voltages, the cations and anions of the electrolyte move toward opposite polarities of the electrode and the effective size of the cations and anions results in the volume change of cathode and anode leading to the bending actuation of the actuator. Compared with the traditional aqueous solutions, room temperature ionic liquids have many advantages including high conductivity, low volatility, and high electrochemical window (>4V)[5-7]. It has been reported that compare with the aqueous electrolytes, ionic liquids can greatly improve the life time of the ionic polymer actuators due to their low vapor pressure at room temperature and allow higher applied voltages because of their high electrochemical windows. Also the high conductivity of ionic liquid can potentially improve the ion mobility and hence the strain speed of the actuator[8-10].

In this study we investigate the Poly(vinylidenefluoridetrifluoroethylene- chlorotrifluoroethylene) PVDF-CTFE copolymer incorporate different content(13wt%,21wt%,and 42wt%) of 1-ethyl-3-methylimidazolium-bis (trifluoromethyl-sulfnyl)imide (EMI-TFSI) ionic liquids as the ion resource. Also the multiwall carbon nanotube was employed as the conductive filler to enlarge the affective surface area in the two electrodes. To correlate the ion transport behavior to the actuation behaviors. The ion transport properties of the PVDF-CTFE gel membranes containing different content of EMI-TFSI were characterized by the newly developed time domain model which can separate the conductivity into the contribution of ion mobility and mobile ion concentration. It was found that all the ion transport properties including conductivity, mobility and mobile ion concentration were slightly depends on the applied voltage at below 1 volt. On the other hand, to further enhance the actuation response of the actuator, we proposed reducing the equivalent young’s modulus of the two CNT/ PVDF-CTFE electrodes by hot embossing corrugate microstructures. A series of high performance bending actuator with large strain up to 2% and high strain speed was reported.

II. EXPERIMENTAL AND THEORY

PVDF-CTFE (MW=48000), high purity MW-CNT, Methyl Pentanone (MP) and EMI-TFSI (MW=391.9) were purchased from Aldrich and used as received. Fig.1 illustrated the configuration of our actuator.

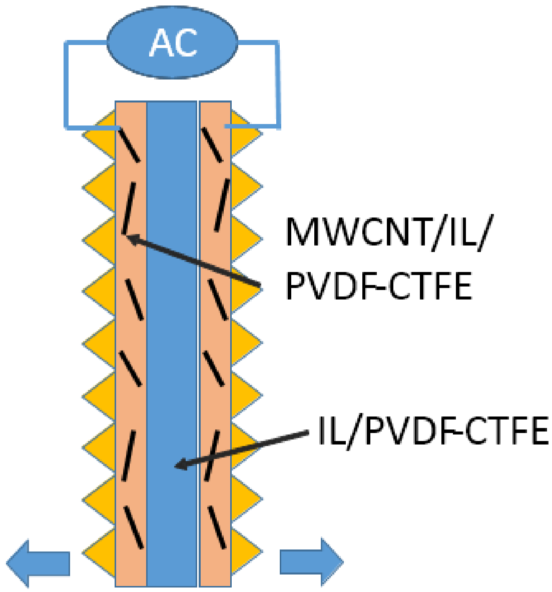

Figure 1. the 3 layer structure of the actuator

The electrode layers were composed of 20wt% of MWCNT, 30wt% of PVDF-CTFE and 50wt% of EMI-TFSI. The internal electrolyte layer was fabricated by casting solutions composed of PVDF-CTFE with 13wt%, 21wt% and 42wt% of EMI-TFSI in 3ml MP. Both the electrode layer and internal electrolyte layer were fabricated by casting suitable amount of each solution in the Teflon mold and evaporating the solvent.

The thickness of the obtained electrode film was 20-25 μm and the obtained electrolyte film was40-45 μm. To reduce the equivalent modulus of the electrodes, a die (Fig.2) with corrugate microstructures which is 25μm in depth and 50μm in pitch was used to hot embossing the electrodes.

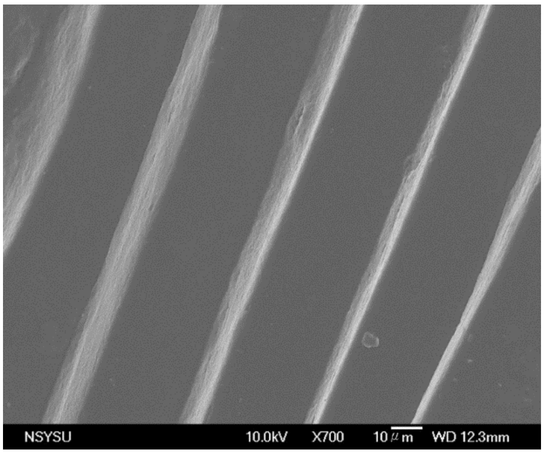

Fig. 2. the microstructure of the die.

Also a mold with four alignment pin was employed to align the corrugate microstructure as possible. The three layer actuator film was processed by hot-pressing electrode and electrolyte layer under 100 ^{O}C. After hot pressing, the total thickness is around 90-110 □ m. Fig.3 shows the corrugated surface structure on the electrodes.

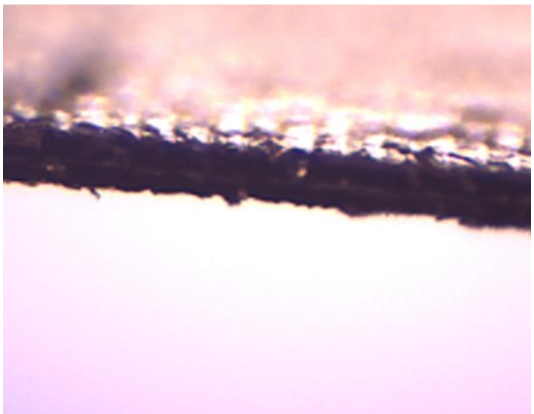

Fig. 3 ionic polymer actuator with corrugated surface.

III. STRAIN RESPONSES

Fig.4 displays the time dependent of deformation of the PVDF-CTFE membraneselectrolyte layer with 42wt% of EMI-TFSI ionic liquid. As can be seem the membrane bend toward anode when 3.5V was applied and the actuator reached to its max bending deformation within 5 seconds.

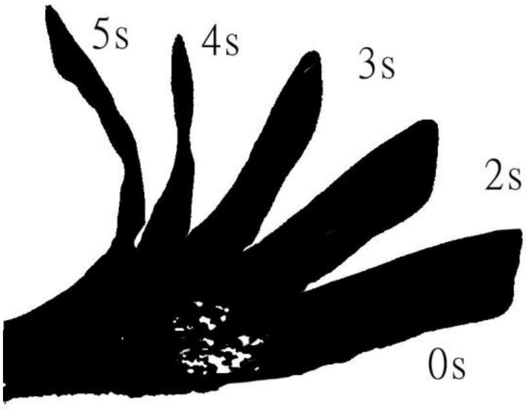

Fig. 4 Deformation of the PVDF-CTFE membrane with 42wt% of EMI-TFSI internal electrolyte layer.

To measure the actuation response at such high strain level, we employed the image process to remove the background image and using our in house image process program to fit the curvature of image as shown in figure 4. The image of the actuator was turned into gray level for pixel calculation to fit the curvature of the image.

The curvature response with time of all the fully plastic actuators with three layer structure was plotted in Fig. 5.

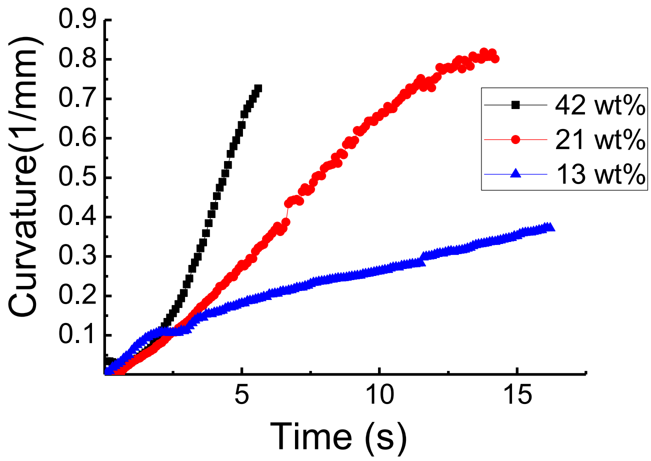

Fig. 5 the curvature response of the three layer structure actuators

It should be note in Fig. 5, because the curvature response of 42wt% sample was so large that the end of the membrane was stopped by the fixture support of our equipment during the strain measurement. The final strain response of the 42wt% membrane is therefore smaller than that of the 21wt% membrane.

To make all the deformation responses comparable, we present the deformation via the dimension less parameter strain. Assume the membrane is an ideal cantileveler beam and from that the strain can be deduced. Fig.6 represents the strain response with time of the PVDF-CTFE membranes with different IL contents.

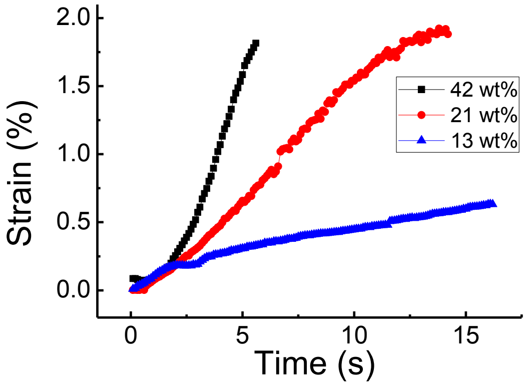

Fig. 6 displays the strain response of actuators containing different concentration of electrolyte.

It is clear that samples with higher IL content have higher and faster strain response. As we discussed previously the sample contains higher IL content have higher conductivity and that it is logical that results in faster strain speed. For samples with 42wt% IL, it takes only 5 seconds to reach it max strain while it takes 17 seconds for samples with 13wt%.

IV. CONCLUSIONS

A series of high performance PVDF-CTFE based actuators with 50 □ m pitch corrugate surface was fabricated. Owing to the corrugate surface of the electrodes, the maximum strain of the actuators can up to 2% at 3.5V and it takes less than 5 seconds to reach it maximum strain. It was found that the EMI-TFSI content affect the charge dynamics of the internal electrolyte layer and hence the strain responses. Samples with higher IL content have higher ion mobility and hence the actuation speed of the actor is therefore faster.

V. ACKNOWLEDGEMENT

This study was supported by ministry of science and Technology, Republic of China (ROC) ,Taiwan under the grant number NSC 102-2218-E-151-003-MY2.

REFERENCES

[1] B. J. Akle, M. D. Bennett, and D. J. Leo, "High-strain ionomeric-ionic liquid electroactive actuators," *Sensors and Actuators a-Physical*, vol. 126, pp. 173-181, Jan 2006.

[2] M. D. Bennett and D. J. Leo, "Ionic liquids as stable solvents for ionic polymer transducers," *Sensors and Actuators a-Physical*, vol. 115, pp. 79-90, 2004.

[3] M. Doyle, S. K. Choi, and G. Proulx, "High-temperature proton conducting membranes based on

perfluorinated ionomer membrane-ionic liquid composites," *Journal of the Electrochemical Society,* vol. 147, pp. 34-37, Jan 2000.

[4] T. Fukushima, K. Asaka, A. Kosaka, and T. Aida, "Fully plastic actuator through layer-by-layer casting with ionic-liquid-based bucky gel," *Angewandte Chemie-International Edition,* vol. 44, pp. 2410-2413, 2005 2005.

[5] J. Lin, Y. Liu, and Q. M. Zhang, "Influence of the Electrolyte Film Thickness on Charge Dynamics of Ionic Liquids in Ionic Electroactive Devices," *Macromolecules,* vol. 45, pp. 2050-2056, Feb 28 2012.

[6] J. H. Lin, Y. Liu, and Q. M. Zhang, "Charge dynamics and bending actuation in Aquivion membrane swelled with ionic liquids," *Polymer,* vol. 52, pp. 540-546, 2011.

[7] J. Torop, V. Palmre, M. Arulepp, T. Sugino, K. Asaka, and A. Aabloo, "Flexible supercapacitor-like actuator with carbide-derived carbon electrodes," *Carbon,* vol. 49, pp. 3113-3119, Aug 2011.

[8] Y. Liu, M. Ghaffari, R. Zhao, J.-H. Lin, M. Lin, and Q. M. Zhang, "Enhanced Electromechanical Response of Ionic Polymer Actuators by Improving Mechanical Coupling between Ions and Polymer Matrix," *Macromolecules,* vol. 45, pp. 5128-5133, Jun 26 2012.

[9] M. D. Bennett, D. J. Leo, G. L. Wilkes, F. L. Beyer, and T. W. Pechar, "A model of charge transport and electromechanical transduction in ionic liquid-swollen Nafion membranes," *Polymer,* vol. 47, pp. 6782-6796, 2006.

[10] S. Liu, R. Montazami, Y. Liu, V. Jain, M. R. Lin, J. R. Heflin*, et al.*, "Layer-by-layer self-assembled conductor network composites in ionic polymer metal composite actuators with high strain response," *Applied Physics Letters,* vol. 95, pp. 023505-1-023505-3, 2009.

[11] F. Beunis, F. Strubbe, M. Marescaux, J. Beeckman, K. Neyts, and A. R. M. Verschueren, "Dynamics of charge transport in planar devices," *Physical Review E,* vol. 78, pp. 011502-1-011502-15, 2008.