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Event: SPIE Smart Structures + Nondestructive Evaluation, 2019, Denver, Colorado, United States

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ABSTRACT

The novelty of correcting optical mirrors surface in a few microns of the desired precisely-shaped are supported by electroactive polymer actuating/sensing devices. The P(VDF-TrFE-CFE) terpolymer with the 10 % DINP plasticizer has field as EAP which showed 10 times higher in longitudinal strain with respect to the neat one and the increase of total axial strain from 0.4 % - 3.0 % with the multilayer sample 1 to 8 layers respectively. The actuator stack was integrated to the mirror in order to prove the concept of adaptive mirror which is able to reach to goal of a few micron mirror deformation.

Keywords: Electroactive-polymer, plasticized-doped-terpolymer, multilayer-actuator, optical-surface-correction

1. INTRODUCTION

EAPs have attracted a great deal of attention, since long, due to their useful properties such as light weight, high mechanical strength, flexibility, transparence, easy processing to large area films, and especially the ability to be molded or 3D printed into a various configuration which would present a very important factor for the revolutionary electronic devices world.[1–5]

A lot of scientific studies have been devoted in enhancing the electromechanical response of dielectric actuated electroactive polymers,[6–10] using different methods such as the control of the electromechanical properties by introducing nanoparticles,[11] or irradiating samples.[12] Such materials seem to be very promising in additive manufacturing whose recent advances become more widespread as it offers exciting opportunities for future development, particularly in high potential applications like astronomy optical communication, remote sensing system, smart medical instruments,[13] structural health monitoring in mechatronics etc. However, enhancement in electromechnical coupling is still in progress for achieving large deformation and load exertion, which is the main reason that limit the current EAPs widely used in actuator industries. To overcome this technological barrier, Capsal et al.,[14,15] invented a revolutionary technique allowing to radically boost the strain response as well as the mechanical energy density of EAPs by doping the P(VDF-TrFE-CFE) terpolymer with the DINP plasticizer. This simple chemical modification leads to large dipolar interfacial effects within polymer matrix, a contribution of charge trapping between amorphous and crystalline phases, giving the increase of dielectric permittivity and simultaneously the decrease of Youngs modulus.[16] Such an approach permitted the uses of exceptional properties of the plasticized terpolymer for an electric field nearly 5 times lower together with an increase of 20 fold in strain response as opposed to the conventional EAPs.[15]

Continuing the exploration of the previous works,[15–17] our ideas here consists in enhancing the electrostrictive behavior of the modified terpolymer based on a new multilayer design, leading to higher mechanical energy density actuation device. The final goal involves in exploiting such a material in hybrid dynamic structures

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Electroactive Polymer Actuators and Devices (EAPAD) XXI, edited by Yoseph Bar-Cohen, Iain A. Anderson,
Proc. of SPIE Vol. 10966, 109662U · © 2019 SPIE · CCC code: 0277-786X/19/$18 · doi: 10.1117/12.2514229

for optical quality surfaces shape control with light dynamic optoelectronic systems. Actuation performance in terms of strain and force ability of the proposed device should be taken in consideration in order to satisfy high-dynamic range observations that are the next frontiers in high-bandwidth communication and precise glass mirror technology.[18–22] Figure 1 illustrates the concept of hybrid active shape control based on EAP actuator and sensor. The novelty is to replace classical rigid and heavy optical mirrors with a thin optical fire-polished glass sheet actively supported by actuating/sensing devices (in Figure 1) integrated and miniaturized via additive manufacturing yielding an aspheric shape that is within a few microns of the desired precisely-shaped optical surface.[23]

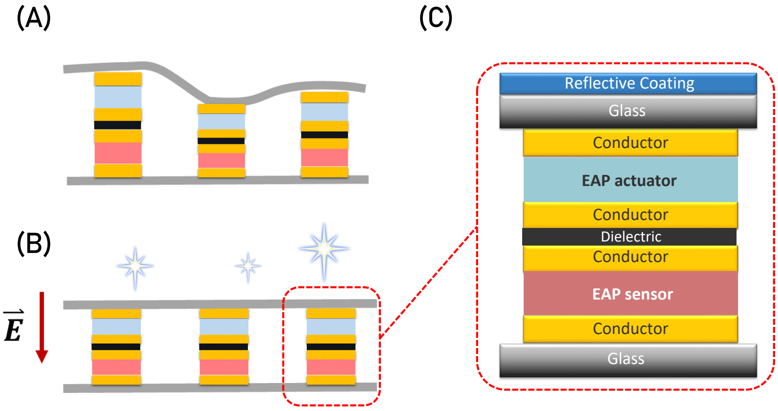

Figure 1. Schematic of hybrid mirror shape control system: (A) without input electric field control, (B) under electric field control, (C) Architecture of hybrid system control based on EAP in both sensor and actuator configurations.

It should be noted that this paper only focused on implementation of actuator device based multilayer modified terpolymer. The sensor functionality is considered to be out of scope of this work but this issue will be undoubtedly one of our priority investigations in future research development.

2. MATERIAL ELABORATION AND ELECTROMECHANICAL CHARACTERIZATION

This section provides information of materials used in this work. We also describe how to prepare modified terpolymer thin film including the preparing technique of multilayer actuator. The electromechanical characterization (longitudinal displacement measurement) is demonstrated in this section.

2.1 Film elaboration and multilayer design

Terpolymer thin films have been done with solution casting method. The commercial P(VDF-TrFE-CFE) 56.2-36.3-7.5 terpolymer powder was purchase from Piezotech SAS (Arkema group). Firstly, the terpolymer powder was dissolved in a Methyl Ethyl Ketone solvent (MEK, sigma-Aldrich) with a mass fraction P(VDF-TrFE-CFE) to MEK of 20 %. Secondly, the plasticizer DINP was added and stirred for 5h in order to get perfectly homogeneous solution. Then, the mixture was casted onto a glass substrate using a Doctor blade (Elcometer) to favor evaporation of solvent. The single layer films were placed in an oven at 102°C for 12h to totally remove the solvent and improve the crystallinity of the samples. The thickness of the as-prepared films was from 200 μm to 250 μm. For the electrical measurement, 25 nm-thickness gold electrodes were sputtered on each side of the sample in a circular form using a Cressington Sputter Coater (208 HR). Finally, the multilayer film design as shown Figure 2 was made by superposing several single layers together. As illustrated in Figure 2, a conductive adhesive and an aluminum fold was inserted between each layer for ensuring the electric connection of the whole sample, which can be modelled as a number of capacitors in parallel. The total thickness of the final layer was

3 mm as measured by a mechanical comparator (FLORENZA THYEZ, France) in 0.001 μm order, which was equal to the sum of the thickness of the individually single layers.

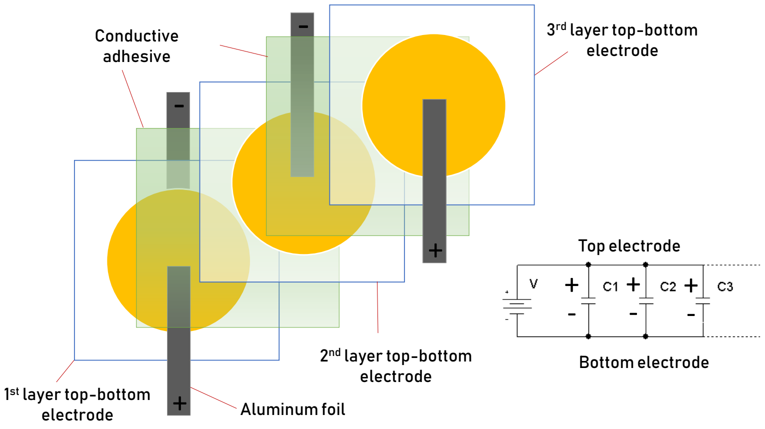

Figure 2. multilayer actuator design corresponding to model of several capacitors connected in parallel.

2.2 Displacement measurement

The technique we used for measuring displacement of polymer film deformation is non-contact capacitive measurement (a variation of the capacitance between the air-gap of sample holder). In Figure 3 (A), sample holder was connected with high voltage supplier, non-contact capacitive sensor, data acquisition (DAQ) and computer. As soon as the film was applied electricity, it would deformed in direction 33 as longitudinal direction. By measuring the capacitance between air-gap of sample holder and converting into voltage, we would obtain the displacement value with sensitivity 0.1 mm/V.

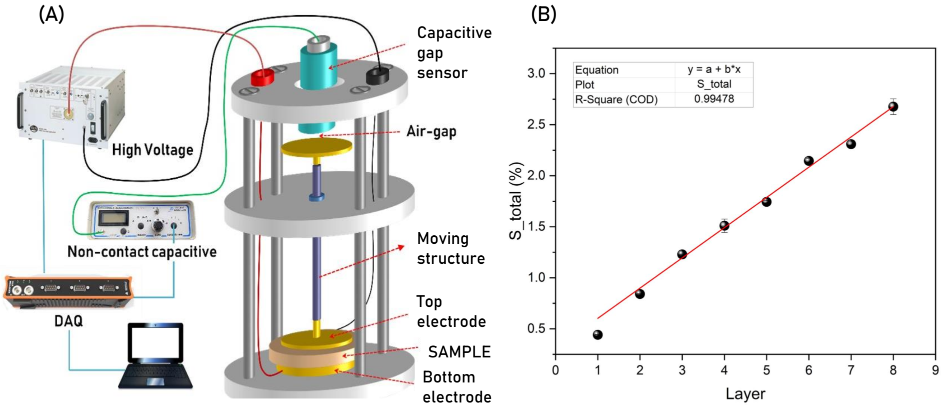

Figure 3. (A) Experimental setup for displacement measure using capacitive displacement sensor to measure the electromechanical activities of EAPs and (B) total strain versus number of layers of terpolymer + 10 % DINP

Figure 3 (B) illustrated the resulting total strain versus the layers number of the eight doped terpolymer actuators that were all excited under an alternative electric field of 10 V/μm amplitude and 50 mHz frequency, accompanied by a supplementary weigh of 142g applied on the samples. In the following, the total strain, estimated by multiplying the measured longitudinal strain and the layers number, was involved to better evaluate the actuation performance of the proposed material. The result showed perfectly linear relationship between the longitudinal strain and the number of layers, which was in good agreement with the theoretical model as following;

$$S_{33} \propto (\frac{\epsilon_0 \epsilon_r}{Y}) E_3^2 \tag{1}$$

Where, S_{33} is longitudinal strain, ϵ_0 and ϵ_r are vacuum and relative permittivity, Y is Young's modulus of sample and E is an applied electric field.

The result shows the strain being proportional to the dielectric permittivity of material. As observed in Figure 3 (B), the total strain increased from 0.4 % to 3.0 % respectively for the single-layer sample to the 8-layer one, reflecting the dependence of the mechanical displacement on the actuator capacitor as well as on the total thickness of multilayer stack.

3. THE PROOF OF MIRROR DEFORMATION CONCEPT

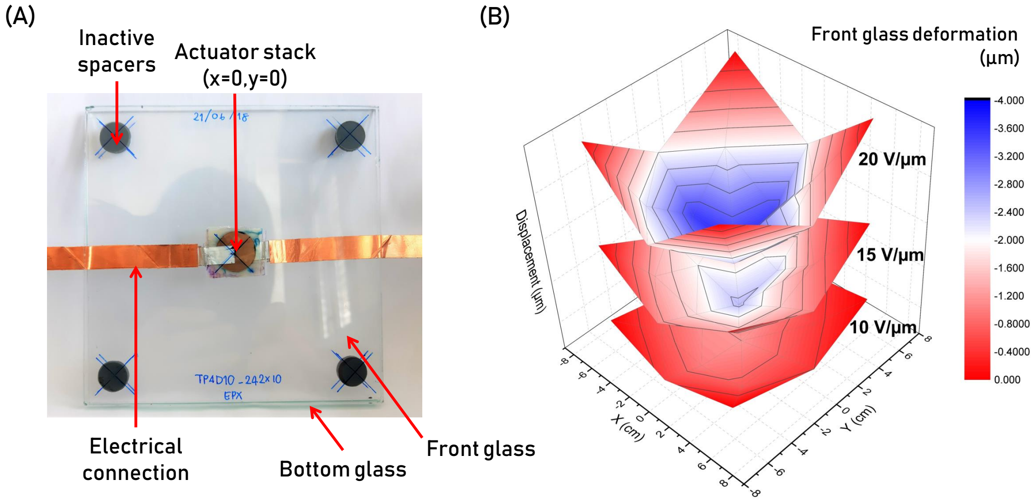

Figure 4. (A) One actuator multilayer stack sandwiched between two plate of glasses staying in parallel with four inactive spacers and (B) corresponding displacement 3D-color map of 8-layer stack under applied electric field of 10, 15 and 20 V/μm.

To validate the proof of concept to develop actuator using for controlling mirror deformation shape, the plasticized terpolymer including 8-layer stack was glued between two flat glasses with 3mm-thickness and in square form of 15cm x 15cm area. As showed in Figure 4 (A), the glasses were settled in parallel with four inactive spacers. In such a configuration, the glasses deformation induced by the displacement of the actuator stack showed the maximum value at the center. Two strips of copper tapes with shiny and reflective surface were connected to the actuator stack making it possible to apply voltage to the sample. The measurement of glass deformation has been done via the non-contact laser sensor (Microtrak II; MTI Instrument, Inc.).

The result illustrated the displacement versus the position of the glass under low electric fields of 10V/μm, 15V/μm and 20V/μm in Figure 4 (B). According to the electrostrictive effect (Equation 1), actuator stack will shrink following the direction of electric field and shape the glasses by pulling down from the initial position. The front glass deformation has attained the maximum value at the center position, and gradually decreased when the distance from the center increased. A slightly asymmetric behavior of the displacement curve was perceived due to the fact that the clamping condition of the glasses were not perfectly identical.

The center point (active area) of glasses-actuator stack prototype was observed the deformation in several applied electric field. According to the prototype structure (Figure 5 (A)), we determined front surface deforming from the initial position (D_0) and calculated longitudinal displacement change on a micron scale (ΔD) by subtraction with the longitudinal displacement under a given electric field E (D_1). The proposed device can achieve a strain of 7.5 μm with sufficient driven force so as to bend the front glass, entirely satisfying requirement of astrophysicists in terms of actuation performance under somewhat low electric field (30V/μm) as shown in Figure 5 (B). Also, experimental results enables to confirm a feasibility to easily control mirror shape based on one EAP actuator, which seems to be very promising in future development regarding integration of smart active structure comprising multi-terpolymer actuator for optical-surface-correction in astronomy.

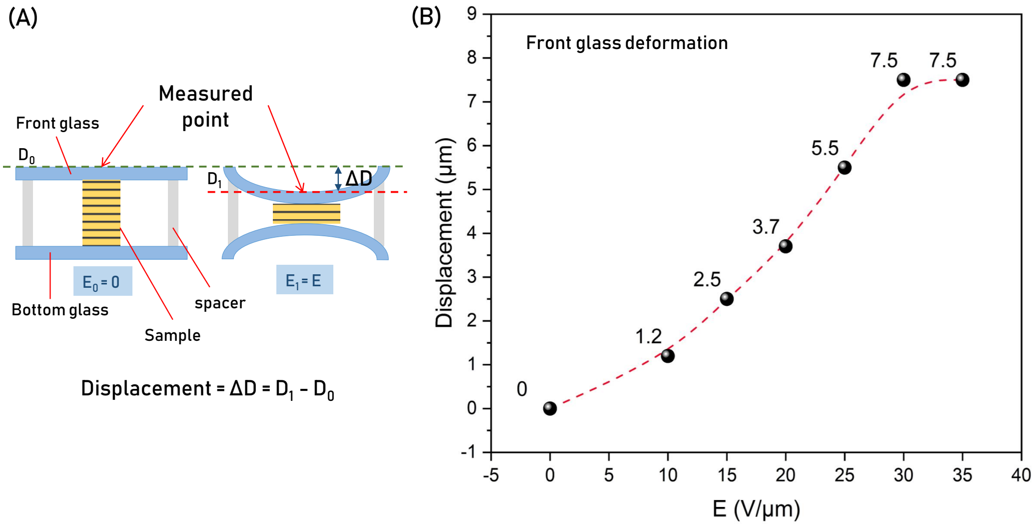

Figure 5. (A) the schematic of glasses-actuator stack with/without an applied electric field and (B) displacement of the front glass deformation at the center of actuator 8-layer stack in several applied electric field

4. CONCLUSION

This work aimed at enhancing the actuation ability of EAPs based on terpolymer doped with 10 % DINP plasticizer and stacking multilayers design. Experimental results revealed that the eight-layer modified sample manifested evidentially a powerful strain response exerting significant applied force under very small driven electric field, which open the door to different scientific investigations especially in hybrid dynamic structures for optical quality surfaces shape control.

Future works investigates on hybrid and multilayered doped terpolymers including smart remote sensing system, pushing development towards the optimized EAP actuator-sensor compliant with the multi-EAPs miniaturization under low voltage. For instance, by 3D printing 50s of terpolymers on the back of the mirror will be able to make incredibly small and accurate adjustments to the mirror so as to maintain their shape in case the telescope environment changes. Another objective of our work consists in enhancing the actuators/sensors performance in order to perfectly control the mirror shape with high dynamic and with many degree-of-freedom. The final goal is to demonstrate that we are able to achieve a novel hybrid meta-material with superior stiffness-to-density ratios properties including miniaturized electronic devices.

ACKNOWLEDGMENTS

This work was support by Live-Mirror project funded by ANR (The French National Research Agency): Project ANR-18-CE42-0007-01 and by DPST jointly administered by the ministry of education and the Institute for the promotion of teaching science and technology Thailand, Franco-Thai scholarship 2016 from Campus France. We are grateful to INSA-Lyon visiting professor program supporting Prof. J.R. Kuhn and also to our collaborators and members of PLANETS Foundation (https://www.planets.life).

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