2012 Hawaii University International Conferences
Education, Math & Engineering Technology
July 31st to August 2nd
Waikiki Beach Marriot Resort & Spa
Honolulu, Hawaii

AN EVALUATION OF THE ELECTRICAL RESISTANCE OF A DI-ELECTRIC ELECTRO-ACTIVE POLYMER UNDERGOING A SERIES OF STRESS-RELAXATION CYCLES

Boon Chai Ng
Gunnar Lovhoiden
Kalyanram Sompalli and
Tanner Williams
Engineering and Computer Science Department
Andrews University
HYH 309
4260 Administration Drive
Berrien Springs, MI 49104-0370

AN EVALUATION OF THE ELECTRICAL RESISTANCE OF A DI-ELECTRIC ELECTRO-ACTIVE POLYMER UNDERGOING A SERIES OF STRESS-RELAXATION CYCLES

Boon Chai Ng, Gunnar Lovhoiden, Kalyanram Sompalli and Tanner Williams
Engineering and Computer Science Department, Andrews University
Berrien Springs, Michigan, USA

Abstract

Di-electric electro-active polymers have potential applications as actuators and sensors. Their core characteristic is the ability to dynamically change their physical shape as a function of an electric stimulus. In this experiment, the electrical resistance of these materials are measured while the material is been subjected to a series of stress-relaxation cycles. The relation between the electrical resistance and the stress-relaxation cycles are determined and analyzed.

Introduction

Electro-active polymers, EAPs, are polymers that exhibit a change in size or shape when stimulated by an electric field. They can be used as actuators or sensors. As actuators, they are characterized by the fact that they can undergo a large amount of deformation while sustaining large forces.

Dielectric EAPs, according to Wikipedia, are materials in which actuation is caused by electrostatic forces between two electrodes which squeeze the polymer. These dielectric elastomers are capable of very high strains. As mentioned by Mohamed Benslimane et al, [1], they are capacitors where a thin dielectric film has both opposite surfaces covered with electrodes. The application of electrostatic forces across the film thickness causes film compression across the thickness, thus inducing in-plane expansion. The larger are these forces, as compared to the counter-forces exerted by the elastomer material and the electrodes, the more in-plane expansion is produced.

PolyPower di-electric electro-active polymer (DEAP) films, developed by Danfoss PolyPower, are made of a silicone elastomer material and the silver electrode is sputter-deposited on the film. One of the film surfaces is made with micro-meter size 3D corrugations. The corrugation depth and period were in the range of 4 and 10 μm, respectively, allowing for up to 33% strain in the compliance direction [2]. In this paper, this material will be referred to as 30% strain DEAP. Danfoss PolyPower had also developed larger strain films, up to 100% [1]. The nominal thickness of the silver coating is 110 nm. These strains levels are limited not by the elastomeric material strain but rather by the corrugated electrode design and material coating thickness.

Since these materials are potential actuators (to transform electric energy to mechanical work) or potential sensors (when these materials are physically flexed, they produce a voltage output), understanding the behavior of the electric resistance of these materials while they are in the process of flexing/stressing and relaxing would prove useful in optimizing the electrical properties for specific applications.

Experimental Procedure

The 30% strain DEAP was provided by Danfoss PolyPower. The DEAP film was cut to sample strips measuring 5.421 in. x 1.021 in. Orientation of the strip was such that stretching will be done in the compliance direction as shown in figure 1. Both faces of the DEAP film were silver coated with silver electrodes sputter coated to the silicone elastomer material. To simplify the experiment, only one face of the film will be measured. On this face, a copper rod was placed across the width of the sample strip, at both end of the sample strip to allow measurement of the electrical resistance of the sample. Two sets of soft elastomer materials were used to protect the film from been damaged by the grippers in the experiment as shown in figure 2. The copper rods are connected to a multi meter (KEITHLEY 2100). The electrical resistance of the sample strip will be recorded during the stress-relaxation cycles.

The tensile machine (INSTRON 3382) was programed to perform 10 stress-relaxation cycles, see figure 3, using a strain rate of 1 in/min to elongate the film by 1 inch (or ~18.% elongation which is within the limit of this material) before relaxing back to its original length. Immediately following the completion of the 10 stress-relaxation cycles, the operator will restart the next 10 cycles.

A total of 750 stress-relaxation cycles were completed in three days with 250 cycles per day. The samples were in the relaxed position overnight while the multi meter was recording its electrical resistance.

A Dino-Lite optical microscope was positioned near the tensile tester to image the sample before and after 250 cycles and a scanning electron microscope was used to examine the sample after the stress-relaxation cycles.

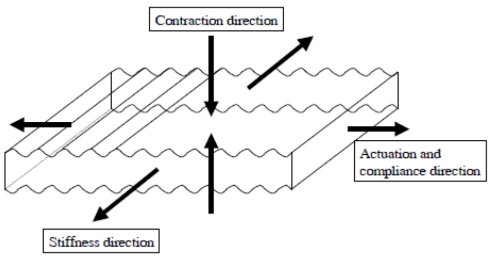

Figure 1. Schematic of the DEAP film with the metallic compliant electrodes deposited on both sides of the film (image taken from [1]. The material is been stretched along the compliance direction as shown in the diagram.

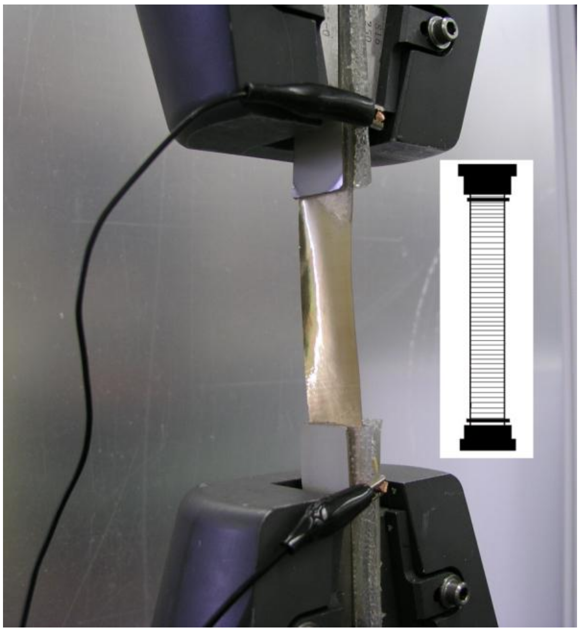

Figure 2. The DEAP film was held between two soft elastomer materials before attaching to the tensile machine grippers. The copper rod was attached to one side of the film to allow measurement of the electrical resistance on that face only. Insert shows a schematic of the sample with the compliant electrodes in the position when the sample is been stretched.

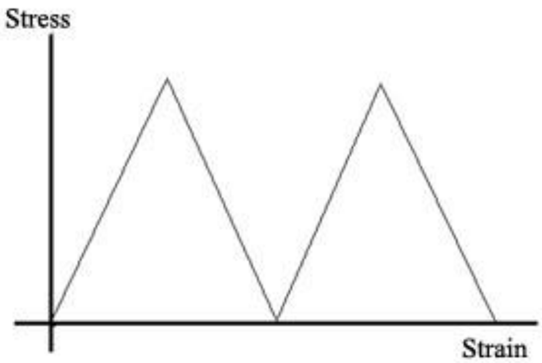

Figure 3. Plot showing two stress-relaxation cycles with a strain rate of 1 in/min.

Results and Discussion

Figures 4, 5, and 6 showed the measured electrical resistance of the 30% strain DEAP sample while been subjected to a stress-relaxation cycle on the tensile tester. These figures show a slight drop in the resistance at the completion of each 10 cycles. This slight drop in the resistance is the result of the material recovering from the recently completed cycle. It took the operator about 30 seconds to restart the program. In general, these figures showed that the electrical resistances gradually increase as the stress-relaxation cycle increases. There was no observed sudden change in the increase in the resistance at any time during the stress-relaxation cycles.

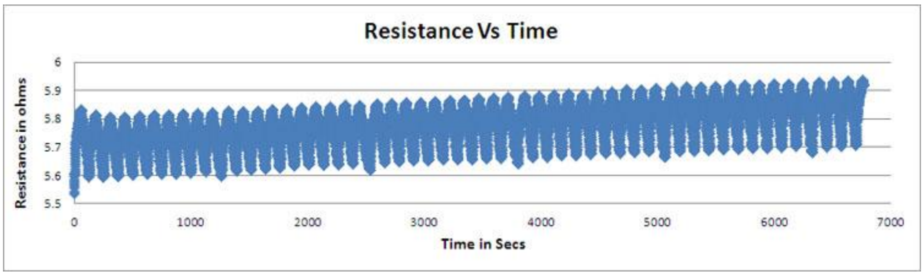

Figure 4. Sample plot showed gradual increase in electrical resistances as stress-relaxation cycles was in progress. Sample data taken on Day One.

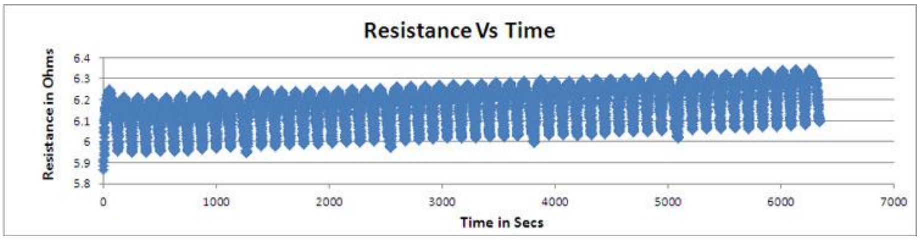

Figure 5. On Day Two, sample plot again showed continued increase in electrical resistances.

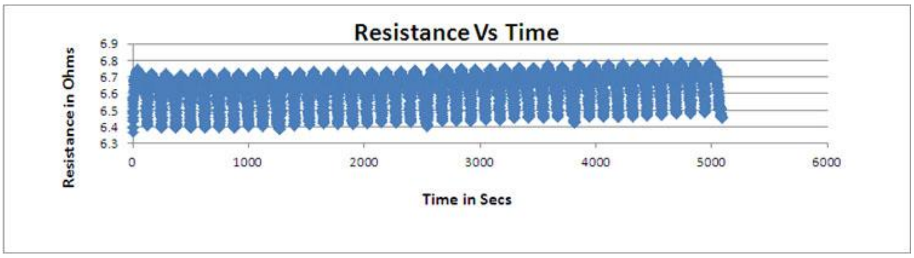

Figure 6. The increase in the resistance of the silver coating had been gradual with no sudden jump in the resistance at this time. This measurement was taken on Day Three.

Figures 7, 8, and 9 showed the recovery of the electrical resistance of the 30% strain DEAP. Note that this material was still in the progress of relaxing after more than 6 hours (21600secs.) suggesting a very slow recovery. This seems to be contrary to [3] where their reports showed that the relaxation time for silicon is below 1 sec. In fact the material never returns back to its original electrical resistance after more than 8 hours of recovery. Another observation in the recovery stage, that was done overnight, is the spike on the first night and the third night. This might be a result in the change in the ambient room temperature. A change in the temperature of the strip would cost a slight change in the resistance of the film.

The electrical resistance of the sample strip before the stress-relaxation cycle was measured at around 5.6 ohms (see figure 4). After all the stress-relaxation cycles and the final overnight recovery, the final electrical resistance of the sample strip was measured at around 6.2 ohms, an increase of only 0.6 ohms. This small increase in the electrical resistance of the DEAP hopefully does not cause any big difference in the performance of actuators or sensors.

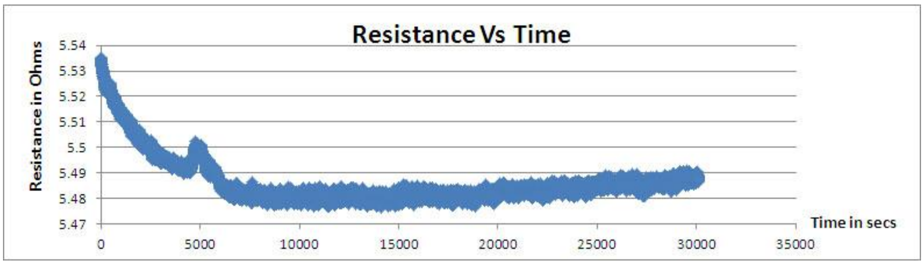

Figure 7, Sample data taken on the first night.

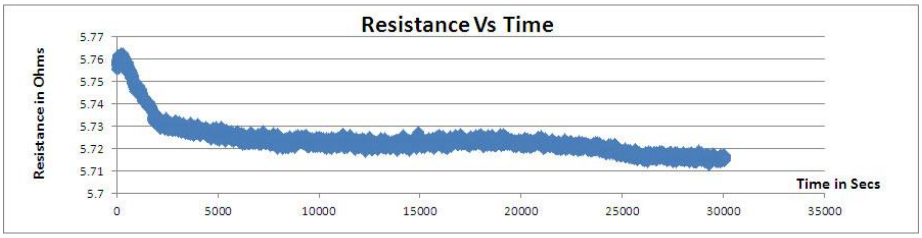

Figure 8, Sample data taken on the second night.

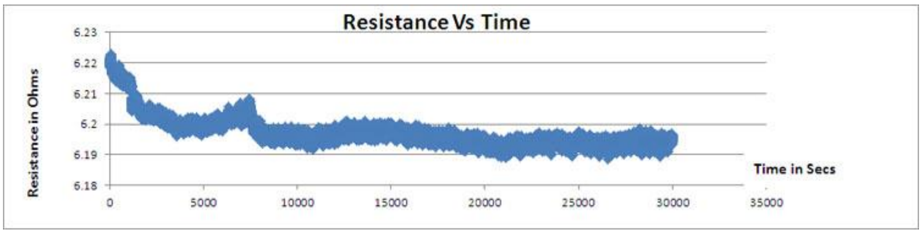

Figure 9, Sample data taken on the third night.

Low magnification optical imaging of the surface of the 30% strain DEAP was shown in figure 10. The left hand image was before any stress-relaxation was performed. Note that there were some creases on the surface. More creases were observed in the same area after 250 cycles.

Secondary electron, SE, imaging of the 30% strain DEAP (figure 11), showed some breaks on the silver coating. This might have been resulted from the pre-straining process. Figure 12 showed a low and higher magnification SE images of the 30% strain DEAP after stress-relaxation cycles. More creases in the silver coating (and possibly the sputtered electrodes might have been broken) was observed in these images. This is consistent with the large number of stretching done on this material during the stress-relaxation cycles. Even though with all the large numbers of breaks in the coating and possibly in the sputtered electrodes, there was no sudden change in the electrical resistance reading. It was reported by Mohamed Benslimane et al, [1], that these damaged or cracked electrodes were 'traces which were still sufficiently bridge to maintain conductive paths across the electrodes.

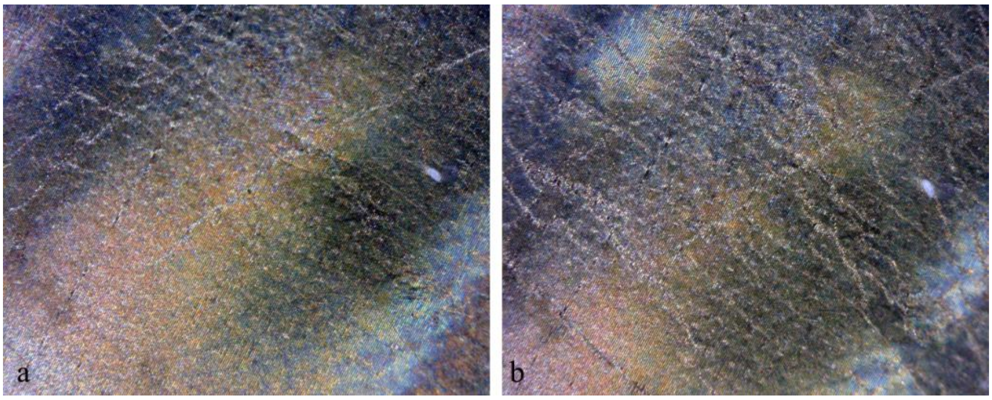

Figure 10 Optical imaging of the sample while it was held between the grippers in the tensile tester before and after 250 cycles.

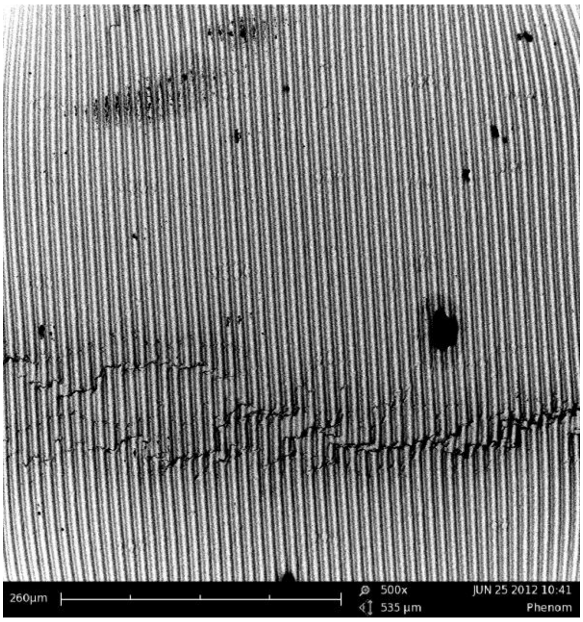

Figure 11. SEM image of a sample any stress-relaxation cycle.

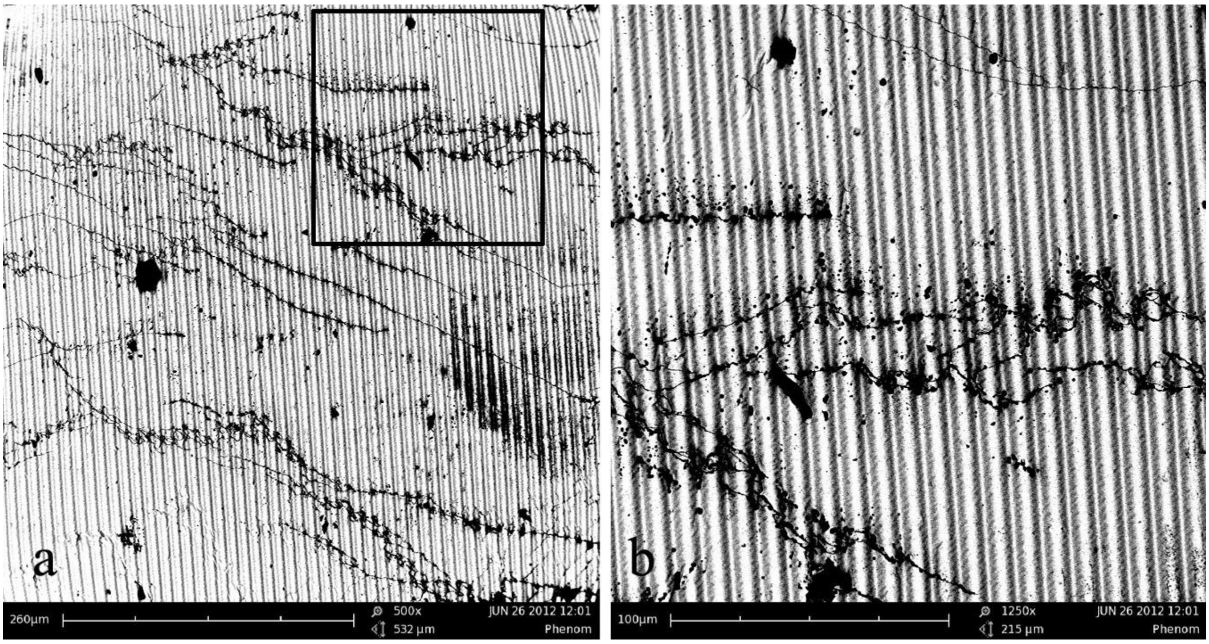

Figure 12, SEM images of the 30% DEAP after the stress-relaxation cycles. a) Low magnification SEM imaging showing numerous creases b) Higher magnification of the highlighted area in image (a) showed that some of the creases are actually breaks in the silver coating.

Conclusion

30% pre-strained di-electric electro-active polymer (DEAP) films were subjected to a total of 750 stress-relaxation cycles over a period of three days. During the stress-relaxation cycles, the electrical resistance of the DEAP film was measured and recorded. The DEAP film was imaged before and after the stress-relaxation cycles using both the optical microscope and the scanning electron microscope.

The results showed that as the stress-relaxation cycles increase, the electrical resistance showed a gradual increase in its resistance. There was no sudden increase or jump in the resistance during these stress-relaxation cycles.

The difference between the initial and the final electrical resistance of the material was only 0.6 ohms after 750 stress-relaxation cycles.

The optical and SE images showed increase in the number of creases and breaks on the coating on the film after the stress and relaxation cycles. But these did not produce any sudden change in the electrical resistance of the film.

Acknowledgement

The 30% pre-strain di-electric electro active polymer, DEAP, was provided by Mohamed Benslimane, Danfoss PolyPower.

References

1. Mohamed Benslimane, Hans-Erik Kiil and Michael J. Tryson "Electro-mechanical properties of novel large strain PolyPower film and laminate components for DEAP actuator and sensor applications" Proceedings of SPIE 7642, 764231 March 2010.
2. Benslimane, M. Y., Gravesen, P. and Sommer-Larsen, P., "Mechanical properties of dielectric elastomer actuators with smart metallic compliant electrodes," Proceedings of SPIE 4695, 150 (2002).
3. Silvain Michel, Xuequn Q Zhang, Michael Wissler, Christiane Lowe and Gabor Kovacs, "A comparison between silicone and acrylic elastomers as dielectric materials in electroactive polymer actuators". Polym. Int. 2010; 59: 391-399.