The 8th Pacific Rim International Congress on Advanced Materials and Processing
Edited by: Fernand Marquis
TMS (The Minerals, Metals & Materials Society), 2013

EVALUATION OF THE ELECTRICAL RESISTANCE AND CAPACITANCE OF A DI-ELECTRIC ELECTRO-ACTIVE POLYMER

Boon Chai Ng, Gunnar Lovhoiden, James Magbanua
Engineering and Computer Science Department, Andrews University
Berrien Springs, Michigan, USA

Keywords: DEAP, Resistance, Capacitance, Relax and Stress Cycles

Abstract

Dielectric Electro Active Polymers (DEAP) have the potential of converting mechanical energy into electrical energy. DEAP consists of a silicone dielectric film material with a special corrugated surface and a very thin layer of metallic electrodes on both sides of the surface allowing for large mechanical deformations with low operating forces. This work examined how the DEAP capacitance and the electrode resistance were affected by repeated stress relaxation cycles.

Three samples of 25% strain DEAP provided by Danfoss Polymer were subjected to 3000 stress relaxation cycles. Sample one was stressed at 4%, another to 10% and the last was stressed to 20%. Measurements were taken in 500 stress cycle intervals. The capacitance of each sample and the resistance of one electrode layer were measured in both the relaxed position and the stressed position once per interval.

The 4% stress sample's capacitance did not indicate any changes up to 3000 stress cycles, but the resistance of the electrode layer had increased uniformly by about 2% by 3000 stress cycles. The 10% stress sample's capacitance and resistance had increase 6% and 4% respectively at 3000 stress cycles. The increase appears to have a slight jump between 1000 and 1500 stress cycles, but seems uniform otherwise.

Overall, there was a small increase in the capacitance of the DEAP material after the 3000 stress cycles but the capacitance reading was never above 2nF.

Introduction

Dielectric electro-active polymers are thin films made of a silicon material that offers a large amount of deformation. This silicon material is covered on both surfaces with metal electrodes. An application of electrostatic forces across the film thickness will cause film compression across the thickness, thus inducing in-plane expansion [1, 2]. These characteristic have potential application as actuators and sensors.

Presently with global interest for renewable energy sources such as wind and ocean waves as alternatives to fossil based sources, a large number of research activities have been exploring the potential of these materials as energy generators for energy harvesting purposes [3].

These energy generators, or DEG, Dielectric elastomer Generator, are variable capacitors, their capacitance is depend on geometry and this changes when they are deformed. A DEG uses this changing capacitance to convert the mechanical energy of deformation into electrical energy [4]. In this generator application, the material needs to be stretch and then allowed to come back to its relaxed condition thus undergoing thickness contraction together with area expansion. The metal electrodes will limit expansion as the electrodes are relatively inflexible compared to the silicon material. DEAP is manufactured with corrugated surfaces to allow for an increase in surface areas as well as compression of the silicon film when stretched. DEAP already have applications as sensors, but its application as an actuator is still considered to be in the research stage.

The success of these materials in such applications is influenced by the materials parameters, e,g. breakdown field, dielectric constant, and elastic modulus which have a direct impact on the driving voltage [5].

Previous work by the same author [6] showed a gradual increase in its resistance when the material was subjected to 750 stress-relaxation cycles. There was no sudden increase or jump in the resistance during these stress-relaxation cycles.

This present work continued to examine the electrical resistance as well as the capacitance of 25% strain Dielectric Electro Active Polymer, DEAP, to provide useful information in optimizing the electrical properties for such applications, and to investigate how the electrical properties are affected by electrical and/or mechanical breakdown. The material samples were subjected to stress relaxation cycles (3000 cycles) under different strains; namely 4%, 10% and 20%.

Theory

The capacitance of DEAP is defined as $C = \frac{\varepsilon A}{d}$, where C is the capacitance, A is the surface area of the film, d is the thickness of the silicon material, and ε is the permittivity of the silicon material. As the capacitance is inversely proportional to the thickness of the silicon, any compression will increase the capacitance. When the DEAP is stretched, an external voltage source is used to charge up the DEAP to the same voltage as the external source. The total charge is given by $Q = CV$, where Q is the total charge, C is the capacitance of the DEAP and V is the voltage of the external source. When the DEAP relaxes to its unstressed state the capacitance decreases, but since the total charge is fixed, the voltage increases. The increased voltage can be estimated from the constant charge formula.

$$C_S V_S = Q = C_U V_{Inc} \xrightarrow{yields} V_{Inc} = \frac{C_S}{C_U} V_S, \quad (1)$$

where C_S is the capacitance when stretched, C_U is the capacitance when relaxed, V_{Inc} is the increased voltage after relaxation, and V_S is the external source voltage.
The electrical energy stored in the DEAP when stretched, W_S, is given by $W_S = \frac{1}{2} C_S V_S^2$, while the electrical energy stored in the DEAP after it has returned to its relaxed position is

$$W_U = \frac{1}{2} C_U V_{Inc}^2 = \frac{1}{2} C_U \left[\frac{C_S}{C_U} V_S\right]^2 = \frac{C_S}{C_U} * \frac{1}{2} C_S V_S^2 = \frac{C_S}{C_U} * W_S. \quad (2)$$

Hence the amount of energy that can be harvested is a fraction of the initial stored energy where the fraction depends on how much the DEAP is stretched. As the capacitance of DEAP is relatively low, it would take a large sample to generate any significant energy. For example, our 4 in^2 sample had a capacitance in the 1nF range. With an external voltage source of 1000V, our sample can store around 1mJ or about 0.25mJ/in^2 of DEAP. Even with significant improvements in the DEAP's energy storage capacity it seems its usefulness in energy generation will be limited to low energy applications.

Material

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 both sides of the silicon elastomer material. Each side of the film surfaces was 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 25% strain in the compliance direction [7]. In this paper, this material will be referred to as 25% strain DEAP. 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.

Experimental Procedure

The 25% strain DEAP was provided by Danfoss PolyPower. The DEAP film was cut to sample strips with width 2.5 cm and gage lengths measuring 10.4 cm, 6.35 cm and 4.4 cm . 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 electrode resistance measurements, only one electrode resistance was measured. Strips of copper tape were placed across the width of each sample at either end as shown if figure 2. A third strip of copper tape was placed across the width of the bottom surface to allow for capacitance measurements. The copper tapes of the top surface are connected to a Keithley Model 2100 digital multi meter (DMM) for resistance measurements while the capacitance measurements were done with a Hewlett Packard Model 4284A Precision LCR Meter.

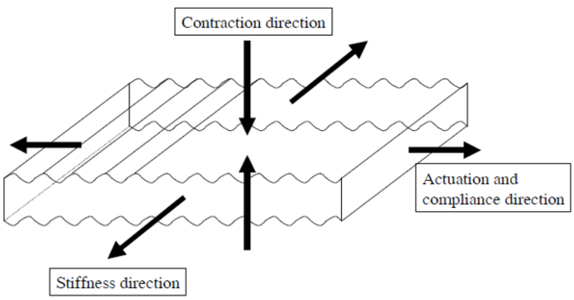

Figure 1. Schematic of the DEAP film with the metallic compliant electrodes deposited on both sides of the film (image taken from [1]. The material is been stretched along the compliance direction as shown in the diagram

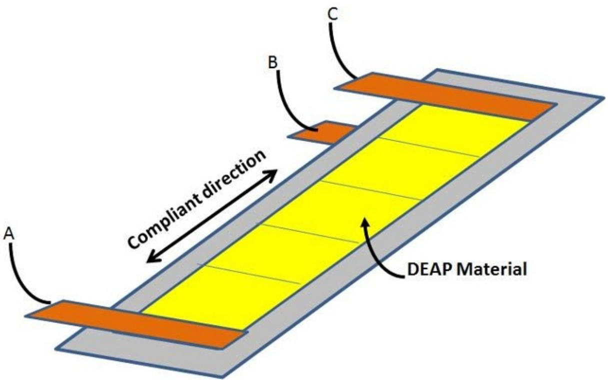

Figure 2 schematic of DEAP attached to copper foils A-C for measurement the resistance and B-C for capacitance measurement.

The whole sample assembly was attached to a fixture as shown in figure 3. A small servo motor turned a linkage that pushed the sample downwards to create the stretching operation (stress) and returned to the starting position to let the sample relax. The supports blocks were adjustable so the effective sample length could adjust to achieve the desired stress. Both samples were exposed to 20 stress relaxation cycles per minute. Every 500 cycles, the electrode resistance and capacitance were measured in both the stressed and relaxed position, up to a total of 3000 stress relaxation cycles. The average of the 10 measurements were recorded.

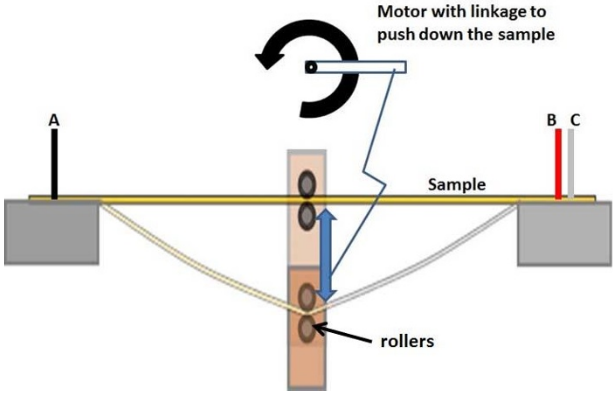

Figure 3 Schematic of the movement of the sample as it is been stretch via a linkage that causes the rollers to move down and upwards in one revolution.

Results and Discussion

The averages of the resistances and the capacitances undergoing stress and relaxation were shown in Table 1 and Table 2. The capacitance was shorted while undergoing 20% strains and as such only the resistances were recorded. For the 10% strain material, the initial stressed data points were not recorded resulting in a blank in for Tables 1 and 2.

Table 1: Resistance measured at relax and stressed level at 4%, 10% and 20%.

Resistance in ohms						
	4%	strain	10%	strain	20%	strain
Revolutions	relax	stressed	relax	stressed	relax	stressed
0	7.89	7.95	6.28		4.15	4.15
500	7.93	7.97	6.4	6.72	4.42	4.65
1000	7.93	7.99	6.56	6.79	4.71	4.93
1500	7.99	8.08	6.57	6.82	4.74	4.94
2000	8.02	8.06	6.55	6.77	4.62	4.83
2500	8.02	8.06	6.57	6.79	4.73	5
3000	8.04	8.08	6.54	6.77	4.68	4.95

Table 2: Capacitance measured at relax and stressed level at 4% and 10%.

Capacitance in nF				
	4%	strain	10%	strain
Revolutio	relax	stressed	relax	stressed
0	1.33	1.42	1.35	
500	1.32	1.4	1.35	1.46
1000	1.32	1.39	1.36	1.48
1500	1.32	1.38	1.4	1.48
2000	1.32	1.39	1.41	1.51
2500	1.32	1.39	1.41	1.49
3000	1.32	1.39	1.42	1.5

Figures 4 -6, showed the measured electrical resistance of the DEAP sample subjected to 4 % 10% and 20% elongation respectively while figures 7 and 8 showed the measured capacitance of the DEAP material subject to 4 % and 10% elongation respectively. Both sets were subjected to 3000 stress relaxation cycles. The data for the capacitance strained to 20% strain was shorted out and could not be recorded.

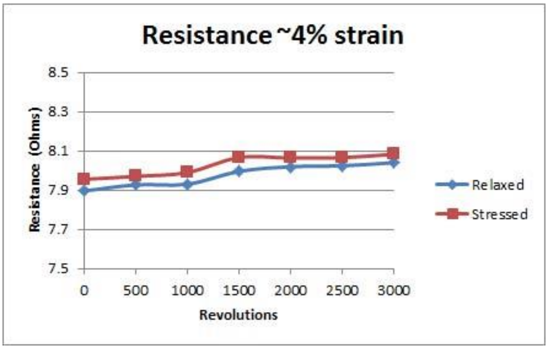

Figure 4. Resistance measurement of sample subjected to 4 % strain

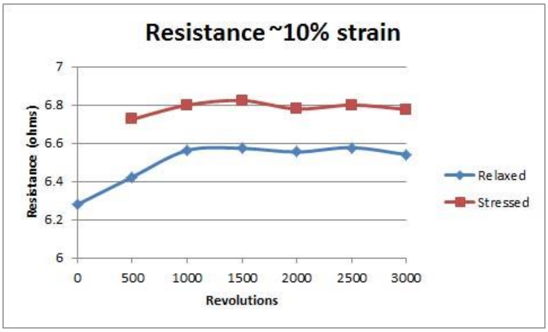

Figure 5. Resistance measurement of sample subjected to 10% strain

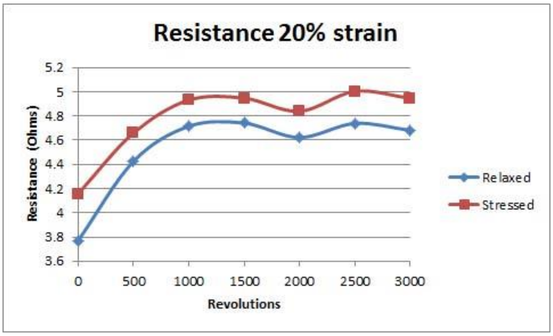

Figure 6. Resistance measurement of sample subjected to 20% strain

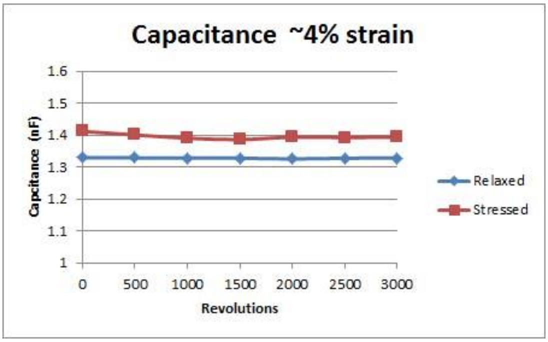

Figure 6. Capacitance measurement of sample subjected to 4% strain

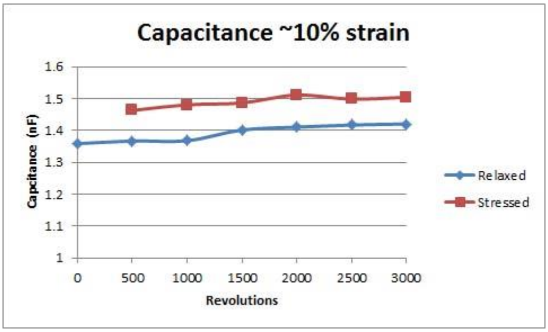

Figure 7. Capacitance measurement of sample subjected to 10% strain

The 4% strain sample's capacitance did not indicate any changes up to 3000 stress cycles whereas the 10% strain sample's capacitance shown in Table 2 and Figure 7 had increased 6% at 3000 stress cycles. The 20% strain sample's capacitance had been shorted so no reading was available. The two samples with recordable capacitance did not show any capacitance reading greater than 2nF.

The 4% strain sample's resistance of the electrode layer had increased uniformly by about 2% by 3000 cycles and the 10% strain sample had an increase of 4% by 1000 stress cycles but did not increase further from 1000 to 3000 stress cycles. The resistance of the 20% strain sample electrode layer had increased by 13% by 3000 stress cycles. Interestingly there is a drop in the resistance for the 10% and 20% strain when they were at the 2000 stress cycles. The reason is not all that clear presently.

These figures show a slight increase in the resistance at the completion of 3000 cycles. Similar to [6] 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 3000 stress-relaxation cycles. Likewise there is only a small increase in the capacitance.

Note that for capacitance, in order to harvest large amounts of electrical energy, high capacitance is required [3] and so straining at 4 – 10 % is very small. Capacitance for a 1KW generator are in the range of 340mF to 1000mF in the relaxed and strained states respectively [3]. As capacitance increase, the electrode resistance increases but change in capacitance is a function of mechanical force which stretches the material. Higher strain levels will increase the change in capacitnace but there is limitation to the amount of strain applied without damaging the silver electrodes that were sputter-deposited on the both sides of the silicon elastomer material. So with our samples low changes in capacitance, these 25% pre-strain DEAP would be limited to low energy applications. Higher/larger strains are needed to achieve the much needed large capacitance but such strains would place additional constraints on the dielectric breakdown performance and the tear resistance of the DEAP materials [3].

Conclusion

Samples of a 25% pre-strain DEAP material were subjected to 3000 relax and stress cycles and their resistances of the electrode layer and the capacitance were measured both at the relax and the stress region.

Change in capacitance after 3000 cycles as a result of the relax and stress cycle did not go beyond 6% or 2nF.

Resistance showed a slight increase in the measurement at the completion of 3000 cycles.

Acknowledgement

The 25% pre-strain di-electric electro active polymer, DEAP, was provided by Mohamed Benslimane, Danfoss PolyPower. This project is funded by the Andrews University Internal Faculty Research Grant.

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. Soo-Lim Chua, Xin-Hui Neo and Gih-Keong Lau, "Multi-Walled Carbon Nanotubes (MWCNT) as Compliant Electrodes for Dielectric Elastomer Actuators". Electroactive Polymer Actuators and Devices (EAPAD) 2011, edited by Yoseph Bar-Cohen, Federico Carpi, Proc. Of SPIE Vol. 7976, 79760V.

3. Mohamed Benslimane, Michael J. Tryson, Jakob Oubak and Hans-Erik Kiil, "Scalable Design of DEAP for energy harvesting utilizing PolyPower", Electroactive Polymer Actuators and Devices (EAPAD) 2011, edited by Yoseph Bar-Cohen, Federico Carpi, Proc. Of SPIE Vol. 7976, 79760I.

4. Ho Cheong Lo, Thomas McKay, Benjamin M. O'Brien, Emilio Calius, Lain Anderson., "Circuit Design Considerations for Regulating Energy Generated by Dielectric elastomer Generators", Electroactive Polymer Actuators and Devices (EAPAD) 2011, edited by Yoseph Bar-Cohen, Federico Carpi, Proc. Of SPIE Vol. 7976, 79760C.

5. Dorina M Opris, Martin Molberg, Frank Nuesch, Christiane Lowe, Christian Walder and Beatrice Fischer, “Dielectric Elastomer Materials for Actuators and Energy Harvesting”. Electroactive Polymer Actuators and Devices (EAPAD) 2011, edited by Yoseph Bar-Cohen, Federico Carpi, Proc. Of SPIE Vol. 7976, 79760G.

6. Boon Chai Ng, Gunnar Lovhoiden, Kalyanram Sompalli and Tanner Williams, “ An evaluation of the electrical resistance of a Di-Electric Electro-Active Polymer Undergoing a Series of Stress-Relaxation Cycles, 2012 Hawaii University International Conferences Education, Math & Technology Proceeding.

7. Mohamed 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).