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Experimental Study on Permittivity of Acrylic Dielectric Elastomer

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Abstract: This paper reports the experimental study on the frequency and stretch dependency of permittivity of a commercially available acrylic dielectric elastomer (VHB 4910) film. The procedure for preparing samples with different thickness using in-house developed uniaxially stretching device is described. Copper tapes are implanted on two opposite sides of a stretched elastomer film and permittivity of this material is estimated from measured capacitance using LCR meter. Variations of permittivity of this material with different pre-strain value and with different applied voltage frequency are studied. Results show that the permittivity of the material decreases with increasing frequency and increasing pre-strain value. The study would be useful for estimation of frequency and strain dependent actuation pressure of a dielectric elastomer actuator.

Keywords: Dielectric elastomer; Maxwell stress; Smart actuator; Permittivity

INTRODUCTION

Dielectric elastomer (DE), a specific class of '*smart*' material in electroactive polymer (EAP) family, is becoming popular actuator material for various kinds of applications such as mechatronics, robotics, micro-fluidics, bionics, *etc.*, due to its large deformation capabilities, fast response, and high efficiency [1-4]. The actuators based on this material are popularly known as dielectric elastomer actuators (DEA). These actuators transform electrical energy into mechanical work based on Maxwell stress principle. Researchers have designed and fabricated dielectric actuators of different shapes successfully [5-7].

A dielectric elastomer actuator (DEA) consists of an elastomeric film coated on either side with compliant electrodes. When electric field is applied, the attractive force between dissimilar charges on the opposite electrode generates compressive stress in the thickness direction [2]. As elastomer is effectively incompressible, decrease in thickness of the elastomeric membrane results a corresponding increase in area, as shown in Fig.1. The effective pressure in thickness direction, known as Maxwell stress, can be written as

$$p = \varepsilon_r \varepsilon_0 E^2 = \varepsilon_r \varepsilon_0 (V/d)^2 \qquad (1)$$

where p is the effective actuation pressure, ε_r is the relative permittivity of the material, ε_0 is the dielectric permittivity of free space (8.854×10^{-12} F/m), E is the electric field strength, V is the applied voltage and d is the thickness of the dielectric film.

Very recently, DE material is also being considered for sensor applications [8]. In sensor application, DE combined with compliant electrodes acts as a sensing device whose capacitance changes with the change in thickness, force, strain, etc. The change in capacitance is sensed by the change in frequency which can be converted to DC voltage by means of electronic circuit [8].

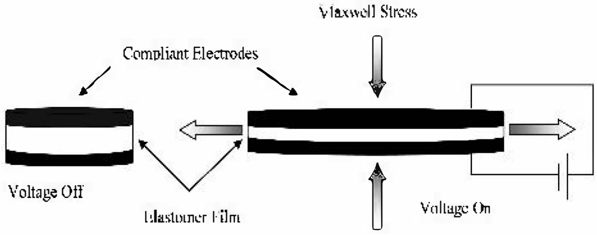

Figure 1 Schematic illustration of dielectric elastomeric actuation

In both sensors and actuators applications, the value of permittivity at different frequency and strain is required to be known to determine the value of Maxwell stress. So the determination of permittivity at different excitation frequency and stretch ratio is very important, the reason why it has been attracted considerable number of researchers.

Kunanuruksapong *et al.* [9] studied the effects of frequency and temperature on permittivity of different acrylic elastomers and styrene copolymers. In a similar work, Liu *et al.* [10] studied the variation of permittivity with the concentration of incorporated particle in a silicone elastomer. Kofod *et al.* [11] reported the values of dielectric constant at different area strain of VHB film. Qiang *et al.* [12] performed experimental study on the variation of dielectric constant of VHB film with frequency, temperature, biaxial stretch ratio, relaxation time, etc. Molberg *et al.* [13] experimentally determined the frequency versus dielectric constant at constant pre-straining of elastomers. Jean-Mistral *et al.* [14] determined the permittivity of polyacrylic material for different area strain.

In this paper, we studied the permittivity variation of VHB 4910 for large range of frequency and high uniaxial stretch value. As most of the DE actuators are built with commercially available VHB films we took the same material for experimental study. Many researchers took relative permittivity value of VHB 4910 as 4.7, irrespective of the prestraining value and

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frequency of actuation [2]. This study would help them to calculate actuation pressure and actuation strain more accurately with exact value of the permittivity.

EXPERIMENTAL PROCEDURE

Material

A commercially available acrylic polymer, VHB 4910 from 3M, of 1mm thick is used as specimen material. Copper tape with conductive acrylic adhesive on one side having grade number ST-7440H is used as electrode material.

Preparation of Samples

The samples are prepared by stretching uniaxially with manually operated in-house fabricated uniaxial stretching device. Fig. 2(a) shows the stretching of VHB 4910 film in the uniaxial stretching device. The stretched film has been sandwiched at room temperature by two rectangular cardboard frames parallel on both surfaces to provide strong support and to hold the film in stretched condition as shown in Fig. 2(b). Due to adhesive nature of the material, dust is easily attracted on it. So, all the arrangements starting from preparation of samples have been made under the dust free environment.

Capacitance Measurement Setup

Two strips of conductive tape having 10mm length and 12.40mm width were mounted on both surfaces of prepared sample with proper alignment. The two ends of conductive electrode tape were connected with properly calibrated LCR Meter (GWINSTEK LCR-8101G) through crocodile probe for capacitance measurement. Fig. 2(c) shows the sample with compliant electrodes connected with LCR meter. Using LCR meter, capacitance has been measured for frequency range of 25Hz to 1MHz. From readings of average capacitance, relative permittivity value was determined via $\varepsilon_r = Cd / A\varepsilon_0$, where A is the electrode area (taken as 12.4mm x 10mm), d is the film thickness, and ε_0=8.854x10^{-12} F/m. All the tests have been carried out at room temperature.

RESULTS AND DISCUSSIONS

Thickness Versus Uniaxial Strain

The measurement of thickness with strain is necessary to determine the value of permittivity from measured capacitance. As accurate measurement sensor is not available with us, we assume constant volume during elongation. With this assumption, thickness is calculated and plotted with uniaxial strain as shown in Fig. 3. As the width remains almost constant during uniaxial elongation, the final thickness is inversely proportional with strain which explains the nature of curve.

Effect of Pre-strain on Permittivity

Exact value of Permittivity is required to be known to calculate Maxwell stress for actuator or sensor applications [8, 15]. To know the variation of permittivity with uniaxial strain, experiments are carried out where permittivity of the material is determined via the measurement of capacitance (using LCR meter) of the samples having uniaxial strain up to 1000%. The measurement is carried out for input sinusoidal signal of 2V and frequency starting from 100 Hz to 1MHz. The VHB 4910 has the property of change in thickness with the application of very high voltage. To avoid the change in thickness during experiment small voltage alternating signal has been applied on the sample.

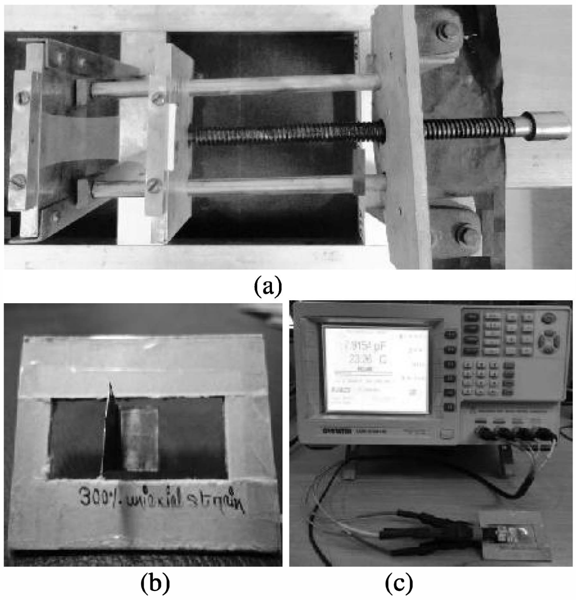


Figure 2(a) Uniaxial stretching device (b) Sample with electrode (c) LCR meter with sample

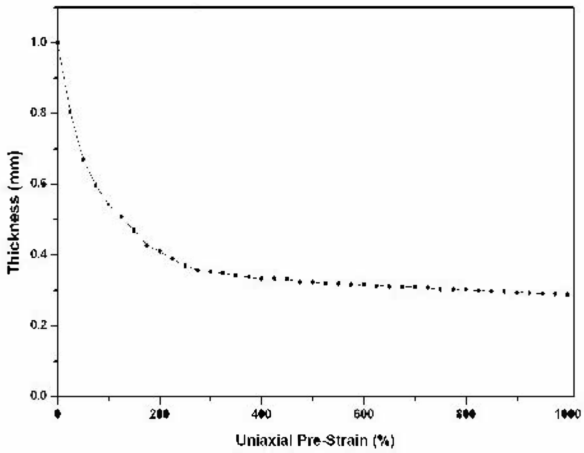
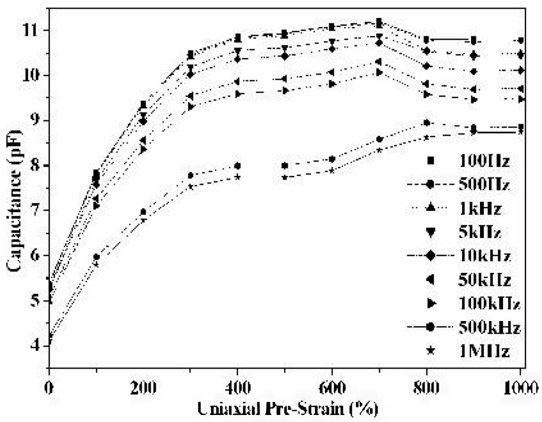
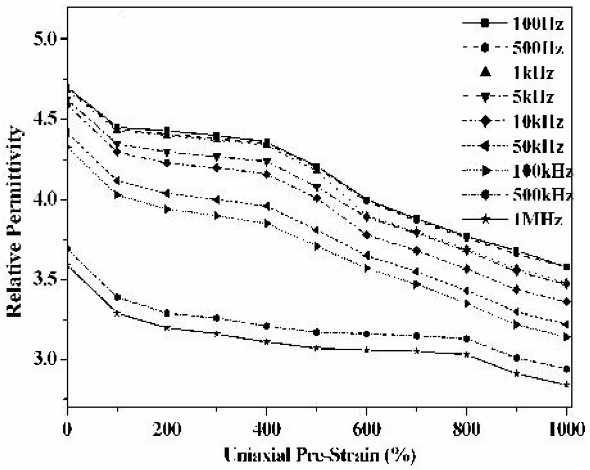


Figure 3 Plot of thickness against the pre-strain

The variations of capacitance and permittivity with uniaxial pre-strain for different frequencies are shown in Fig. 4(a) and Fig. 4(b), respectively. The experimental results reveal that the relative permittivity decreases nonlinearly with strain. From the Fig. 4(b), it may also be noticed that with increase in uniaxial pre-strain value the relative permittivity decreases slightly. A possible reason for the drop of permittivity with strain is due to polar segments of a dielectric elastomer get less movement space under stretched condition. With the strain, the affinity of alignment of polar molecule decreases lowering the dielectricity. For a fixed strain sample, with the increase of frequency, the permittivity value also decreases.



(a)



(b)

Figure 4 (a) Plot of capacitance versus uniaxial strain at different frequency (b) Plot of permittivity versus uniaxial strain at different frequency

Effect of Frequency on Permittivity

Permittivity of the DE is highly affected by the frequency of input excitation voltage. We studied the variation of relative permittivity with the wide range of input excitation frequency (25Hz to 1MHz) for different uniaxial pre-strain value. The measured value of capacitance with variation of frequency at different strain is plotted in Fig. 5. From the capacitance value, the permittivity is calculated and plotted against frequency as shown in Fig. 6. It is observed that from 25Hz to 1KHz, permittivity of DE is almost same for a particular pre-strain. Permittivity decreases in regular interval from 1KHz to 1MHz. During the interval of 100KHz to 1MHz, the curves are nonlinear in nature. The nature of the curve in high frequency range may be due to less time the dipoles get to orient themselves in the direction of applied field. Also at high frequency, the periodic alternation of applied electric field drastically reduces the diffusion of dipoles in the field direction, which results in decline the values of polarization as well as the permittivity [13, 16].

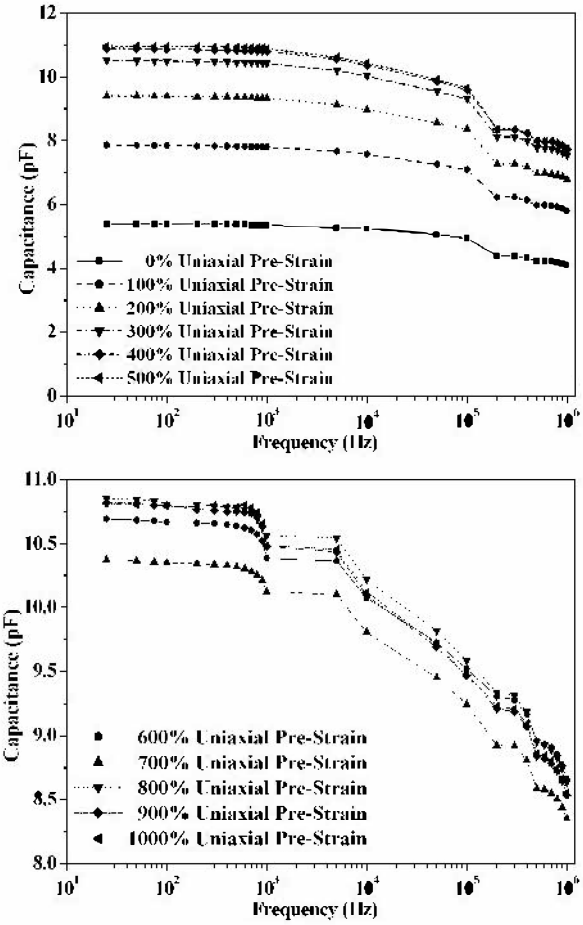


Figure 5 Plot of capacitance as a function of frequency for different uniaxial pre-strain values

CONCLUSION

In this paper we reported (i) the decrease of relative permittivity with increase in strain of VHB 4910 film in a nonlinear fashion; (ii) decrease of relative permittivity with increase in frequency for a fixed uniaxially strained sample. The study will be helpful to a designer for accurate estimation of frequency and strain dependent actuation pressure of a dielectric elastomer actuator. As no physical model is available to capture the variation of permittivity, development of model would remain under the scope of future work.

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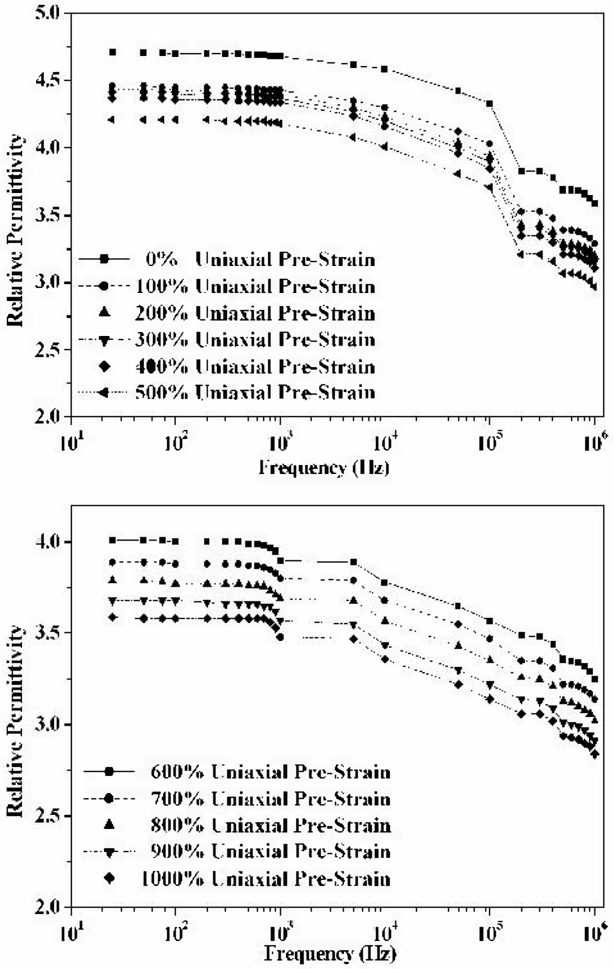

Figure 6 Plot of permittivity with frequency at different uniaxial pre-strain value

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