Transparent Electroactive Films for Optical Applications

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Electrostrictive polyurethane elastomer films were prepared using the solvent casting technique with tetrahydrofuran (THF) as a solvent followed by annealing at 95°C in vacuum for 45 minutes. Sample films of 50mm diameter were rigidly attached to circular frames and tested under applied field in the range of 0-25 kV/mm and tested under various environmental conditions. To investigate the electroactive response and optical properties of these lens-type films, single and two-layer lenses were made of these films. Each film was stretched and coated on both sides by depositing conductive and transparent polypyrrole polymer. Various film thicknesses were tested for transmission and reflection. 83% light transmittance was achieved for each individual coated film. The deformation response in the single layer is 0.2mm when subjected to a DC voltage of 17.73kV. This translates into a lens focal length of 1.871 m and a power of +0.534 DS. However, the two layer lens offers deformation in the order of 0.59 mm, which translates into a 0.317 m focal length and a +3.152 DS power when subjected to the same voltage. Further suggestions for improvement are proposed.

Keywords: Electroactive polymer, electrostrictive polyurethane and conductive polymer.

1. INTRODUCTION

A new class of actuator materials with wide applications are emerging from the use of Electroactive polymers (EAP). These materials undergo changes in size, shape, or stress state with the application of an electrical stimulus. The main attractive feature of these materials is their speed of response to induce relatively large bending or longitudinal strain upon application of a voltage [1]. This can be sufficiently enhanced, and designed to emulate operation for specific applications. Recently, actuation techniques have been developed using variations in the properties of EAPs, to provide superior electromechanical coupling. Actuator designs vary depending on the application. For example actuators designed for the leg movement employ a different design from the ones needed for facial movements or eye dilation [2]. The former require a high mechanical output from relatively small and compact actuators while the latter require a relatively smaller mechanical output. A compact multilayer structure such as rolled actuators is most likely to be used for the leg while a single layer device such as a framed actuator would be more suited for facial movement.

Among the many kinds of EAPs, electrostrictive polyurethane elastomer (PUE) materials are potentially attractive to smart optical applications because of their good transparency, light weight, flexibility and acceptable electromechanical characteristics [3]. They have high abrasion and chemical resistance, and can be fabricated into useful actuators by the traditional thermoplastic moulding technique or by the solvent casting technique [4]. This paper focuses on the deformation response of thin films made up of PUE materials for optical applications. These films, when provided with compliant transparent electrodes, can deform in response to the Maxwell stress.

However, significant enhancement of the strain response can be achieved using the same principle of operation as dielectric elastomer actuators (DEA) [2, 3, 5].

2. EXPERIMENTAL INVESTIGATION

Polyurethane elastomer pellets, Pellethane 2103 – 90 AE, were obtained from DOW Chemical. A solvent casting technique [6, 7] was used to produce polyurethane films by completely dissolving the pellets in tetrahydrofuran (THF). The resulting solution was placed on a glass petri dish and left for approximately 24 hrs to allow the THF to completely vaporize at ambient temperature leaving a solidified thin polyurethane film. The film was then annealed at 95 ^{o}C in vacuum for about 45 minutes.

Using an in-situ deposition technique, several samples of the films were coated with a thin layer of transparent conductive polymer to produce the basic element of the smart lens. Each one of these samples was then tested for the optical properties, which included the refractive index and the light transmission. The former was determined using a Refractometer (type ETI Belgium) having a refractive index range of 1.300 to 1.700 while the latter using a Pharmacia Biotech Ultrospec 2000 UV/ visible spectrophotometer operating in the transmission mode. For the latter the films were cut into standard rectangular pieces of approximately (30mm x 5mm), and transmission spectra relative to air were obtained.

A lens was made by stretching the PUE film and coating it with conductive polymer PPy electrodes deposited on both sides. The stretched film was sandwiched between two circular ring-type frames designed to hold the lens and to produce the necessary clamping conditions at the film boundaries. On each side of the lens and close to its boundaries an electrical lead wire was bonded to the electrode surface using conductive silver epoxy which required 24 hours to dry. To avoid any damage to the film, the two lead wires were passed through a groove made in the frame. The two wires were then connected to the power supply. Although this method introduces boundary constraints, it supports the film and eliminates boundary arcing.

After stretching the film and sandwiching it within the frame, a 0.1mm thickness and 50 mm net diameter lens was produced, see Figure 1. Several samples were prepared and tested for electroactive response and optical characteristics.

3. ELECTROACTIVE CHARACTERIZATION

The prepared lens was tested to determine the deformation as a function of the applied electric field at ambient conditions. When a DC voltage is applied to the electrodes, the PUE film deforms, causing a compression in the thickness and an expansion in the area of the PUE film. There are two intrinsic mechanisms behind this behaviour [3, 6, 9, 10]; namely, the electrostriction effect, due to reorientation of the polar phases in response to an applied electric field, and the Maxwell stress effect, which is attributed to the fact that the free charges on the electrodes squeeze and stretch the PUE film resulting in electrostatic forces. The contribution from both mechanisms exhibits a quadratic dependence on the applied electric field. Since the PUE film was clamped at the edges and fixed to the frame, the in-plane displacement was restricted and this caused the PUE film to bend**.** After deformation the film assumes a concave surface with a maximum deflection (δ) at its centre. δ is measured at different applied voltages. Figure 2 shows the experimental setup for the electroactive test. Various driving DC voltages were applied from the high voltage converter source (AC to DC) type EMCO DX250, and a Keystone laser displacement detector to measure the deflection at the centre. A digital voltmeter and software program were used to acquire and digitize the deflection in the PUE film.

4. RESULTS AND DISCUSSION

The proposed lens was tested for optical and electroactive characteristics.

4.1 Refractive Index

Using a Refractometer, the refractive index (*n*) of the proposed lens before and after coating with the electrode material was measured. These values are given in Table 1. In the same table n values of some available lens materials [8, 11] are given for comparison purpose. It is clear that the refractive index of the PUE material compare well with other available lens materials; however, it is at the upper end of the scale when coated. The coated lens shows *n* values above 1.7 compared with the uncoated of 1.6. This introduces a problem in using the refractometer directly to measure n values. Normally the refractometer is used to measure a fluid's refractive index which is smaller than 1.7. Therefore, to get *n* for the present material using the Refractometer, some modification has to be made. In this work an approximate method is used based on extrapolation between the percent of the total light transmission as discussed in the next section.

Table 1. Refractive index of various materials.

Material	Refractive Index
HYPERINDEX	1.6
ophthalmic crown glass	1.523
Plastic (CR-39)	1.498
high RI flint glass	1.79
PUE film (proposed lens) before coating	1.6
PUE film (proposed lens) after coating	1.7

Visual testing of the PUE films has indicated that all the films were very clear and had no appearance of chromatic dispersion. The latter is attributed to the fact that these films have the same reflective index for all wavelengths [8]. These properties distinguish clearly PUE film from polycarbonate and HYPERVIEW lenses [11], which have a high chromatic dispersion, see Figure 3.

Since the refractive index measures the angle of deviation of light that passes through the material, the higher it is, the wider the angle of deviation and the lower the aberrations for a given correction. Thus using high refractive index materials such as PUE would achieve a given power with smaller surface curvature and with smaller applied voltage [12]. Further, a high refractive index lens has a lighter weight, smaller thickness [11] and is more convenient to the wearer.

4.2 Transmission

The amount of light reflected (*Ir*) by the film surfaces in air can be determined using the Fresnel equation [8]:

$$Ir = \frac{(n-1)^2}{(n+1)^2} x \, (100) \tag{1}$$

Using the measured values of n=1.6 (Table1), the percentage of light lost by reflection at the front surface of the lens (Ir_1) is 5.325%. Because clear lens absorbs no light, the percentage of incident light remaining (I_R) when the light reaches the back surface of the lens is:

$$I_R = 100 - I_{r1} \tag{2}$$

For PUE, this gives I_R =94.67%. Thus the light lost by reflection at the back surface Ir_2 =5.04. The percentage of the total transmitted light (T) can be calculated by

$$T = 100 - (I_{r1} + I_{r2}) \tag{3}$$

For the PUE this gives T= 89.63%.

To calculate a refractive index higher than 1.7, one can use the material dispersion formula [12]

$$n = \left[\left(\frac{B_1 \lambda^2}{\lambda^2 - C_1} \right) + \left(\frac{B_2 \lambda^2}{\lambda^2 - C_2} \right) + \left(\frac{B_3 \lambda^2}{\lambda^2 - C_3} \right) + 1 \right]^{\frac{1}{2}} \tag{4}$$

However, this formula requires a number of parameters including the wavelength λ and the optical constants of the material which are not available in this work. Therefore an approximate extrapolation procedure is used as follows:

Using Eq. (1), the total transmitted light in the visible range (400 -700 nm) is 89.63 % for a clear PUE film, while the measured value using the spectrophotometer is 89.3 % for the same film. Since these values are very close, extrapolation is justified and used to determine the refractive index above 1.6. For an uncoated PUE film the measured transmitted light is 89.3% and the corresponding refractive index is 1.6. However, for the coated film the measured transmitted light is 83.4%. Using linear extrapolation gives a refractive index for the coated film of 1.835.

Figure 4 shows the spectral transmission for a clear PUE and after depositing the transparent electrode material (DTEM). The percentage of total transmitted light in the visible range 400 -700 nm is reduced by about 5.9 %.This is due to the fact that the transparent electrodes act as a filter which alters the intensity and sometimes the spectral distribution of the light passing through it [13]. The reflecting filter in a normal lens is made of a thin film material deposited on the surface of the lens to reduce the visible, UV and infrared portions of the spectrum. Figure 4 also shows that the clear and coated PUE films provide excellent protection from UV radiation in the far band (200 to 290nm) portion and adequate protection in the near band (300 to 390nm) portion which can be used in any environment in which the intensity of far or near UV radiation is greater than the normal intensity. The results of the percentage of total transmitted light for a clear PUE film is 89.3 % and for the coated film is 83.4 %. These results compare well with ideal plastic and glass lens materials which have percentage of total transmitted light of 92.2 % and 91.6 % respectively [8].

4.3 Electroactive Characterization

Voltages in the range of 3.5-25 KV are applied to the prepared lens and the deformation at the centre of each film was measured using the laser displacement sensor and the result is summarised in Figure 5. This figure shows that the film deformation increases with the applied voltage and reaches a maximum deflection of

0.2 mm at a voltage of 17.73 KV before it starts to decrease. This is transferred to a maximum focal length of +0.534 Dioptre. To improve these values and obtain a larger range of optical lens variation, stacking of more than one film is suggested for a stiffer lens and better deformation [15]. This procedure is currently under investigation and will be reported in a future paper.

5. CONCLUSIONS

Electrostrictive polyurethane elastomer films were prepared and tested under various environmental conditions. Lenses were made consisting of single-layer film and two-layer films and were tested for transmission and reflection. 83% light transmittance was achieved for each individual coated film. When a DC voltage was applied to the electrodes, the PUE film deformed, causing compression in the thickness and expansion in the area of the film. Since the film was clamped at the edges and fixed to the frame, the displacement was constricted and caused the film to bend**.** The results show that for a given applied voltage, the deformation of the two-layer film is significantly larger than that of a single-layer film.

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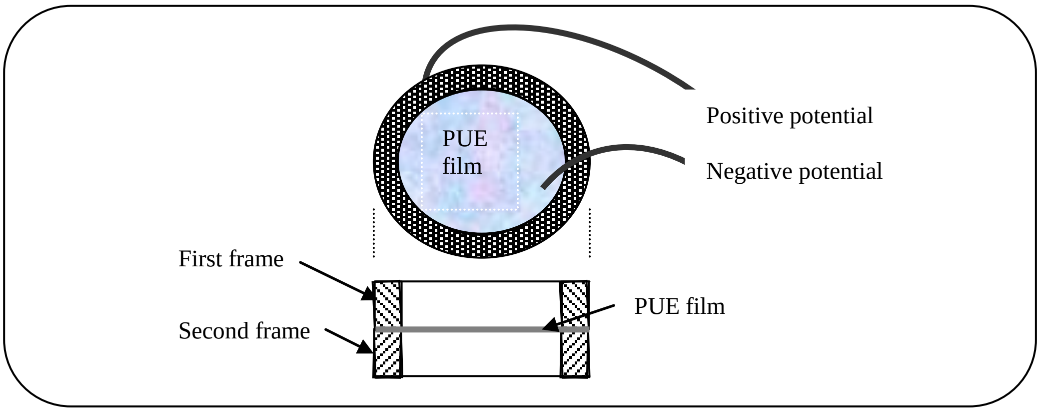


Figure 1: Schematic diagram of a single-layer lens.

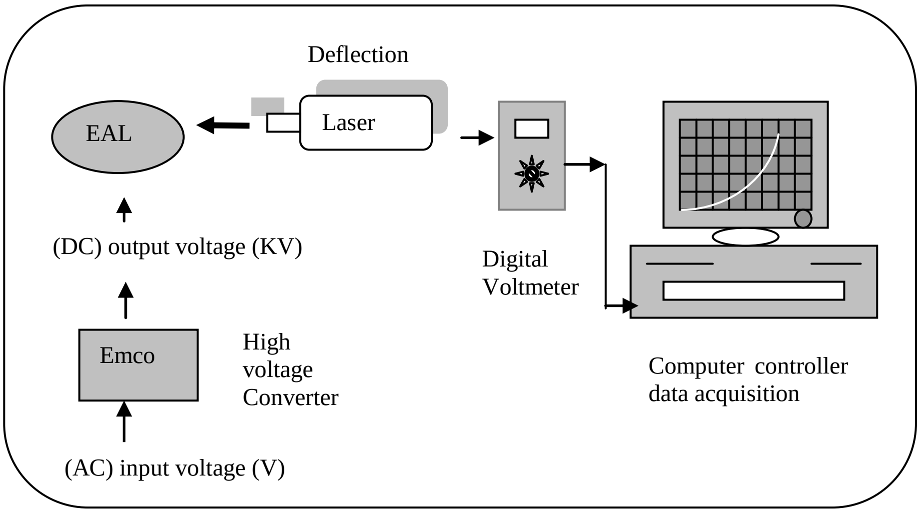
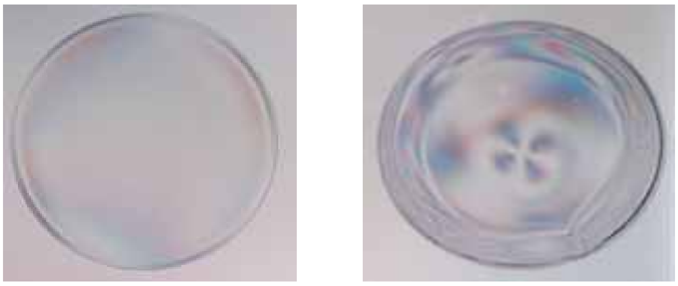


Figure 2: Schematic diagram of the experiment setup for data acquisition of the deformed film.

a- clear PUE film (EAL)



b- HYPERVIEW (1.66) **c- Polycarbonate**

Figure 3: The comparison between a- EAL, b-HYPERVIEW (1.66) lens, and c- Polycarbonate.

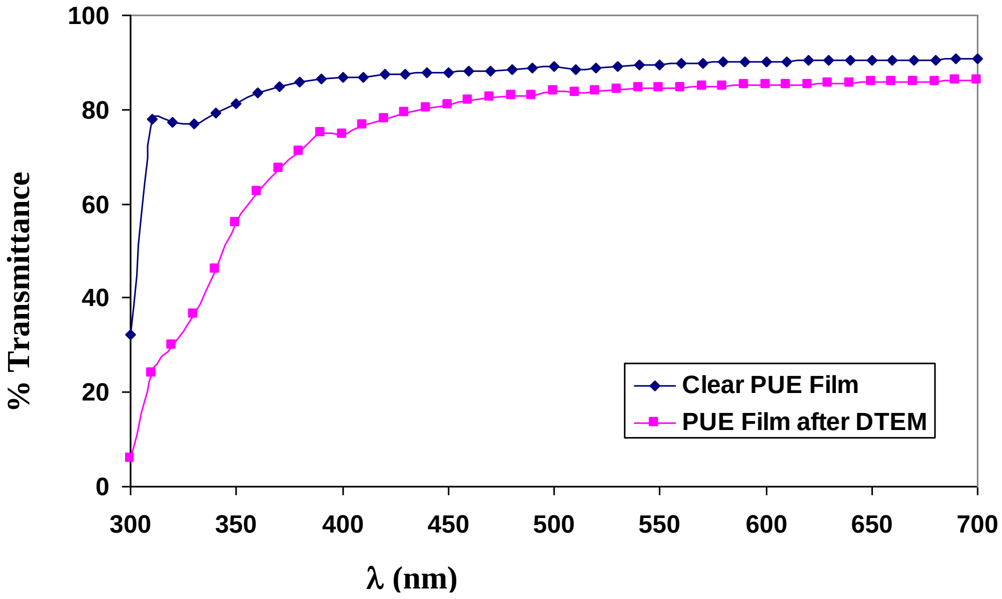


Figure 4: Spectral transmittance curves of clear PUE film before and after DTEM.

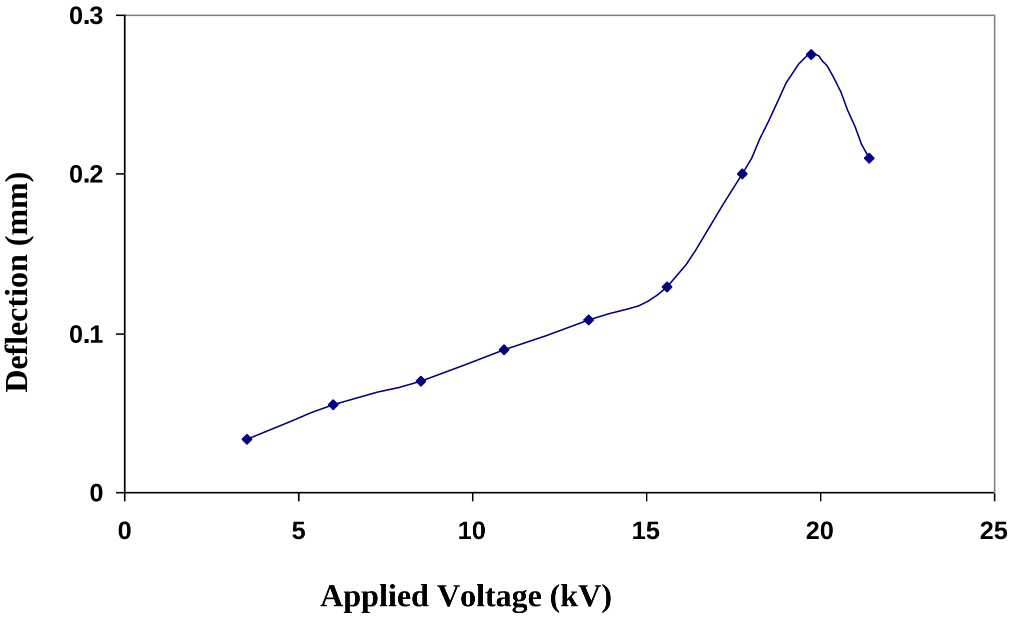


Figure 5: Deflection of PUE film at various driving DC voltage.