Enhancing storage permittivity by incorporating PDMS-PEG multi block copolymers in binary polymer blends

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Enhancing storage permittivity by incorporating PDMS-PEG multi block copolymers in binary polymer blends

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Background of dielectric elastomer (DE)

DE - changes size/shape (presence of electrical field)
- compliant capacitor (electrostatic stress > elastic stress)

DEs: silicones, acrylates, polyurethanes and thermoplastic elastomer copolymer.

Actuator
Herbert Shea – EPFL Switzerland

Generator
Roy Kornbluh et al - SRI International, USA

Sensor
Ben O’Brien – University of Auckland
DE as an actuator

![Diagram showing DE actuator behavior with expansion and compression](image-url)
DE as a generator

High mechanical potential  Low mechanical potential
Low electrical potential  High electrical potential

Deflation
DE as a sensor

Reference state

Dielectric elastomer

Compliant electrodes

Pressure mode

Stretch mode

Shear mode

Proximity mode

Touch mode

Proximity

Pressure, stretch & shear

Touch

\[ C = \varepsilon_0 \varepsilon_r \frac{A}{t} + C_{parasitic} \]
Morphology in block copolymers

Multiblock copolymer

(AB)_n

Common morphologies of block copolymers

Spheres  Cylinders  Gyroids  Lamellar

Increasing volume fraction (f_A)

Domain spacings

PDMS versus PEG

Polydimethylsiloxane (PDMS)

- Low modulus
- Low conductivity
- Low permittivity (net dipole moment, $\mu=0.6 \text{–} 0.9 \text{ D}^4$)

Polyethyleneglycol (PEG)

- High Permittivity (a dipole moment, $\mu=3.91 \text{ D}^5$)
- High conductivity
- Not flexible

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Experimental

Sample details for PDMS-PEG multiblock copolymers

<table>
<thead>
<tr>
<th>PDMS-PEG block copolymer</th>
<th>Number average molecular weight of H-PDMS ( (M_{n,PDMS}) ) [g/mol]</th>
<th>Number of repeating units in PDMS ( (m) )</th>
<th>Theoretical number of repeating units in ( (PDMS-PEG)_x ) ( (X) )</th>
<th>Stoichiometric ratio ( (r_1) )</th>
<th>Volume fraction of PDMS ( (f_A) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDMS81-PEG</td>
<td>6000.00</td>
<td>81</td>
<td>5</td>
<td>1.21</td>
<td>0.94</td>
</tr>
<tr>
<td>PDMS14-PEG</td>
<td>1050.00</td>
<td>14</td>
<td>23</td>
<td>1.04</td>
<td>0.75</td>
</tr>
<tr>
<td>PDMS7-PEG</td>
<td>550.00</td>
<td>7</td>
<td>37</td>
<td>1.03</td>
<td>0.62</td>
</tr>
<tr>
<td>PDMS3-PEG</td>
<td>208.00</td>
<td>3</td>
<td>56</td>
<td>1.02</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Note: \( M_n \) of PEG in PDMS-PEG block copolymer is 250 g/mol
The blends and sample preparation

1. Synthesis PDMS-PEG prepolymer
2. 1) Crosslink PDMS-PEG block copolymer (BCP) with 9-functional (9-f) crosslinker
   2) Blend the block copolymer with commercial PDMS (MJK) and crosslink with 9-f crosslinker
3. 1) 1 mm film – rheology & permittivity
   2) 100 μm film – dielectric breakdown strength
Relative permittivity VS dielectric loss factor (BCP)
Conductivity and shear modulus (BCP)

**Conductivity, $\sigma$ (S/cm)**

- PDMS elastomer (MJK)
- PDMS81-PEG
- PDMS14-PEG
- PDMS7-PEG
- PDMS3-PEG

**Storage modulus, $G'$ (Pa)**

- PDMS elastomer (MJK)
- PDMS81-PEG
- PDMS14-PEG
- PDMS7-PEG
- PDMS3-PEG

**Loss modulus, $G''$ (Pa)**

- PDMS elastomer (MJK)
- PDMS81-PEG
- PDMS14-PEG
- PDMS7-PEG
- PDMS3-PEG
Relative permittivity VS Dielectric loss factor (MJK/PDMS7)

"Relative permittivity, $\varepsilon'_r$
Frequency (Hz)
- PDMS Elastomer (MJK)
- 5wt% MJK/PDMS7
- 10wt% MJK/PDMS7
- 15wt% MJK/PDMS7
- 20wt% MJK/PDMS7
- PDMS7-PEG

Dielectric loss factor, $\tan(\delta)$
Frequency (Hz)
- PDMS Elastomer (MJK)
- 5wt% MJK/PDMS7
- 10wt% MJK/PDMS7
- 15wt% MJK/PDMS7
- 20wt% MJK/PDMS7
- PDMS7-PEG"
Conductivity & shear modulus (MJK/PDMS7)

- **Conductivity (S/cm)** vs. Frequency (Hz)
  - PDMS Elastomer (MJK)
  - 5wt% MJK/PDMS7
  - 10wt% MJK/PDMS7
  - 15wt% MJK/PDMS7
  - 20wt% MJK/PDMS7
  - PDMS7-PEG

- **Storage modulus, G' (Pa)** vs. Frequency (Hz)
  - G' PDMS Elastomer (MJK)
  - G' 5wt% MJK/PDMS7
  - G' 10wt% MJK/PDMS7
  - G' 15wt% MJK/PDMS7
  - G' 20wt% MJK/PDMS7

- **Loss modulus, G'' (Pa)** vs. Frequency (Hz)
  - G'' PDMS Elastomer (MJK)
  - G'' 5wt% MJK/PDMS7
  - G'' 10wt% MJK/PDMS7
  - G'' 15wt% MJK/PDMS7
  - G'' 20wt% MJK/PDMS7
Dielectric breakdown ($E_{BD}$) strength (MJK/PDMS7)

<table>
<thead>
<tr>
<th>MJK/ PDMS7</th>
<th>Dielectric breakdown $E_{BD}$ (V/µm)</th>
<th>Weibull $\eta$-parameter</th>
<th>Weibull $\beta$-parameter</th>
<th>$R^2$ of linear fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>MJK</td>
<td>93 ± 7</td>
<td>98</td>
<td>17</td>
<td>0.92</td>
</tr>
<tr>
<td>5 wt%</td>
<td>103 ± 4</td>
<td>105</td>
<td>31</td>
<td>0.84</td>
</tr>
<tr>
<td>10 wt%</td>
<td>92 ± 3</td>
<td>94</td>
<td>31</td>
<td>0.93</td>
</tr>
<tr>
<td>15 wt%</td>
<td>93 ± 8</td>
<td>96</td>
<td>13</td>
<td>0.99</td>
</tr>
<tr>
<td>20 wt%</td>
<td>101 ± 5</td>
<td>103</td>
<td>25</td>
<td>0.95</td>
</tr>
</tbody>
</table>
# Figure of merit ($F_{OM}$) - actuator

<table>
<thead>
<tr>
<th>MJK/PDMS7</th>
<th>Young’s modulus, $Y^*$ (kPa)</th>
<th>Normalised $F_{OM}$ (DEA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 wt% (MJK)</td>
<td>205</td>
<td>6.1</td>
</tr>
<tr>
<td>5 wt%</td>
<td>123</td>
<td>17.2</td>
</tr>
<tr>
<td>10 wt%</td>
<td>169</td>
<td>9.6</td>
</tr>
<tr>
<td>15 wt%</td>
<td>238</td>
<td>8.0</td>
</tr>
<tr>
<td>20 wt%</td>
<td>203</td>
<td>11.2</td>
</tr>
</tbody>
</table>

* $Y = 3G'$

\[
F_{OM} (DEA) = \frac{3\varepsilon_r\varepsilon_0 E_{BD}^2}{Y}
\]

$F_{OM} (DEA)$ of Elastosil RT625 ($1.86 \times 10^{-24}$)
Conclusion

• Incorporating conducting PDMS-PEG block copolymer with non-conducting PDMS elastomer:
  • Improve relative permittivity up to 60% with low loss permittivity and non-conducting.
  • Maintain **low modulus** (obtain soft elastomer).
  • Based on FOM, the actuation improves by **17-fold** compared to reference material (Elastosil RT625).
Thank you & questions

DPP Group

Current members

Previous members