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

Expansion

Compression

Methodology

Results (block copolymer)

Results (binary polymer blends)

Conclusion
DE as a generator

High mechanical potential
Low electrical potential

Low mechanical 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

\[ C = C_0 \varepsilon_r \left( \frac{A}{t} \right) + C_{parasitic} \]

Touch
Morphology in block copolymers

Multiblock copolymer

\[(AB)^n\]

Common morphologies of block copolymers:
- Spheres
- Cylinders
- Gyroids
- Lamellar

Increasing volume fraction \((f_A)^1\)

Domain spacings

PDMS versus PEG

Polydimethylsiloxane (PDMS)

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

Polyethyleneglycol (PEG)

- High Permittivity (a dipole moment, $\mu=3.91$ 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 ((\text{PDMS}-\text{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) Crosslink PDMS-PEG block copolymer (BCP) with 9-functional (9-f) crosslinker
3) Blend the block copolymer with commercial PDMS (MJK) and crosslink with 9-f crosslinker

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)

Dielectric elastomer

Block copolymers

PDMS vs. PEG

Methodology

Results (block copolymer)

Results (binary polymer blends)

Conclusion
Relative permittivity VS Dielectric loss factor (MJK/PDMS7)
**Conductivity & shear modulus (MJK/PDMS7)**

**Conductivity**

- **PDMS Elastomer (MJK)**
- **5wt% MJK/PDMS7**
- **10wt% MJK/PDMS7**
- **15wt% MJK/PDMS7**
- **20wt% MJK/PDMS7**
- **PDMS7-PEG**

**Frequency (Hz)**

- **Storage modulus, G’ (Pa)**
- **Loss modulus, G” (Pa)**

**Conclusion**
### 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>

* $Y = 3G'$

$$F_{OM}(DEA) = \frac{3\varepsilon_r\varepsilon_0E_{BD}^2}{Y}$$

$F_{OM}(DEA)$ 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