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.
DE as an actuator
DE as a generator

High mechanical potential  Low mechanical potential
Low electrical potential  High electrical potential
DE as a sensor

Reference state

Pressure mode

Stretch mode

Shear mode

Proximity mode

Touch mode

$C = \varepsilon_0 \varepsilon_r \frac{A}{t} + C_{\text{parasitic}}$

Proximity

Pressure, stretch & shear

Touch
Morphology in block copolymers

Multiblock copolymer

\[(AB)_n\]

**Diblock**

\[a\]

**Multiblock**

\[b\]

**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, $\mu=0.6 - 0.9$ D$^4$)

Polyethyleneglycol (PEG)

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

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DTU Chemical Engineering, Technical University of Denmark
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) 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 mm film – rheology & permittivity
   2) 100 μm film – dielectric breakdown strength
Relative permittivity VS dielectric loss factor (BCP)

Relative permittivity, $\varepsilon'$

Dielectric loss factor, $\tan(\delta)$

Frequency (Hz)

PDMS elastomer (MJK)
PDMS81-PEG
PDMS14-PEG
PDMS7-PEG
PDMS3-PEG
Conductivity and shear modulus (BCP)

Conductivity, $\sigma$ (S/cm)

Frequency (Hz)

Storage modulus, $G'$ (Pa)

Frequency (Hz)

Loss modulus, $G''$ (Pa)

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

Conductivity (S/cm)

Frequency (Hz)

Storage modulus, G' (Pa)

Loss modulus, G'' (Pa)
Dielectric breakdown \((E_{BD})\) strength (MJK/PDMS7)

<table>
<thead>
<tr>
<th>MJK/PDMS7</th>
<th>Dielectric breakdown (E_{BD}) (V/(\mu)m)</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