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
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

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

Proximity, pressure, stretch & shear

Touch
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, $\mu=0.6 - 0.9 \, \text{D}^4$)

**Polyethyleneglycol (PEG)**

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

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**Methods**

- Dielectric elastomer
- Block copolymers
- PDMS vs. PEG
- Methodology
- Results (block copolymer)
- Results (binary polymer blends)
- Conclusion

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DTU Chemical Engineering, Technical University of Denmark

November 2014
# 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) 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)

Dielectric elastomer  Block copolymers  PDMS vs. PEG  Methodology  Results (block copolymer)  Results (binary polymer blends)  Conclusion
Conductivity and shear modulus (BCP)

Conductivity, $\sigma$ (S/cm)

Frequency (Hz)

Storage modulus, $G'$ (Pa)

Frequency (Hz)

Loss modulus, $G''$ (Pa)
Relative permittivity VS Dielectric loss factor (MJK/PDMS7)

Graphs showing
- Relative permittivity $\varepsilon'_r$ vs. Frequency (Hz)
- Dielectric loss factor $\tan(\delta)$ vs. Frequency (Hz)

Legend:
- PDMS Elastomer (MJK)
- 5wt% MJK/PDMS7
- 10wt% MJK/PDMS7
- 15wt% MJK/PDMS7
- 20wt% MJK/PDMS7
- PDMS7-PEG
Conductivity & shear modulus (MJK/PDMS7)

Dielectric elastomer
Block copolymers
PDMS vs. PEG
Methodology
Results (block copolymer)
Results (binary polymer blends)
Conclusion
## Dielectric breakdown ($E_{BD}$) strength (MJK/PDMS7)

![Image of dielectric breakdown]

<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

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

<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>

\(\text{F}_{OM}\) (DEA) of Elastosil RT625 (1.86 \times 10^{-24})

* \(Y = 3G’\)
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