A soft and conductive PDMS-PEG block copolymer as a compliant electrode for dielectric elastomers

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A soft and conductive PDMS-PEG block copolymer as a compliant electrode for dielectric elastomers

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Motivation

Principle of dielectric elastomer (DE) as an actuator:

Requirement of compliant electrodes: 1) Inherently soft 2) conductivity
Stereotypes of electrodes

1) A conductive material is generally non-stretchable.

2) A stretchable material is usually non-conductive.

Our goal: soft-conductive polymer
Conventional electrodes for DEs

1) **Losse carbon black**
   - Samuel Rosset (EPFL)
   - Helmut Schlaak (University of Darmstadt)

2) **Carbon grease**
   - Samuel Rosset (EPFL)

**Alternative electrodes:**
1) Ionic conductor (hydrogel)
2) Silver nanowires
3) Conductive rubber
**PDMS3-PEG copolymer**

1. **Hydrosilylation reaction of PDMS-PEG copolymer:**

   \[
   \text{PDMS3-PEG} \quad + \quad 2+ \quad \text{Pt} \quad \xrightarrow{60 \, ^\circ \text{C}} \quad \text{high conductivity (10}^{-8} \, \text{S/cm)}
   \]

2. **Conductivity (PDMS-PEG copolymers)**

   - PDMS3-PEG → high conductivity (10^{-8} \, \text{S/cm})

   ![Conductivity graph](chart)

3. **Linear viscoelasticity-LVE (PDMS-PEG copolymers)**

   - PDMS3-PEG → Stiff

   ![Linear viscoelasticity graph](chart)

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**Compliant electrodes**

**PDMS-PEG**

**MWCNTs**

**Dielectric properties**

**Rheology**

**Stress-strain**

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**DTU Chemical Engineering, Technical University of Denmark**

30 June 2016
Chain-extended PDMS3-PEG copolymer

1. To obtain a soft-conductive polymer → Chain extended PDMS-PEG copolymer

\[
\text{PDMS} - \text{PEG (vinyl terminated)} + \text{PDMS232 (hydride terminated)} \quad \xrightarrow{23 \text{ deg. C}, \text{Pt}^{2+}} \quad \text{(PDMS - PEG) - PDMS232 (hydride terminated)}
\]

2. Crosslinked copolymer:
Chain-extended PDMS-PEG copolymer + 15-functional vinyl crosslinker + 30 ppm Pt catalyst

\[
\text{Mn} = 38 \text{ kg/mol}
\]
# Multi-walled carbon nanotubes (MWCNTs)

1. Conductivity (PDMS3-PEG) → add conductive nanofillers (MWCNTs)

2. Obstacle → MWCNTs entangle

### SEM image of pure MWCNTs showing entanglements.

### 3. Dispersion methods:

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Mechanical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation process by acid e.g. HNO₃ &amp; solution of H₂O₂/NH₄OH</td>
<td>1) Probe sonicator</td>
</tr>
<tr>
<td></td>
<td>2) Ball milling</td>
</tr>
<tr>
<td>Drawback: intrinsic properties of MWCNTs are destroyed due to structural defects</td>
<td></td>
</tr>
<tr>
<td>Drawback: rupture MWCNTs into smaller lengths</td>
<td></td>
</tr>
</tbody>
</table>

### 4. Non-covalent physical treatment

Mechanism of flocculation of CNTs via surfactant molecules.¹

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30 June 2016
Multi-walled carbon nanotubes (MWCNTs)

- Dispersion of MWCNTs → Rastogi et al.¹, Geng et al.² and Goswami et al.³

1. Stability versus time for a reference method (MWCNT/NMP/Triton X-100) dispersed by a mechanical shaker at 23 °C: a) Immediately b) 5 min c) 30 min d) 60 min.

2. Stability versus time for MWCNT/NMP/Triton X-100 dispersed by water-bath ultrasonication at 23 °C for 6 hours: a) Immediately b) 5 min c) 30 min d) 60 min.

3. Optical microscope image of this film containing MWCNTs (0.07 phr) in PDMS-PEG matrix.

Conductivity & permittivity

![Conductivity graph](image_url)
Modulus

![Graph showing storage modulus and modulus loss factor as functions of frequency for different composites.](attachment:image.png)
Stress-strain plots

![Stress-strain plots](image)

- **0CNT Si3PEG_H25**
- **1CNT Si3PEG_H25**
- **2CNT Si3PEG_H25**
- **3CNT Si3PEG_H25**
- **4CNT Si3PEG_H25**
- **LR 3162**

- Y = 0.23 MPa
- Y = 0.47 MPa
- Y = 0.70 MPa
- Y = 0.92 MPa
- Y = 1.17 MPa
- Y = 0.26 MPa

**Stress (MPa)**

**Strain (%)**
Conclusion

- The cross-linked conductive PDMS-PEG copolymers were successfully prepared with addition of different MWCNT concentrations.
- The conductivity of the chain-extended elastomers increases nearly to $10^{-3}$ S/cm;
  - < LR3162 = $10^{-1}$ S/cm
- The mechanical properties of chain-extended PDMS-PEG copolymers with MWCNTs (< 3 phr) indicate soft networks with low modulus losses.
- Future work:
  - The conductivity can be improved by adding silver nanoparticles in the system if properly designed.
  - Measure the conductivity of samples in “stretch” mode.
Acknowledgement