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:

$$\begin{align*}
\text{PDMS3-PEG} & \rightarrow \text{Stiff} \\
\text{PDMS} & \rightarrow \text{Stiff}
\end{align*}$$

2. Conductivity (PDMS-PEG copolymers)$^1$

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

3. Linear viscoelasticity-LVE (PDMS-PEG copolymers)$^1$


Compliant electrodes  PDMS-PEG  MWCNTs  Dielectric properties  Rheology  Stress-strain

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

\[
\begin{align*}
\text{PDMS} - \text{PEG} \quad &+ \quad \text{PDMS232} \\
\text{23 deg. C} \quad &\quad \text{Pt}^{2+}
\end{align*}
\]

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 2) Ball milling</td>
</tr>
</tbody>
</table>

Drawback: intrinsic properties of MWCNTs are destroyed due to structural defects

Drawback: rupture MWCNTs into smaller lengths

4. Non-covalent physical treatment

Mechanism of flocculation of CNTs via surfactant molecules.

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Multi-walled carbon nanotubes (MWCNTs)

• Dispersion of MWCNTs → Rastogi et al.\textsuperscript{1}, Geng et al.\textsuperscript{2} and Goswami et al.\textsuperscript{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

Fig. 1

Conductivity (S/cm) vs. Frequency (Hz)

- OCNT Si3PEG_H25
- 1CNT Si3PEG_H25
- 2CNT Si3PEG_H25
- 3CNT Si3PEG_H25
- 4CNT Si3PEG_H25
- LR 3162

Retest with normal force = 10 N


**Modulus**

![Graph showing storage modulus and modulus loss factor vs. frequency](image)

- **Storage modulus (Pa):**
  - 0CNT Si3PEG_H25
  - 1CNT Si3PEG_H25
  - 2CNT Si3PEG_H25
  - 3CNT Si3PEG_H25
  - 4CNT Si3PEG_H25
  - LR 3162

- **Modulus loss factor:**
  - 0CNT Si3PEG_H25
  - 1CNT Si3PEG_H25
  - 2CNT Si3PEG_H25
  - 3CNT Si3PEG_H25
  - 4CNT Si3PEG_H25
  - LR 3162

**Frequency (Hz):**

- $10^{-2}$
- $10^{-1}$
- $10^0$
- $10^1$
- $10^2$
Stress-strain plots

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

Stress (MPa)
Strain (%)

Y = 1.17 MPa
Y = 0.92 MPa
Y = 0.70 MPa
Y = 0.47 MPa
Y = 0.26 MPa
Y = 0.23 MPa
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} \text{S/cm};
  - < LR3162 = 10^{-1} \text{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