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:

\[ \text{PDMS}3 - \text{PEG} \rightarrow \text{high conductivity (10}^{-8} \text{ S/cm)} \]

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

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

\[ \text{PDMS3-PEG} \rightarrow \text{Stiff} \]

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Chain-extended PDMS3-PEG copolymer

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

\[
\text{PDMS} - \text{PEG (vinyl terminated)} \quad \text{+} \quad \text{PDMS232 (hydride terminated)}
\]

\[
\begin{array}{c}
\text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_3 \\
\text{Si} - \text{O} \quad \text{Si} - \text{O} \quad \text{Si} \\
\text{CH}_3 \quad \text{CH}_3 \quad m \text{CH}_3
\end{array}
\]

23 deg. C  Pt\(^{2+}\)

\[
\begin{array}{c}
\text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_3 \\
\text{Si} - \text{O} \quad \text{Si} - \text{O} \quad \text{Si} \\
\text{CH}_3 \quad \text{CH}_3 \quad m \text{CH}_3
\end{array}
\]

(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. \(\downarrow\) conductivity (PDMS-PEG) \(\rightarrow\) add conductive nanofillers (MWCNTs)

2. Obstacle \(\rightarrow\) MWCNTs entangle

Fig. 1

SEM image of pure MWCNTs showing entanglements.

3. Dispersion methods:

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Mechanical</th>
</tr>
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</table>
| Oxidation process by acid e.g. \(\text{HNO}_3\) & solution of \(\text{H}_2\text{O}_2/\text{NH}_4\text{OH}\) | 1) Probe sonicator  
  2) Ball milling |

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.


DTU Chemical Engineering, Technical University of Denmark
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.

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Conductivity & permittivity

![Graph showing conductivity and frequency relationship for different samples.]

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

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

Retest with normal force = 10N
Modulus

![Graph showing moduli and modulus loss factors against frequency](image)

- **Storage modulus (Pa):** The graph displays the storage modulus for different samples (0CNT Si3PEG_H25, 1CNT Si3PEG_H25, 2CNT Si3PEG_H25, 3CNT Si3PEG_H25, 4CNT Si3PEG_H25, LR 3162) across a frequency range from $10^{-2}$ to $10^2$ Hz. The storage modulus is measured in Pascals (Pa).

- **Modulus loss factor:** Similar to the storage modulus, the modulus loss factor graph also shows the variation of loss factor with frequency for the same samples. It is typically measured in dimensionless units.

The graph provides insights into the viscoelastic properties of the materials under study, crucial for applications in fields such as biomedicine, electronics, and materials science.
Stress-strain plots

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

Stress (MPa) vs. 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 $10^{-3}$ S/cm;
  - $< \text{LR3162} = 10^{-1}$ 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