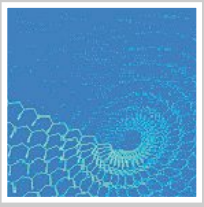
doi:10.2533/chimia.2015.548



Polymer and Colloid Highlights

Division of Polymers, Colloids and Interfaces
A Division of the Swiss Chemical Society

Polysiloxanes with Increased Permittivity as Artificial Muscles

Dorina M. Opris* and Simon J. Dünki

*Correspondence: Dr. D. M. Opris, Empa, Swiss Federal Laboratories for Materials Science and Technology, Laboratory for Functional Polymers, Dübendorf; E-mail: dorina.opris@empa.ch

Keywords: Dielectric elastomer actuators · High permittivity elastomer · Silicones

Imagine there was a material that could mimic the function of a natural muscle, which thus could extend and contract on demand and heal when damaged. Such material could be used to replace malfunctioning muscles such as sphincters and heart valves, or could make paralyzed lower or upper limbs to move again. This dream is getting closer to reality now thanks to the progress in dielectric elastomer actuator (DEA) technology. This progress is based upon the design and the creation of new polymeric materials, whose properties are significantly closer to the requirements for such technology than previous materials. Of the various properties which have to be met for the rather complex DEA technology, the driving voltage is of special concern. Already without being a specialist in the field it is understandable that a high driving voltage is likely to preclude applications of *e.g.* an artificial sphincter muscle in humans, even if this muscle would exhibit an optimum elastic responsivity. Driving voltages of several kV are not uncommon and this highlight will explain what has been done to improve the materials properties in order to lower the voltage range such that applications appear more realistic now.

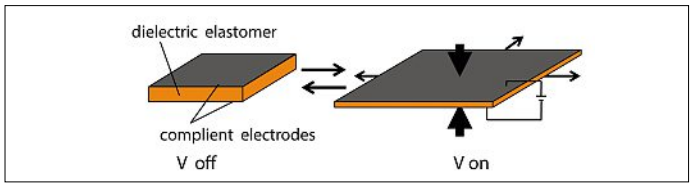


Fig. 1. Working principle of dielectric elastomer actuators.

DEA are stretchable capacitors constructed from a thin elastic film on which two compliant electrodes are applied.[1] When DEA are charged or discharged, a reversible deformation similar to that of natural muscle is observed (Fig. 1). An attractive way to reduce the driving voltage is to increase the dielectric permittivity of the elastomer used. Our attempts towards developing such materials went through several phases,[1,2] and resulted in polysiloxanes and polysiloxane-based composite materials with driving electric fields of about 30 V/µm, strains at break of higher than 500% and elastic moduli below 200 kPa. While these properties pointed in the right direction, in particular the driving voltage was still not where we wanted it to be. Further improvements were recently achieved with polymethylvinylsiloxanes, the fine-tuning of the dielectric properties of which could be achieved by the introduction of polar groups into the side chains.[3] The pendent vinyl groups were reacted with the thiol compounds 1-butanethiol and 3-mercaptopropionitrile both separately as well as in various ratios. Fig. 2 shows key structural elements. The resulting polymers combine permittivities (ε') ranging from ε' = 4.7 to 18.4 (!) with glass transition temperatures that are well below room temperature. Gratifyingly, with this attractive material free standing, homogeneous elastic films could be obtained in a process so simple that it could be employed on a technical scale.[4] Thus, we now have in our hands a film that has the following attractive characteristics: permittivity up to 10.1 at 10 kHz, elastic modulus at 10% strain Y = 154 kPa, and strain at break of 260%. Furthermore, actuators constructed with this material show the large actuation strain of 20.5% at an electric field as low as 10.8 V/µm (Fig. 3). Devices for implantation into humans cannot be operated above 24 V. With the properties mentioned, such conditions could be met with films the thickness of which is below 2 µm. While we did not yet reach this value, given the available thin film technology, 2 µm can be achieved. Finally it is noted that actuators constructed from our material can actually self-heal (Fig. 3).

The example described here shows that given the proper structure design, synthetic chemistry can contribute to the creation of novel devices with societal relevance.

Received: July 15, 2015

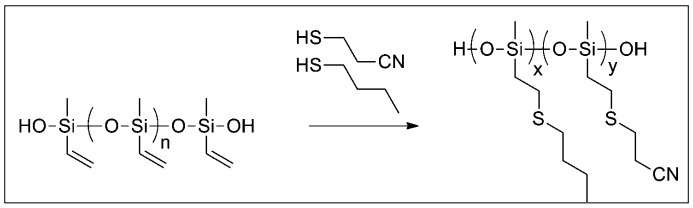


Fig. 2. Modification of polymethylvinylsiloxane with 1-butanethiol and 3-mercaptopropionitrile.

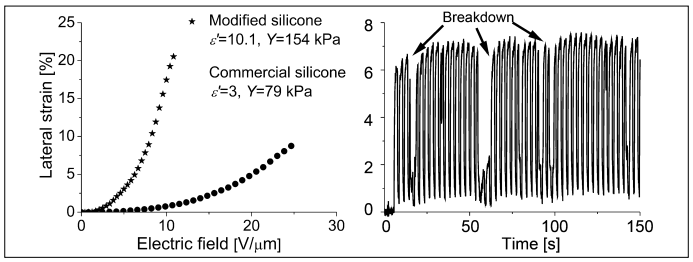


Fig. 3. Lateral actuation strain as function of electric field (left) and the self-healing of an actuator tested for 100 cycles at 8.3 V/µm (right). Several breakdowns and self-healing events can be seen.

[1] D. M. Opris, M. Molberg, C. Walder, Y. S. Ko, B. Fischer, F. A. Nüesch, *Adv. Funct. Mater.* **2011**, *21*, 3531.
[2] J. E. Q. Quinsaat, M. Alexandru, F. A. Nüesch, H. Hofmann, A. Borgschulte, D. M. Opris, *J. Mater. Chem. A* **2015**, *3*, 14675.
[3] S. J. Dünki, M. Tress, F. Kremer, S. Y. Song, F. A. Nüesch, C.-D. Varganici, C. Racles, D. M. Opris, *RSC Advances* **2015**, *5*, 50054.
[4] S. J. Dünki, Y. S. Ko, F. A. Nüesch, D. M. Opris, *Adv. Funct. Mater.* **2015**, *25*, 2467.