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Polydimethylsiloxane thin film preparation for dielectric elastomer actuators

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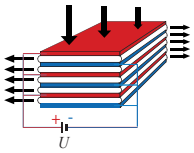
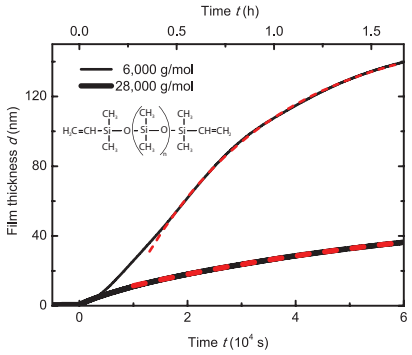
Introduction



Research on dielectric elastomer actuators (DEA) for medical implants face a significant challenge; to reduce the actuation voltages below 42 V. Currently available polymer films are micrometer-thick and voltages in the kV-range are necessary to reach strains above 10 % [1]. We aim to restrict the polymer layer thickness to the sub-micrometer range by using molecular beam deposition (MBD). To reach high actuation forces, stacked actuators consisting of multiple layers are needed. To fabricate multilayers, both the thermal evaporation and polymerization of the dielectric elastomer layer must be reliably repeated.

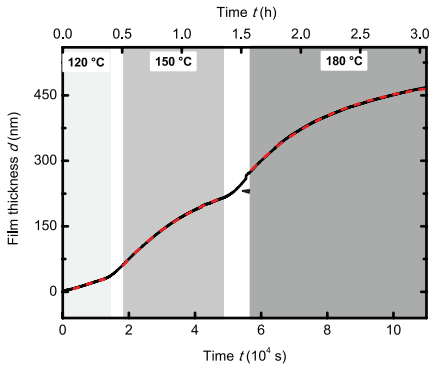
Molecular beam deposition



Molecular beam deposition of vinyl-terminated PDMS at pressure p of 10^{-8} mbar shows:

(I) Restricted deposition rate of polymers with molecular weight larger than 1000 g/mol

(II) Optimized deposition rates for a polymer molecular weight of 6000 g/mol occur at evaporation temperatures of T = 180 °C

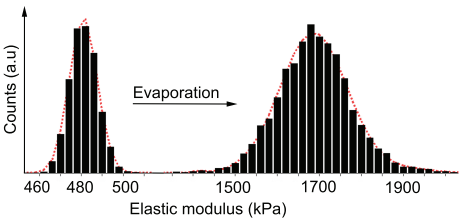


After deposition, UV-cross-linking is established by a deuterium-lamp with a 170 - 400 nm emission spectrum.

Characterization

(I) Nanoindentation

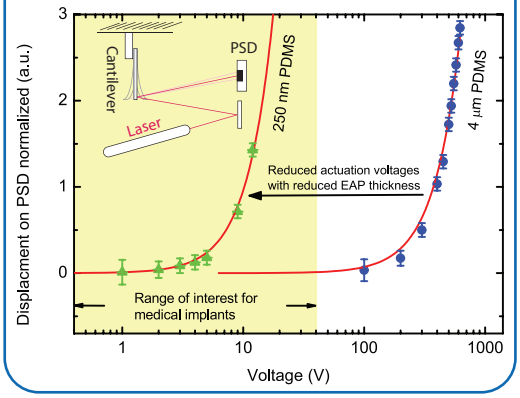
Nanoindentation data show a four-times higher elastic modulus of 6000 g/mol vinyl-terminated PDMS after thermal evaporation and condensation.



(II) Cantilever bending method

Actuation measurement of a 25 µm PEEK-cantilever with spin-coated PDMS (blue) and thermally evaporated PDMS (green). Latter in medically-acceptable voltage range [2]. Actuation is proportional to the ratio squared of applied voltage *U* to polymer layer thickness *d*:

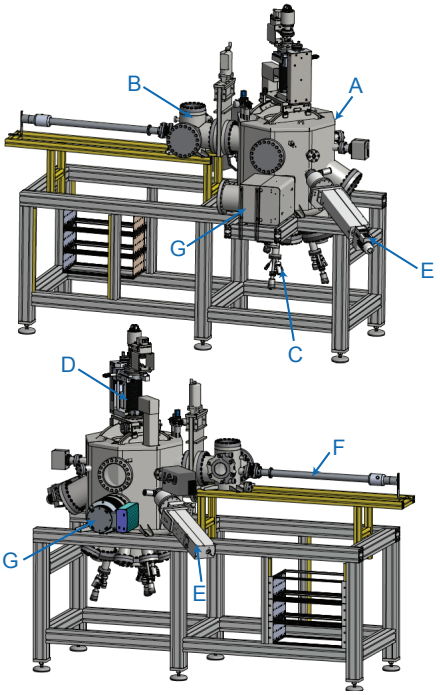
$$S = -\frac{1}{E}\epsilon_r\epsilon_0\left(\frac{U}{d}\right)^2$$



Next-generation MBD

Working vacuum during deposition: 10^{-8} mbar
Sample size: 2-inch wafers
Number of atomic/molecular sources: 4

In-situ ellipsometry
In-situ UV cross-linking



(A) Deposition chamber
(B) Load-lock chamber for rapid sample insertion and removal
(C) Temperature-controlled effusion cells produce evaporated polymers and metallic gases
(D) Substrate is mounted on a manipulator
(E) Deposited film thickness monitored by ellipsometry
(F) Linear translation arm transport sample between chambers
(G) Turbomolecular + ion getter & Ti sublimation pumping system

Challenges on the way to biomimetic artifical muscles

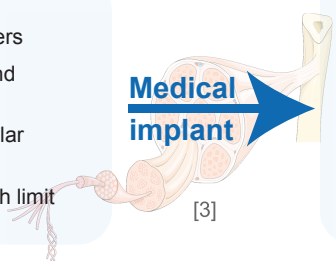
(I) Actuation voltages in the range of *kV*

(II) Stack actuators with tens of µm-thick polymer layers

(III) Spin-coated polymer layer with restricted purity and homogeneity

(IV) Limited deposition rates for polymers with molecular weigth larger than 1000 g/mol

(V) Cross-linking density results in elastic moduli which limit the actuation efficiency



(I) Actuation voltages lower than 42 V

(II) Stack actuators with hundreds of nm-thin polymer layers

(III) Thermal evporation under ultra-high vacuum conditions with homogeneity better than 2 %

(IV) Polymer molecular weight of 1000 g/mol to be used for evaporation temperature of T = 200 °C

(V) Tailoring of elastic moduli by functional groups

The authors thank Christian Bippes and Marco Portalupi from Nanosurf AG, Liestal Switzerland for the AFM data and Victrex Europe for providing us with PEEK cantilevers.

[1] R. Pelrine *et al.*, High-field deformation of elastomeric dielectrics for actuators. Mat. Sci. and Eng.: C, 2000. 11(2): 89-100.
[2] T. Töpper *et al.*: Sensors and Actuators, submitted and in review.
[3] http://www.eurostemcell.org/

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