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Polydimethylsiloxane thin films for dielectric elastomer actuactors characterized by spectroscopic ellipsometry

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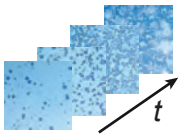
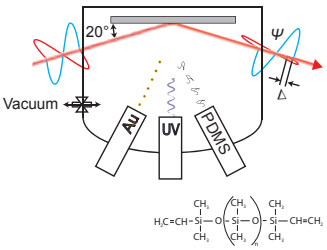
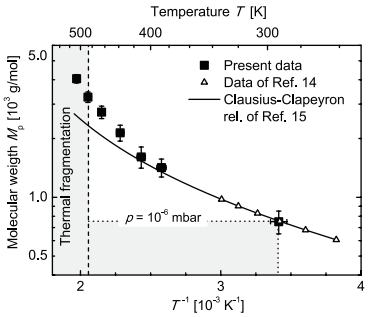
Introduction



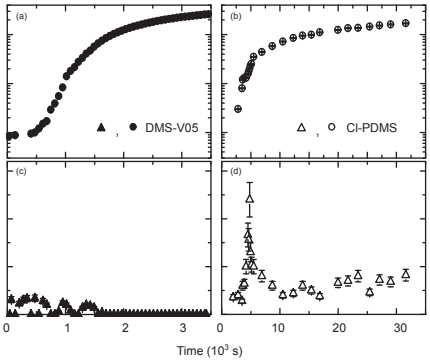
Currently, dielectric elastomer actuators (DEA) are mainly based on micrometer-thin polymer films and require operating voltages of several hundred volts. DEAs for medical implants, however, face a significant challenge; to reduce the actuation voltages as low as a very few tens of volts. We demonstrate that alternating current, electro-spray deposition (ESD) as well as thermal evaporation allow for the fabrication of homogenous, nanometer-thin polydimethylsiloxane (PDMS) films. To reach high actuation forces, stacked actuators consisting of multiple layers are needed. Thus both the growth and polymerization of the PDMS-layer must be reliably repeated.

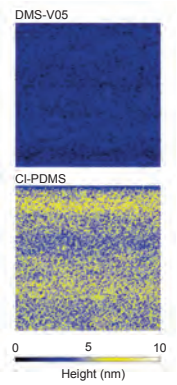
Molecular beam deposition





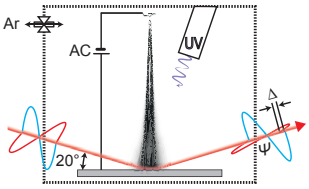
Thermally evaporated linear PDMS serves thin polymer films with a tailored molecular weight distribution. Limited by intermolecular interactions between the methyl side groups, molecular weights corresponding to up to 80 repeating units of dimethylsiloxane are evaporated before thermal degradation. [3]





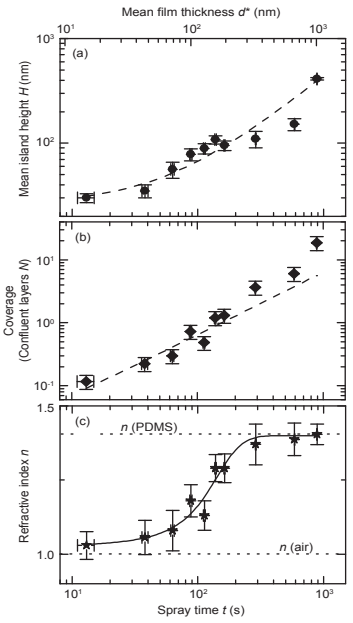
The choice of polymer influences the film morphology: A comparison of linear vinyl-terminated PDMS (DMS-V05) and a cloride dimethyl copolymer (Cl-PDMS) reveals an increased roughness during growth and after ultra violet light curing for the CL-PDMS film, given by the increased polarity of the cloride side groups. [4]

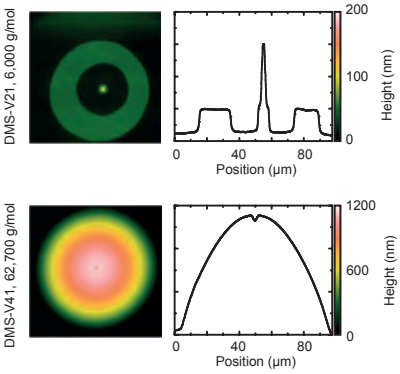
Electro-spray deposition



Alternating Current ESD (ACESD): Applying an alternate current onto the nozzle causes the emission of oppositely charged packs of droplets. Due to solvent evaporation the volume to charge ratio increases until it reachs a critical value. Above this value the droplets splits into several smaller droplets coating the substrate.

Quasi-dynamic spectroscopic ellipsometry data reveals the formation of a confluent PDMS film. [2]





Island morphology obtained by AFM from depositits of 5 vol.% vinyl terminated PDMS with mean number molecular weigths between 800 - 62,700 g/mol and subsequent UV curing [2]. With increasing molecular weight the PDMS molecules become less mobile. This pronounces island formations for PDMS with high molecular weight.

Challenges on the way to biomimetic artifical muscles

(I) Growth rates approximatly 0.1 nm/s ≈ 1 µm/h

(II) Excellent homogenity: roughness < 1 nm

(III) PDMS and metal deposited sequentially in vacuum enviroment

(IV) Limited range of molecular weights below 6,000 g/mol

(V) Relativly expensive equipment due to vacuum conditions

(I) Growth rates up to 5 nm/s ≈ 50 µm/h

(II) Increased inhomogenity (above 100 nm) with inreased growth rate due to island growth, but flattening during UV-curing

(III) Electrode layer requires add-on deposition technique

(IV) Unlimited range of polymers, only requirement is the solubility

(V) Multi nozzels for low-cost large area production

[1] F. M. Weiss, et al. “Electrospraying Nanometer-Thin Elastomer Films for Low-Voltage Dielectric Actuators”, Advanced Electronic Materials, DOI:10.1002/aelm.201500476

[2] F. M. Weiss, et al. “Thin Film Formation and Morphology of Electro-sprayed Polydimethylsiloxane” ,Langmuir, DOI:0.1021/acs.langmuir.6b00476

[3] T. Töpper, et al. “Tailoring the mass distribution and functional group density of dimethylsiloxane-based films by thermal evaporation” Applied Physics Letters (Under revision)

[4] F. M. Weiss, et al. ,”Molecular beam deposition of high-permittivity polydimethylsiloxane for nanometer-thin elastomer films in dielectric actuators”, Materials and Design, (Under revision)