Nanomechanical characterization of polydimethylsiloxane films

Bekim Osmani[1], Tino Töpper[1], Florian Weiss[1], Fabian Wohlfender[1], Vanessa Leung[1], Christian Bippes[2], and Bert Müller[1]

[1]Biomaterials Science Center, University of Basel, c/o University Hospital, 4031 Basel, Switzerland, [2]Nanosurf AG, Gräubernstrasse 12-14, 4410 Liestal, Switzerland

INTRODUCTION: Polydimethylsiloxane (PDMS) is the most widely used silicon-based organic polymer. Its applications range from cochlear implants for the inner ear to microfluidic chips. They are also often referred as the dielectric layer of choice for electrically activated polymer actuators (EAP). EAPs show millisecond response times and have a specific continuous power up to 10 times higher than human skeletal muscles [1]. PDMS films have to be below 1 µm in thickness for actuations below 42 V and strains above 20% [2]. A proper determination of the Young's modulus is therefore crucial.

METHODS: PDMS films were prepared, see Table 1, by mixing a siloxane base/cross linking agent (Dow Corning® 184 Silicone Elastomer Kit, Dow Corning Europe S.A, Belgium) with a methylsiloxane based solvent (Dow Corning® OS-20 Fluid, Dow Corning Europe S.A, Belgium).

Table 1. Preparation parameters of PDMS films.

Sample	PDMS/OS20	RPM	Film thickness
1	1:0	1000	192 ± 10 µm
2	1:0	6000	8.5 ± 1.0 µm
3	1:1	6000	2.4 ± 0.5 µm
4	1:5	6000	0.9 ± 0.2 µm

The mixtures were stirred for 1 minute, spin-coated on 3-inch Si-wafers (Si-Mat Silicon Materials, thickness 381 ± 25 µm) and thermally cross-linked at a temperature of 75 °C for a period of 24 h. After curing, 400 indentations were performed on a $60 \times 60\ \mu m^2$ array at loads of 12, 24, 36 and 48 nN. A cantilever with a spring constant of 0.16 N/m and a spherical tip (B150_CONTR, Nanotools, Germany) with a radius of 144 nm was mounted on a AFM Scan Head (FlexAFM C3000, Nanosurf Liestal, Switzerland). Calculations based on the Hertzian contact theory were performed using the ARTIDIS® software (Automated Reliable Tissue DIagnosticS). The film thicknesses were measured using a 3D Laser Microscope with a spatial resolution of 0.5 nm in z-direction (Keyence VK-X200, Keyence International, Belgium).

RESULTS: The calculated Young's moduli for the 6'400 nanoindentations are visualized in Figure 1. The results were well reproducible indicated by the statistical error. There is an increase of the Young's modulus for thinner films. It is getting lower for higher loads exhibiting a softer 'bulk' of the film.

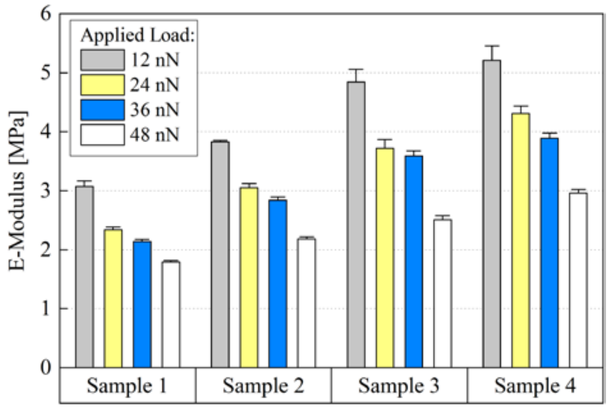

Fig. 1: Young's modulus of PDMS films.

DISCUSSION & CONCLUSIONS: The decrease of the Young's modulus at higher loads reveals a possible heterogeneity of the PDMS film, with an increased modulus at the surface. These results are in agreement with previously obtained data [3, 4]. Substrate effects can be excluded, since the modulus is decreasing at higher loads and indentations depths were below 60 nm. A Hertz model taking into consideration the interfacial adhesive forces is supposed to be more appropriate, but is not implemented in the software yet. Nanoindentations in liquid could also reduce the thermodynamic work of adhesion.

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ACKNOWLEDGEMENTS: The financial support of the Swiss National Science Foundation (Project 200021-135496) and the nano-tera.ch initiative *SmartSphincter* is gratefully acknowledged.