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Surface modification of flexible plain and microstructured hard and soft PDMS-thin films by plasma treatment and layer deposition for improved usability for biomedical applications

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Motivation

- **Polydimethylsiloxane (PDMS)** polymers:
  - Widely applied for tissue engineering, and lab on chip techniques[1-3]
  - Well-known materials with extraordinary and multi-purpose properties
  - Biocompatibility and low cost producibility
  - Strong hydrophobicity limits usage in some biomedical fields (e.g. as substrate material for cell cultures)[3,4]

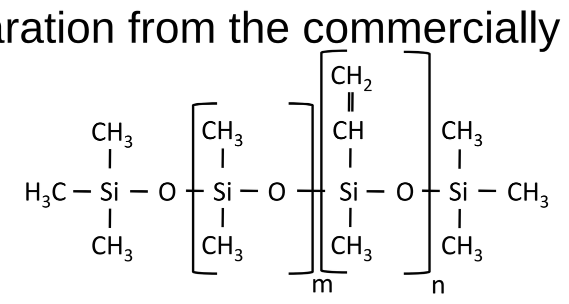
Aim

- Manufacture flexible plain and microstructured PDMS-thin films similar to stamp manufacturing for substrate conformal imprint lithography (SCIL[5,6])
- Adjust surface properties in terms of wettability
- Modify intrinsic hydrophobicity of PDMS-layers by plasma treatment or deposition of Al_2O_3 by atomic layer deposition (ALD)

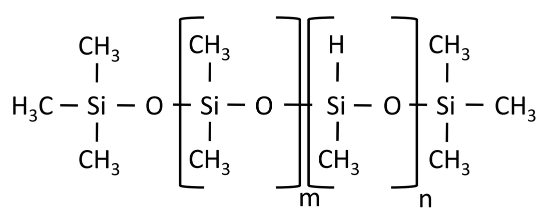
Material

Soft PDMS (S-PDMS[5,6])

- Advantages: softness, flexibility
- Preparation from the commercially available two component PDMS system*



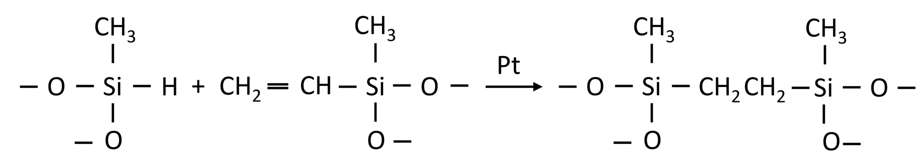
vinyl functionalized linear di-methyl-siloxane



silicon-hydride functionalized linear di-methyl-siloxane

Hard PDMS (H-PDMS[5,6])

- Advantages: high durability, high Young´s modulus
  - (H-PDMS: 8-12 MPa; S-PDMS: 2-3 MPa)
  - Higher stability and better pattern transfer fidelity
- Two-component system* with an additional platinum catalyzed system
  - Formation of network with increased Young´s modulus

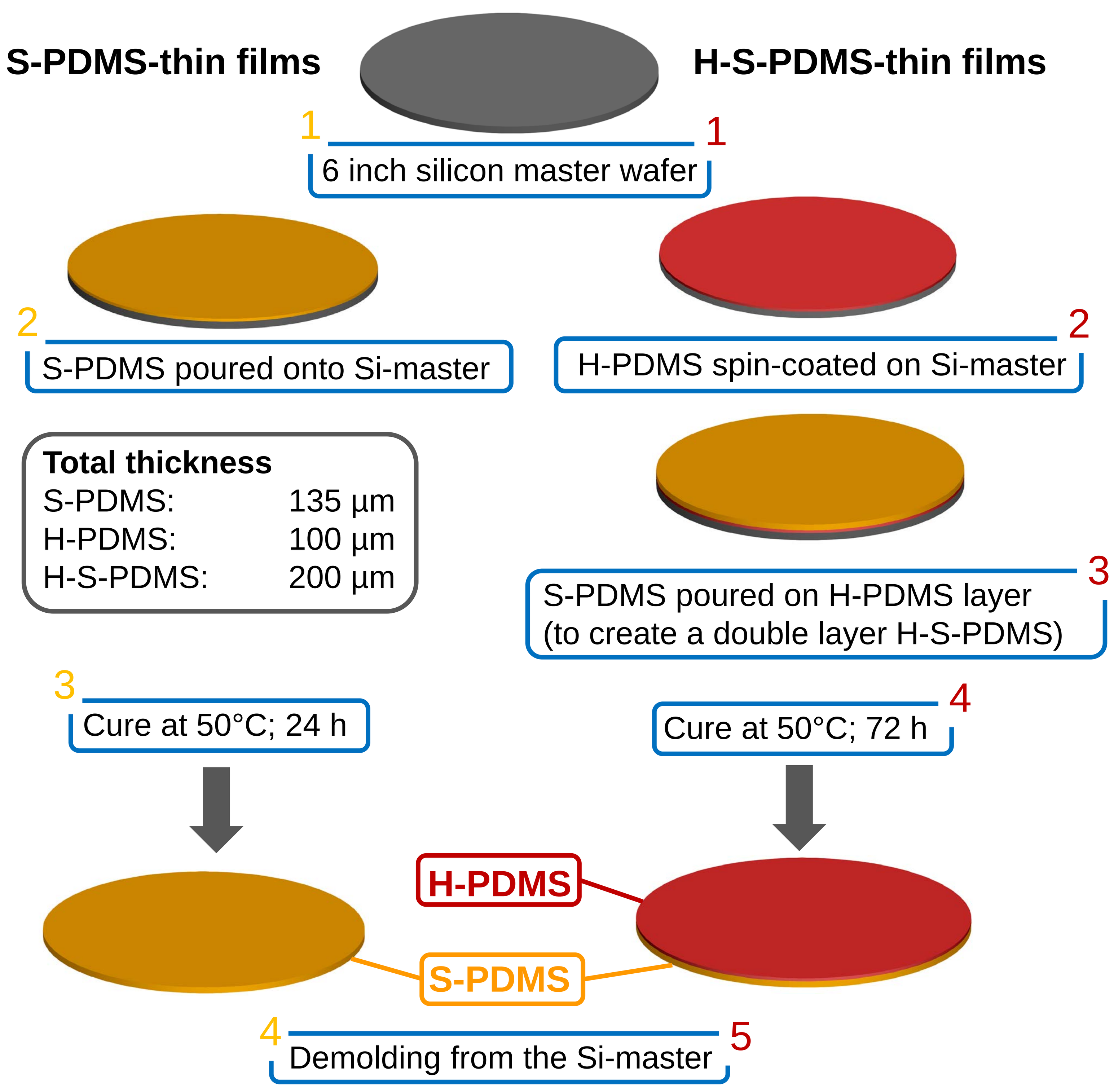


addition reaction of a silicon hydride group and a vinyl group

* Sylgard 184 consists of a liquid silicone rubber base and a curing agent

* Gelest Inc.

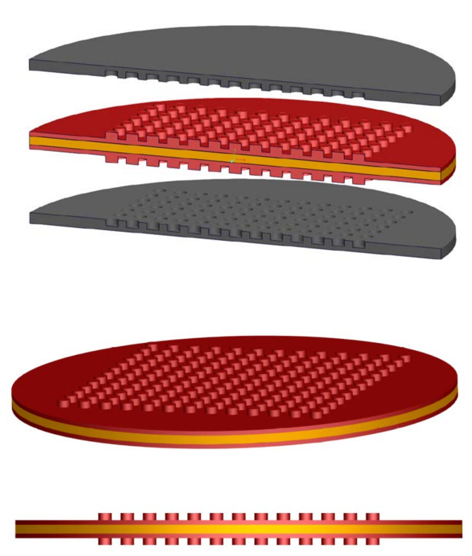
Fabrication and surface modification of thin films

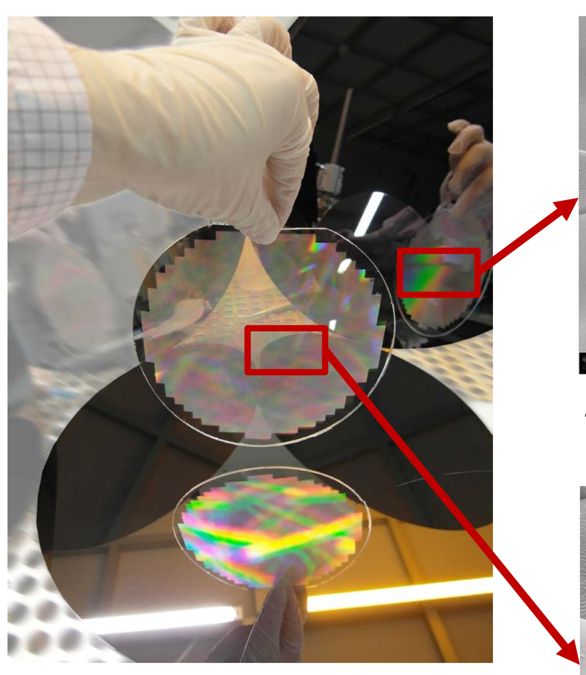


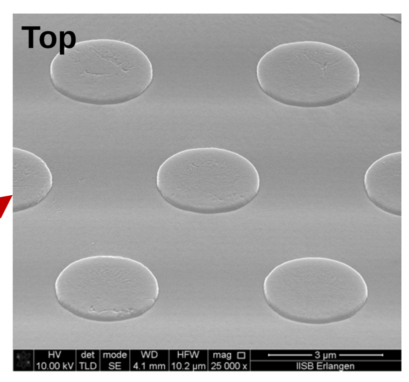
Surface modification

- Activating PDMS surfaces by Ar/O_2 plasma treatment
  - 6 min, 350 W, chamber pressure 1.5 mbar
- ALD surface layer deposition
  - 20 nm thick Al_2O_3 layer at 150°C

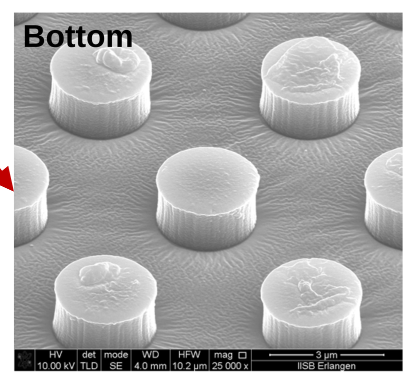
Both side patterned H-S-H-PDMS-thin films







2.5 µm in diameter, 180 nm in height



2.5 µm in diameter, 1.8 µm in height

PDMS films patterned on both sides using the same process sequence as for the double-layer PDMS but with two Si-masters with different pillar structures

Experimental results

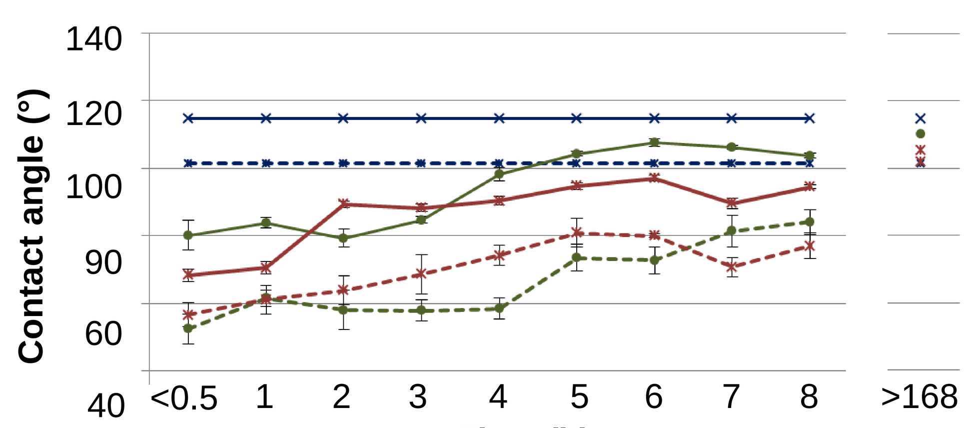
Surface characterization

- Contact angle (CA) and surface energy (SE) measurements
  - Method used for calculation: Owens-Wendt-Rabel and Kaelbe
- Monitoring of cell activity (attachment/spreading of HEC cells on PDMS)

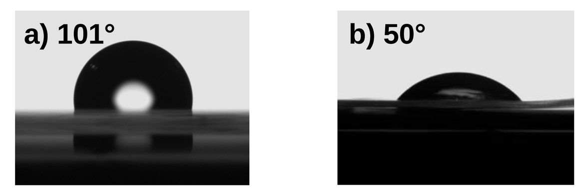
Results for plain H-S-PDMS-thin films

PDMS type	Surface energy (mN/m)	Dispersive component (mN/m)	Polar component (mN/m)	Contact angle (°)
S-PDMS	10.17 ± 0.71	8.93 ± 0.69	1.25 ± 0.19	114.6 ± 0.5
H-S-PDMS	14.91 ± 0.86	11.85 ± 0.76	3.05 ± 0.40	101.4 ±1.2

- → Differences in SE and CA between untreated S- and H-S-PDMS
- → Higher polar component for H-S-PDMS compared to S-PDMS → increase of dipole-dipole interactions and decrease of CA

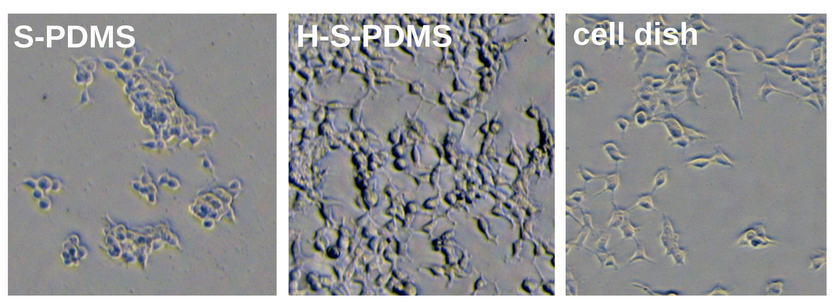


Variation of contact angles (water/surface) with time



H-S-PDMS (a) before and (b) after plasma treatment

- → Immediately after plasma treatment and ALD: increase of hydrophilicity
- → After 8 h: H-S-PDMS remains hydrophilic, after one week: hydrophobicity recovery

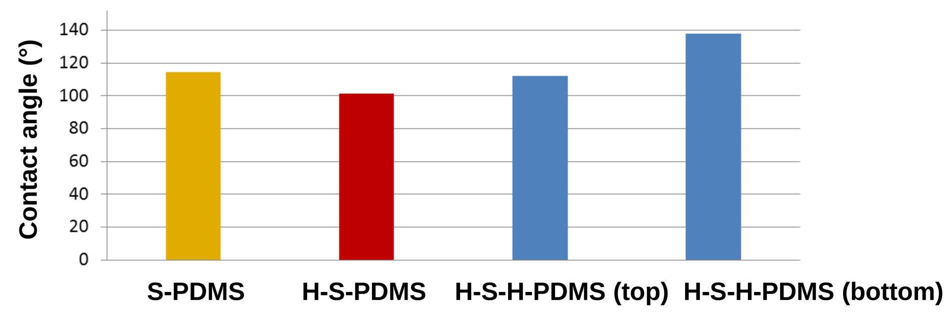


- → Higher agglomeration on S-PDMS
- → Similar morphology on H-S-PDMS compared to regular cell dish

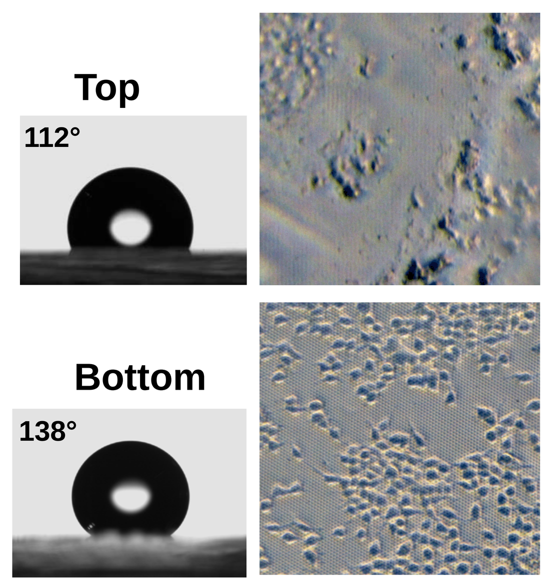
HEC cells cultured on S- /H-S-PDMS and a regular cell dish

Results of microstructured H-S-H-PDMS-thin films

H-S-H-PDMS type	Surface energy (mN/m)	Dispersive component (mN/m)	Polar component (mN/m)	Contact angle (°)
Top	15.03 ± 1.23	14.16 ± 1.19	0.87 ± 0.30	112.3 ± 1.8
Bottom	5.59 ± 0.27	5.59 ± 0.27	0.00 ± 0.00	138.1 ± 2.6



Variation of contact angles (water/surface)



HEC cells cultured on structured PDMS

- → Higher CA of both sides of PDMS films compared to plain films, but different SE
- → Particularly, a strong hydrophobicity with lower SE at the surface with higher pillars
- → No observation of polar components for all surfaces on the bottom side
  → important for better wettability, but improving of HEC cells adhesive behavior

Summary

- Plain and microstructured PDMS films were successfully prepared
- H-S-PDMS films (material with higher networking) are advantageous for improving wettability
- Using deposited Al_2O_3 as surface layer is a promising approach to achieve better wettability. So far, no long-term improvement in wettability could be achieved
- Micro structuring of surfaces with dedicated geometry leads to an increase of CA and a modification of cell-substrate adhesion behavior
- Further studies will be performed to fully clarify the relationship between wettability, surface geometry and cells adhesion

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