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Investigations of hybrid elastomer substrates for stretchable devices

Gerhard Domann,
S. Beranek, S. Arzuman, A. Räder,
J. Ziegler, S. Steenhusen, J. Clade
Fraunhofer Institute for Silicate Research
Wuerzburg, Germany

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SA2 Flexible and Stretchable, Substrate and Display

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Outline

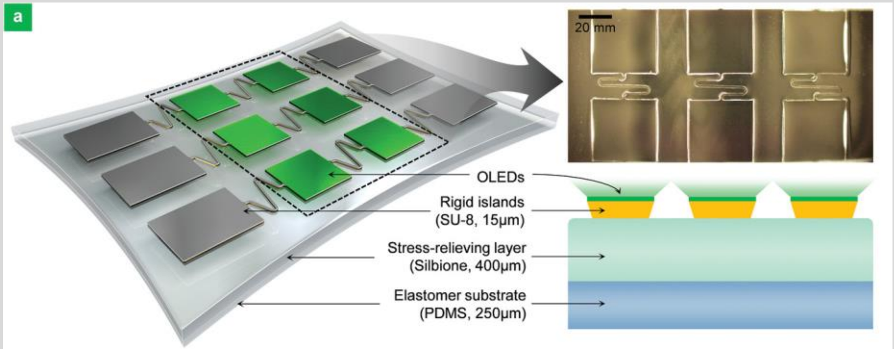
- Motivation
- Approach for stretchable display substrates
- Simulation
- Mechanical properties
- Further properties: Optics, Shelf life, Ageing
- Dielectrics and Conductors
- Outlook and Conclusion

Motivation: Substrates for stretchable Displays

Different approaches to engineer substrates for stretchable Displays

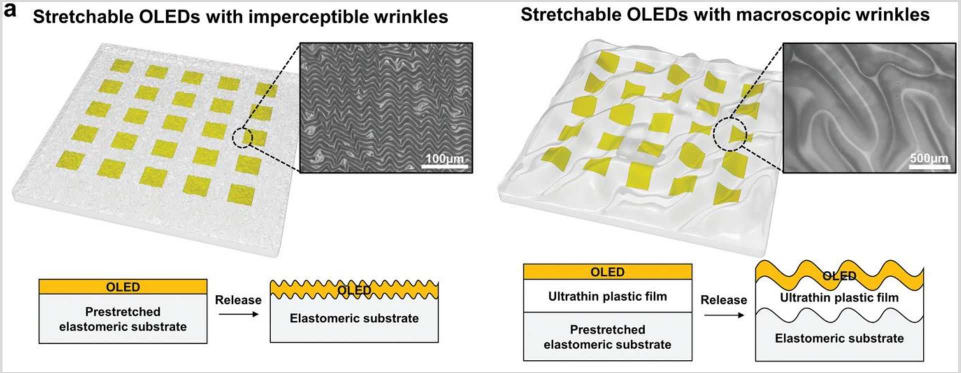
KAIST: Rigidization (Island-Bridge) by SU-8 on PDMS

Kim, T., Lee, H., Jo, W., Kim, T.-S., Yoo, S., Realizing Stretchable OLEDs: A Hybrid Platform Based on Rigid Island Arrays on a Stress-Relieving Bilayer Structure. *Adv. Mater. Technol.* 2020, 5, 2000494. https://doi.org/10.1002/admt.202000494



Seoul National University: (μ-)Wrinkling approaches

Jeong, S., Yoon, H., Lee, B., Lee, S., Hong, Y., Distortion-Free Stretchable Light-Emitting Diodes via Imperceptible Microwrinkles. *Adv. Mater. Technol.* 2020, 5, 2000231. https://doi.org/10.1002/admt.202000231



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Motivation: Substrates for stretchable Displays

Frequent Challenges

Island-Bridge structures

- Scaling of rigid islands
- Mechanical stability (border between rigid and elastic parts)
- Transparency / Scattering
- Alignment
- Elastic conductors needed

Wrinkling / Buckling structures

- Waviness
- Mechanical stability (release process)
- Functional, conformable materials needed

Mechanically engineered substrates

Approach by Fraunhofer ISC in cooperation with Korea University

- Small Scale rigidization by μ-patterning techniques
- Mechanical integrity by mechanical gradient between soft and rigid parts
- Good optical quality by high transparent material and low variation of refr. Indices between soft and rigid parts
- Low surface roughness
- No ageing

→ Patent filed in 2019

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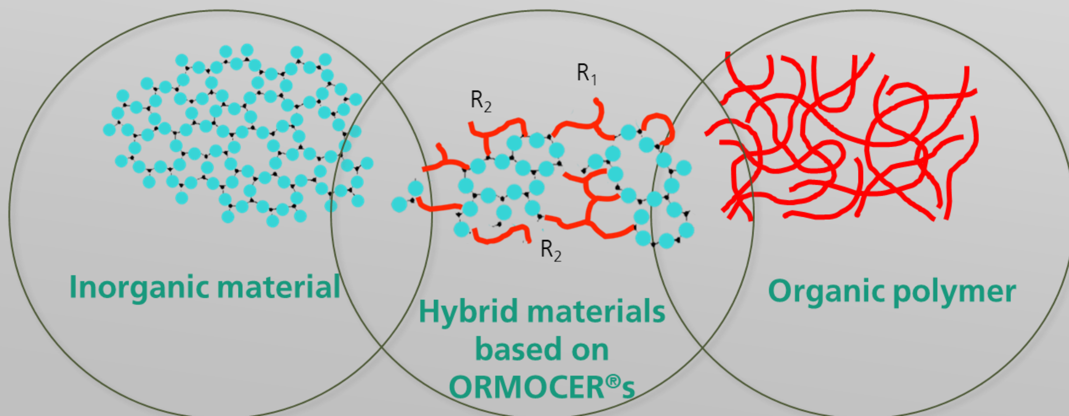
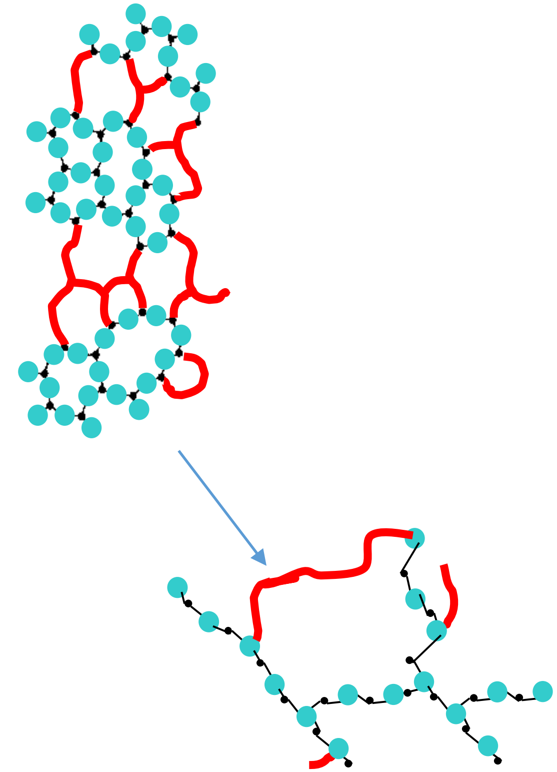
Dual-Cure approach for elastomeric substrates

Base technology

ORMOCER®
creative use of adjustable material properties generates new functions





→ Inorganic part was changed to become elastic (similar to PDMS): 2-dim network
→ Organic Part is used to rigidize the elastic substrate by UV cross-linking

ORMOCER®s, developed by Fraunhofer ISC, trademark of Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., München

Dual-Cure approach for elastomeric substrates

1.Synthesis of modified PDMS precursors that contains different reactive groups

R1, **R2**

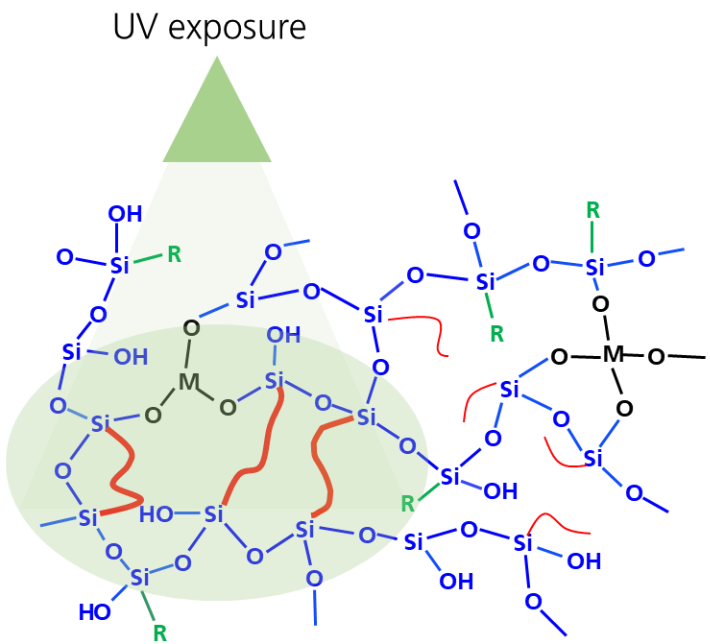
2. Adding components to carry out hydrosilylation using by thermal curing

R1 (forming the elastomeric network)

3. UV lithography (in absence of oxygene) in order to additionally cross-link on selected locations using

R2 (forming the rigid island)

→ Stretchable substrates with rigid islands
→ soft mechanical transition
→ Low optical differences
→ No topography



→ Molar Ratio between R1 and R2 controls the elasticity and the increase in mechanical stiffness

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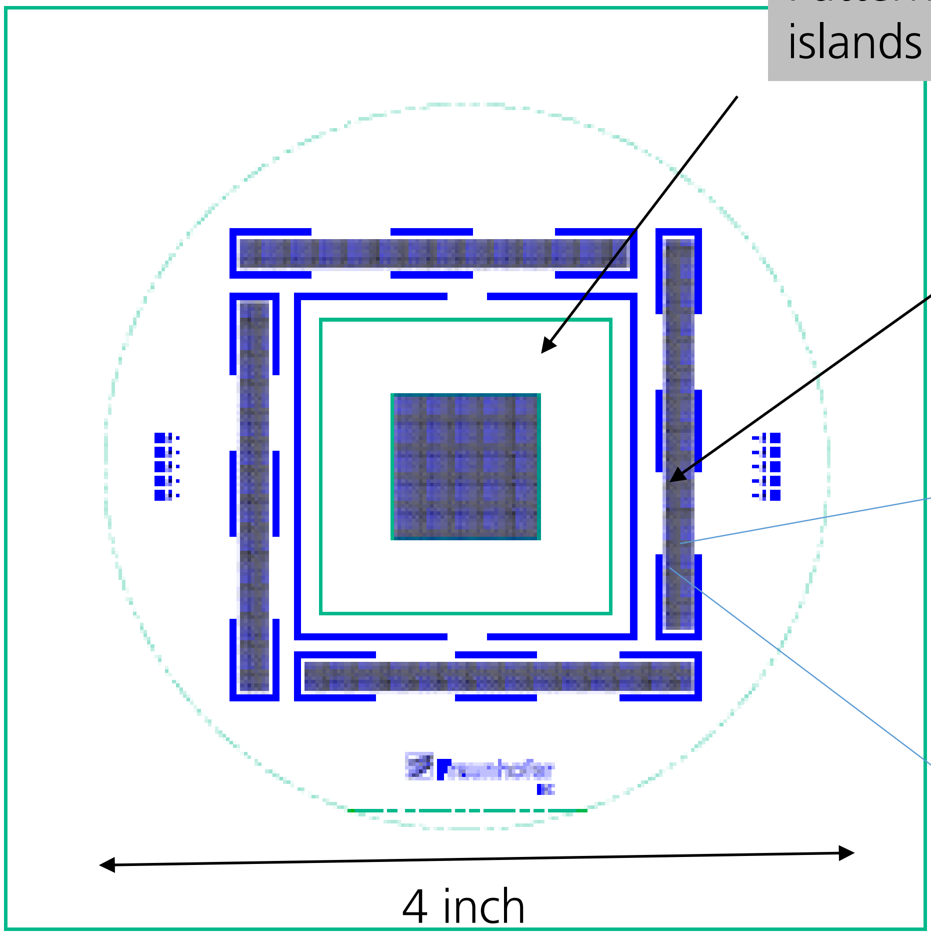
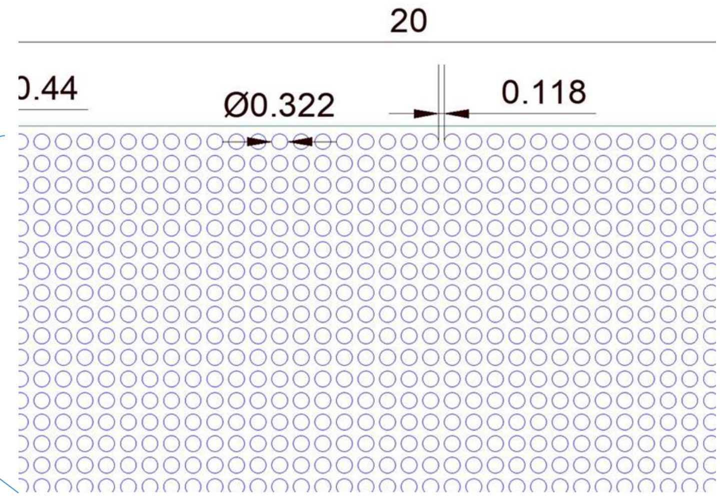
UV mask design: mechanical characterization

Pattern with rigid islands

Exposed area: 41%

Samples for tensile strengths with pattern (rigid islands)

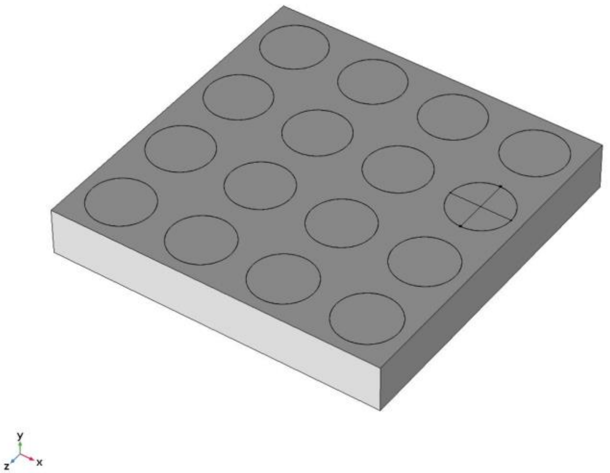




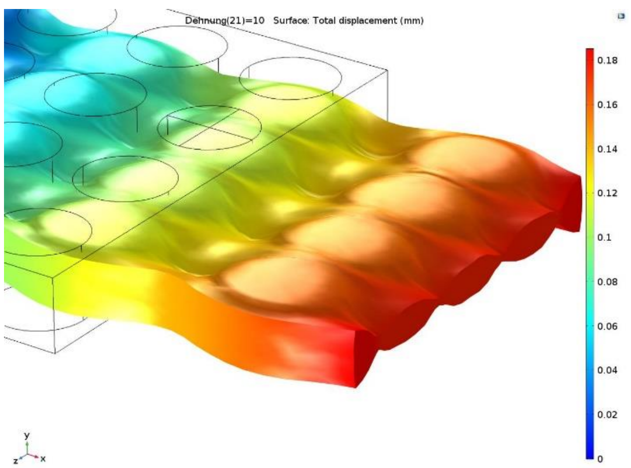
Circles: Rigid part
Between Circles : Soft part

Simulation

Model with locally increased Young's Modulus (without stretching)



10% Stretching



- Deformation on elastic parts
- Small deformation on rigid parts
- Revealing of a topography

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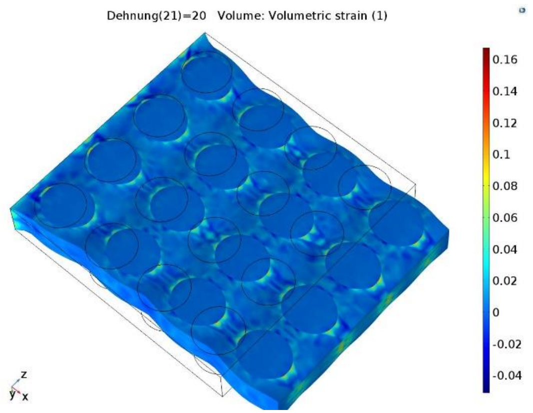
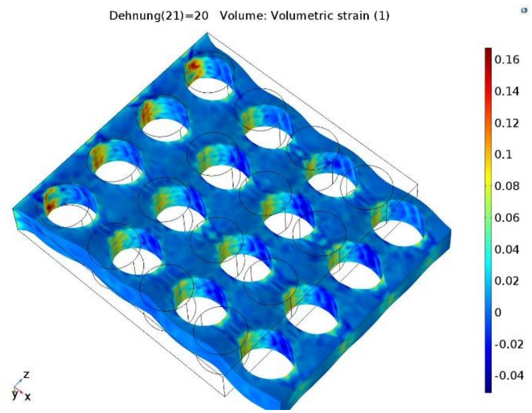
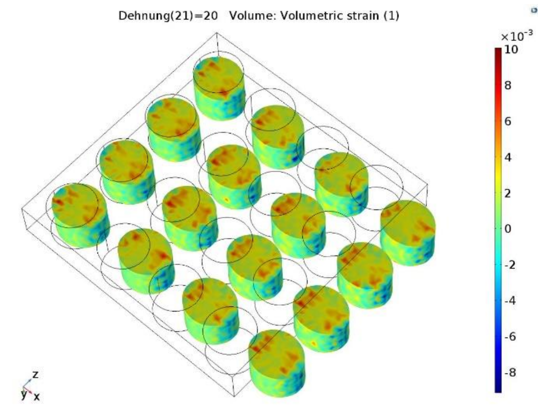
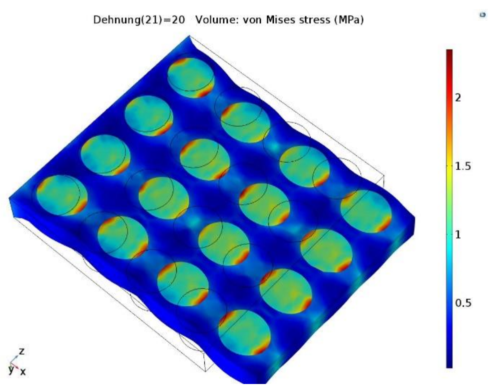
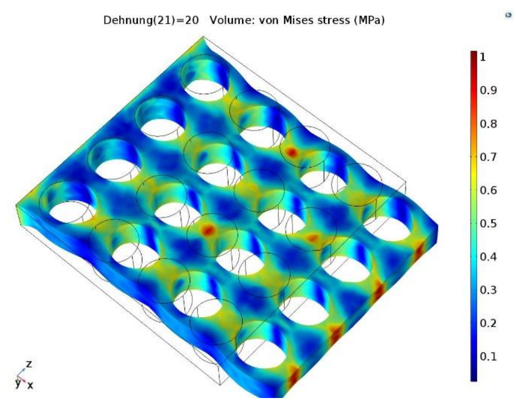
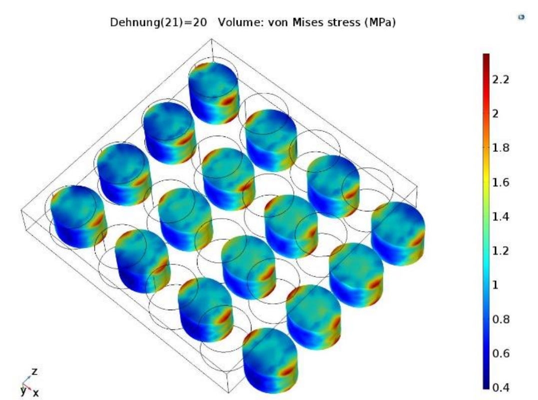
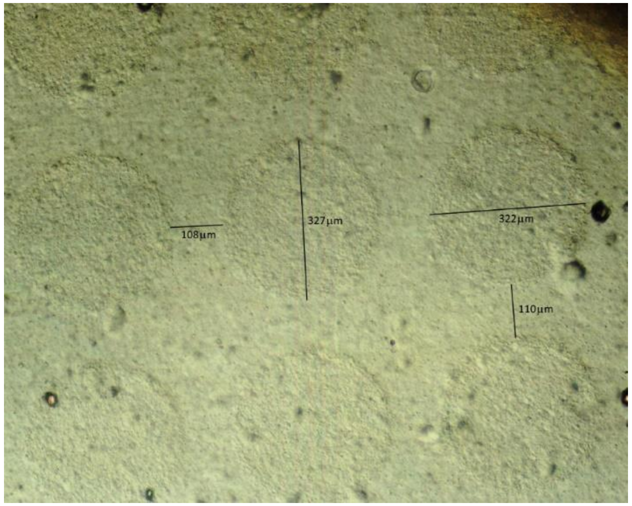
Simulation

	total	not exposed parts	exposed parts
Stretching			
Strain			

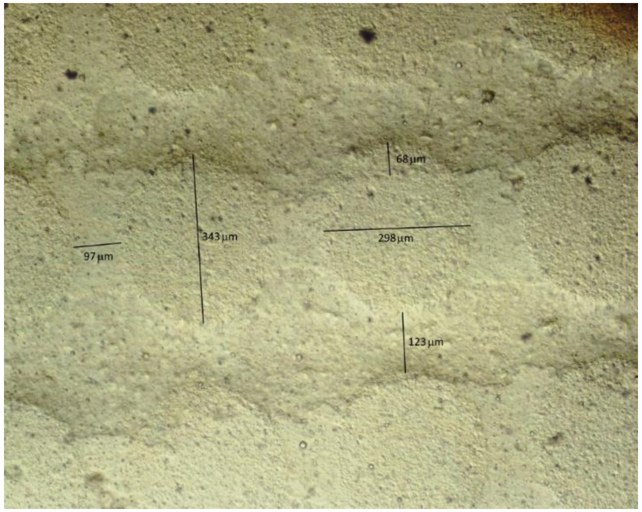
Largest stretching on border between rigid and soft parts
Strain maximum between the rigid parts

Characterization by microscopy

Non stretched sample



Overall Stretching of 10%



Circle Diameter: 325 µm

Stretching rigid parts: 5.5%;
stretching soft parts: 11,8%

→ Difference between Young's exposed and non-exposed parts have to be increased

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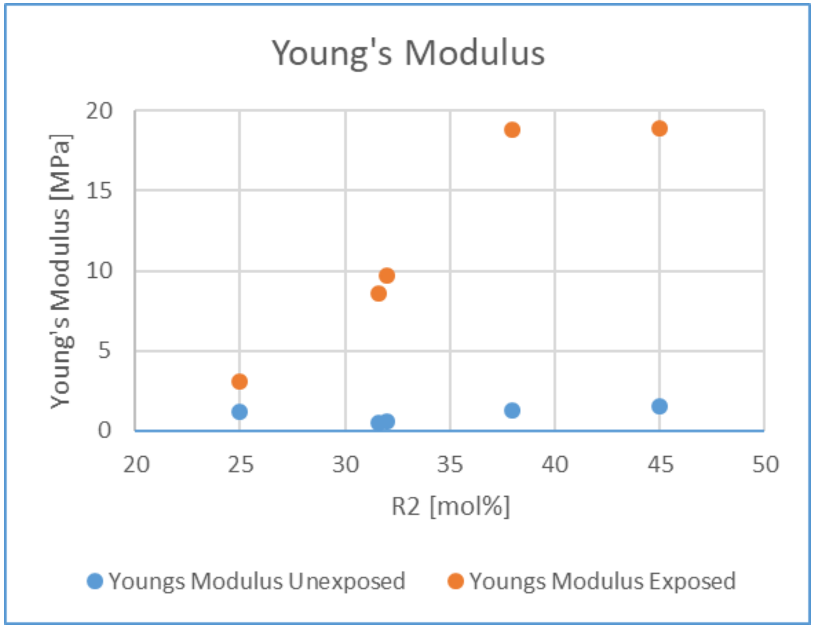
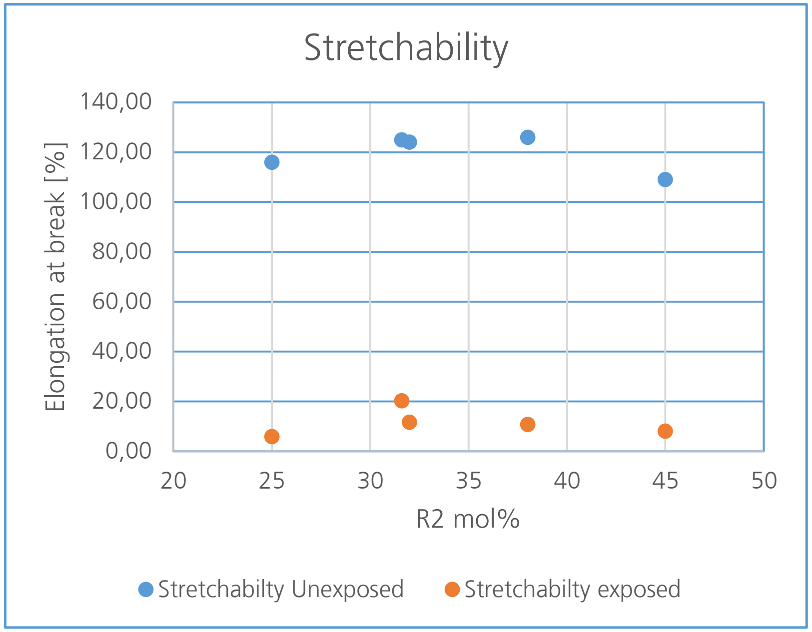
Increase the rigidization factor by changing molar ratio between R1, R2

In order to increase the rigidization factor, the molar ratio between the reactive groups canbbe changed → the total mechanical characteristic is changed

	R1 mol%	R2 mol%	Young's Modulus (unexposed) [MPa]	Young's Modulus (exposed) [Mpa]	Stretchability (unexposed]	Stretchability (exposed]
Sample A	35	25	1.22	3.10	115.8%	58.8%
Sample B	35	31.6	0.54	8.60	124.8%	20.2%
Sample C	35	32	0.56	9.71	123.7%	11.7%
Sample D	35	38	1.30	18.80	125.5%	10.7%
Sample E	35	45	1.50	18.90	109.1%	8.3%

Increase the ridigization factor by changing molar ratio between R1, R2





→ Young's Modulus is not further increased over ~ 38 mol%

→ Elongation at break seems to achieve a maximum value at 38 mol%

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Mechanical characterization on µ-scale?

Nano-indentation:

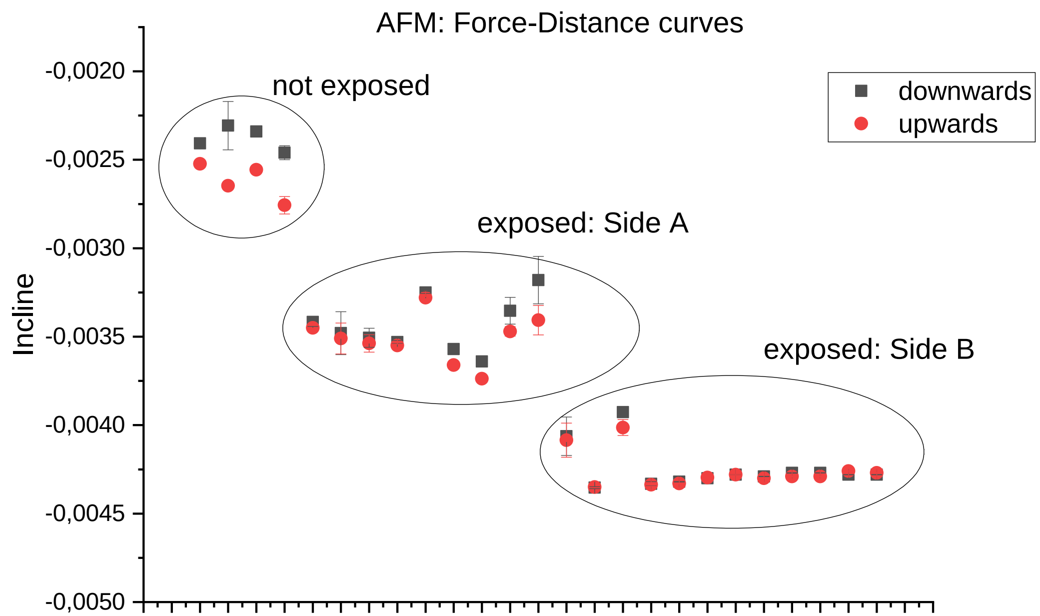
- Difficulties to locate the indenter
- Effects of underlying substrates

Mapping of a sample via Force-distance curves via AFM measurements

→ Incline of the curve correlates with the hardness of the sample

→ No/Low hysteresis observed

→ Different behavior on top side / back side (exposed to UV)



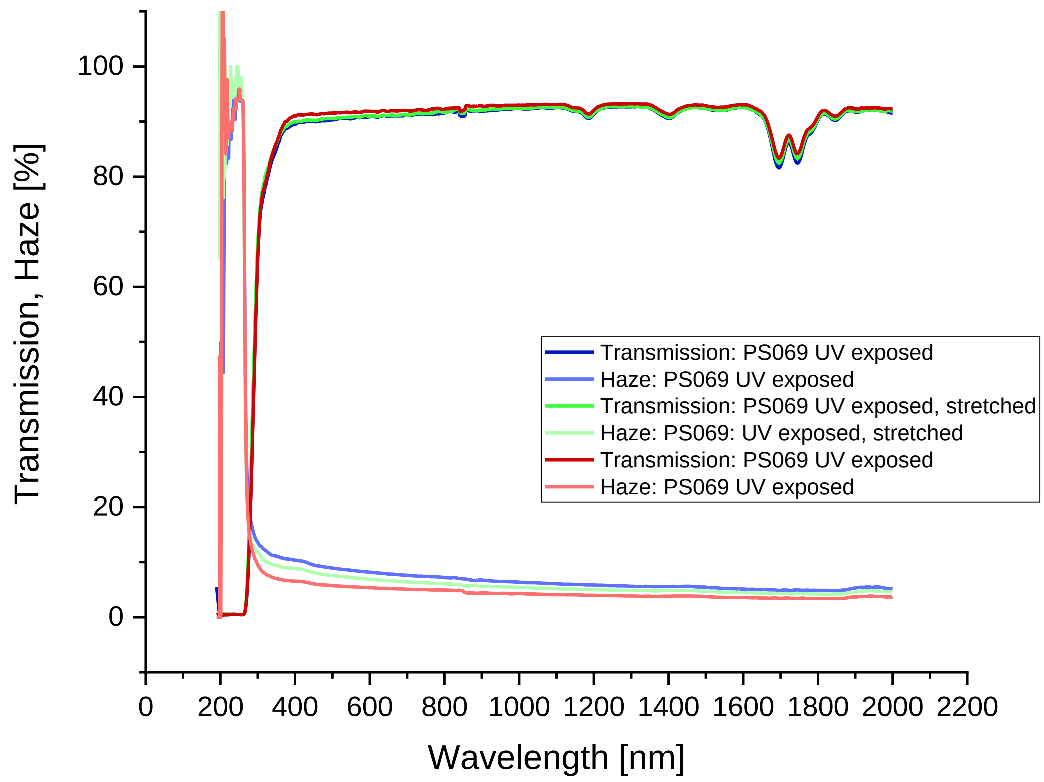
Quantitative correlation to Young's Modulus could not be realized

Further properties: Optical transparency

Measurement of transparency and haze:

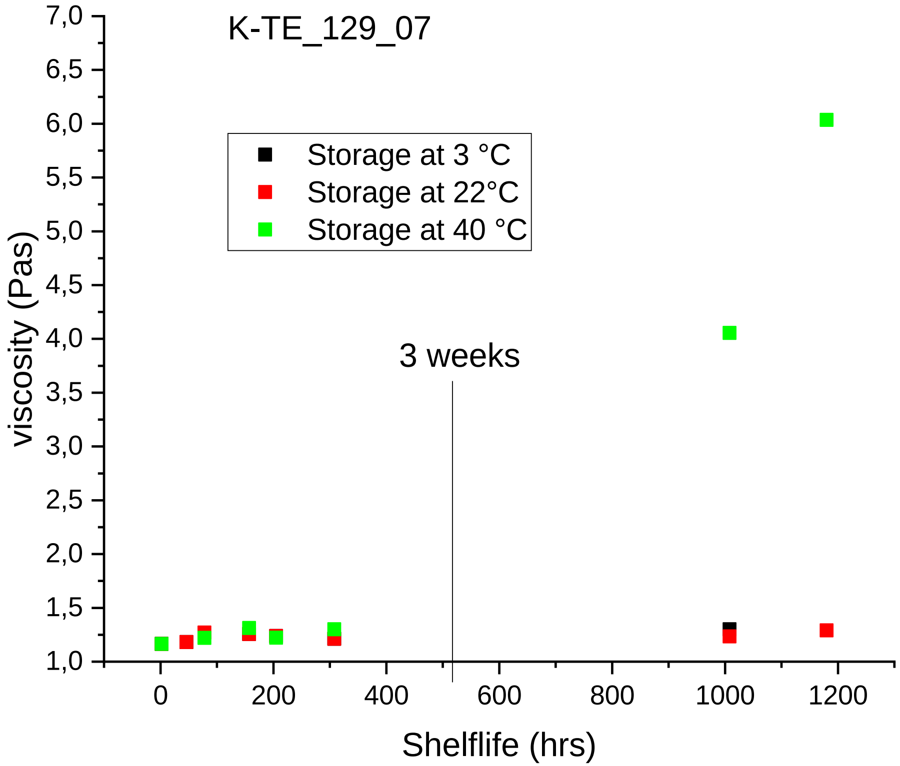
- UV unexposed
- UV exposed
- UV exposed after stretching

→ No yellowing
→ No significant increase in haze after stretching or UV exposure
→ Absorption edge between 380 and 400 nm



Further properties: Shelf life

- Formulation prepared (without UV initiator and catalyst)
- Measurement of viscosity when stored at different temperatures
- Storing at room temperature: no increase in viscosity after 1200 hrs (50 days)
- When stored at 40 °C, viscosity increases after about 3 weeks



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Further properties: Ageing

How sensitive are the soft parts when stored in ambient UV light or exposed by UV light in presence of oxygen?

Storage Time	Young's Modulus	Elongation at break
0 d	1.16 MPa (± 0.15)	106.3% (± 19.1)
7 d	1.05 MPa (± 0.10)	107.5% (± 23.5)
14 d	1.58 MPa (± 0.15)	94.5% (± 25.3)
Fully exposed	8.13 MPa (± 0.31)	27% (± 1.8)

→ In Presence of oxygen, there is almost no increase in Young`s Modulus by ambient UV light
→ UV exposure in presence of oxygen does also not result in an increase of Young's Modulus
→ Additional UV protection can be applied

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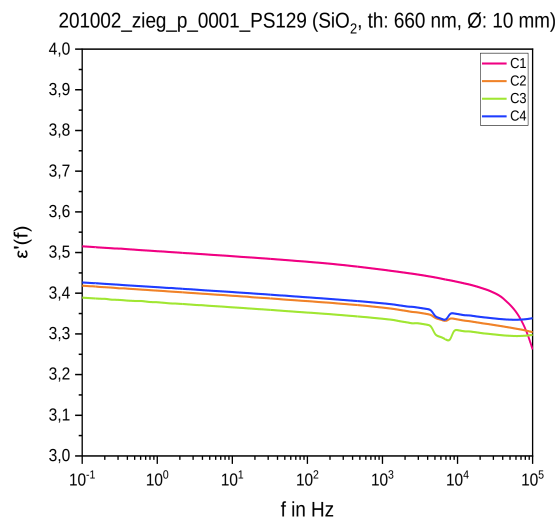
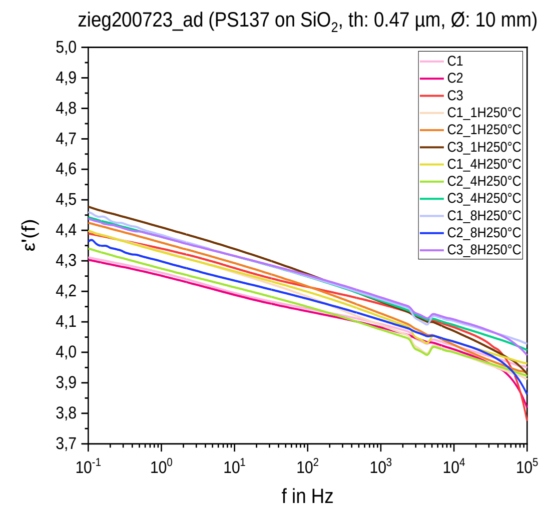
Dielectrics and Conductors

By changing the process sequence, the material can be used as stretchable patternable dielectric or matrix for composites, such as Ag-Nw

→ Application of the material on a substrate
→ Patterning the material by UV exposure, (cross-linking R2)
→ Development of the material in organic developer
→ Curing the sample, cross-linking R1

→ Stretchable Dielectrics:
  → „Low-k“: $\varepsilon_r = 3.4$
  → „High-k“: $\varepsilon_r = 4.3$





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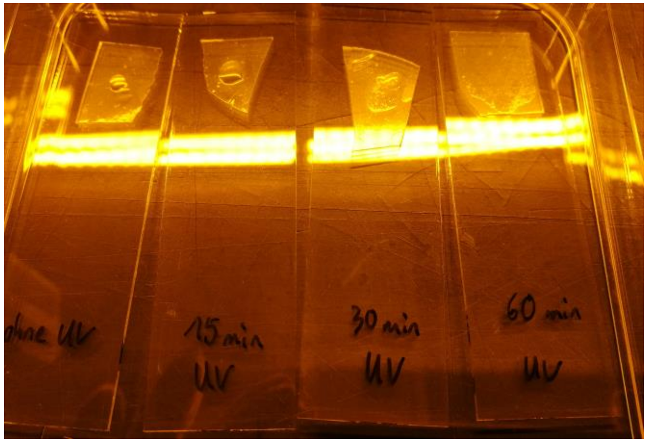
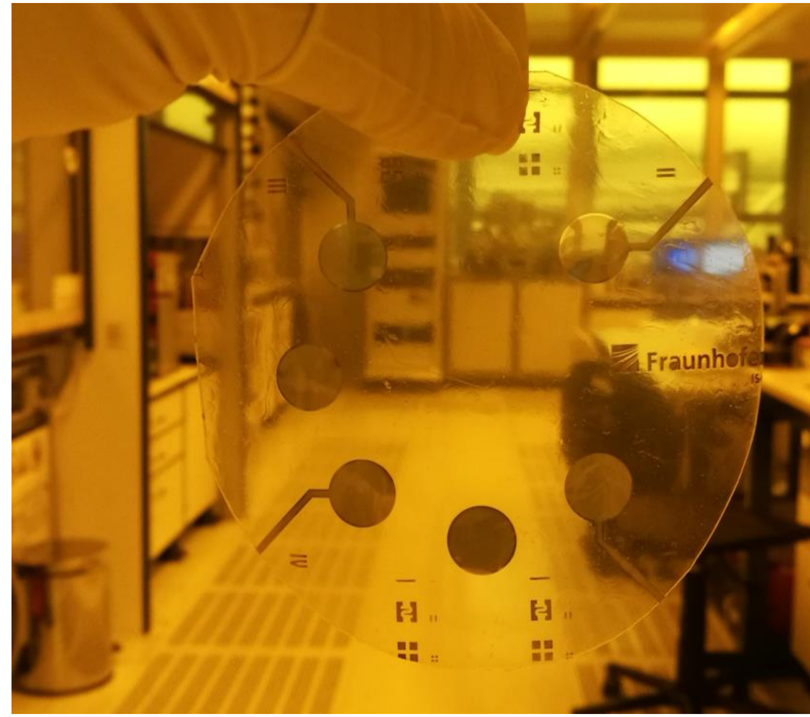
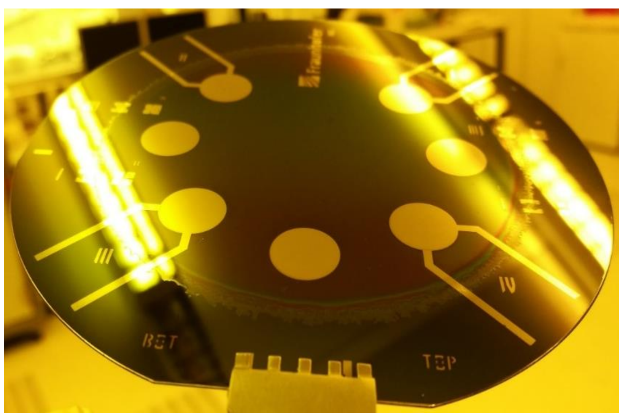
Subsequent processing



Wetting behavior on stretchable substrates can be improved by combined UV/ozone treatment



Thins film capacitors built up on stretchable substrate using stretchable dielectrics



201002_zieg_p_0001_36h250°C_PS129 (th: 0,47 µm)

Test wafer for thermal stressing: Dielectric layer after 36hrs, 250 °C

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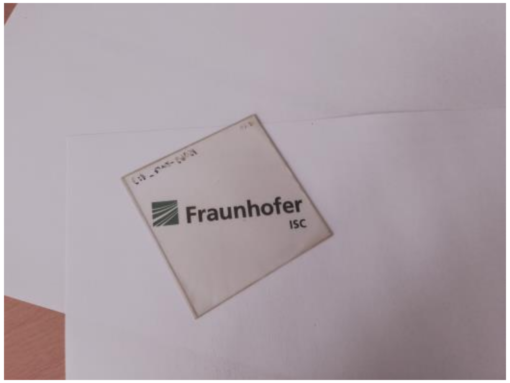
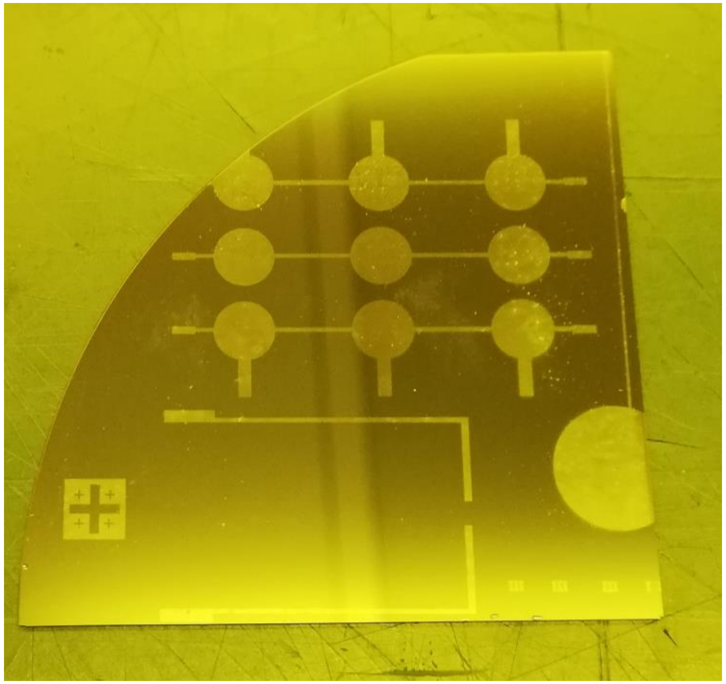
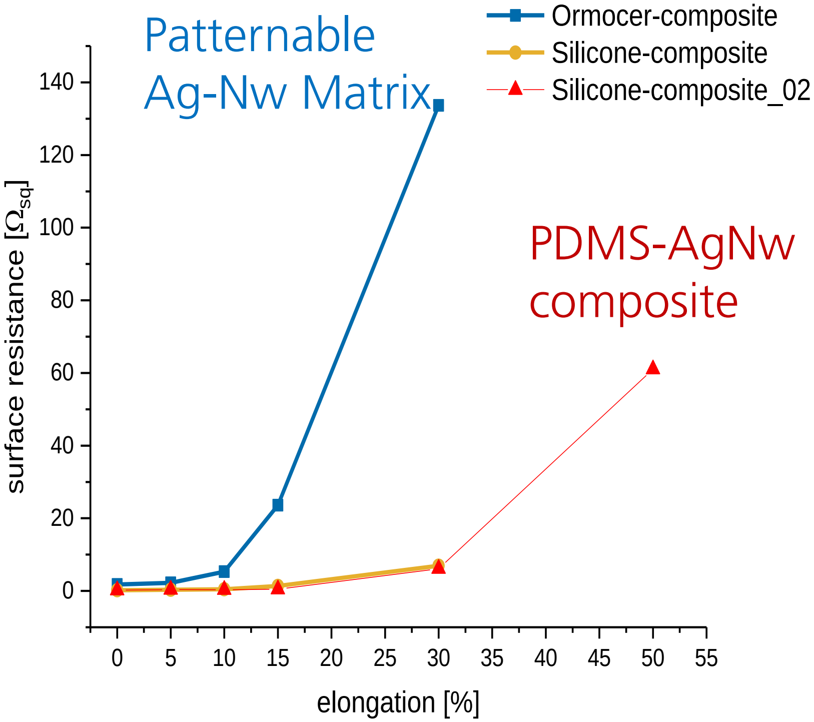
Stretchable Conductors



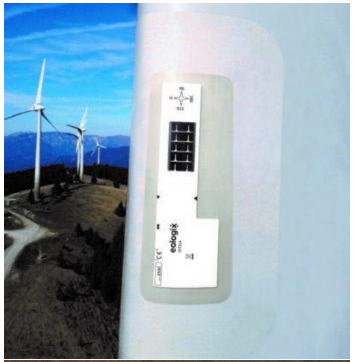
Ag-Nw can be incorporated into the stretchable matrix and can be patterned





AgNw-Composite

Outlook: Symphony – Stretchable Energy Harvester (EU project)



Stretchable Nanogenerators to harvest energy from vibrations, deforming and stray fields:

- Piezoelectric
- Triboelectric
- Magnetoelectric

Based on composites of PVDF

→ In order to apply large deformations to non-stretchable PVDF piezopolymers, stretchable PVDF composites will be investigated

Conclusion

- Dual-Cure elastomeric hybrid polymer might be a well suited substrate for stretchable displays
- Requirements important when used in industrial process can be met
- The difference in mechanics between soft and rigid areas might be enhanced further
- Concept can also be applied for
  - Dielectrics
  - Conductive composites such as AgNw-composites
  - Sensors (→ Symphony)

Thank you for your attention

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SYMPHONY

Fraunhofer Institute for Silicate Research ISC
Neunerplatz 2
97082 Würzburg
Germany

Gerhard Domann
Phone +49 931 4100-551
Email
gerhard.domann@isc.fraunhofer.de

www.cesma.de
www.isc.fraunhofer.de

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