Silicone rubber for energy harvesting: Material and process development and testing of dielectric elastomers

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SILICONE ELASTOMERS WORLD SUMMIT

Silicone Elastomers World Summit 2018
27 - 28 November | Milan, Italy

Center Smart Materials CeSMa Partner der Wirtschaft

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Outline

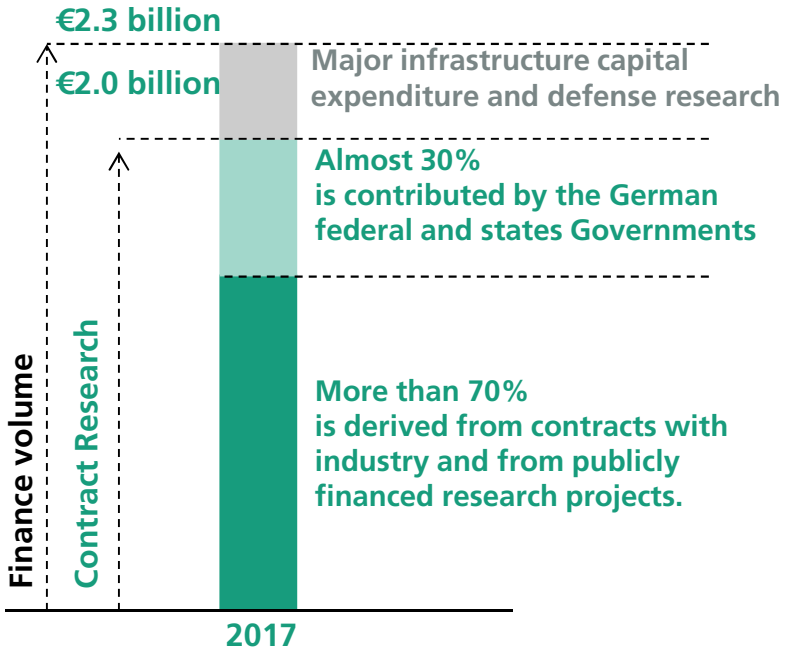
- Overview of Fraunhofer Society and Fraunhofer ISC
- Rubber for energy harvesting: operating principle
- Research project: “DEGREEN”
  - Material development
  - Process development
  - Testing of dielectric elastomers
- Conclusion

The Fraunhofer society at a Glance

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society.

25,327 staff

72 institutes and research units



… Facts: Fraunhofer Institute for Silicate Research ISC

480 employees (2017)
(350 permanent)

5 locations:
Würzburg | Alzenau |
Hanau | Bayreuth |
Bronnbach
with approx. 10 000 m²
lab and technical space

2 Application Centers:
Aschaffenburg | Hof

35,2 Mio Budget (2017):

5,3 Mio Invest
8,3 Mio Contract venue (industry)
12,6 Mio Project funding (nat. | internat.)

8,6 Mio Public funding

in Euro

SUBJECT: MATERIALS MEET …

… ENERGY

… RESOURCES

… BIOMEDICINE

… CLEAN ENVIRONMENT

… ADAPTIVE SYSTEMS

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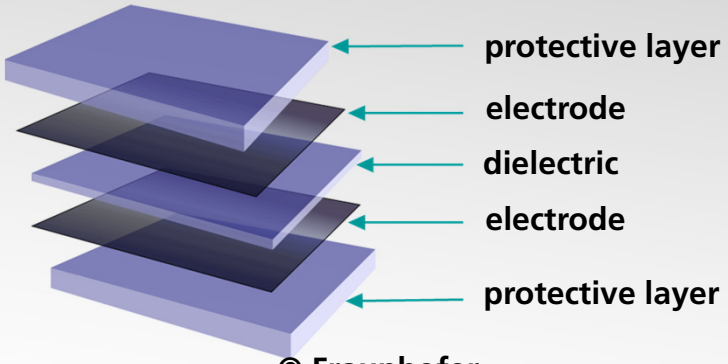
Rubber for energy harvesting: operating principle

Using dielectric elastomers

- Dielectric elastomers consist of a very stretchable elastomer film (e.g. silicone, polyurethane), coated on both sides with highly stretchable electrodes (silicone rubber filled with carbon black, graphite, metal particles)
- Highly stretchable (up to 100 % elongation)
- Further applications of dielectric elastomers: actuator and mechanical sensor (pressure, strain)



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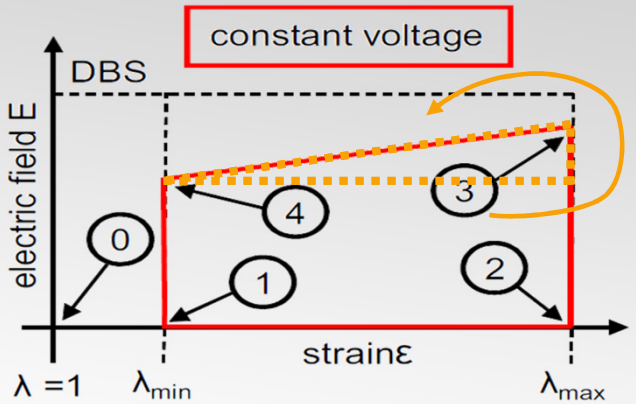
Rubber for energy harvesting: operating principle

Using dielectric elastomers

- Transformation of mechanical energy into electrical energy inside the dielectric layer
- Continuous stretching and relaxing of the dielectric elastomer while applying a constant voltage
- Electrical net energy gain by changing the capacitance of the dielectric elastomer
- Converted energy for one cycle:

$$\Delta W = \frac{1}{2} * \Delta C * U^2$$



Graf, C.; Maas, J.; Schapeler, D.: Optimized Energy Harvesting based on Electro Active Polymers. 10th IEEE International Conference on Solid Dielectrics ICSD2010, pp. 752-756, 2010.

Research project: DEGREEN

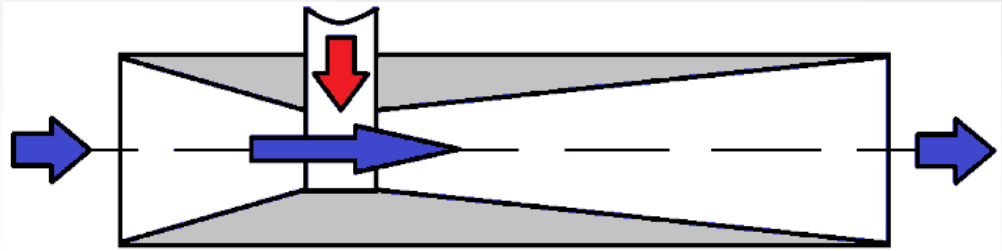
DEG for energy harvesting

- **"DEGREEN":**
  Use of Dielectric Elastomer Generators for Regenerative Energies
- **Publicly funded by the Bavarian state**
- **Project term: 06/2012 – 05/2019**
- **Aim: development of energy converters based on dielectric elastomers for slow flowing waters**
- **The impact on landscapes, flow situations in rivers, restrictions of flora and fauna as well as noise nuisance have to be prevented as far as possible**

Research project: DEGREEN

DEG for energy harvesting

- The electrical energy is to be used for environmentally-friendly decentralized energy supply of e.g. remote areas or for the recharge of electric vehicles in rural areas
- Kinetic energy: water flow of small rivers
- Transformation of kinetic energy into negative pressure by using a venturi nozzle → negative pressure strains the rubber film biaxial



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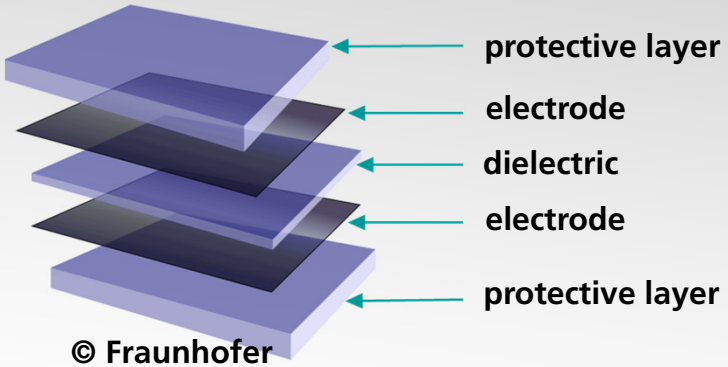
Research project: DEGREEN

Material development

- Extreme mechanical and electrical requirements:
  no commercial silicone material with flexible processing parameters available
  → Development of specific silicone formulations and adaptation to the processing for multilayer films
- Different developments of silicone formulations for
  - the dielectric/protective layers
  - the conductive layers
- Good adhesion between the layers



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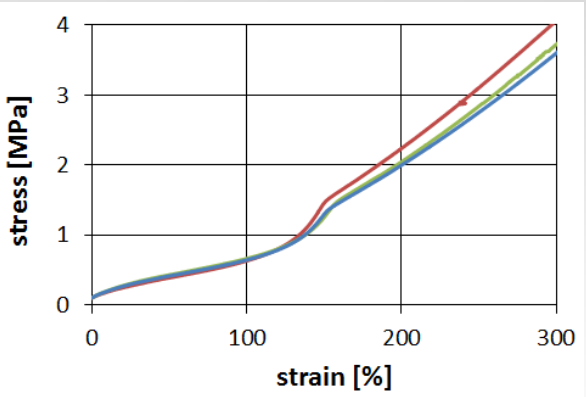
Research project: DEGREEN

Material development

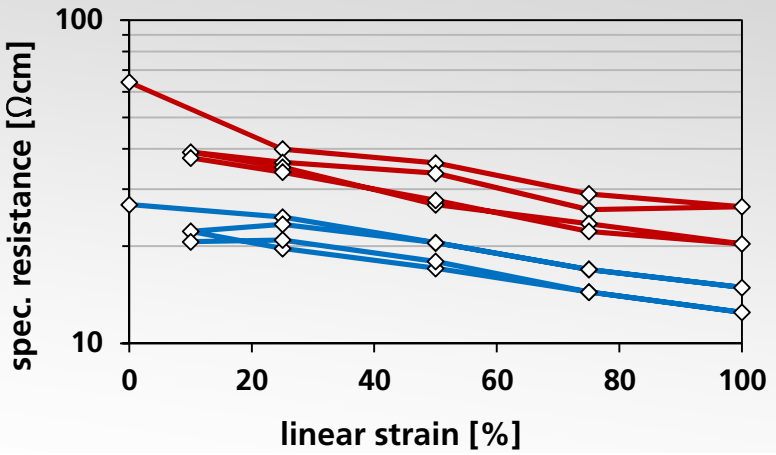
- Achieved dielectric properties:
  - High dielectric strength: 97,4 kV/mm
  - Adjusted elastic modulus: 1,2 MPa
  - Elongation at break > 300 %
  - Low processing viscosity 25 Pas @ 1 s^{-1}
  - High dielectric permittivity $\varepsilon_r > 3$ (concepts available)
  - Good behavior during fatigue testing
  - Adjusted curing parameters



Research project: DEGREEN

Material development

- Achieved electrode properties:
  - Low specific resistance, even under strain (up to 100 %)
  - Low increase of resistance during fatigue testing
  - Adjusted viscosity for processing with rotary screen printing unit
  - Adjusted curing parameters



Research project: DEGREEN

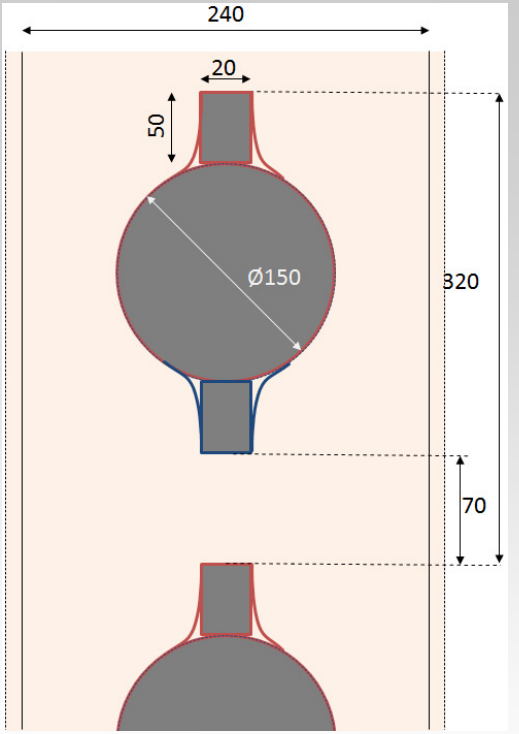
Process development

- Modular roll to roll (R2R) unit for large scale production of thin multilayer films
  - Coating width up to 0.5 m
  - Cleanroom for high quality layers
- Slot die coating for dielectric layer
- Rotary screen printing for patterned electrode layer

Research project: DEGREEN

Process development

- Challenges in process development:
  - Stable multilayer coating process (Slot die and rotary screen printing)
  - Constant thickness of each layer
  - Purity of the dielectric layers (cleanroom and filtration)
  - Opaque and precise printing of the electrode layers
  - Precise winding and unwinding of the substrate
  - Electrostatic charge on top of the substrate



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Research project: DEGREEN

Process development

- Achieved multilayer properties:
  - Successfully coated 150 meters with almost 500 generator films
  - 11 layers processed: 5 electrode, 4 dielectric and 2 protective layers
    → 4 layers for converting energy in each rubber film!
  - Total thickness: 1.7 mm
  - Electric test with high voltage (un-stretched):
    10 kV
    → yield of 90 %!

Research project: DEGREEN

Testing of dielectric elastomers

	Dielectric layer	Electrode layer (encapsulated)	Multilayer composite
Measurand	Mech. failure	Resistance + mech. failure	Capacitance + mech. failure
Failure monitoring	Ultrasonic sensor	Load cell	Ultrasonic sensor
Strain cycles	Biaxial	Linear	Biaxial
Strain excitation	Compressed air	Eccentric drive	8 cylinder drive
Frequency	< 1 Hz	5 Hz	1 – 5 Hz

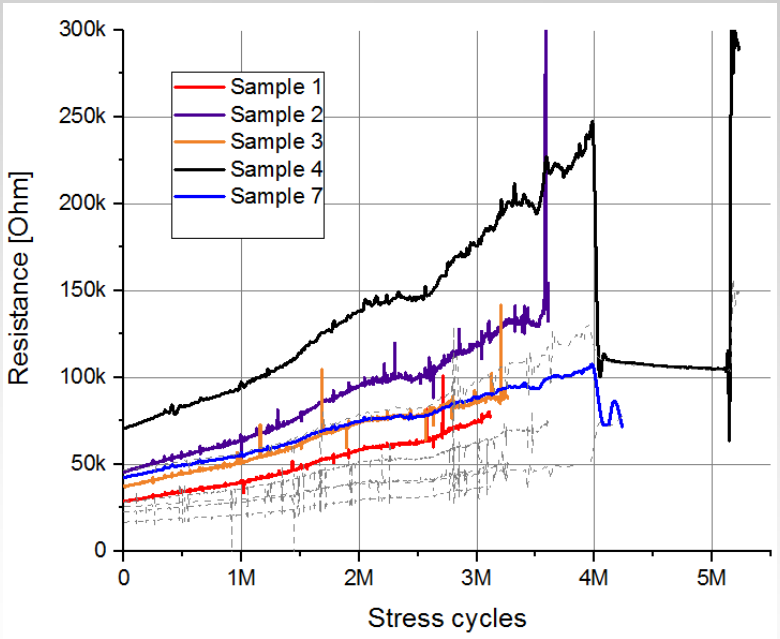
Research project: DEGREEN

Testing of dielectric elastomers

- **Electrode layer:** 8 Load cells

Electrode layer (encapsulated)
Resistance + mech. failure
Load cell
Linear
Eccentric drive
5 Hz

8 samples Linear strain



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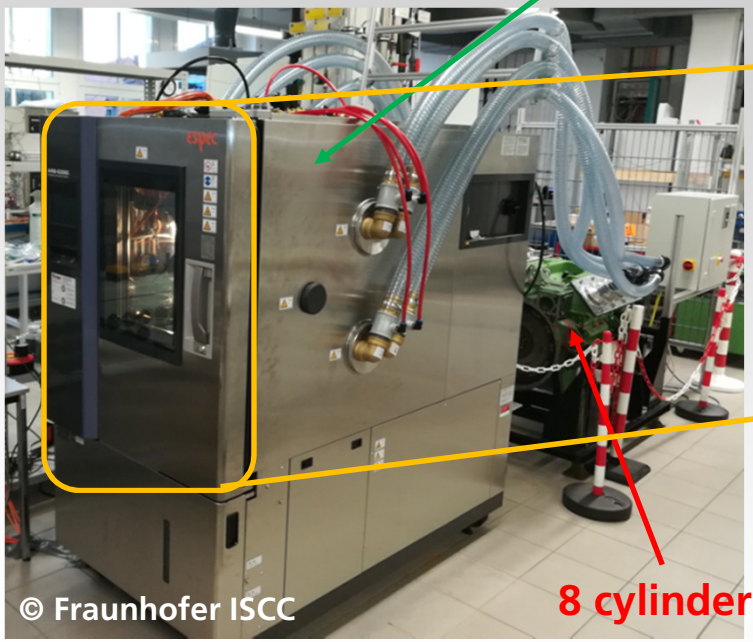
Research project: DEGREEN

Testing of dielectric elastomers

- **Multilayer composite:**

Multilayer composite
Capacitance + mech. failure
Ultrasonic sensor
Biaxial
8 cylinder drive
1 – 5 Hz



Research project: DEGREEN

Testing of dielectric elastomers

- Multilayer composite - mechanical stability:
  - Surface enlargement: 100 %
  - Frequency: 1 Hz
  - C-measurement not implemented yet
  - 8 samples

→ Averaged cycles: at least 5 million cycles under biaxial load

→ No delamination!

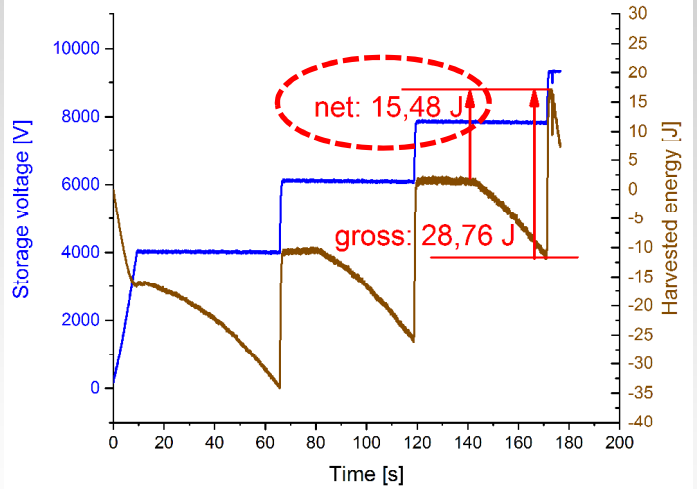
Research project: DEGREEN

Testing of dielectric elastomers

Latest high voltage test:

- **Using compressed air for biaxial strain**
- **74 rubber films**
- **Test voltage: 4 kV**

→ **Harvested Energy per cycle: 15,5 J**



Research project: DEGREEN

Advantages

Advantages of using DEG:

- **Minimum impact on environment: no dam and fish pass necessary**
- **Modular: adaptable to flow situation of small rivers**
- **Silent and self-sufficient system**
- **Continuous (24h/365d) and decentralized energy supply**

Concept for 100 W unit
LxWxH: 2,0 x 2,6 x 1,4 m³

Research project: DEGREEN

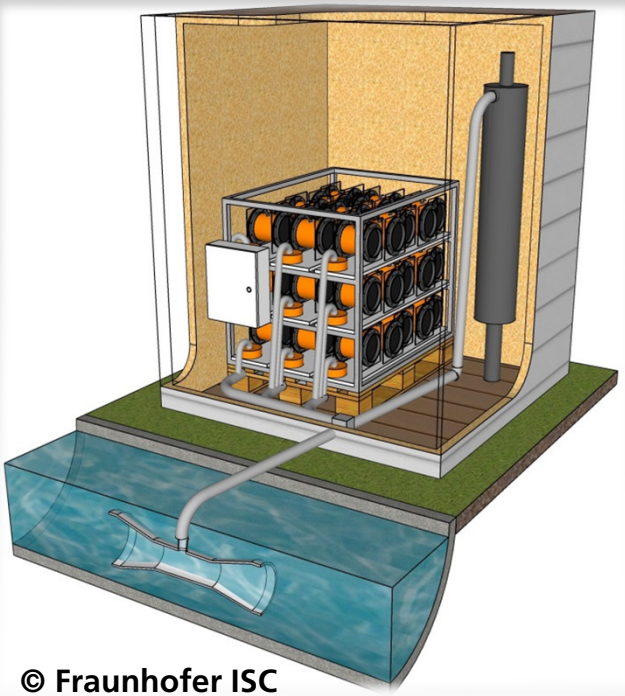
Outlook

For higher energy output increase of …

- **electric field**
- **conversion of water flow to negative air pressure**

Converted energy for one cycle:

$$\Delta W = \frac{1}{2} * \Delta C * U^2$$



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Conclusion

Feasibility study about using dielectric elastomers for energy harvesting:

- **Material development:**

  long-term stable mechanical and electrical properties
- **Process development:**

  high yield manufacturing process for complex multilayer system
- **Testing of dielectric elastomers:**

  high material fatigue of multilayer composite without delamination

→ Proven feasibility, further improvements must be made for commercialization

Interested?


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Thank you for your attention!
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