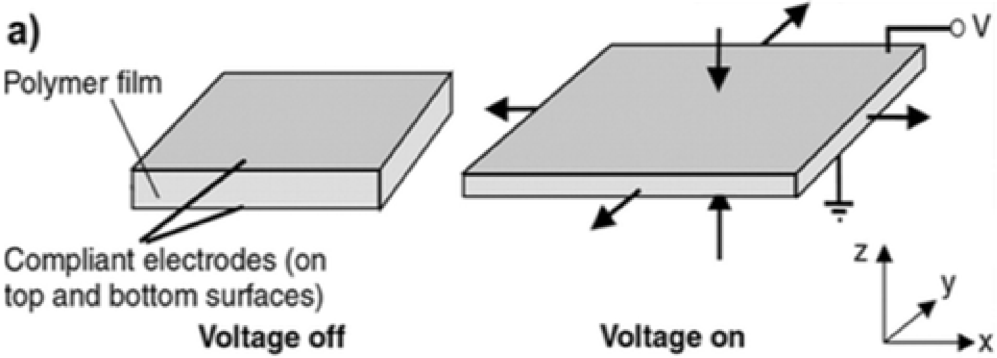
Elastomeric materials for energy and harvesting applications

IOM3: Elastomer use in sustainable energy generation

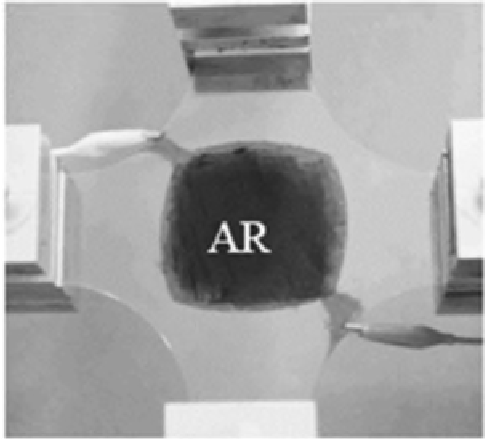
Professor Chris Bowen, C.R.Bowen@bath.ac.uk

19th March 2021

Dielectric elastomers



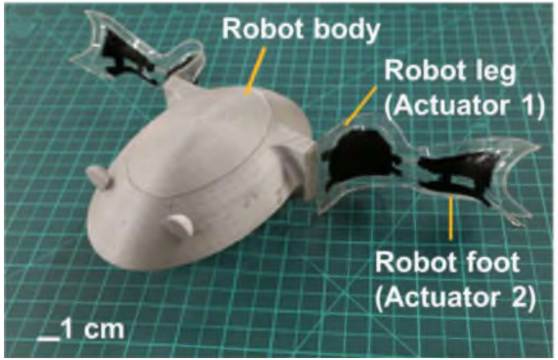
b)



Need to maximise strain: $$s_z = \frac{-\varepsilon_0 \varepsilon_r . E_{breakdown}^2}{Y}$$

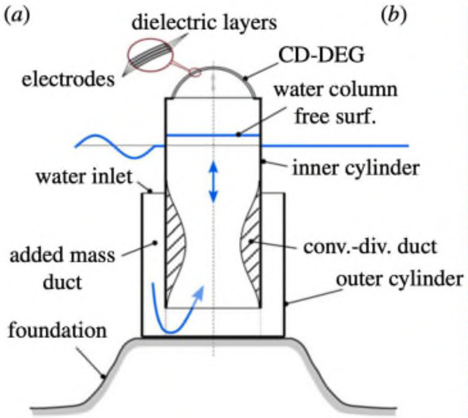
L.J. Romasanta et al. / Progress in Polymer Science 51 (2015) 188–211 193
Keogh and Iravani et al. Actuators 2016, 5, 20; doi:10.3390/act5030020 University of Bath

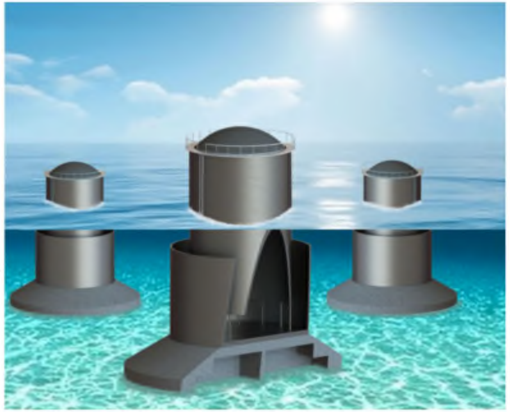
Applications



Soft actuators

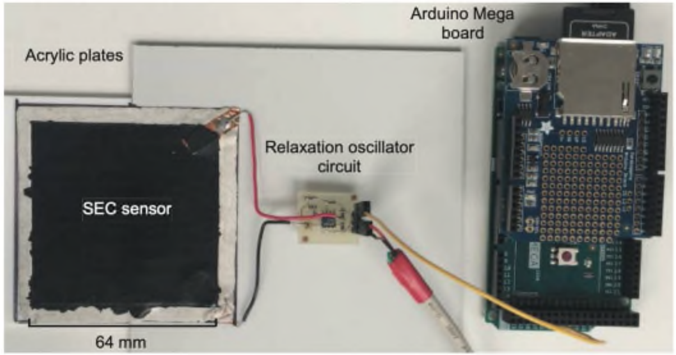
Tang et al. IEEE, DOI: 10.1109/IROS.2017.8206054





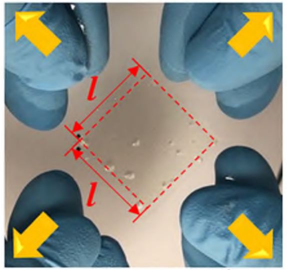
Energy harvesting

Moretti et al. Proc. R. Soc. A 475: 20180566.



Soft sensors

Zoltán Rácz et al. / Procedia Eng., 2016, 168,721.



$$\varepsilon_{biaxial} = \frac{(l' - l)}{l}$$

Stretchable capacitors

Yun et al. Chem Eng J 2020 387 124076

$$\varepsilon_0 \varepsilon_r . E^2_{breakdown}$$

Applications of interest

ACS APPLIED MATERIALS & INTERFACES

Research Article

Cite This: ACS Appl. Mater. Interfaces 2018, 10, 38438−38448

www.acsami.org

Intrinsic Tuning of Poly(styrene−butadiene−styrene)-Based Self-Healing Dielectric Elastomer Actuators with Enhanced Electromechanical Properties

Christopher Ellingford,[†] Runan Zhang,[‡] Alan M. Wemyss,[§] Christopher Bowen,[‡] Tony McNally,[†] Łukasz Figiel,[†] and Chaoying Wan*[,†]

[†]International Institute for Nanocomposites Manufacturing (IINM), WMG, and [§]Department of Chemistry, University of Warwick, Coventry CV4 7AL, U.K.

[‡]Department of Mechanical Engineering, University of Bath, Bath BA2 2ET, U.K.

ACS Appl. Mater. Interfaces 2018, 10, 38438
with University of Warwick

Dr. Chaoying Wan, Prof. Tony McNally

FULL PAPER

ADVANCED FUNCTIONAL MATERIALS

Actuators

www.afm-journal.de

Electrical and Mechanical Self-Healing in High-Performance Dielectric Elastomer Actuator Materials

*Yan Zhang, Christopher Ellingford, Runan Zhang, James Roscow, Margaret Hopkins, Patrick Keogh, Tony McNally, Chris Bowen, and Chaoying Wan**

Adv. Funct. Mater. 29, 1808431 2019

Matter

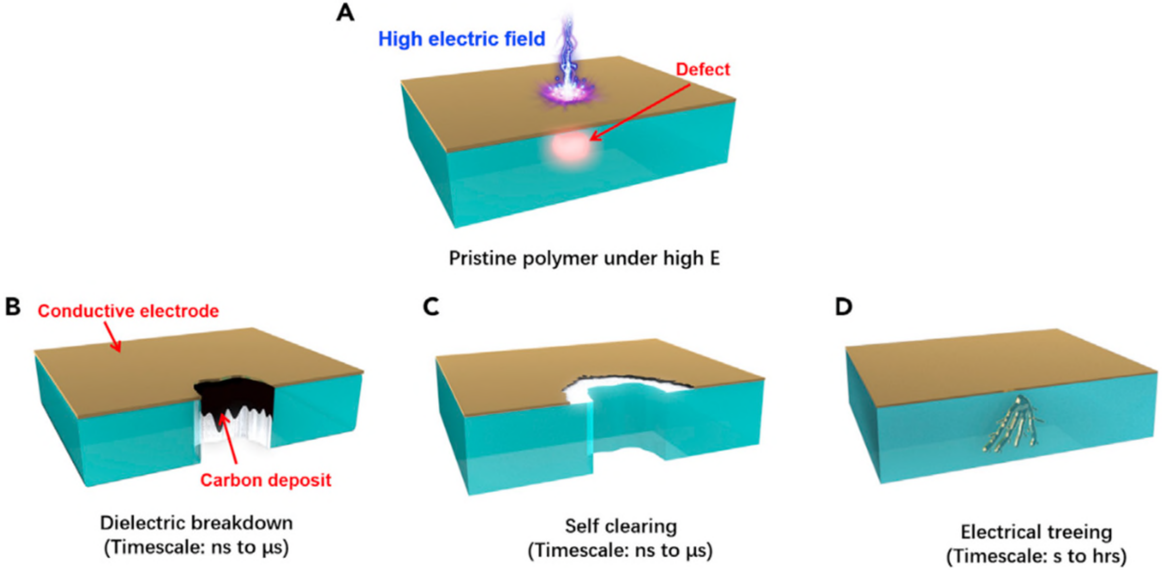
Perspective

Self-Healing of Materials under High Electrical Stress

Yan Zhang,[1] Hamideh Khanbareh,[2] James Roscow,[2] Min Pan,[2] Chris Bowen,[2,*] and Chaoying Wan[3,*]

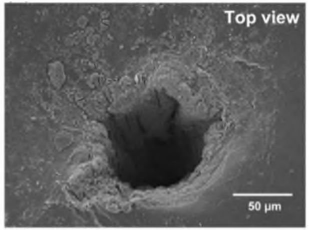
Matter 2020, 3, 989

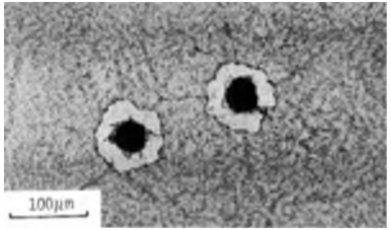
Dielectric Breakdown



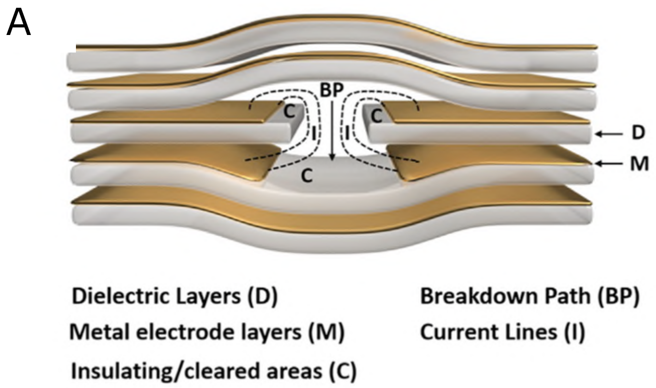
Matter 2020, 3, 989

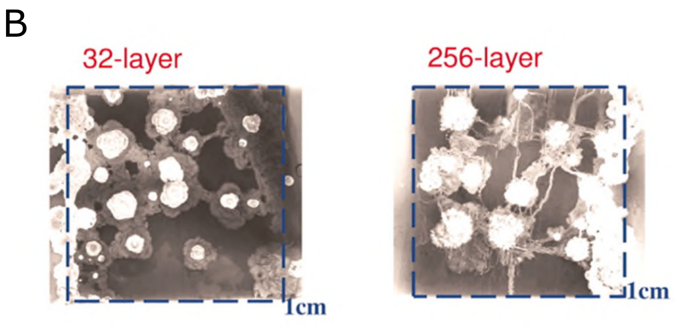
Figure 1. Mechanisms of Electric Breakdown in a Dielectric Elastomer





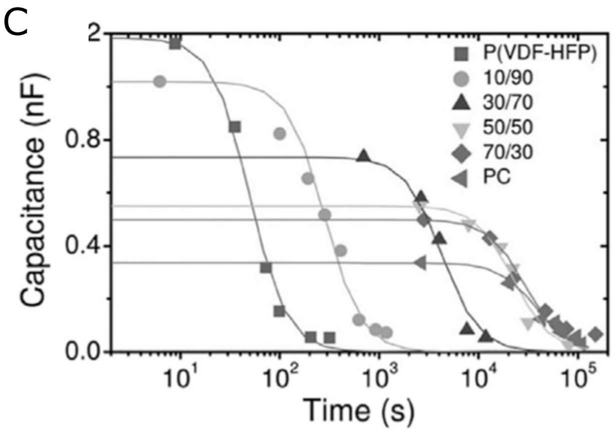
Self-clearing: inc. capacitors for energy storage





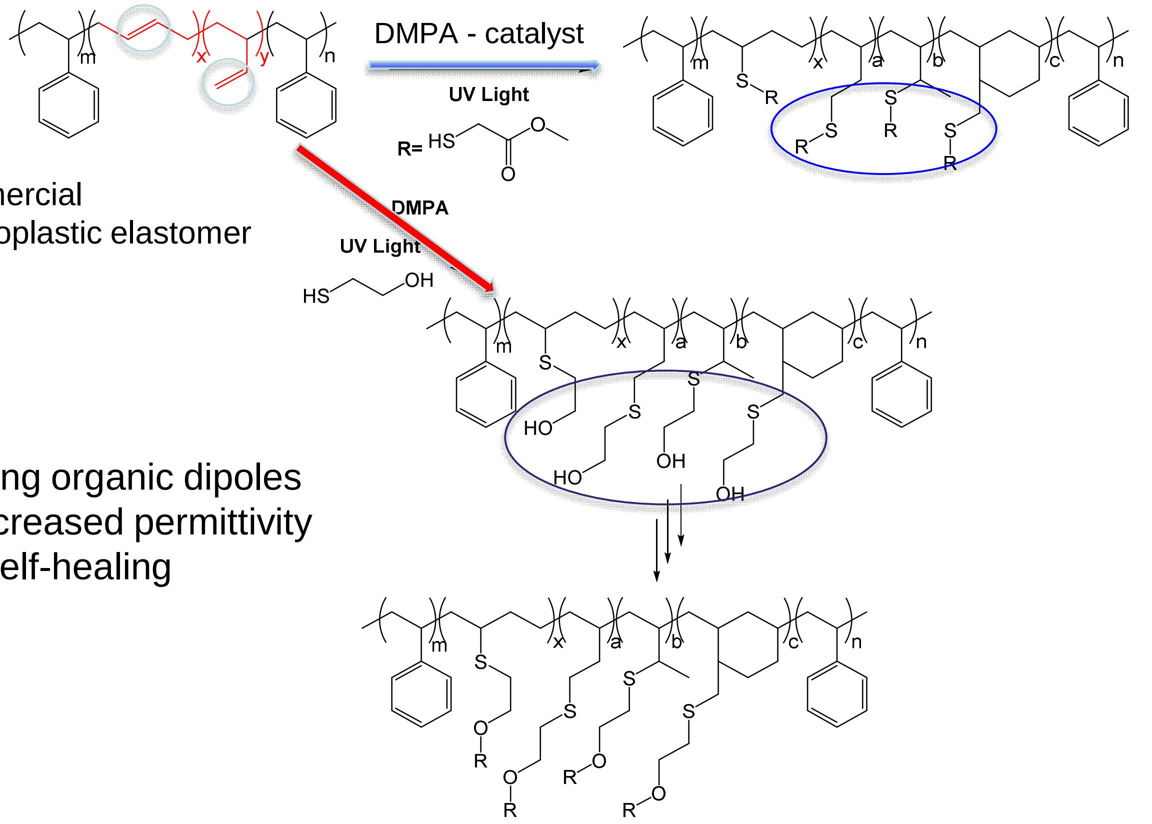
Gradual decay in capacitance

Mechanical properties?



Self-healing elastomer (Dr Chaoying Wan)

UNIVERSITY OF BATH



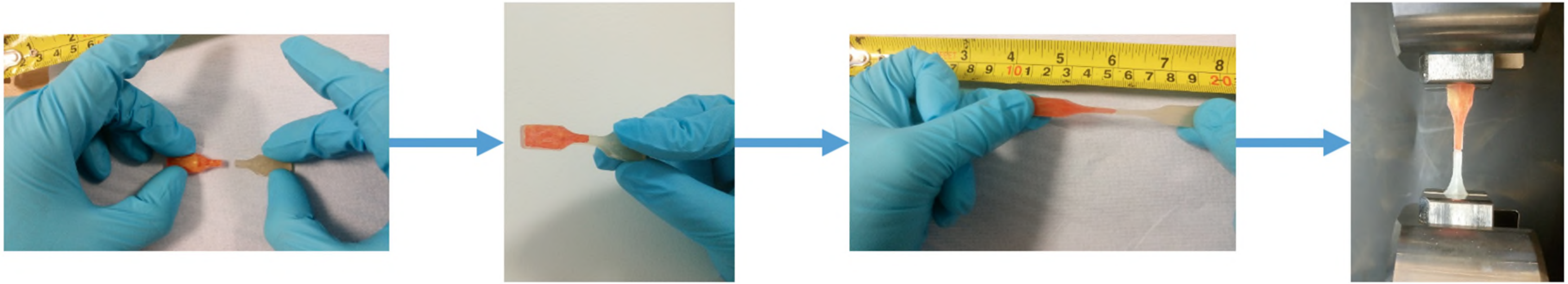
SBS
Commercial
thermoplastic elastomer

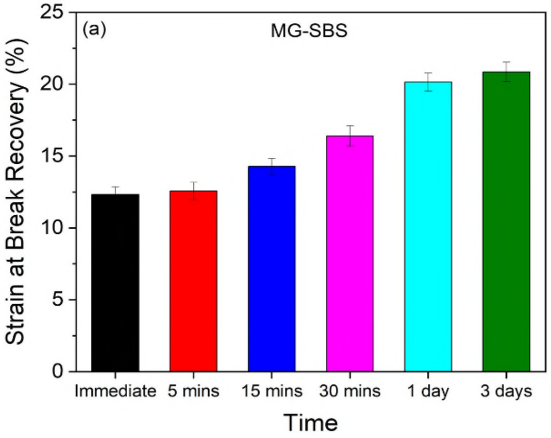
Grafting organic dipoles
for increased permittivity
and self-healing

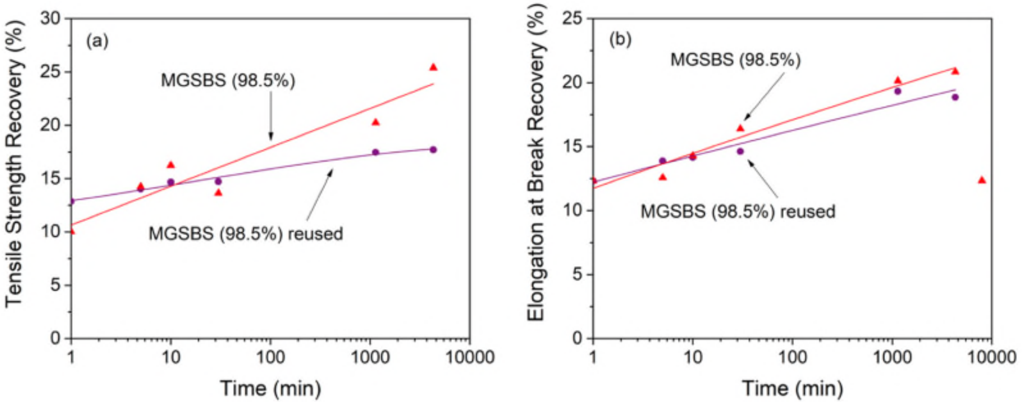
- Methyl thioglycolate (MG) was grafted to the butadiene block via a one-step thiol−ene “click” reaction under UV at 25 °C
- UV photo-polymerisation
Room temperature, 5-20 mins
- Grafting ratio ~98%
- Up-scalable

Wan et al., ACS Appl. Mater. Interfaces 2018, 10, 38438

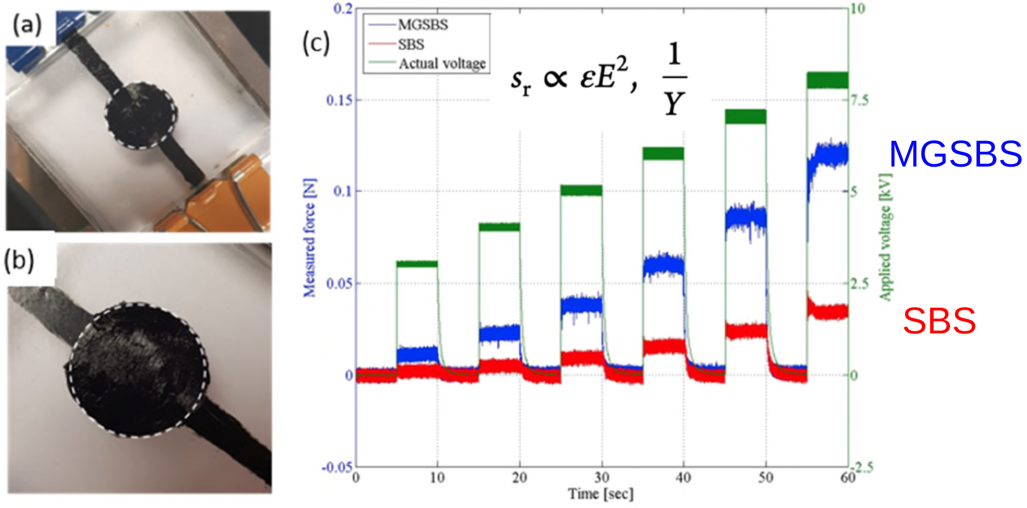
Self-healing MGSBS elastomer

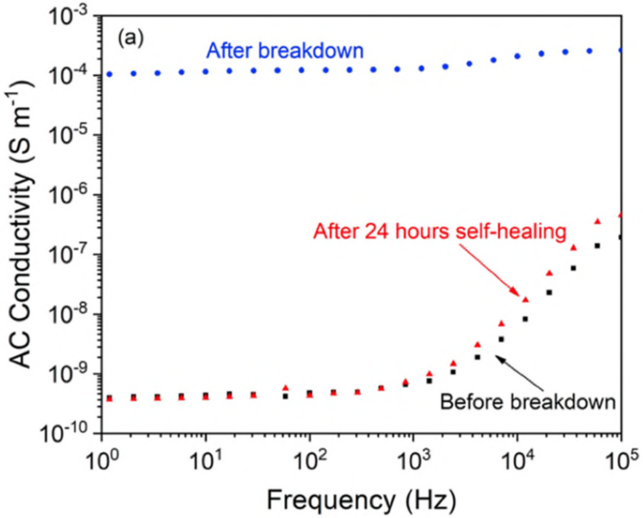






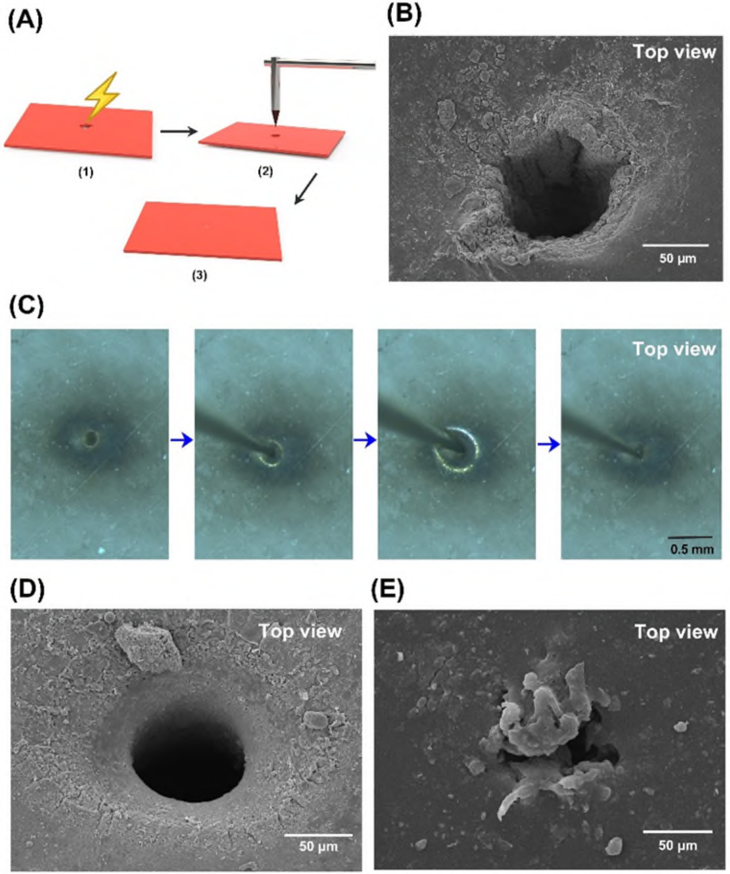
Self-healing MGSBS elastomer

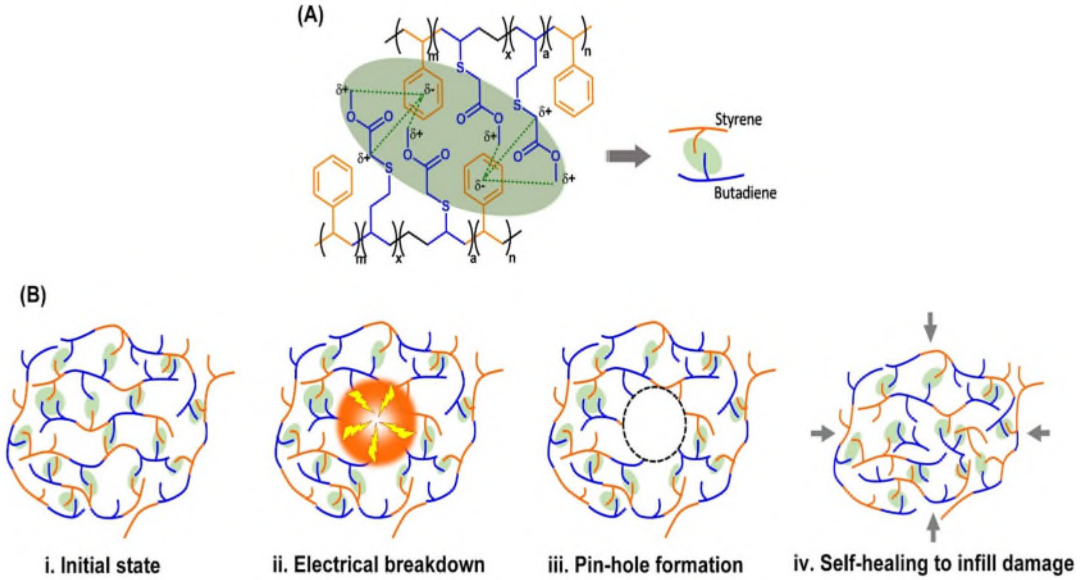




Low-field electrical properties (1V)

Dielectric breakdown / healing high field properties





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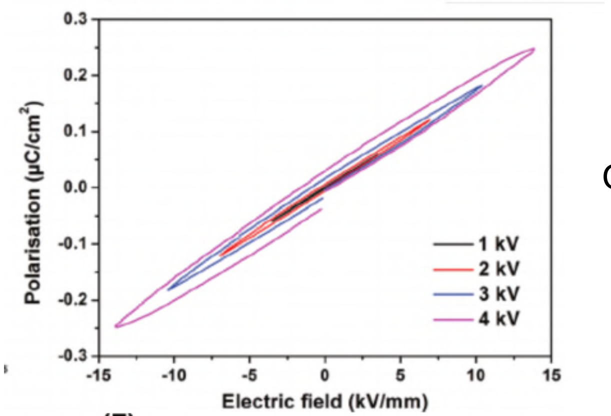
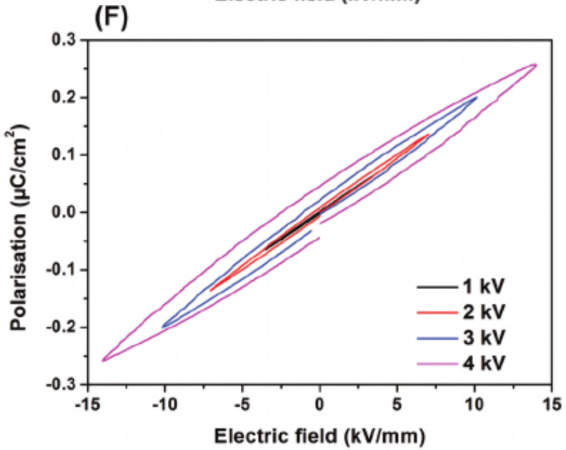
Recovery of **high-field** properties (4kV)

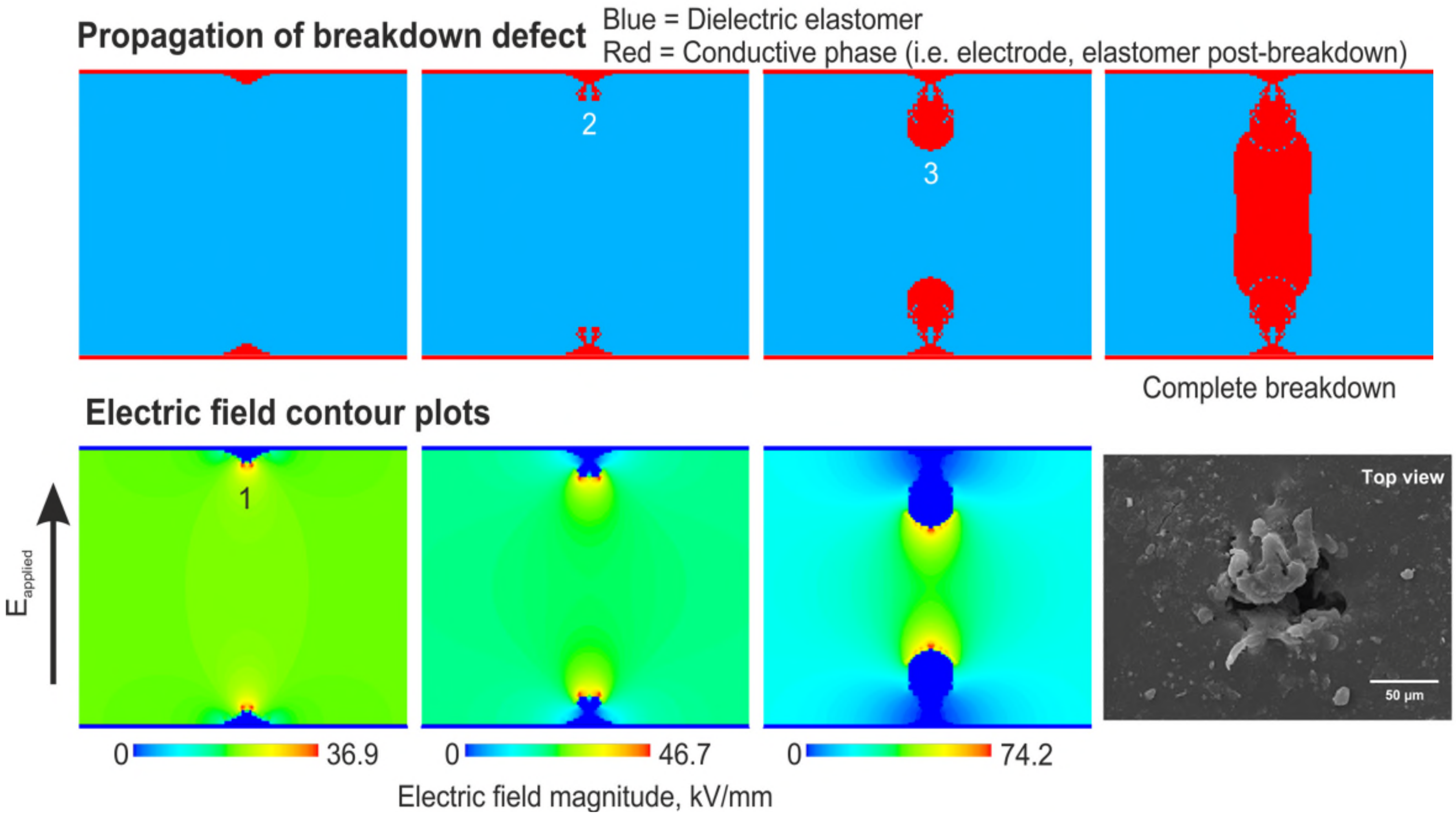


Original material

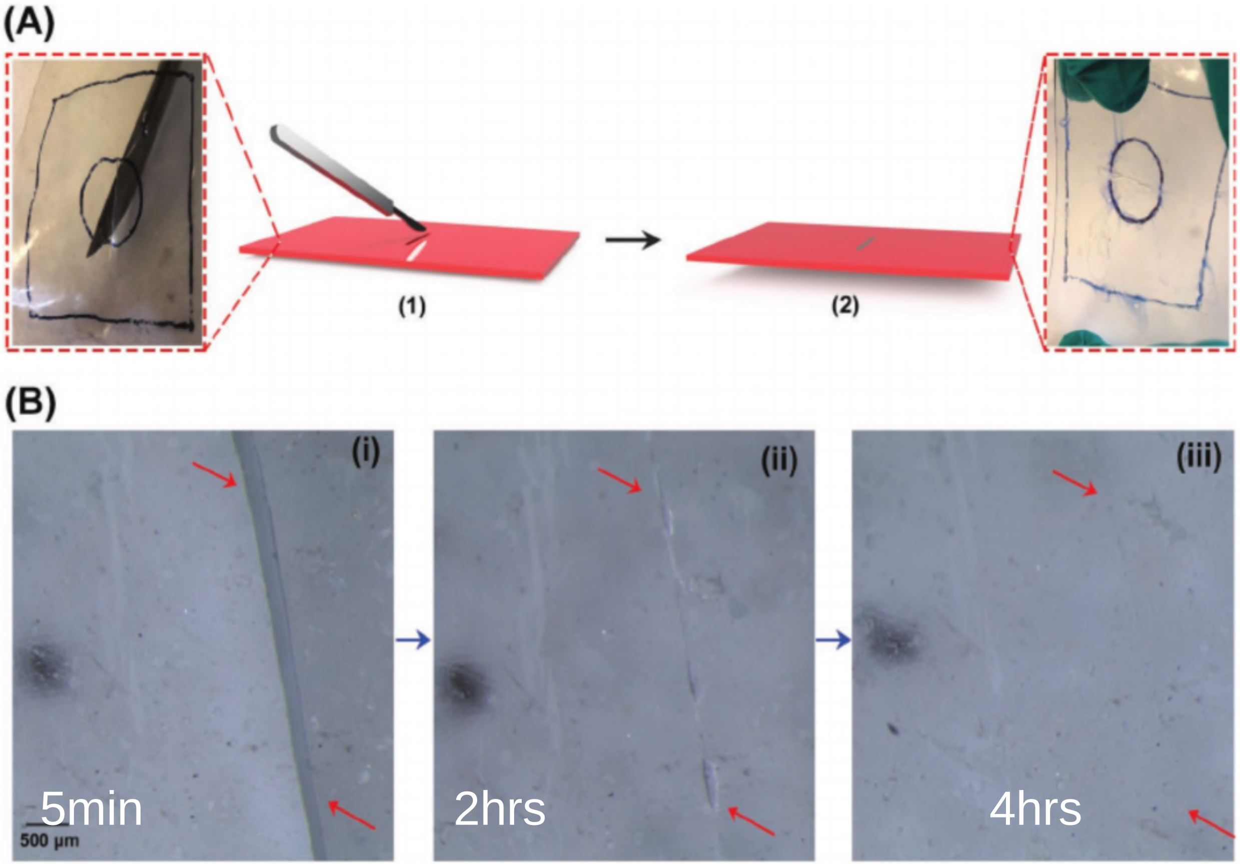


Fine – needle at 24 hrs healing after breakdown

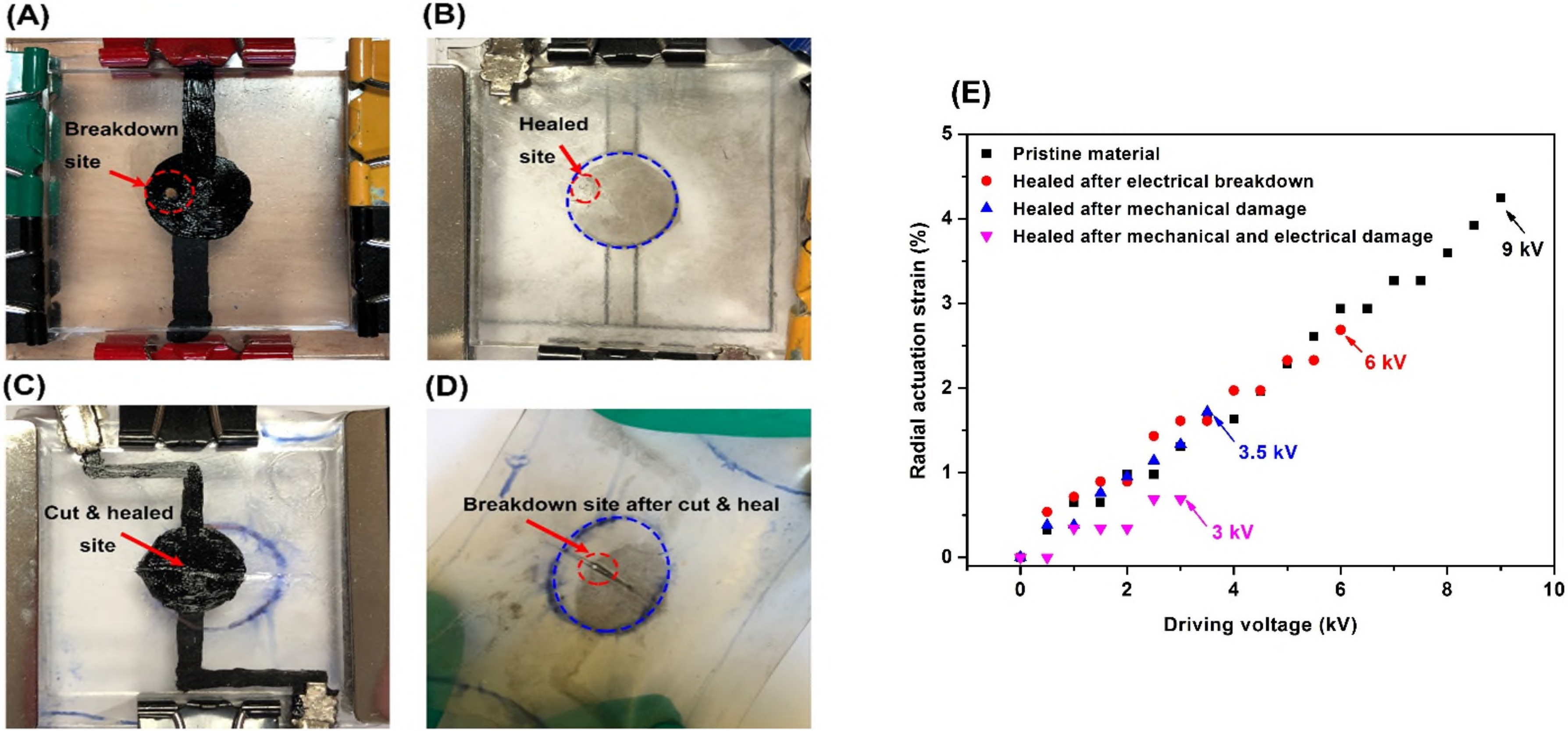
Dielectric breakdown modelling



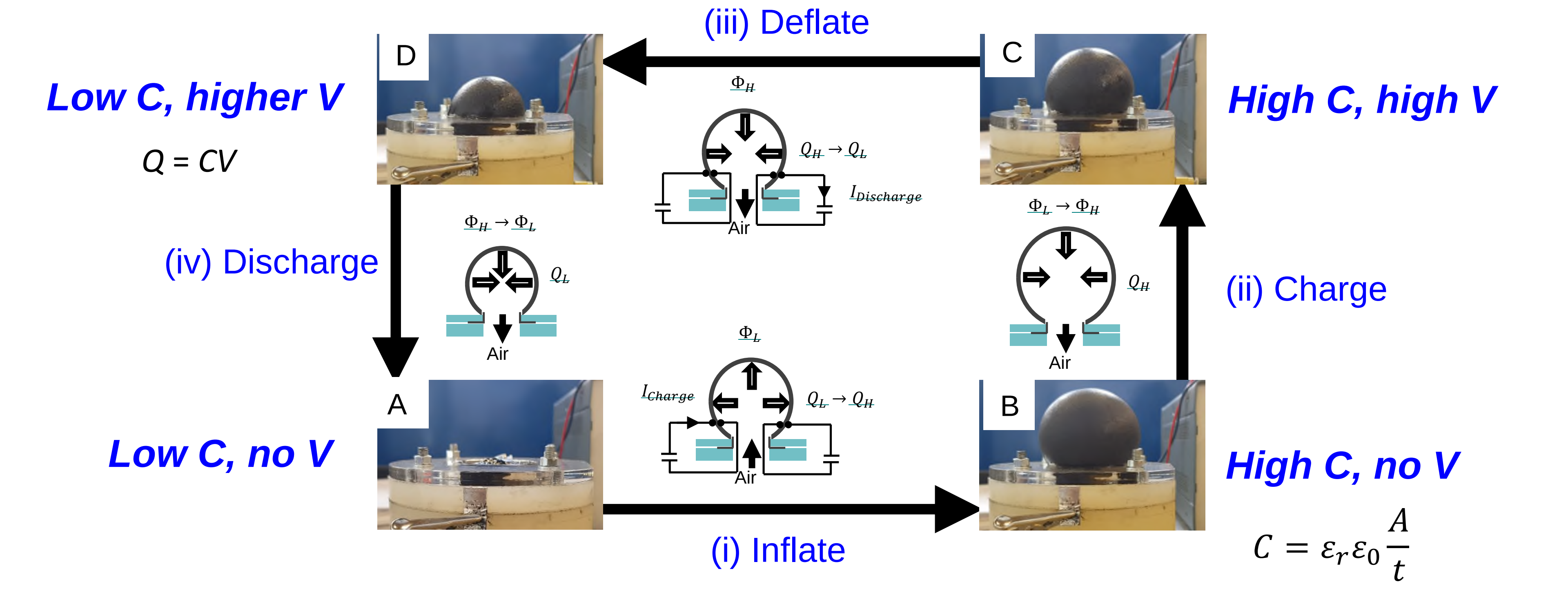
Recovery of mechanical damage/cuts



Actuator healing



DEG energy harvesting cycle

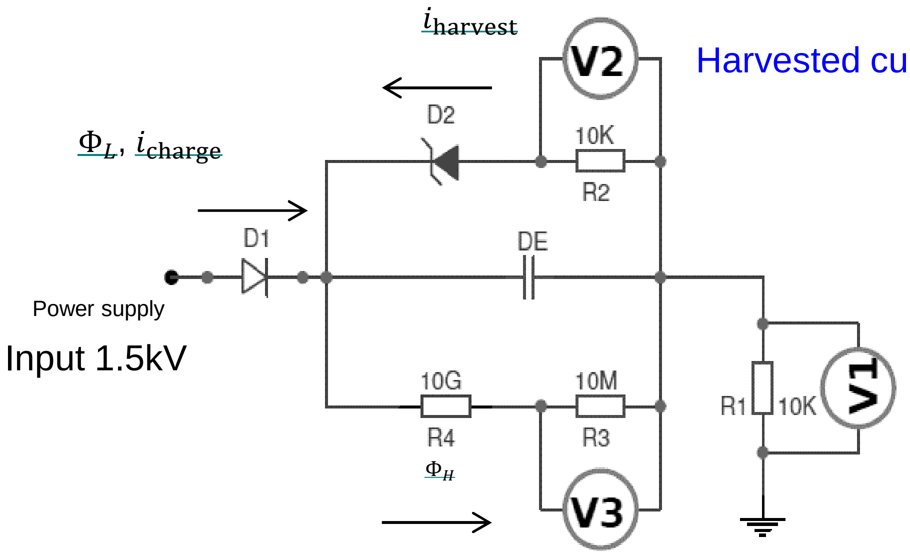


$$\frac{harvested\ energy}{volume} = \frac{1}{2}\varepsilon_0 \varepsilon_r E_{max}^2 \left[1 - \frac{A_{min}^2}{A_{max}^2}\right]$$

Energy harvesting cycle ABCD

D2 constant harvesting voltage of Φ_H =2.4 kV

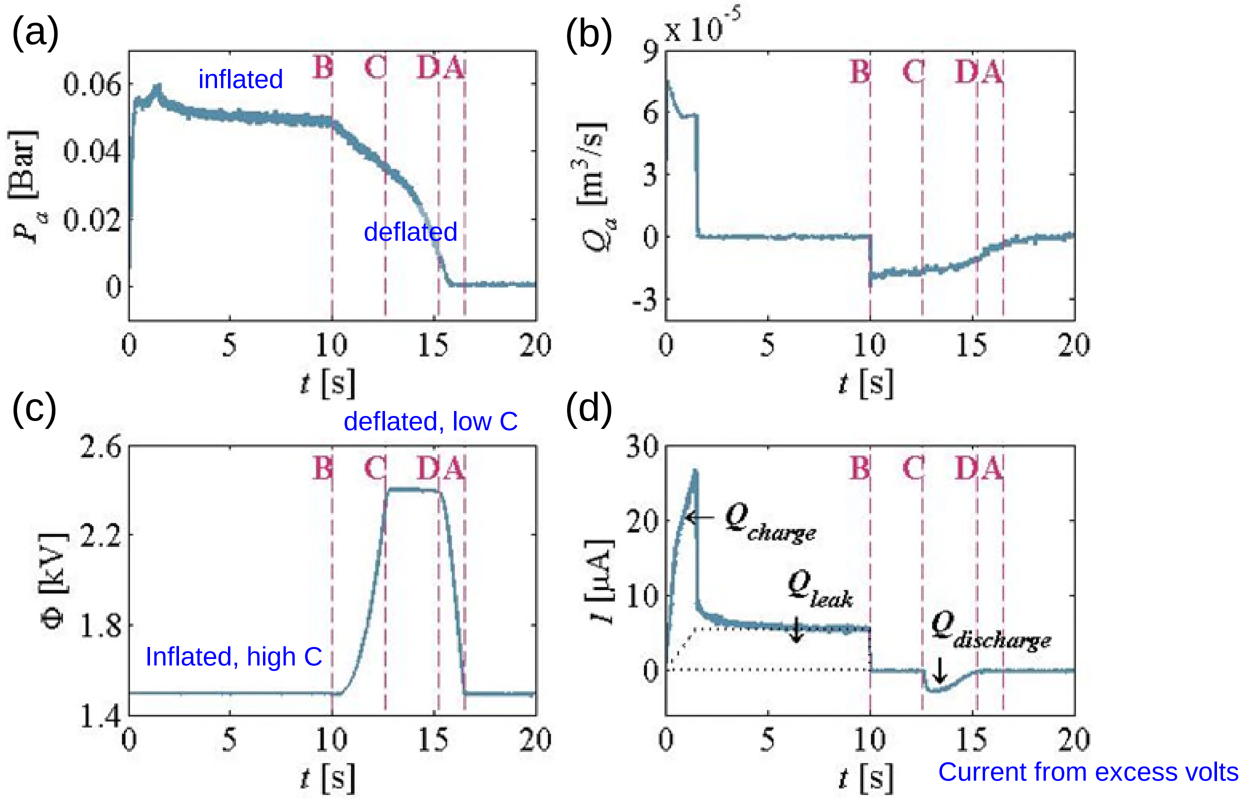
Harvested current from voltage V2



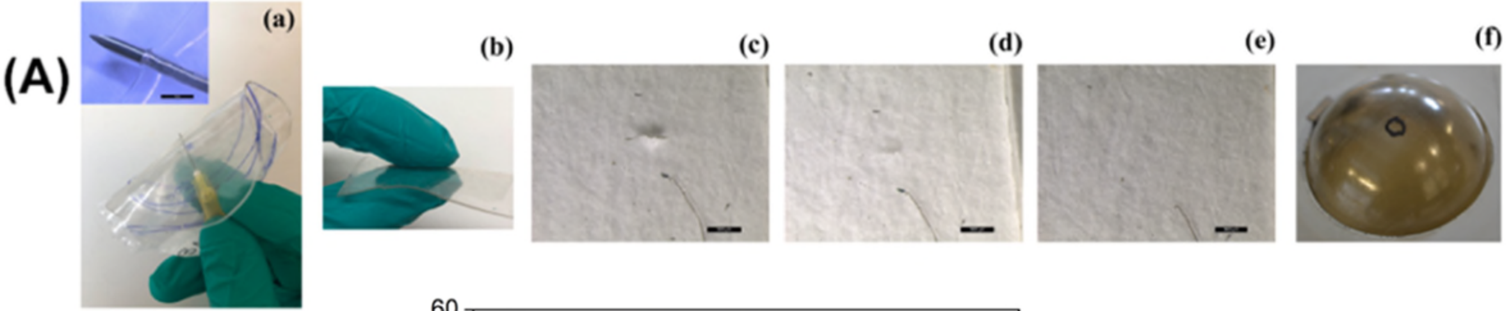
Harvester voltage V3

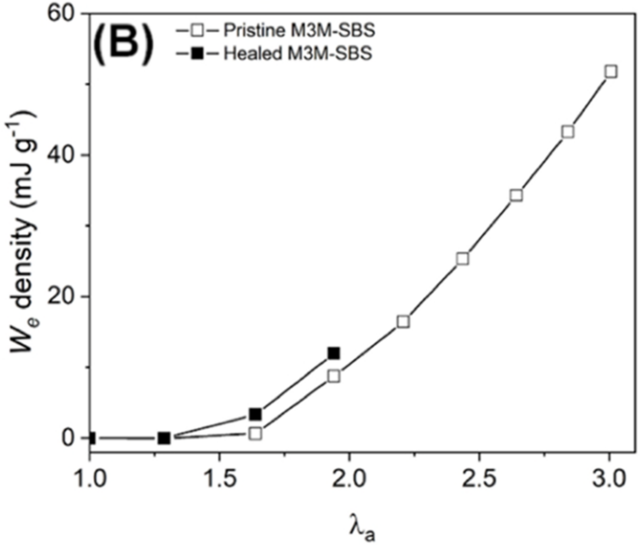
Electrical circuit for energy harvesting Voltage input is 1.5 kV (i.e. Φ_L =1.5 kV). Diode D1 allows the measurement of harvested voltage at voltmeter V3; D2 is an assembly of Zener diodes in series to establish a constant harvesting voltage of Φ_H =2.4 kV and allows measurement of the harvested current across a resistor R2 at voltmeter V2.

Harvesting cycle. Pressure (P), flow (Q_a), V (Φ), I



Self-healing of DEGs: High strain & electric field !





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Self-Healing Dielectric Elastomers for Damage-Tolerant Actuation and Energy Harvesting

Christopher Ellingford, Runan Zhang, Alan M. Wemyss, Yan Zhang, Oliver B. Brown, Hongzhao Zhou, Patrick Keogh, Christopher Bowen,* and Chaoying Wan*

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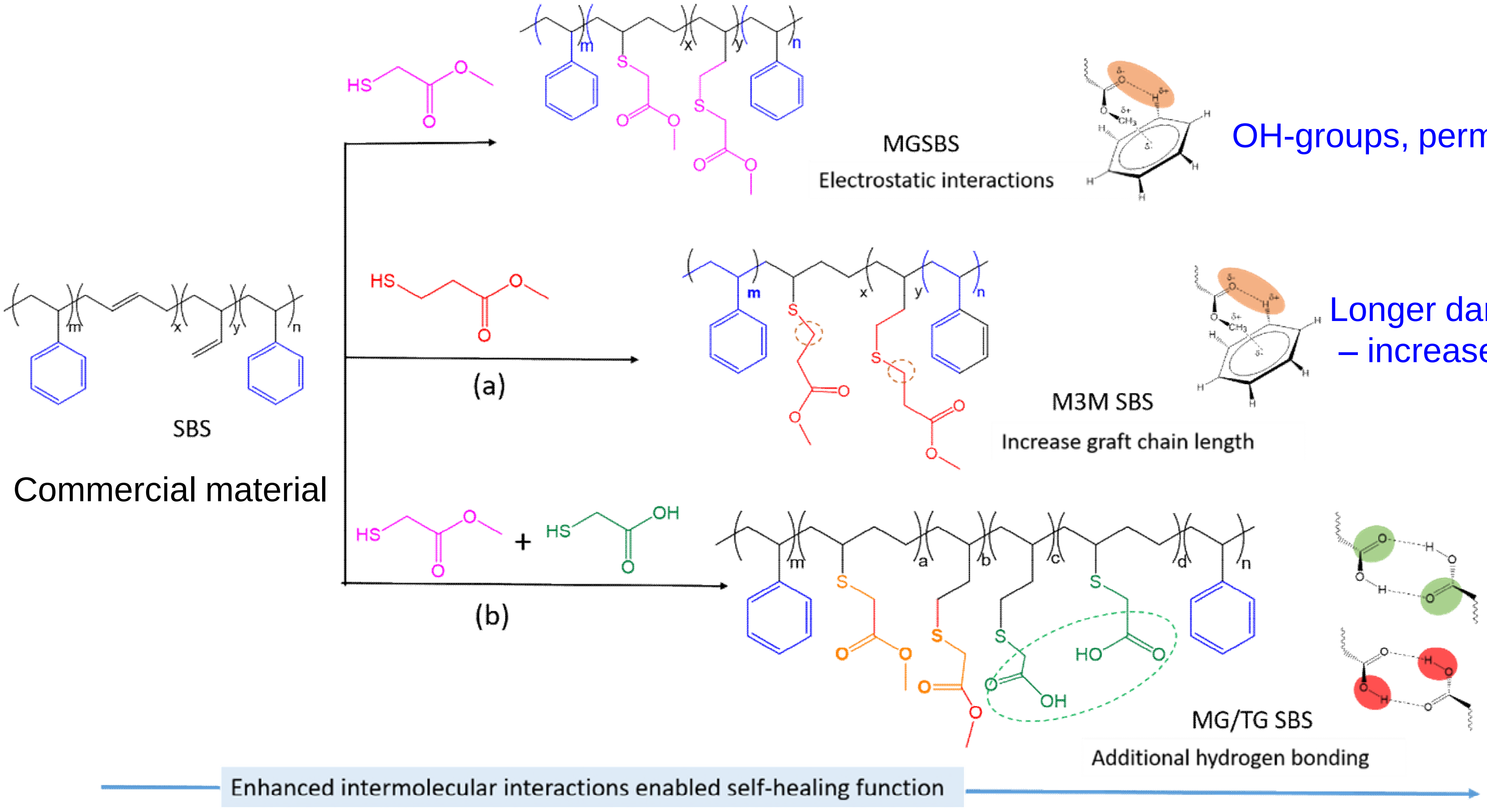
Variation on MGSBS (Dr Chaoying Wan)



OH-groups, permittivity & healing

Longer dangling side chain – increased flexibility

Dual groups for permittivity, mech. props. & healing

Summary

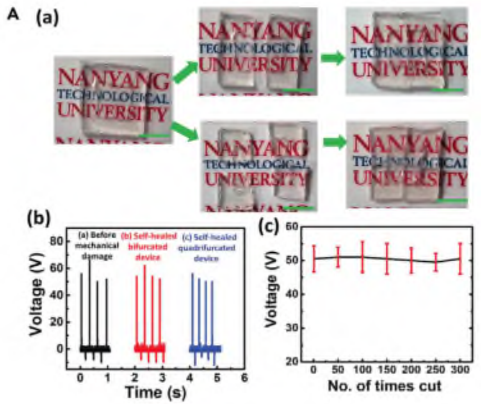
Elastomer design for energy generation applications:

Adaptation of commercial materials for:

- ➢ Mechanical properties (Y, elastic strain, visco-elastic)
- ➢ Dielectric properties (permittivity, loss)
- ➢ Self-healing functionality (dielectric/mechanical damage)

Dielectric generators
Energy storage (capacitors, flexible electronics)

Less on tribo-electric and piezo-electric systems



Parida *et al.*, Adv Mat 2017, 29, 1702181

Acknowledgment

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