Topic: Elastomer Use in Sustainable Energy Generation

Commercial Rubber-based Triboelectric Generators for Environmentally Viable Energy Harvesting Applications

March 19, 2021
IOM3 Webinar

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Triboelectricity – Definition

Triboelectric Effect and Triboelectric series

contact electrification in which certain materials become electrically charged after coming into contact with another different material, and are then separated.

Example : Amber / Wool

Balloon / Hair

Day to Day activities

Small shock from a doorknob after walking on a carpet with shoes.

Removing sweater by pulling over your head.

Triboelectric series

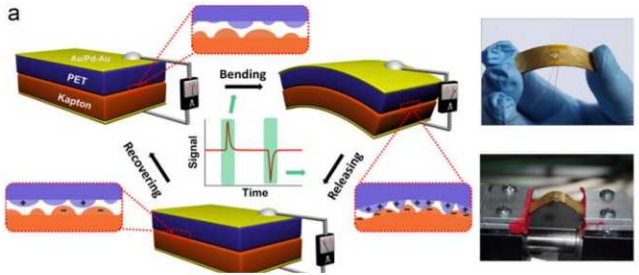
Any two kinds of materials from triboelectric series in contact and separation mode to produce electricity

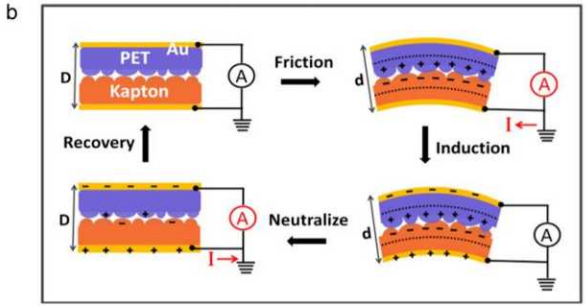
Images: wiki/Creative Commons

Triboelectric Nanogenerators (TENGs)

Triboelectricity was considered as a negative effect and avoided in many technologies

- **First report in 2012 by Wang et al., Flexible triboelectric generator, Nano energy, 2012, 1 (328).**
- **Triboelectric effect can be used to harvest energy**
- **In triboelectric generator (TEG), Mechanical energy converted to electrical energy**
- **coupling effects between triboelectrification and electrostatic induction through contact separation or sliding between two triboelectrically opposite materials.**

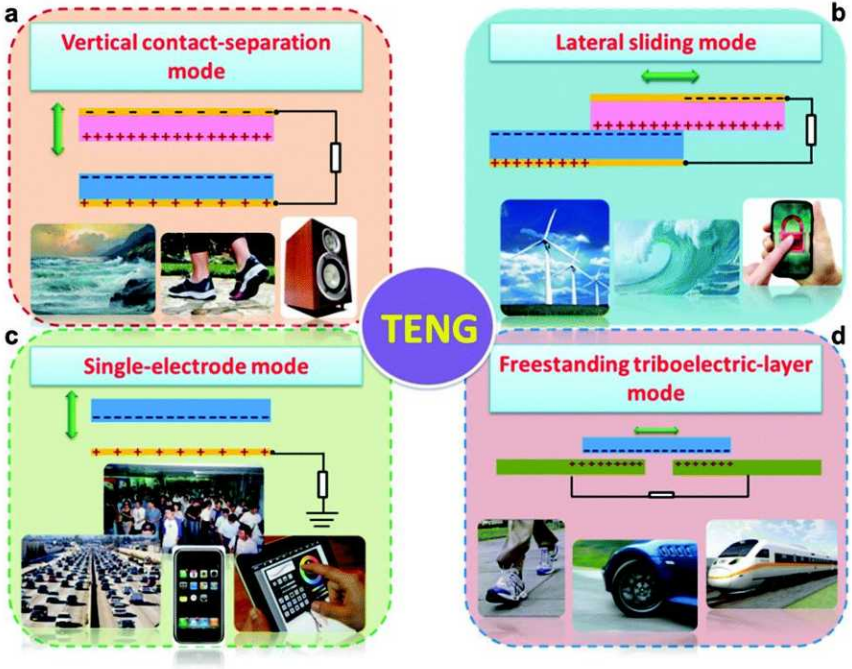


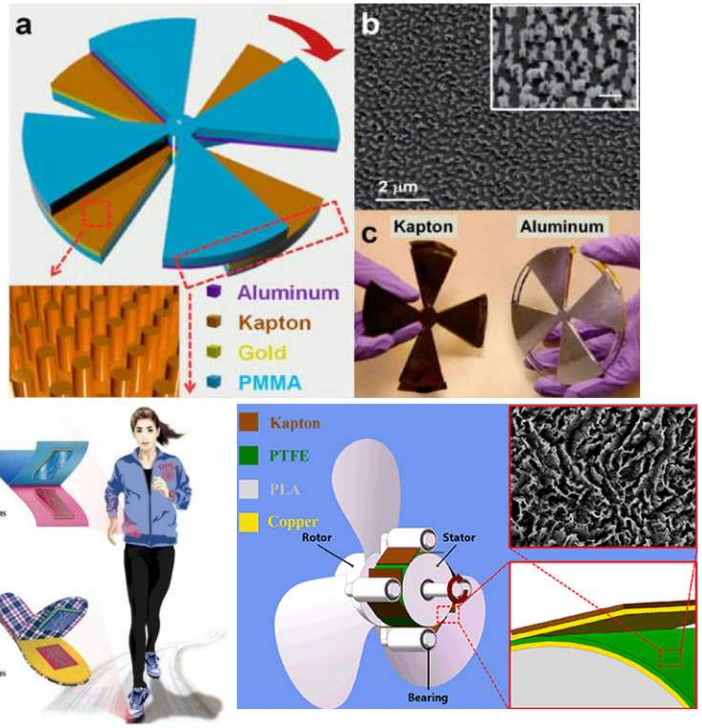


Fan, Feng-Ru, Zhong-Qun Tian, and Zhong Lin Wang. *Nano Energy* 1.2 (2012): 328-334.

Working modes of TENG

- Various modes of operation for TEG/TENG: engineering concepts for energy harvester



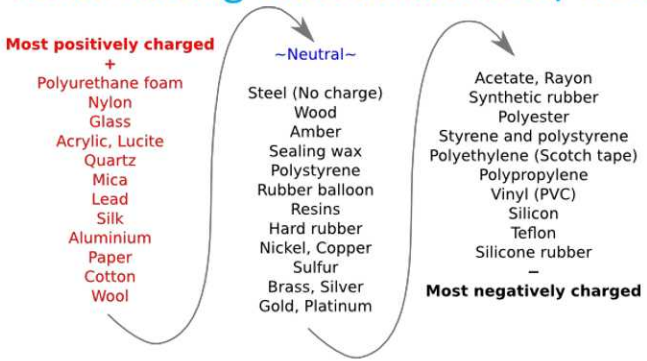


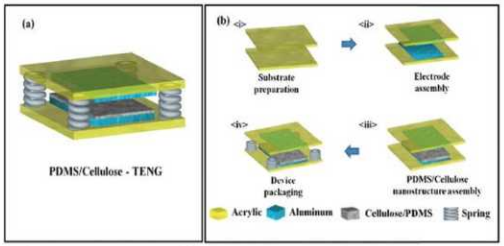
Wang, Zhong Lin, Jun Chen, and Long Lin. *Energy & Environmental Science* 8.8 (2015): 2250-2282.

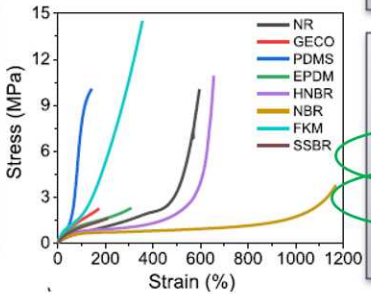
TENGs based on Rubber and its composites

PDMS/Silicone rubber widely chosen as triboelectric layer due to position (negative) in triboelectric series.

PDMS along with Aluminum/Cellulose/nylon/PVDF has been widely used







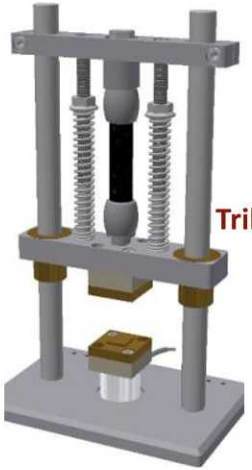
- Along with PDMS, various rubbers are also being utilized

PDMS -	silicone rubber
FKM -	fluoro elastomer
GECO -	epichlorohydrin
EPDM -	ethylene propylene rubber
IR-	isoprene rubber

CR -	chloroprene rubber
SBR -	styrene butadiene rubber
NR -	natural rubber
NBR -	nitrile rubber
HNBR -	hydrogenated nitrile rubber

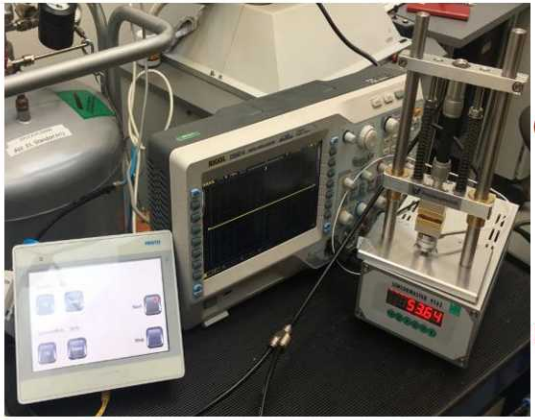
Chandrasekhar, A., Alluri, N. R., Saravanakumar, B., Selvarajan, S., & Kim, S. J.(2017) *Journal of Materials Chemistry C*, *5*(7), 1810-1815

Triboelectric Nanogenerators: measurement set up



Triboelectric Measurement Unit (in-house developed)

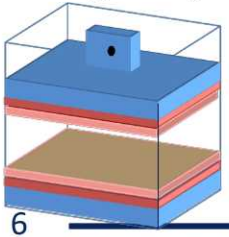
Festo Pneumatic Controller



Oscilloscope

Force Sensor Display

This instrument is coupled with a force transducer as well as with pneumatically controlled pressure unit (Festo Corporation) for variable frequency, displacement, contact time, mode of striking like pulse mode, sinusoidal etc.



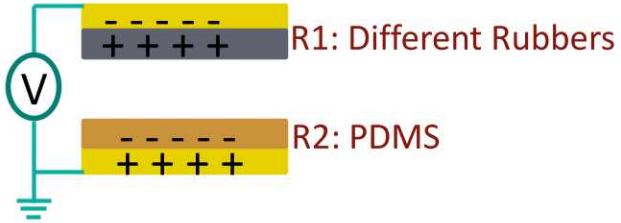
Electrodes are copper-made with specimen placed on top (Rubber 1)

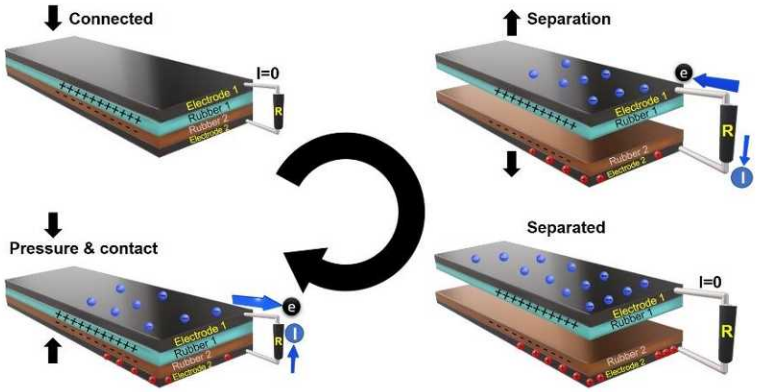
Typical thickness of rubber films ~120 μm

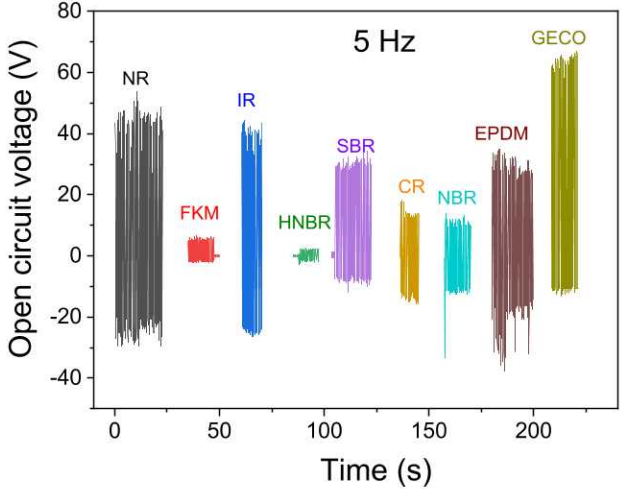
Rubber I: various surface engineered rubbers; Rubber II: PDMS

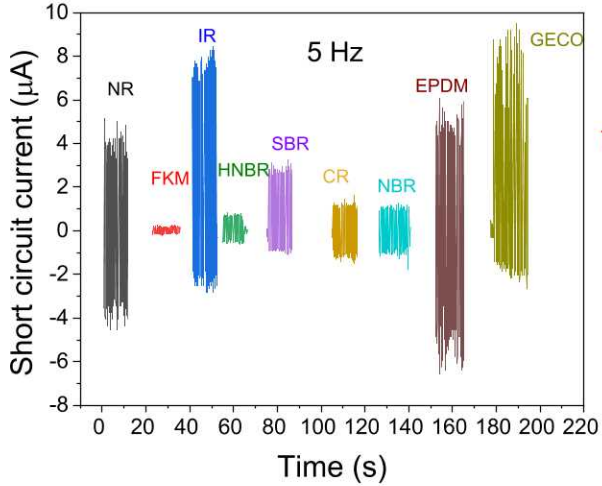
Natarajan et al., Robust Triboelectric Generators by All-In-One Commercial Rubbers, ACS Appl. Electron. Mater. 2020, 2, 12, 4054–4064

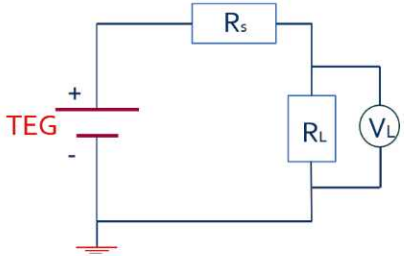
Output characteristics









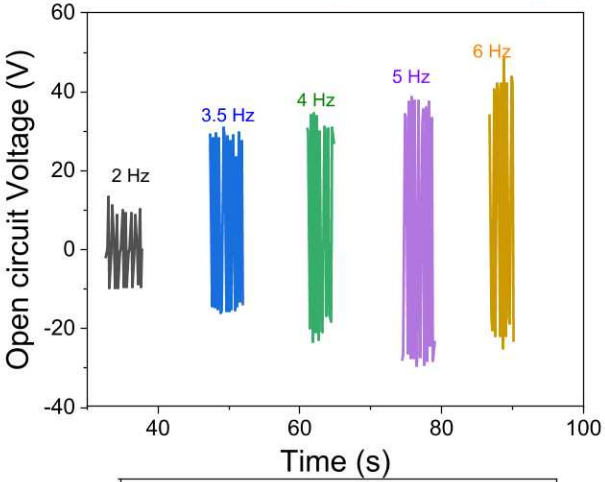


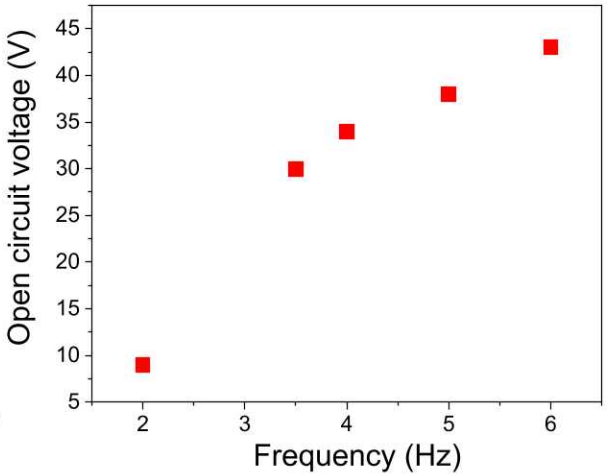
$$\text{Current} = \frac{V_L}{R_S + R_L}$$

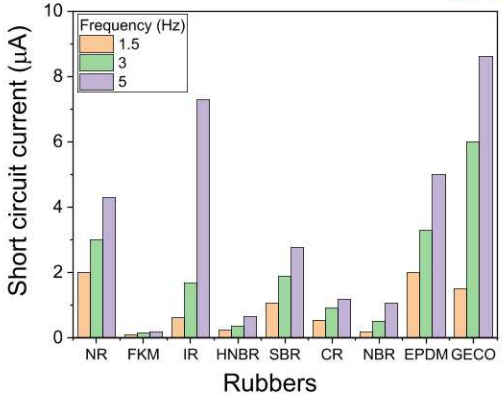
V_{OC} and I_{SC} with time for 5 Hz frequency for different rubbers for R1; R2 is PDMS (for all)

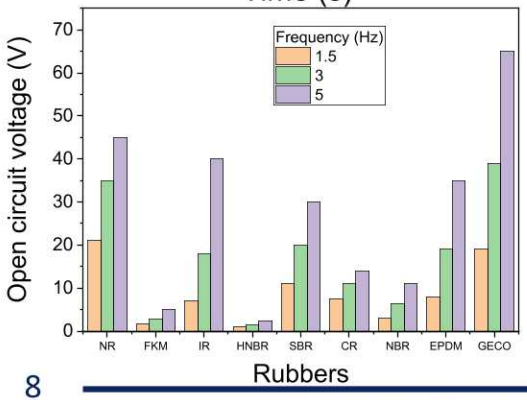
Natarajan et al., Robust Triboelectric Generators by All-In-One Commercial Rubbers, ACS Appl. Electron. Mater. 2020, 2, 12, 4054–4064

Effect of operating frequency on Triboelectric effect









Higher the frequency – higher the output characteristics

Rating based on Power Density (P = V×I/A):

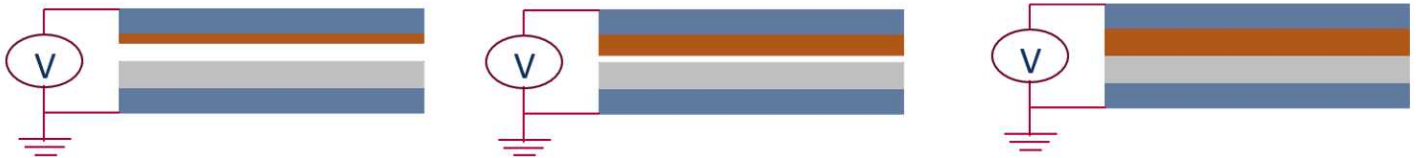
1. GECO : 107 μW/cm^2
2. IR : 85 μW/cm^2

Other factors: surface roughness, contamination, humidity

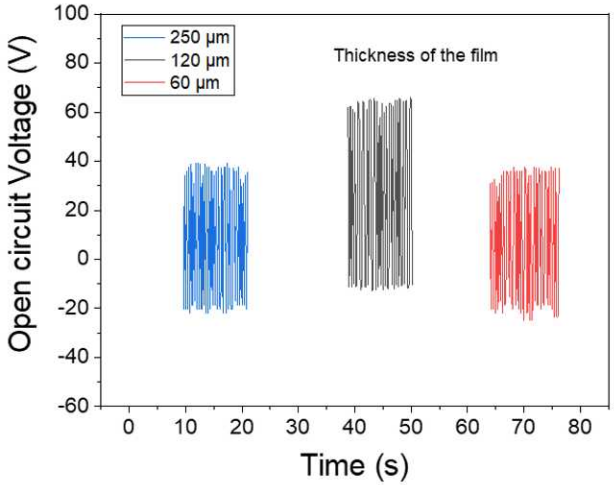
GECO
NR
IR
SBR
EPDM
CR
NBR
FKM
HNBR

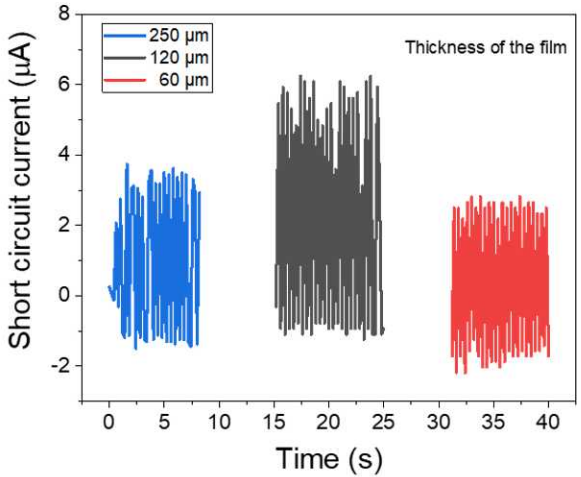
Natarajan et al., Robust Triboelectric Generators by All-In-One Commercial Rubbers, ACS Appl. Electron. Mater. 2020, 2, 12, 4054–4064

Effect of thickness of the tribo-layer



60 µm 120 µm 250 µm





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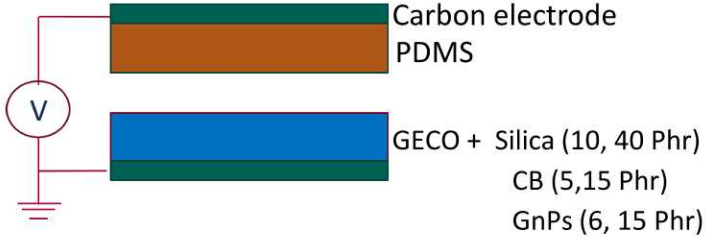
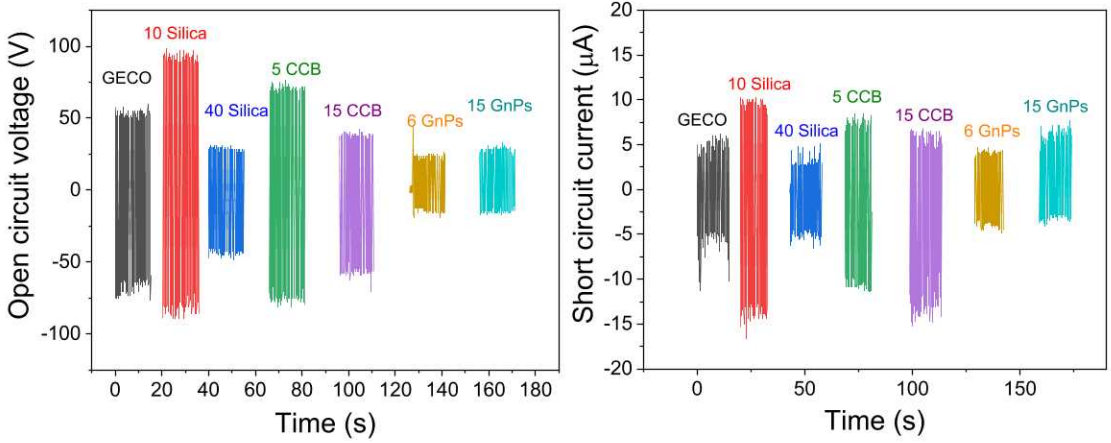
Effect of fillers





Effect of fillers conc. on GECO

	Peak to peak voltage (V)	Peak to peak current (μA)	Power density μW/cm²
GECO	125	11	171
10 Silica	185	24	555
40 Silica	63	9	71
5 CCB	153	18	344
15 CCB	97	20	242
5 GnPs	40	8.5	43
12 GnPs	43	9.5	51

Fillers below Percolation threshold is better

Silica is present in Top of the Triboelectric series(Positive)Silica

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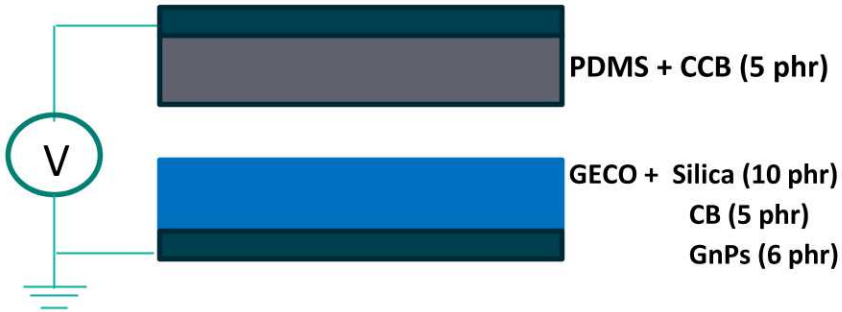
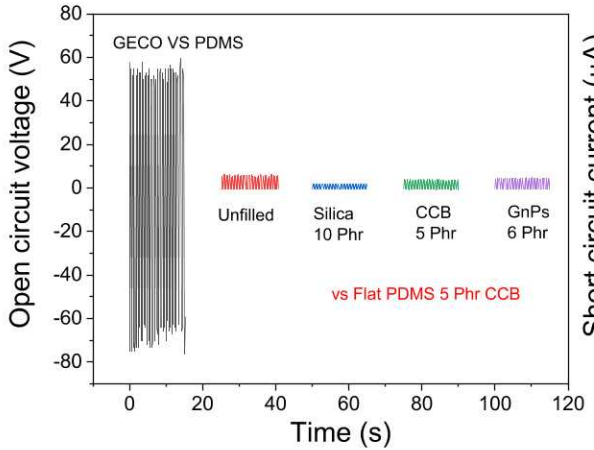
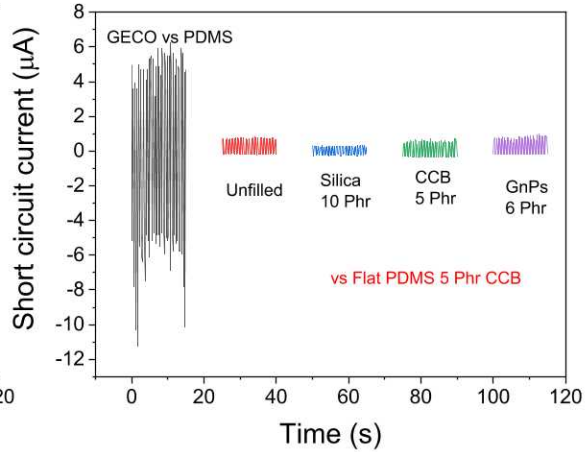
Effect of filler in PDMS layer



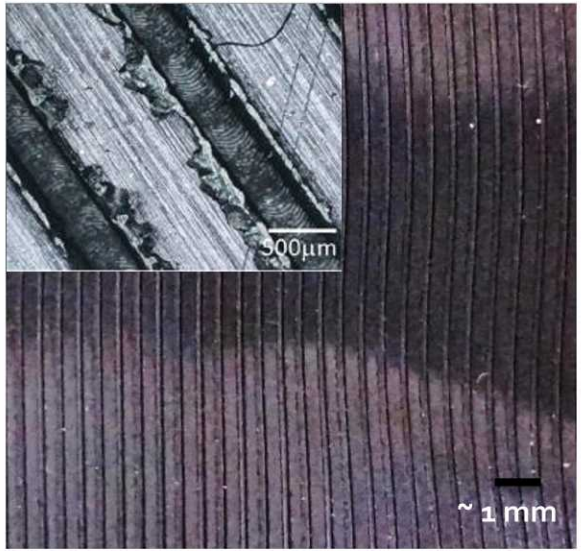




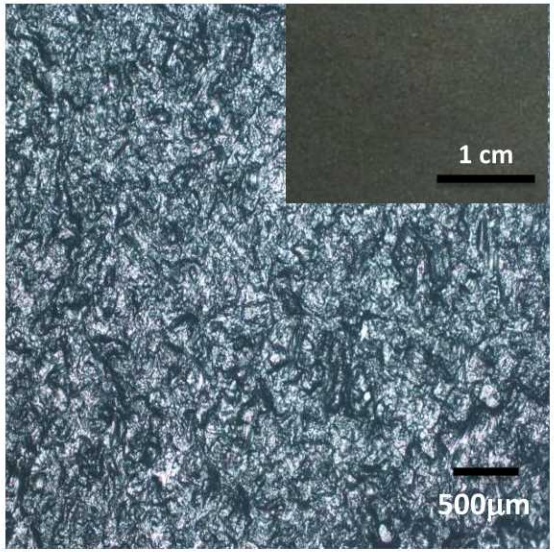
Natarajan et al., In Situ Polymorphic Alteration of Filler Structures for Biomimetic Mechanically Adaptive Elastomer Nanocomposites, *ACS Applied Materials & Interfaces* 2018, 10, 18, 16148-16159

Surface modification/texture

Micro-line grafted Mold



Sand-blasted Mold



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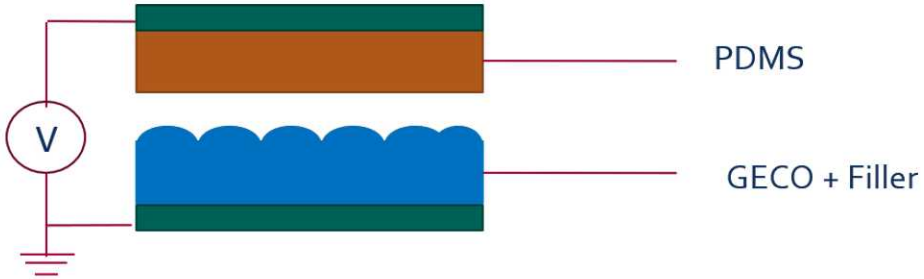
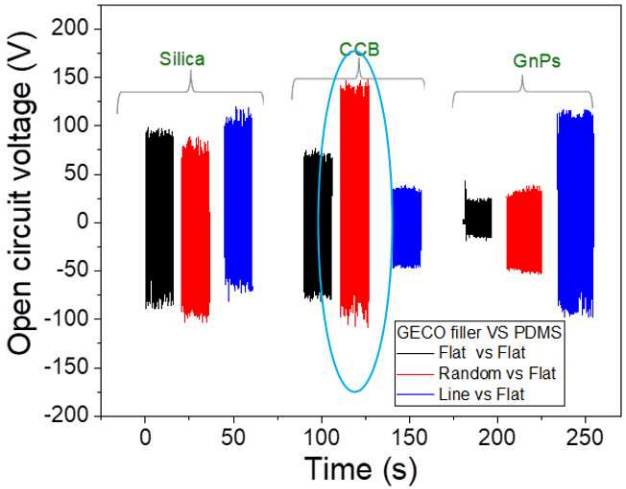
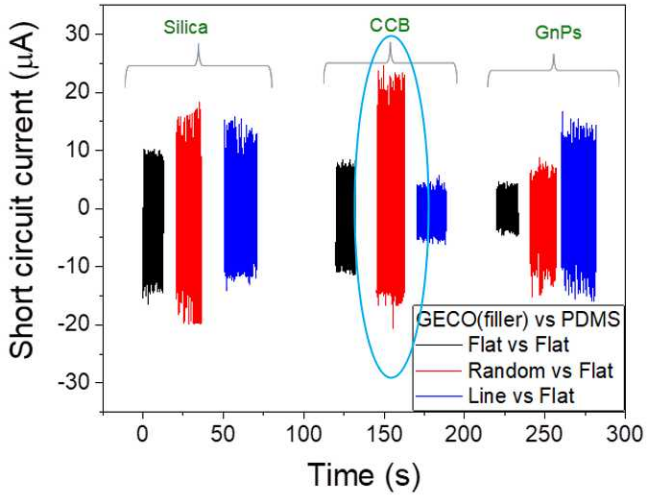
Surface modification/texturing on one side







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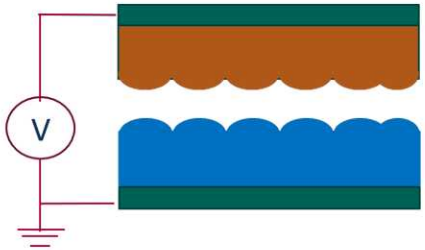
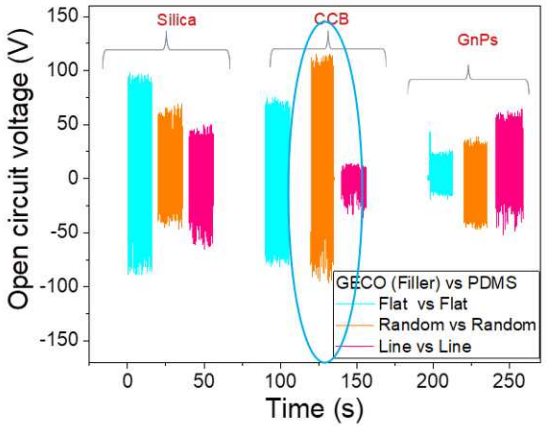
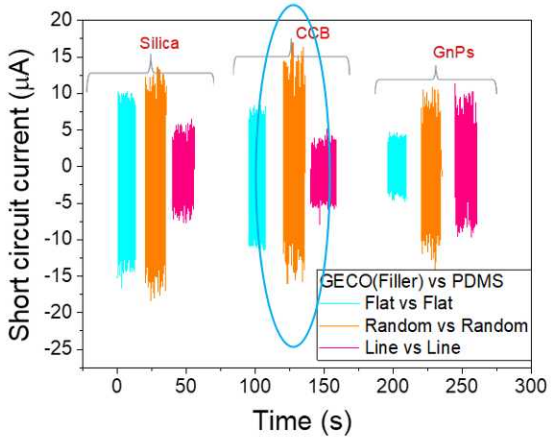
Surface modification/texturing on both side



Best performing pair: Micro-indented PDMS
Micro-indented GECO/5 phr CCB

192 V, 27 μA, 540 μW/cm^2





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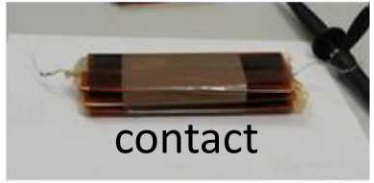
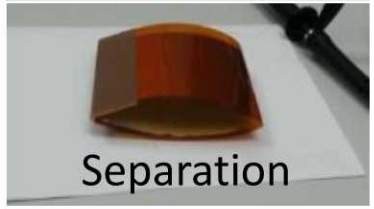
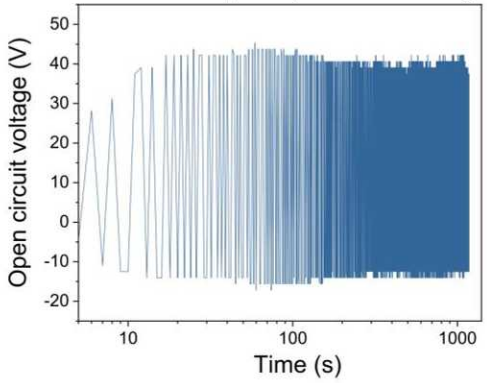
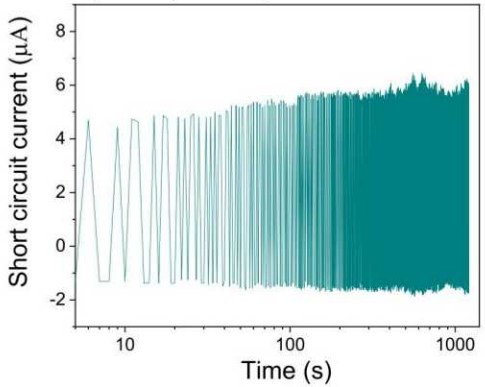
TENG – Energy harvesting from rotating tires





Durability experiment (2400 cycles/ 2Hz)





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Conclusion & Outlook

1. Triboelectric generators have been successfully fabricated using different inexpensive rubbers

2. Simplification of the layer structure by minimizing the collectors (electrode)- tire body as electrode

2. In detail electrical properties like- charging a capacitor, internal resistance, drawing current, application the technique to a real sensors etc.

What can we do in future

3. Further optimization of the efficiency of the generator by new elastomeric materials- surface roughness, thickness, stiffness, elasticity etc.

4. Long-time experiment to study the stability of the thin film and nanostructured surfaces

5. Understanding the low frequency power generation and using rain, wind and human movement as mechanical source

6. Setting up a proper measuring device to study more precisely.

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Acknowledgment

- The work is financially supported by The Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) project ID 330167 – SPP 2100
- The speaker also acknowledges the Continental Tires for partial financial assistance of this project

Thank you for your attention

Open to questions / discussion