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ELECTRO INTRUSION

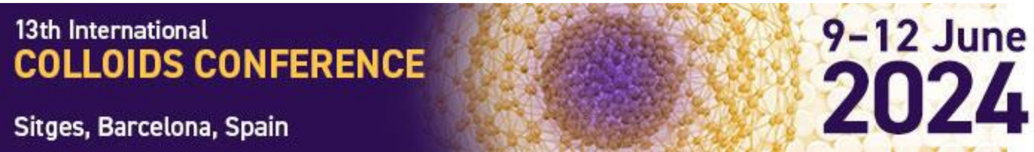
Contact electrification during water intrusion-extrusion into-from nanopores for self-powered pressure/temperature nanosensors and thermomechanical energy harvesting

LUIS BARTOLOMÉ

13th Colloids Conference

11th June 2024, *Sitges (Spain)*

This project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017858



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2. **Monolith configuration**
3. **Nanoporous silica configuration**
4. **Electro-Intrusion project**
5. **Conclusions**

Triboelectric generators

Technology for converting irregular and distributed mechanical energy into electric power by using a conjunction of triboelectrification and electrostatic induction[1].

2012 Prof. WANG Zhong Lin

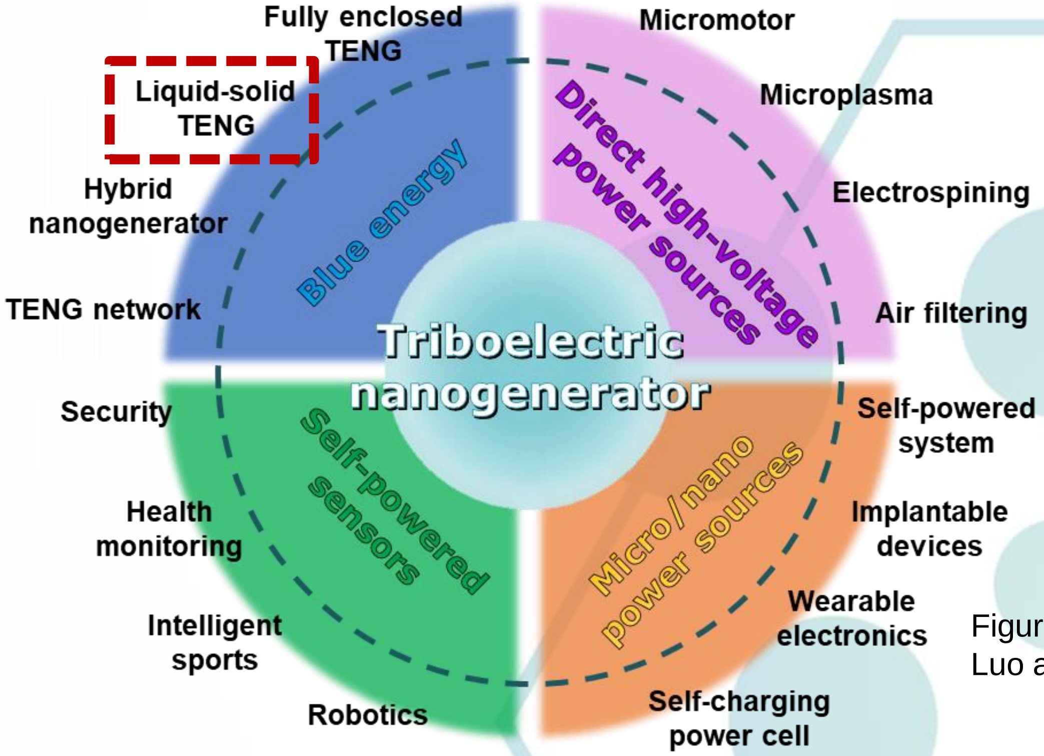
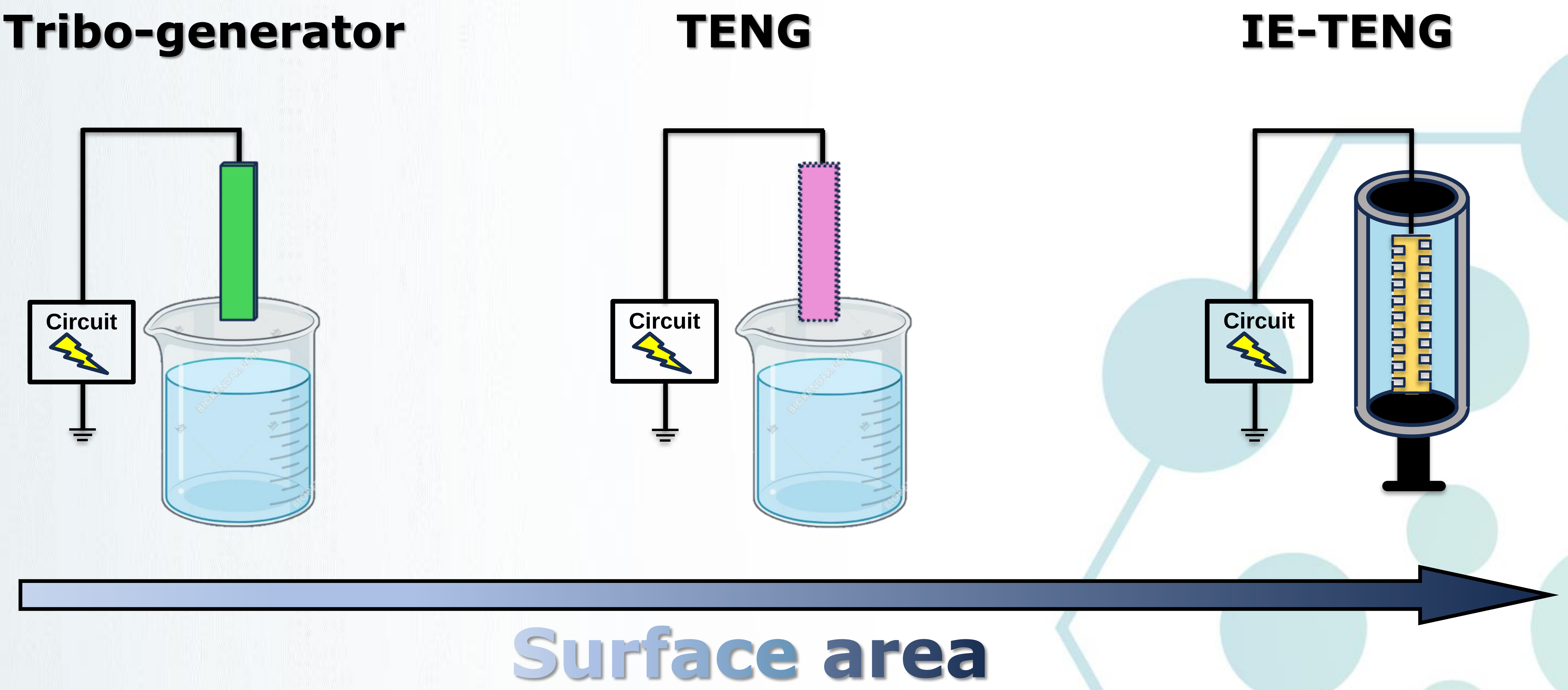


Figure adapted from Luo and Wang, 2020[2]

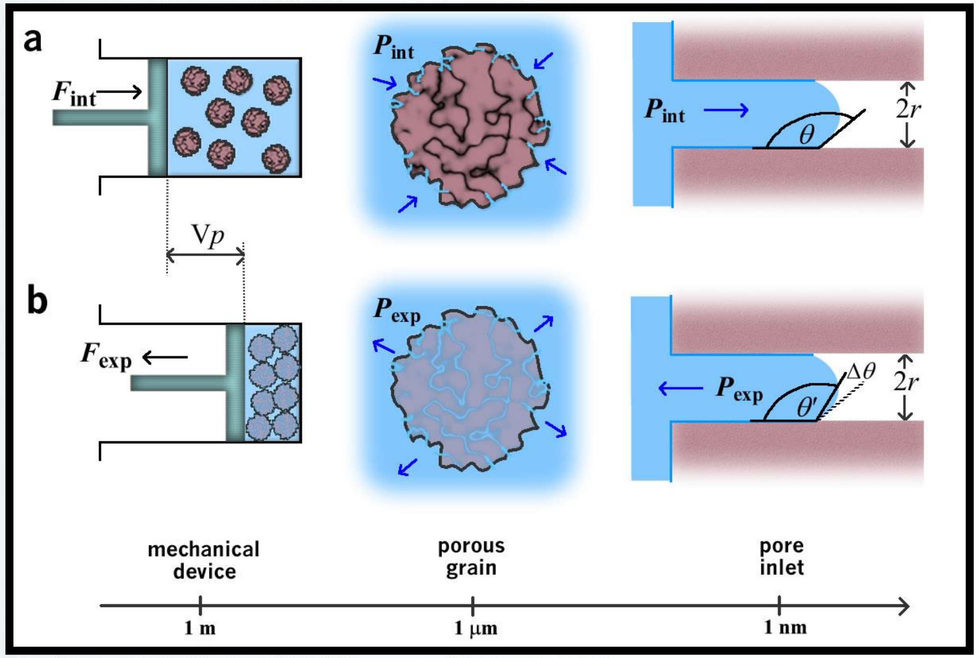
[1] Wang, Z.L., 2021. From contact electrification to triboelectric nanogenerators. *Reports on Progress in Physics*, *84*, p.096502.
[2] Luo, J., Wang, Z.L., 2020. Recent progress of triboelectric nanogenerators: From fundamental theory to practical applications. *EcoMat*, 2(4).

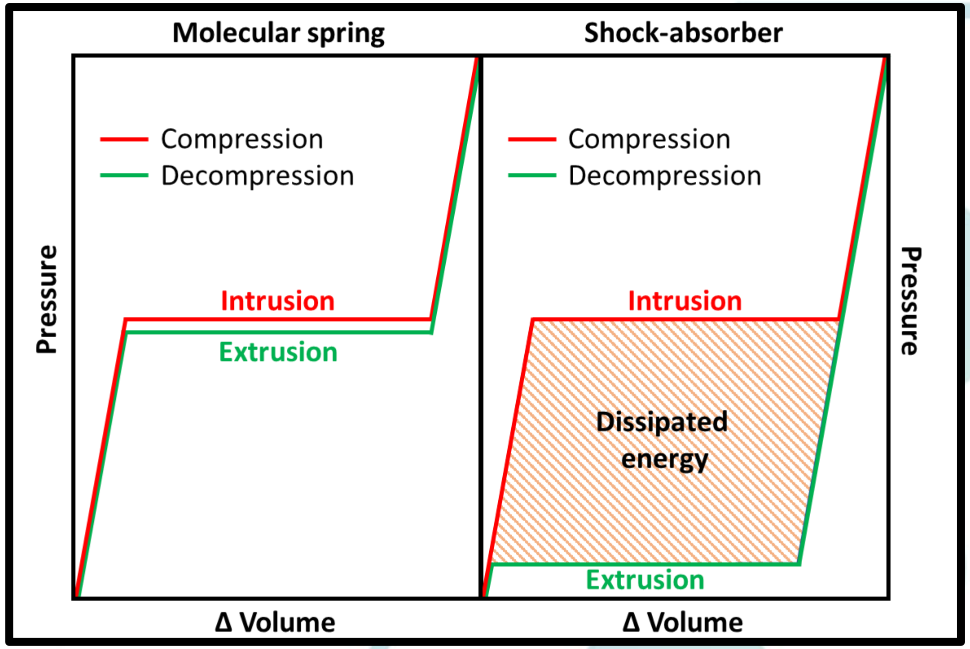
Strategy



Tribo-generator
TENG
IE-TENG
Circuit
Circuit
Circuit
Surface area

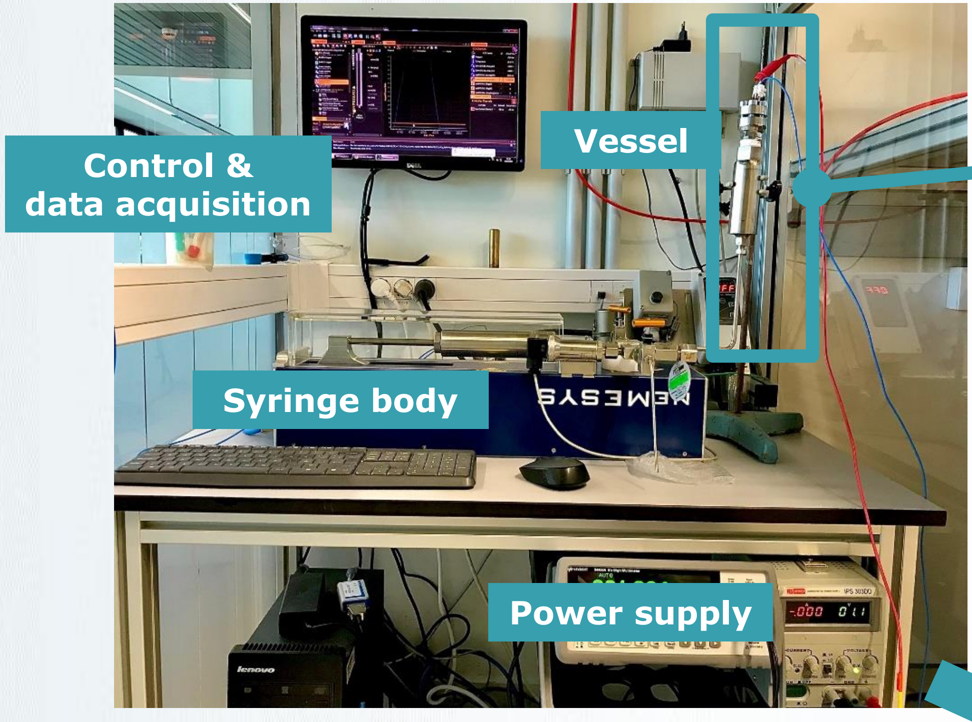
Intrusion–extrusion process



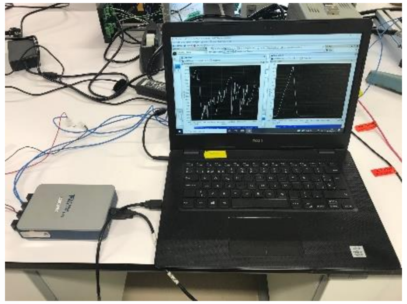


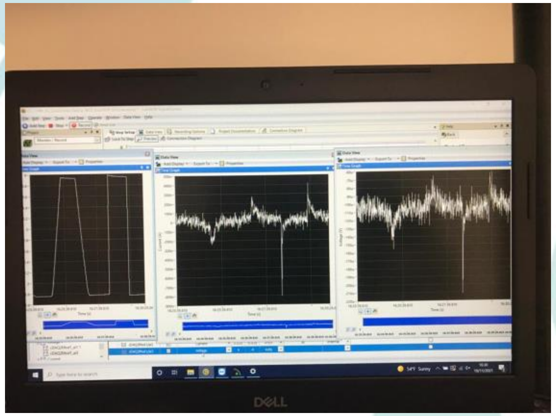
1. Introduction

High-pressure electrification setup



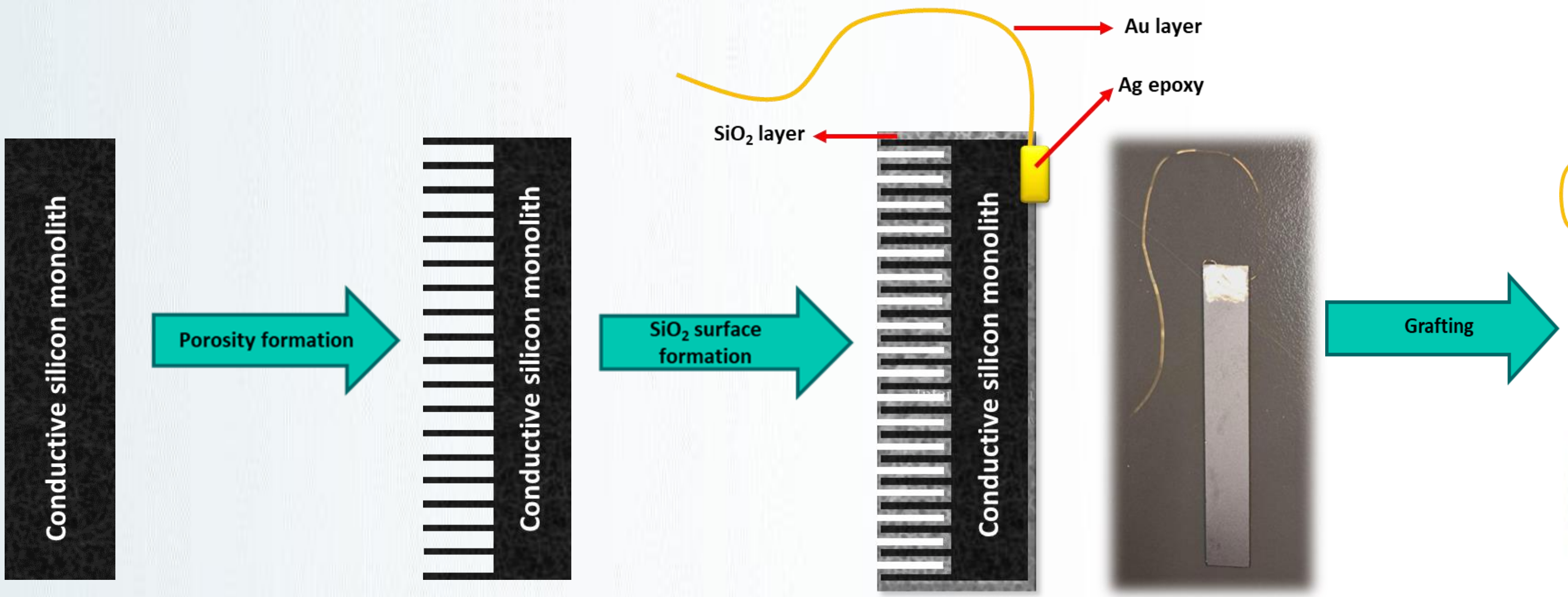
ADC & laptop





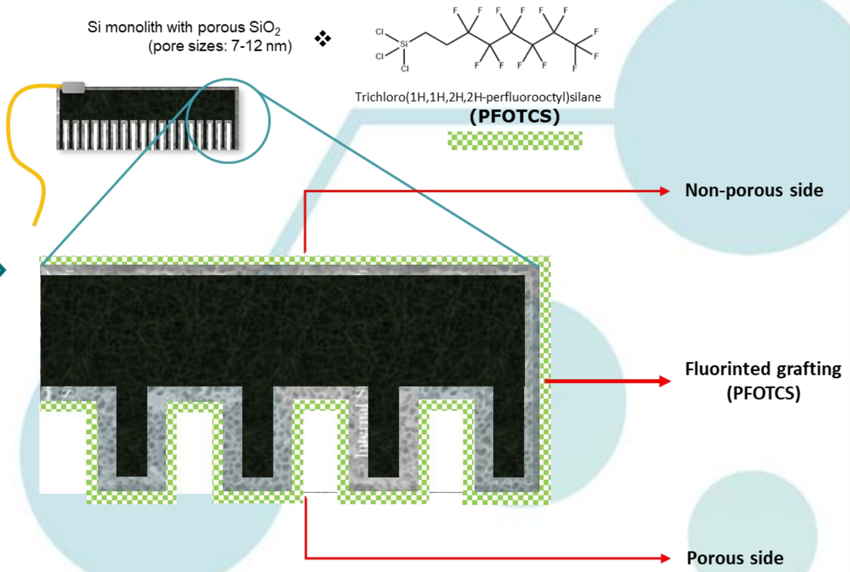
2. Monolith configuration

Silicon monolith preparation



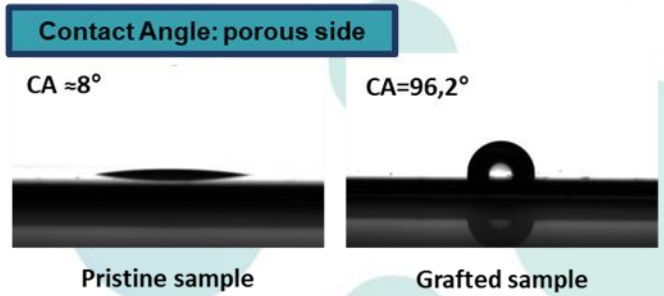
Porosity formation applying electric current

Formation of SiO_2 external layer

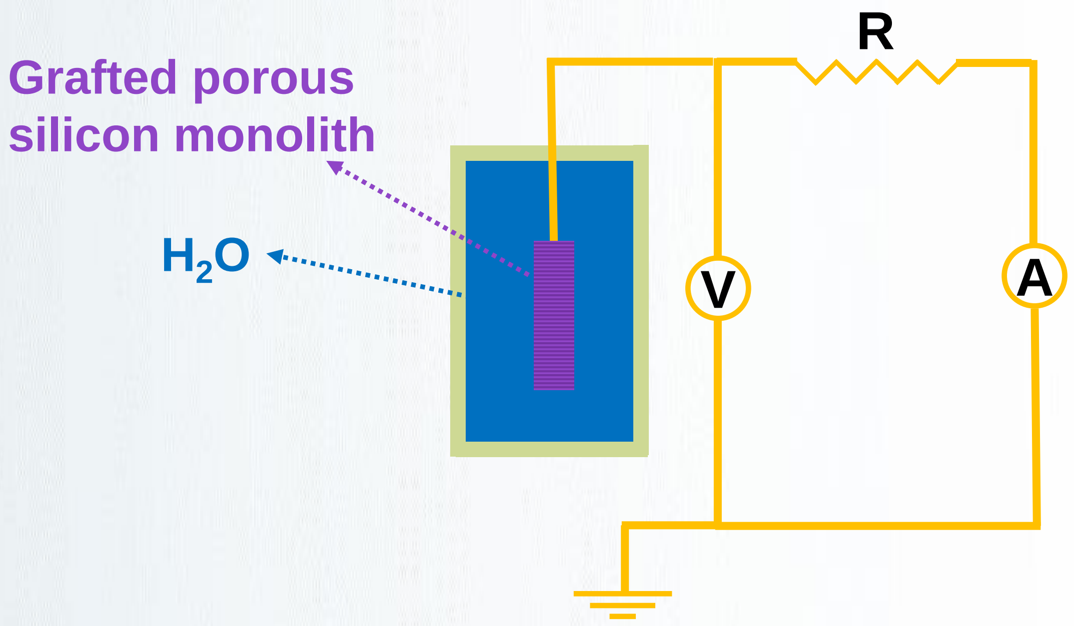


TUHH Patrick Huber's group

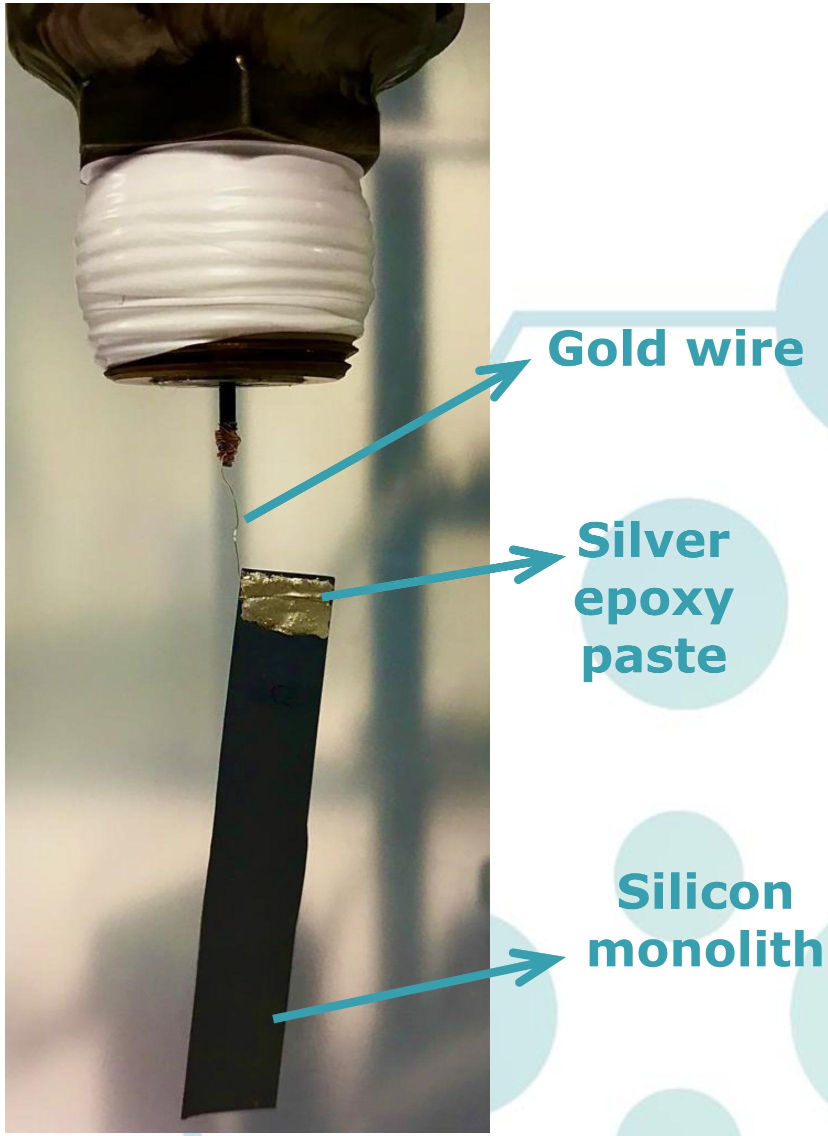
Hydrophobization



Silicon monolith configuration

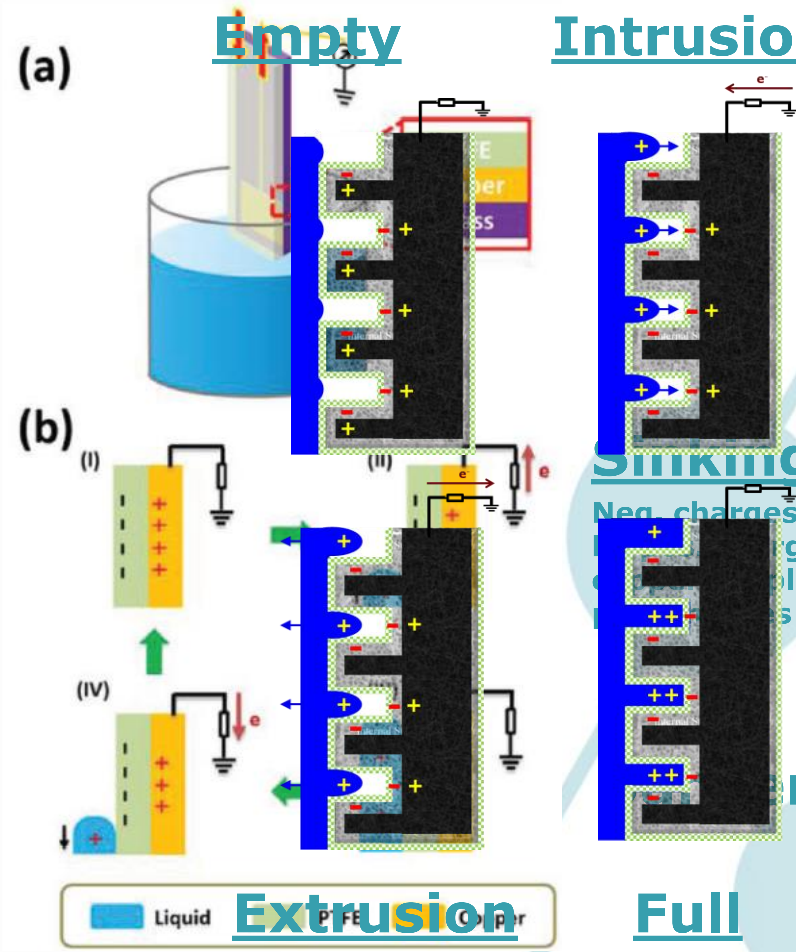


Compression/decompression tests



2. Monolith configuration

Monolith intrusion–extrusion triboelectrification principle



Empty

Intrusion

Sinking into water

Neg. charges of PTFE are compensated ... ges from water. Then the ... lies e⁻ to compensate the ... s on PTFE

Air

Lift from water

Neg. charges of PTFE are released by removing of pos. charges from water. Then e⁻ leave the copper

...en into water

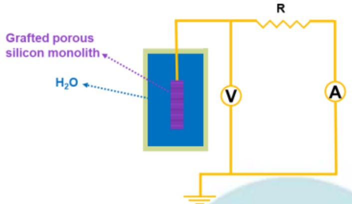
Extrusion

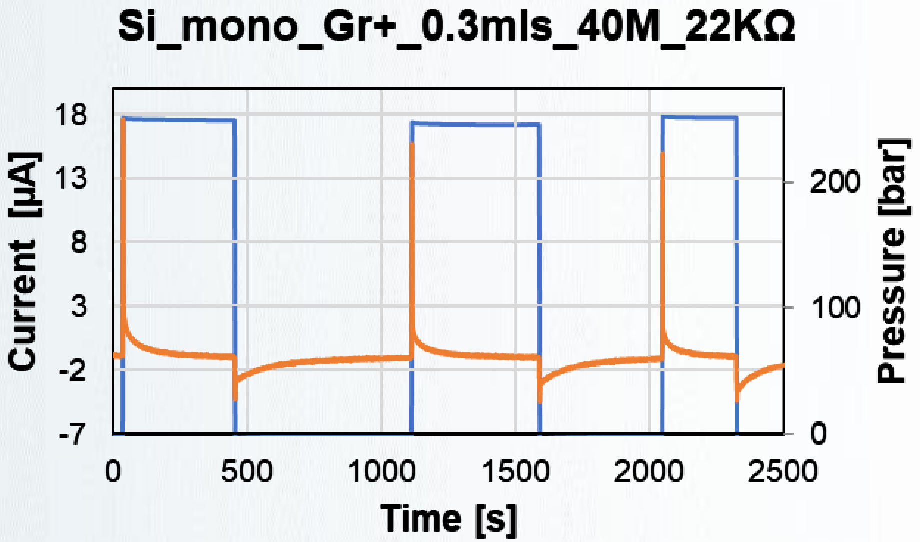
Full

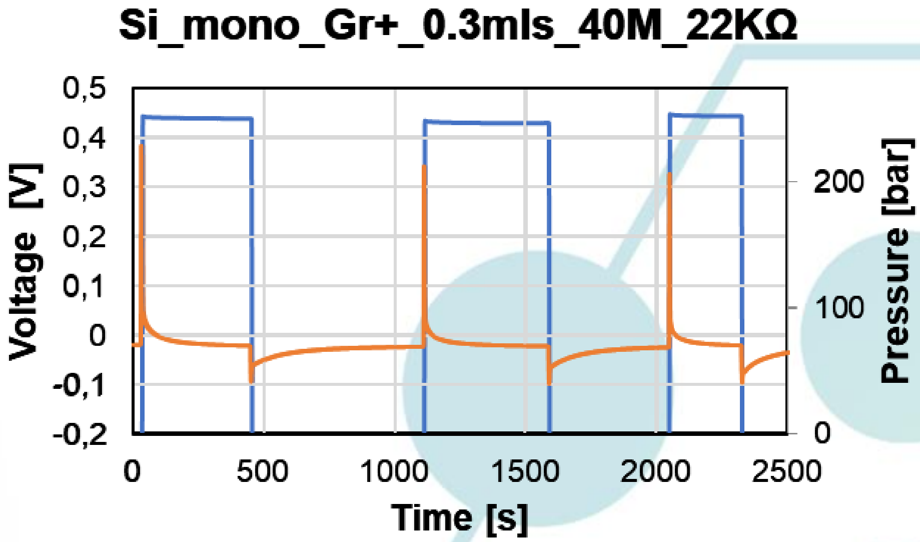
Jiang, P., Zhang, L., Guo, H., Chen, C., Wu, C., Zhang, S. and Wang, Z.L., 2019. Signal output of triboelectric nanogenerator at oil–water–solid multiphase interfaces and its application for dual-signal chemical sensing. *Advanced Materials*, *31*(39), p.1902793.

2. Monolith configuration

Si-monolith: current and voltage results

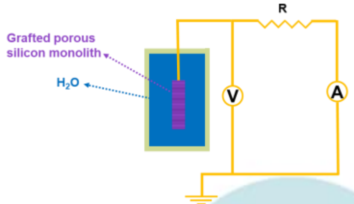


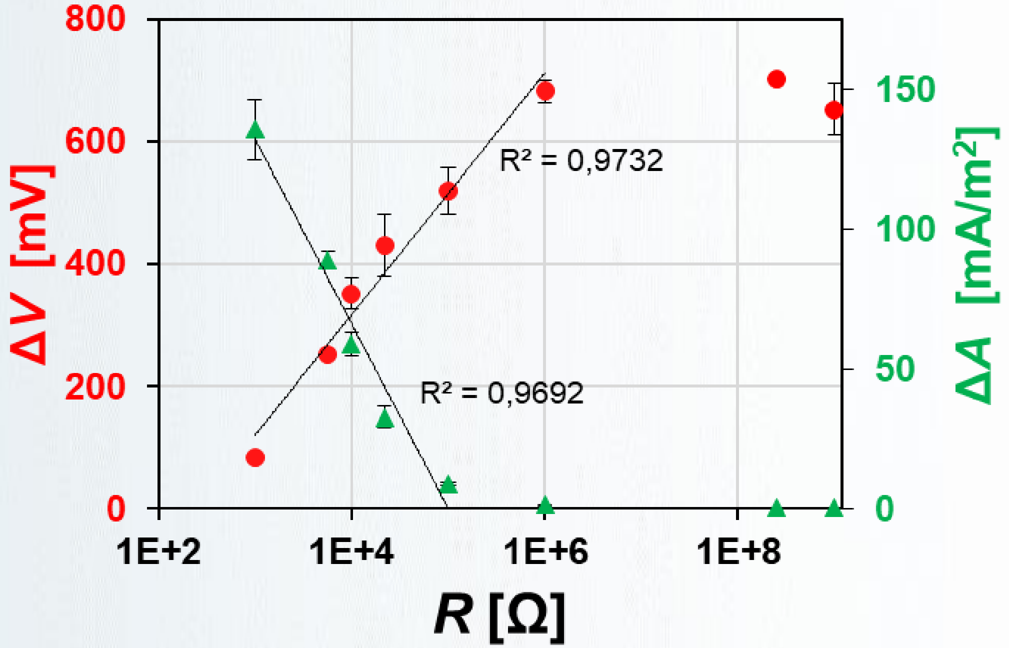


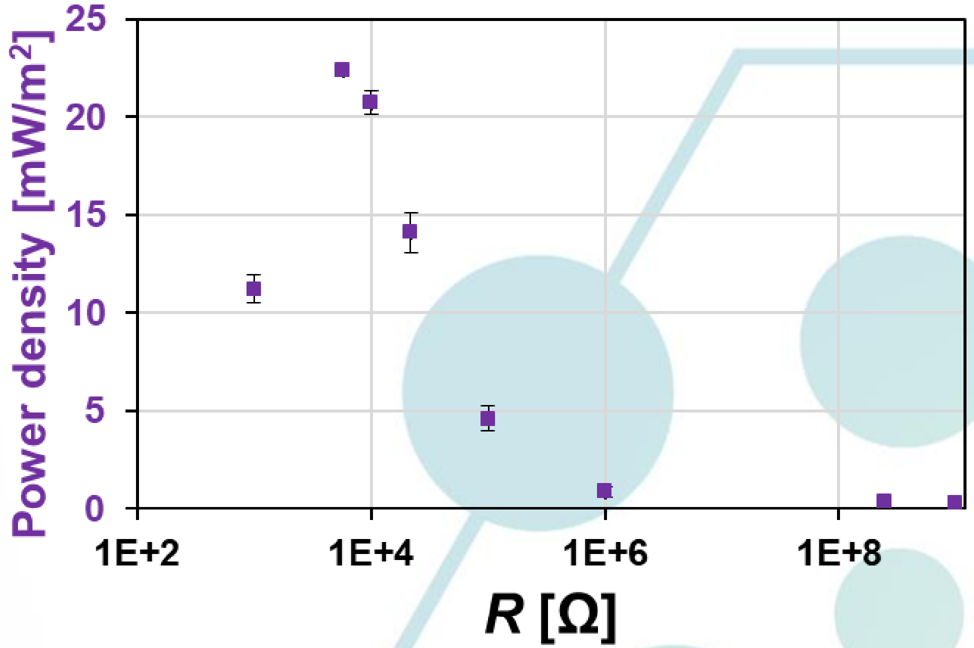


2. Monolith configuration

Si-monolith: peak amplitudes & power density



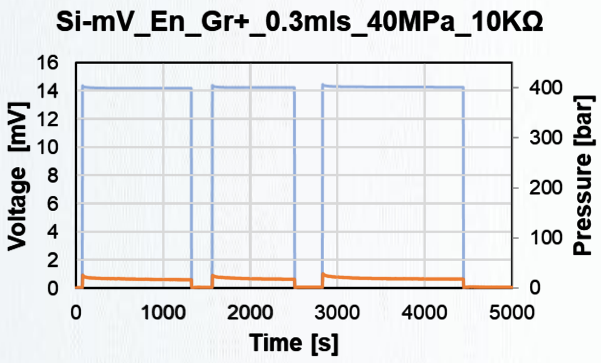


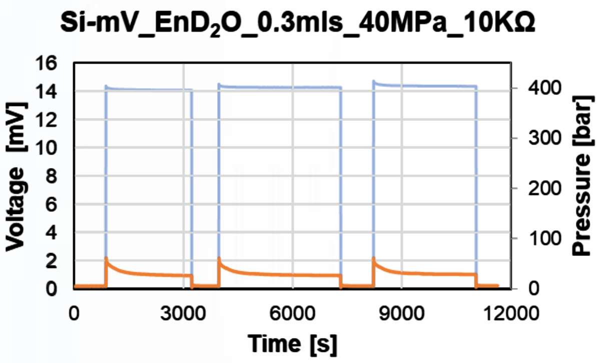


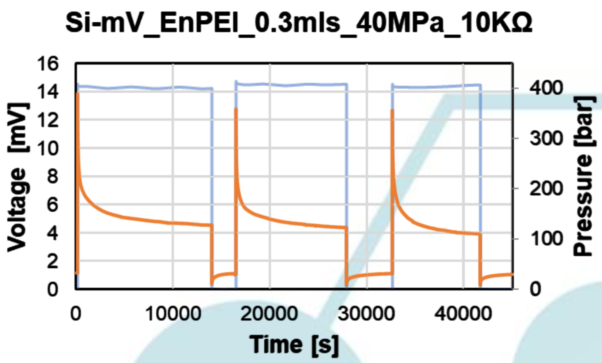
Maximum power density at ~10 KΩ (optimal load)

2. Monolith configuration

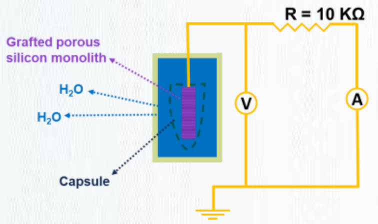
Si-monolith: different liquids



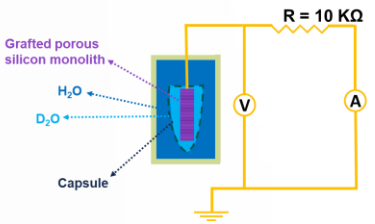




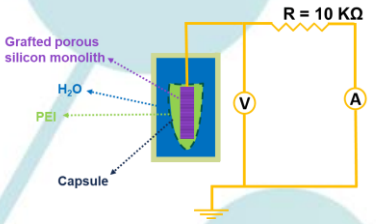
H_2O



D_2O



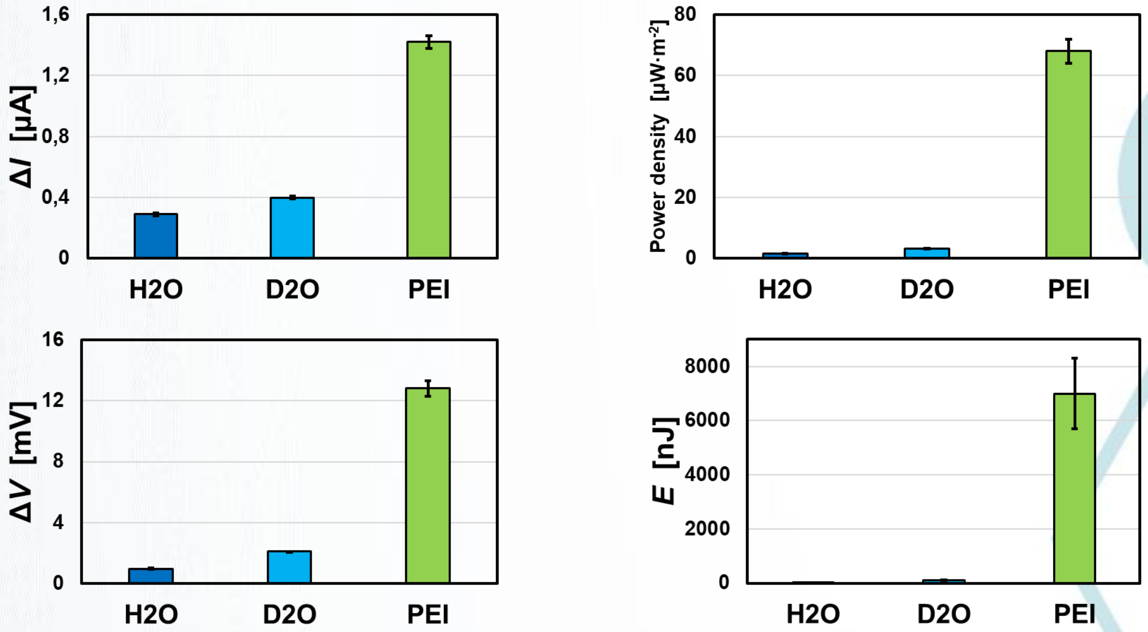
PEI



2. Monolith configuration

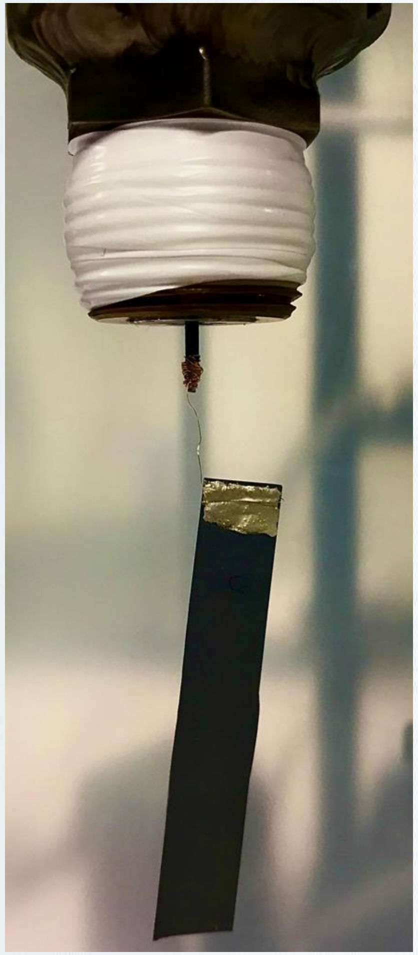
Si-monolith: different liquids

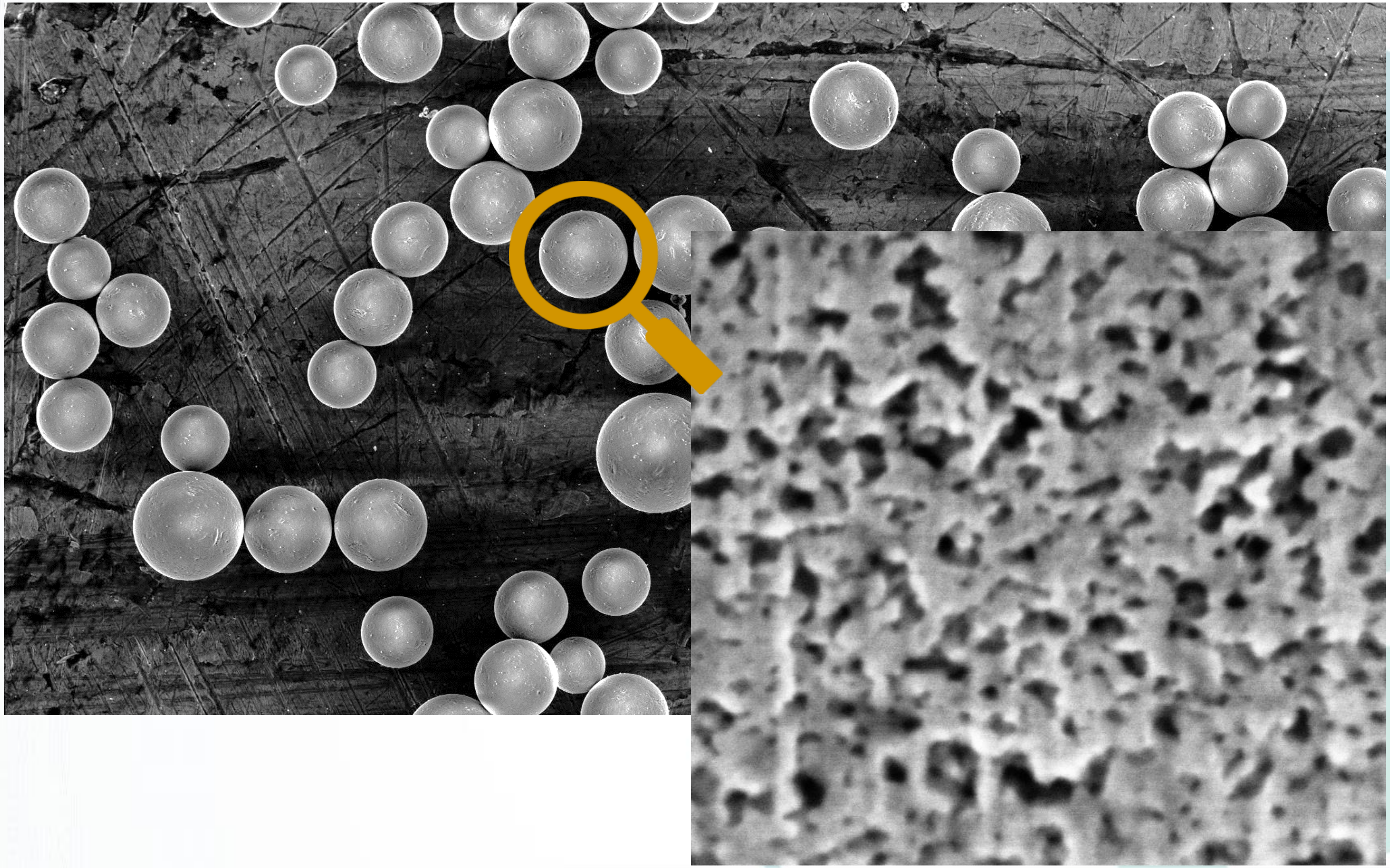
	H_2O	D_2O	PEI
ΔI [μA]	0.29±0.01	0.40±0.01	1.42±0.04
ΔV [mV]	0.96±0.05	2.1±0.01	12.8±0.5
Power density [$\mu W \cdot m^{-2}$]	1.6±0.08	3.18±0.08	68±4
E_1 [nJ]	17±5	110±5	7000±1300



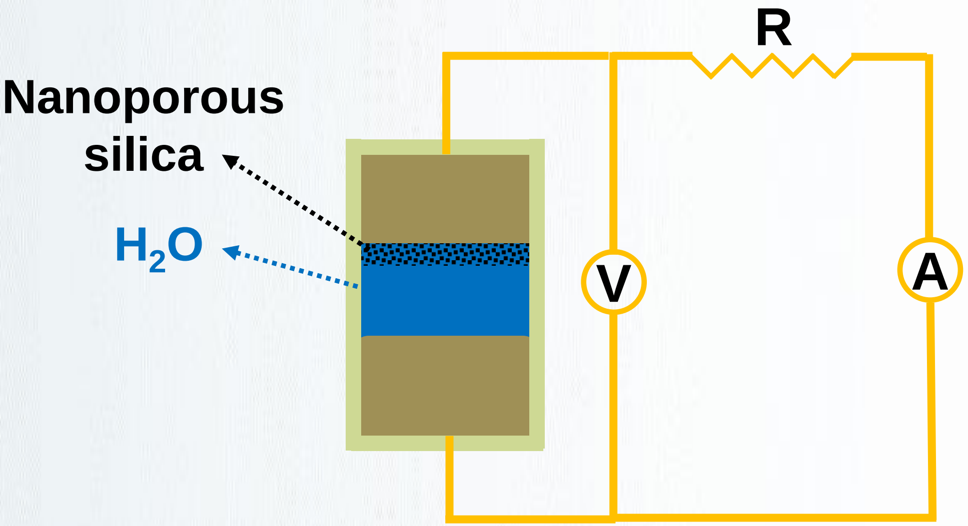
Electric output:
H_2O < D_2O < PEI

Si-monolith: challenge low intrusion volume





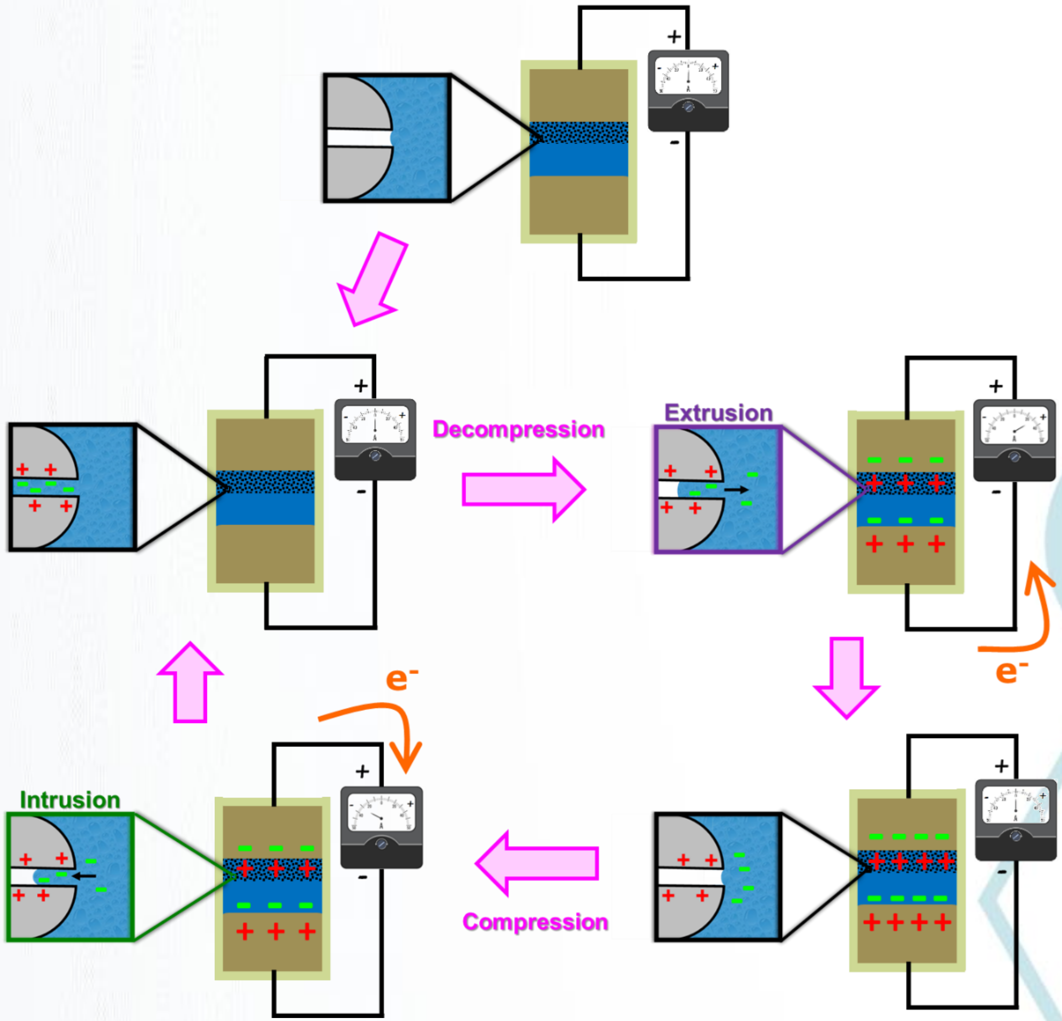
Passive configuration: powder silica



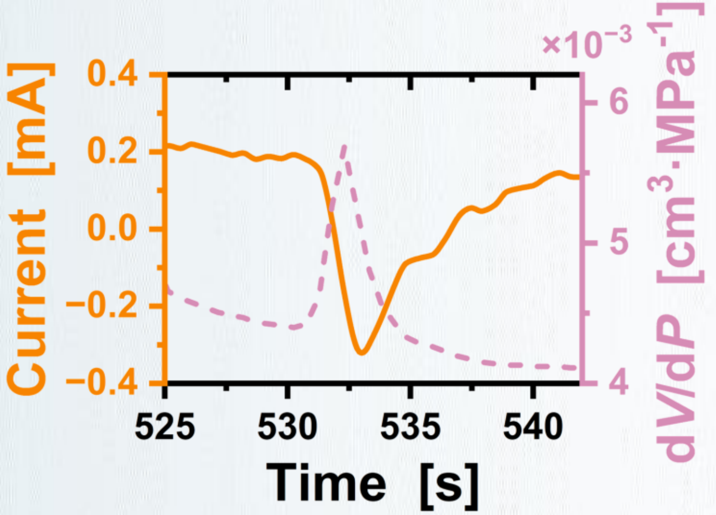
Compression/decompression tests

3. Nanoporous silica configuration

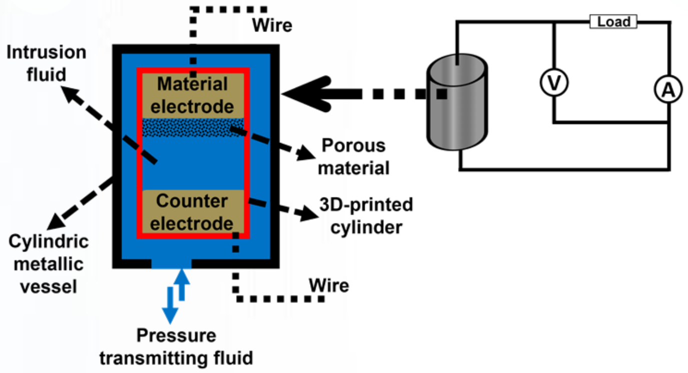
Passive conf.: intrusion-extrusion triboelectrification principle

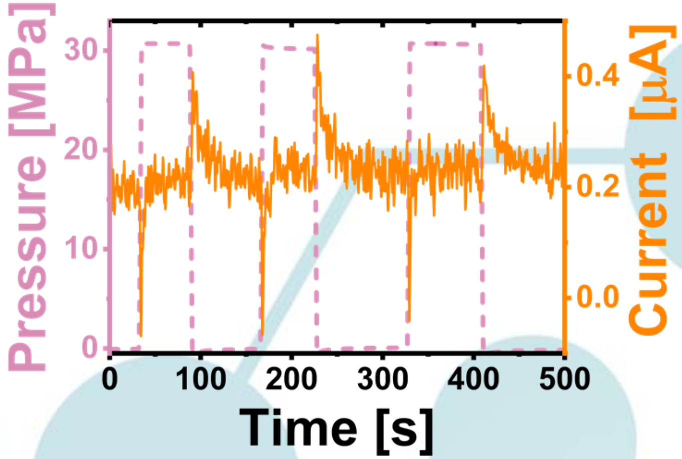


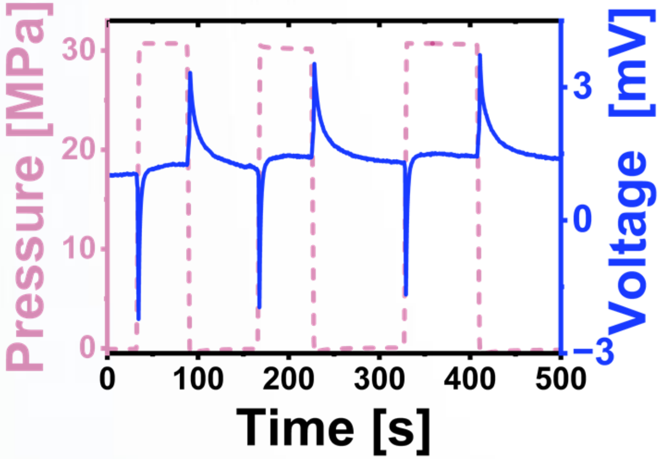
Passive conf.: powder silica triboelectrification results

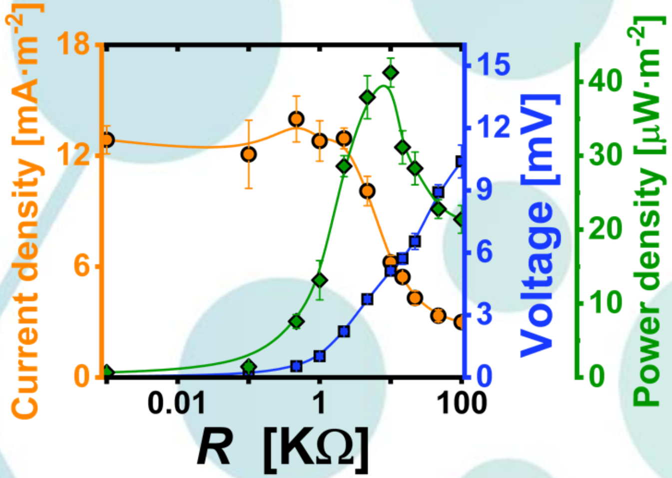


Intrusion and triboelectrification at the same time

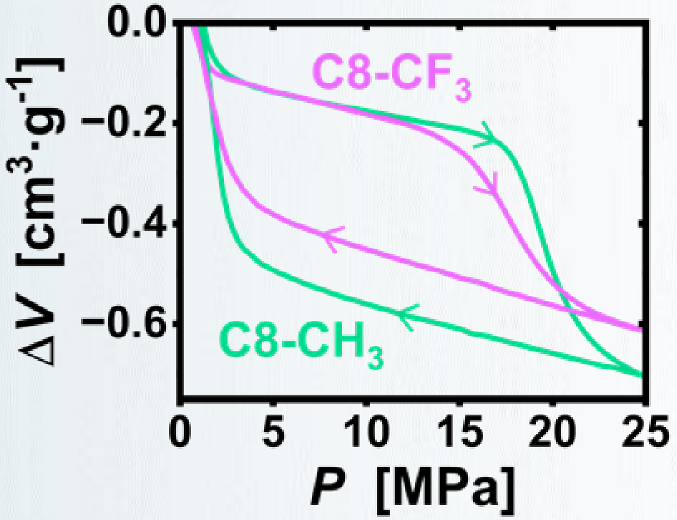


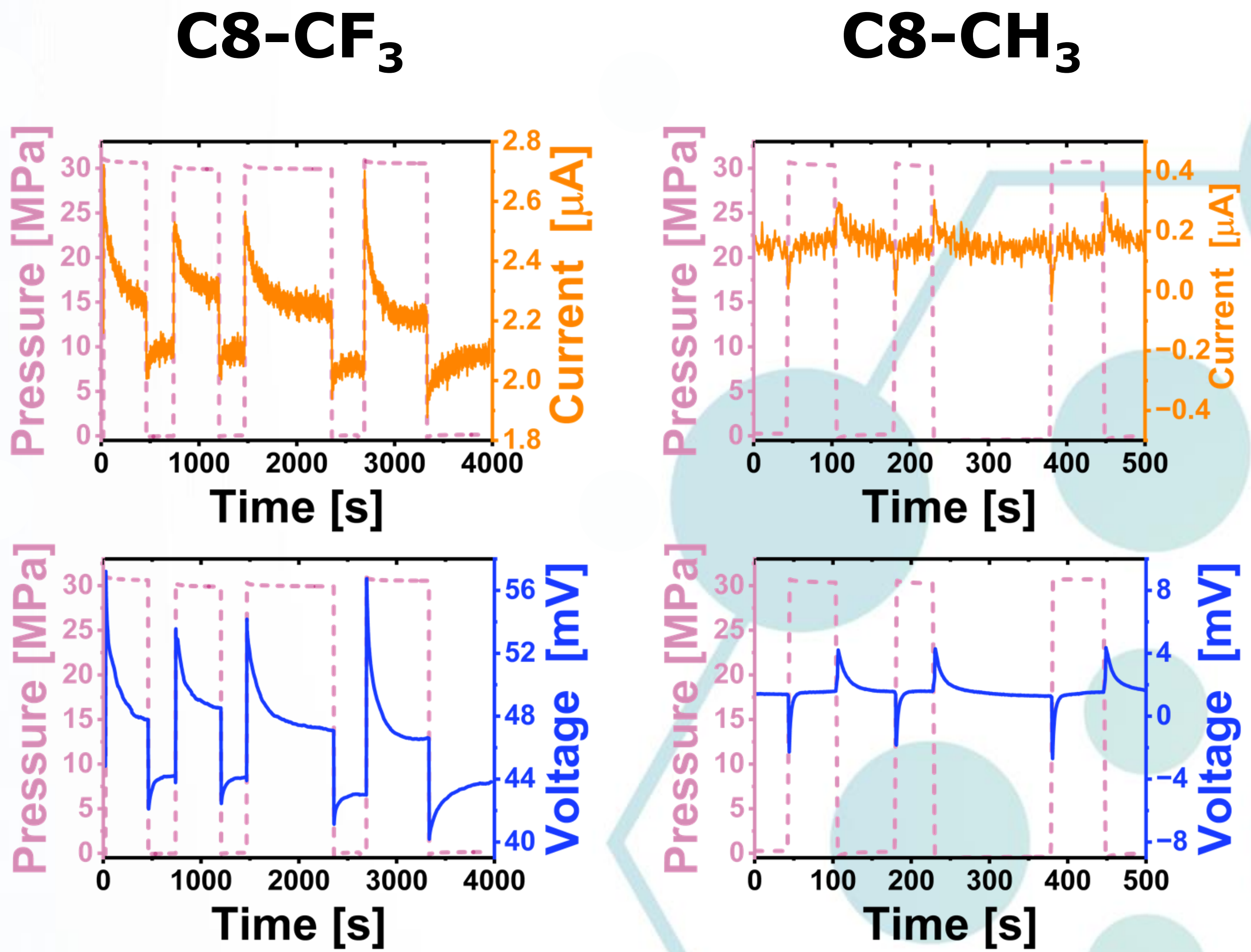






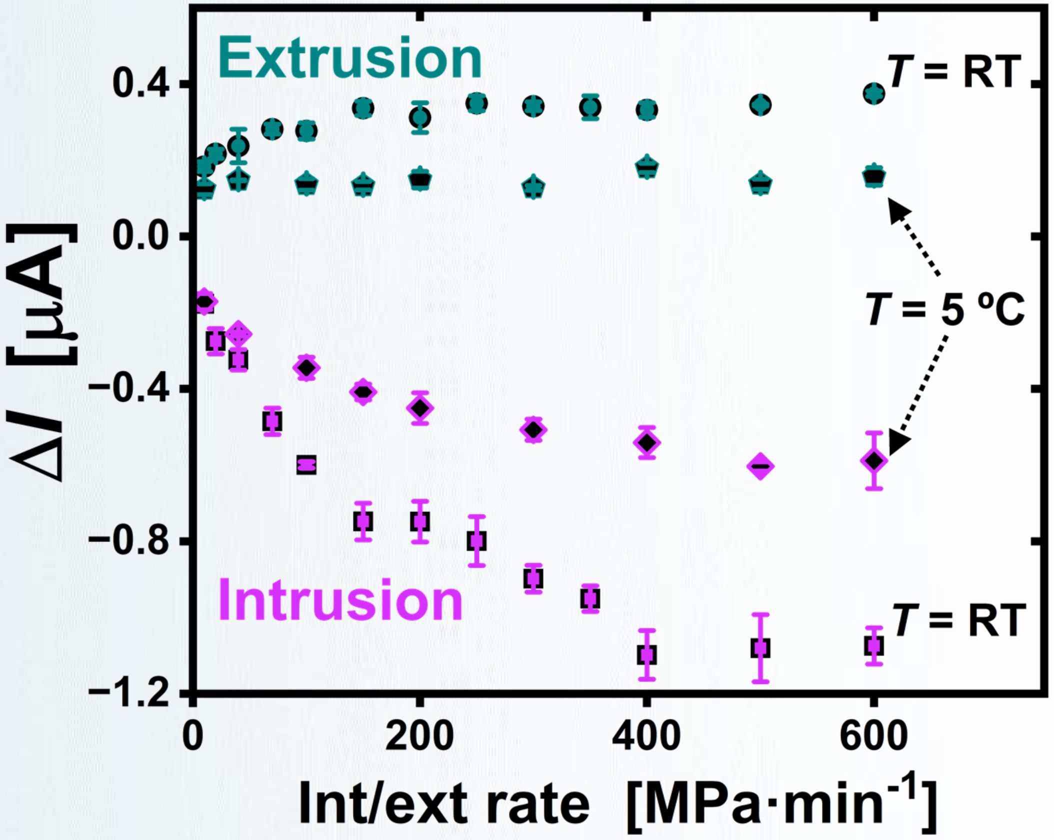
Passive configuration: effect of grafting on triboelectrification

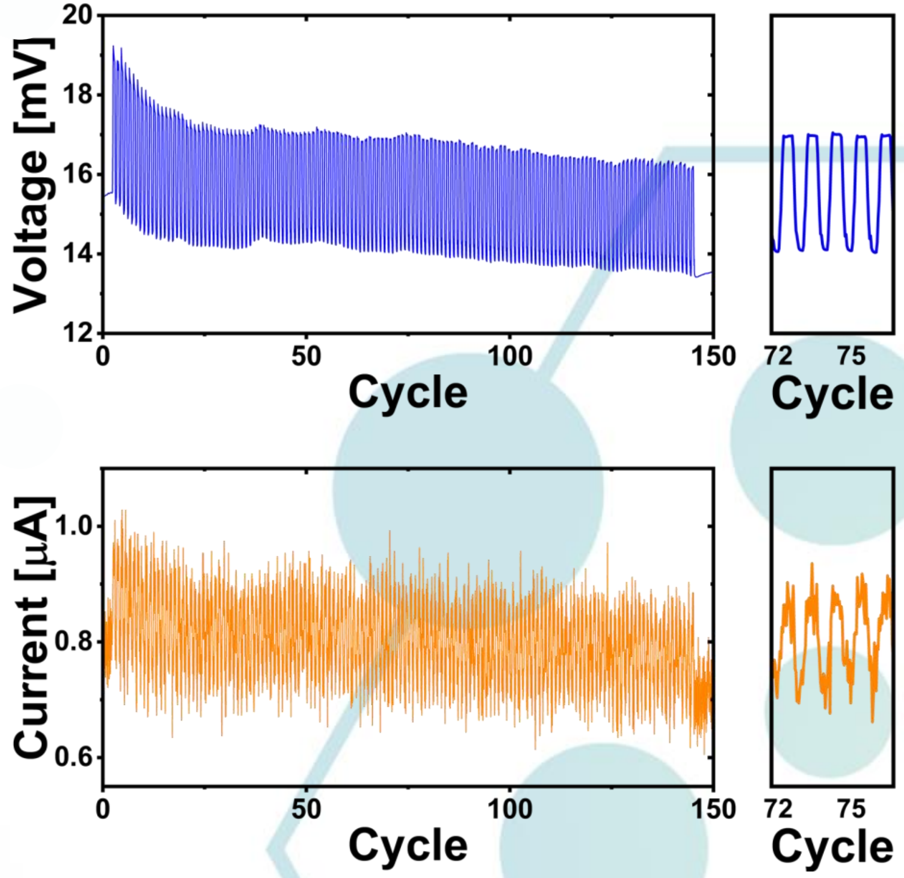




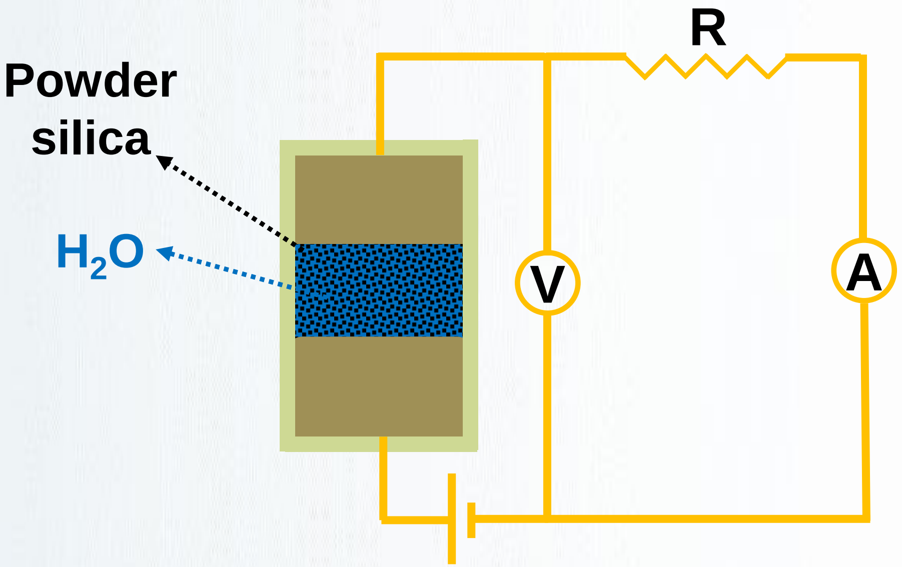
3. Nanoporous silica configuration

Passive configuration: effect of speed and temperature





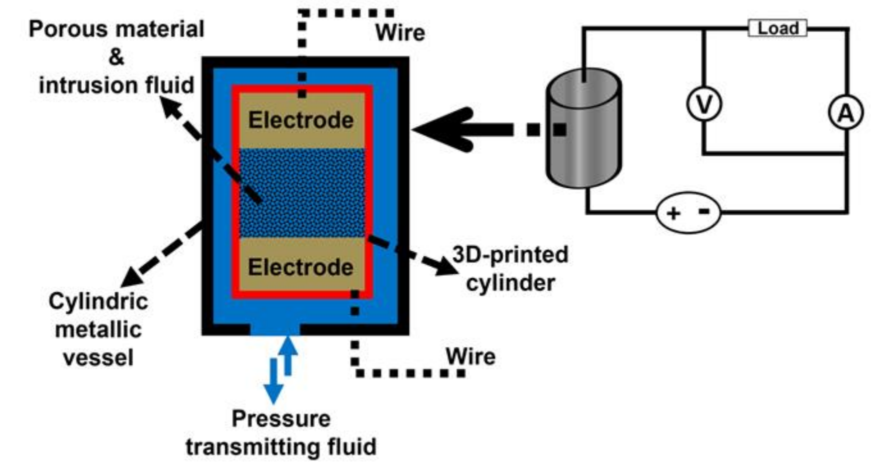
Active configuration: powder silica

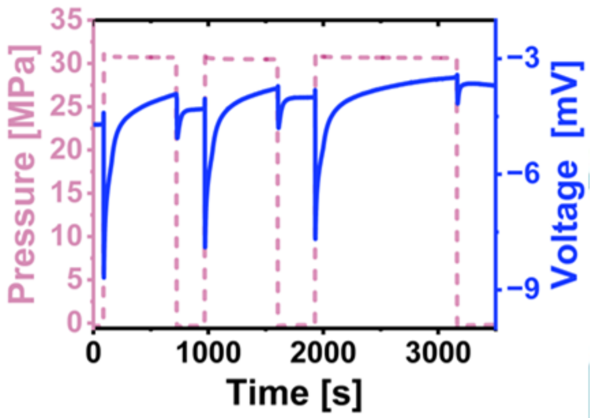


Compression/decompression tests

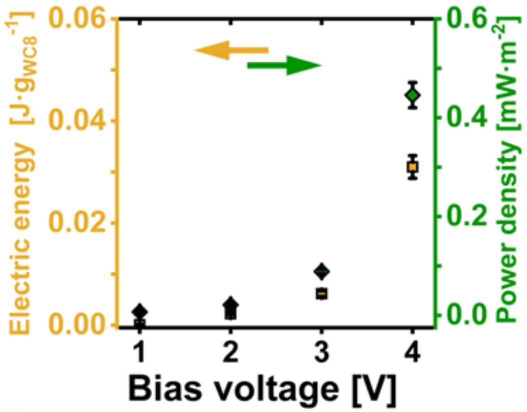
3. Nanoporous silica configuration

Active conf.: powder silica triboelectrification results

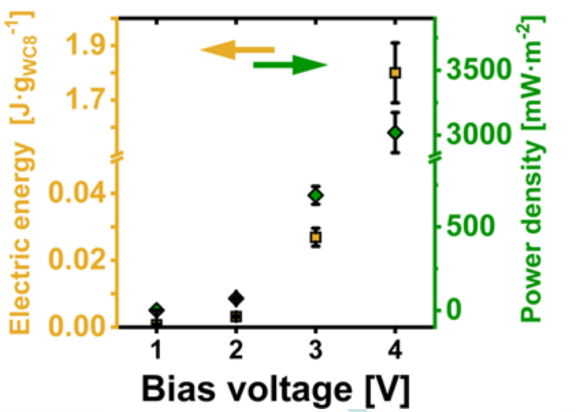




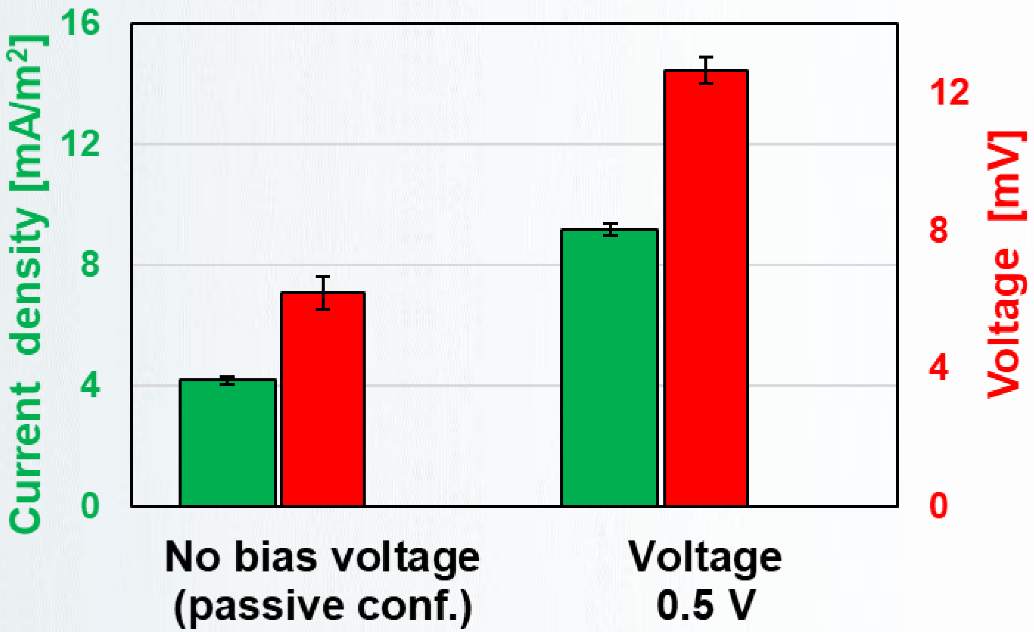
5.2mm

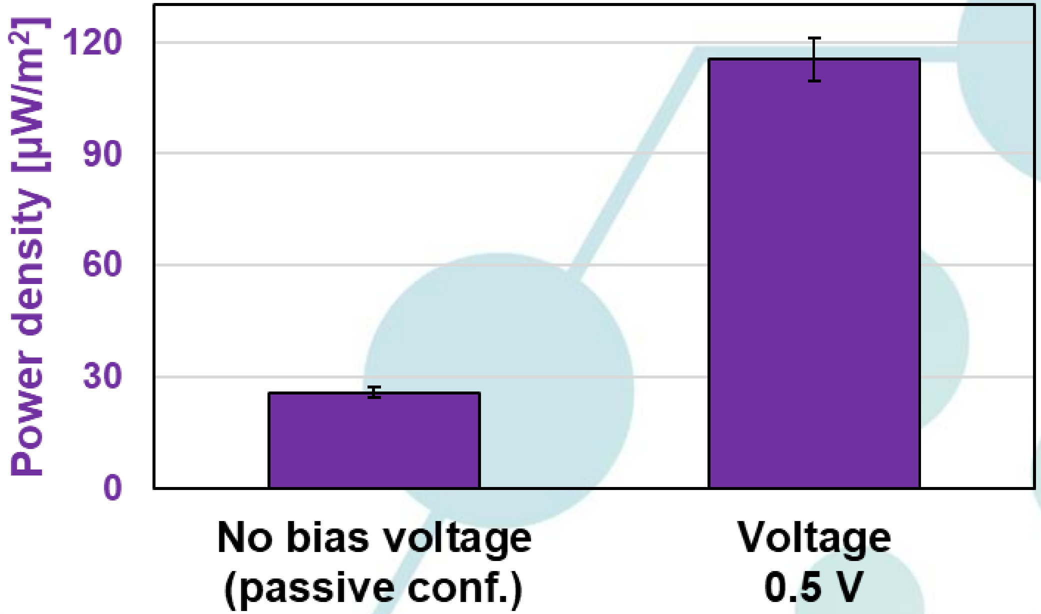


1.77 mm



Powder silica: passive *vs*. active configurations

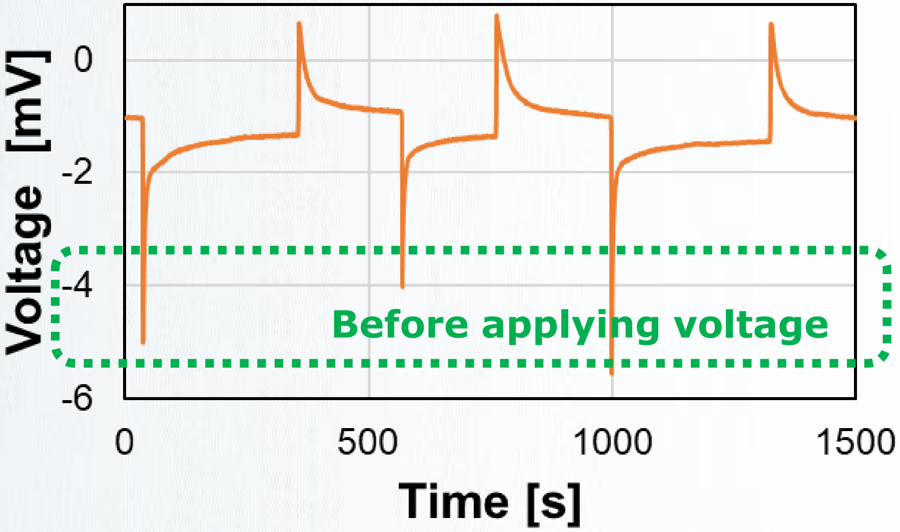


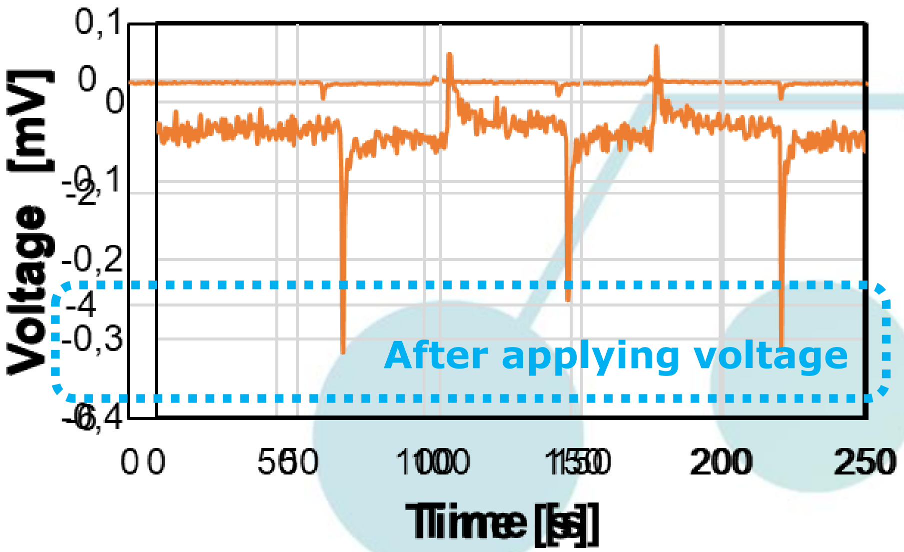


The power density increases 4 times

3. Nanoporous silica configuration

Active configuration: silica stability





Degradation: peak amplitudes one order of magnitude lower

Figure of merit comparison

Power density [μW/m²]	Voltage [V]	Frequency [Hz]	FOM[a] [(10³·μW)/mm²·Hz·V²]	Type	Reference
924	8	250	$5.8\cdot10^{-5}$	Electrostatic	Basset et al [a]
$100\cdot10^{6}$	60	2	13.9	Electrowetting	Krupenkin et al.[b]
$100\cdot10^{6}$	4.5	300	16.5	Electrowetting	Hsu et al.[c]
960	1.2	6	0.1	Electrowetting	Huynh et al.[d]
$110\cdot10^{6}$	24	3	63.4	Electrowetting	Yang et al.[e]
$38.2\cdot10^{6}$	6	4	265.27	NTE	Liu et al [f]
533	0.01	3	1776.7	Electrowetting	Adhikari et al. [g]
30	0	10	∞	Electrowetting	Kim et al.[h]
$3\cdot10^{6}$	**4**	**Quasistatic**	**35456**	**NTE**	**Our project[1]**
38	**0**	**Quasistatic**	**∞**	**NTE**	**Our project[2]**
115	**0.5**	**Quasistatic**	**260.4**	**NTE**	

$$^{[a]}\mathbf{FOM} = \frac{P}{f \cdot V_b^2 \cdot A}$$

P – power
f – frequency
V_b – bias voltage
A – electrode area

(1) Double-electrode: WC8 touching both electrodes
(2) Double-electrode: WC8 touching one electrode

[a] Basset, P., Galayko, D., Paracha, F.M., Marty, F., Dudka, A. & Bourouina, T. A batch-fabricated an electret-free silicon electrostatic vibration energy harvester. *J. Micromech. Microeng*. 19, 115025 (2009)
[b] Krupenkin, T. & Taylor, J. A. Reverse electrowetting as a new approach to high-power energy harvesting. *Nat. Commun*. 2, 1–8 (2011)
[c] Hsu, T. H., Manakasettharn, S., Taylor, J. A. & Krupenkin, T. Bubbler: a novel ultra-high-power density energy harvesting method based on reverse electrowetting. *Sci. Rep*. 5, 16537 (2015)
[d] Huynh, D.Het al. Environmentally friendly power generator based on moving liquid dielectric and double layer effect. *Sci. Rep.* 6, 1–10 (2016)
[e] Yang, H., Hong, S., Koo, B., Lee, D. & Kim, Y. B. High-performance reverse electrowetting energy harvesting using atomic-layer-deposited dielectric film. *Nano Energy* 31, 450–455 (2017)
[f] Liu, W., Wang, Z., Wang, G., Liu, G., Chen, J., Pu, X., Xi, Y., Wang, X., Guo, H., Hu, C. & Wang, Z.L. Integrated charge excitation triboelectric nanogenerator. *Nat Commun*. 10, 1-9 (2019)
[g] Adhikari, P.R., Tasneem, N.T., Reid, R.C. & Mahbub, I. Electrode and electrolyte configurations for low frequency motion energy harvesting based on reverse electrowetting. *Sci. Rep.* 11, 5030 (2021)
[h] Kim et al. Energy harvesting performance of an EDLC power generator based on pure water and glycerol mixture: analytical modeling and experimental validation. *Sci Rep* 11, 23426 (2021)

4. Electro-Intrusion project

13th International
COLLOIDS CONFERENCE
Sitges, Barcelona, Spain

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Consortium of FET Proactive project (Horizon 2020)

www.electro-intrusion.eu

6 Partners:
- **1 R&D Institute**
- **4 Universities**
- **1 Company**

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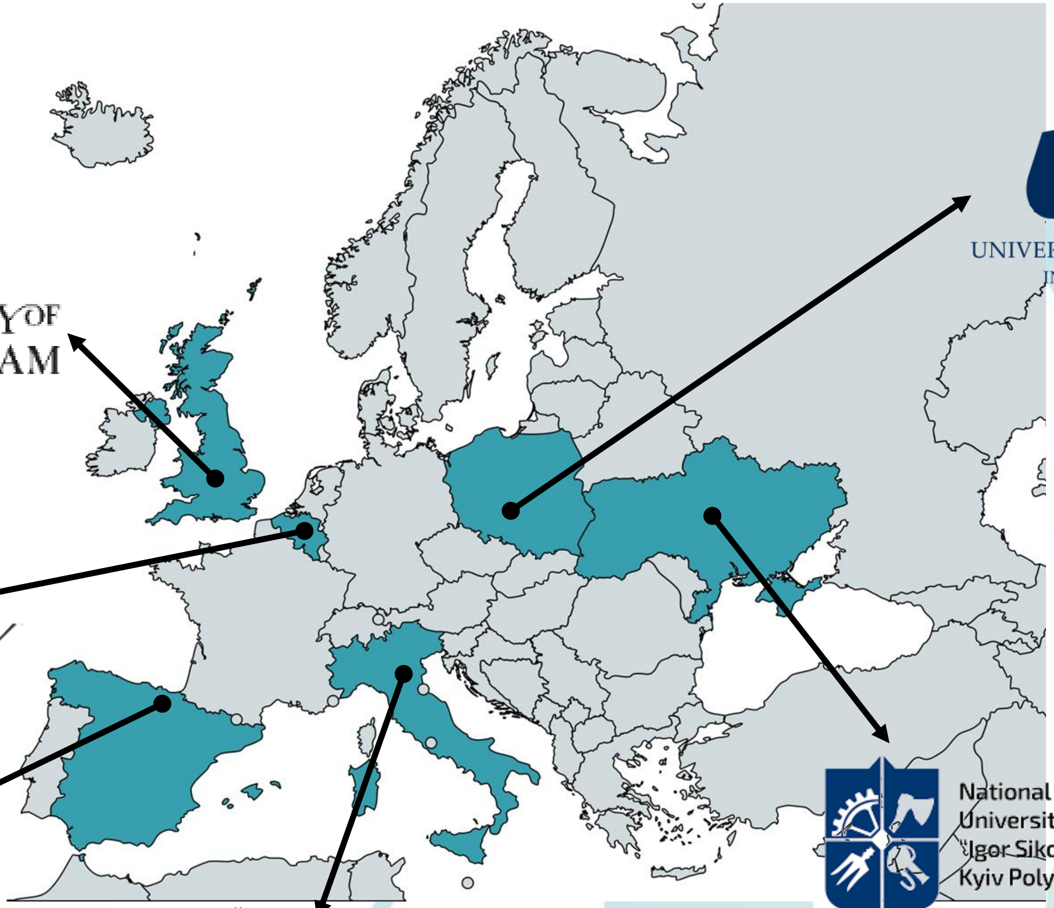

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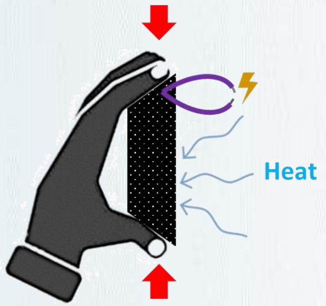
Università degli Studi di Ferrara

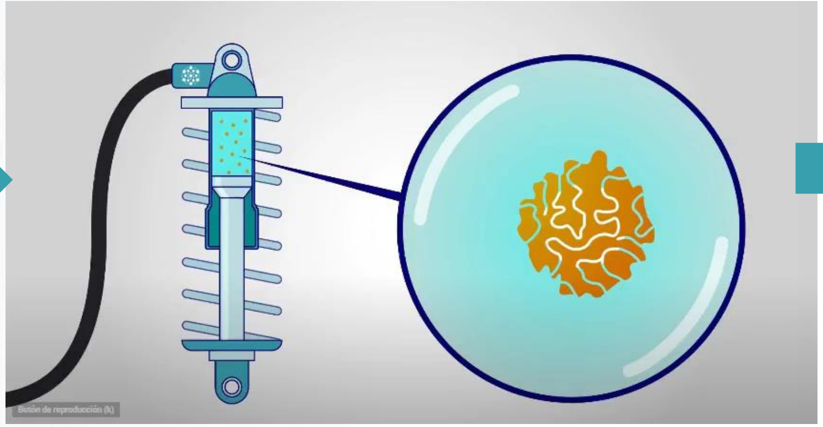
4. Electro-Intrusion project

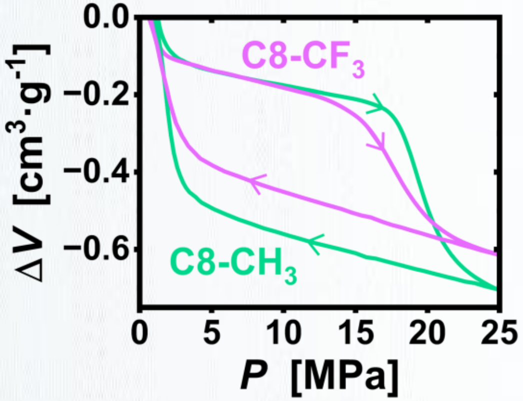
Aims & goals

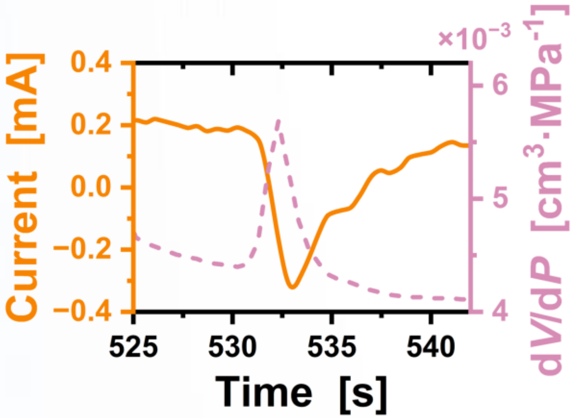
Intrusion-extrusion
Triboelectric generator

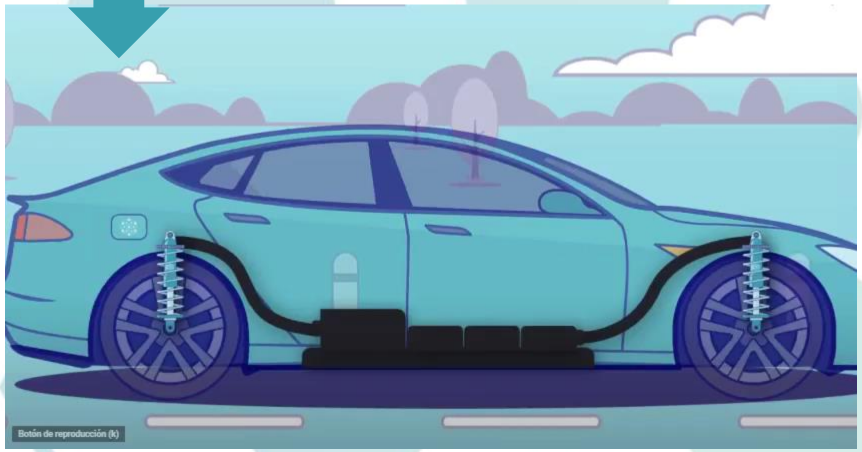


Work
\+ → **Electricity**
ambient Heat



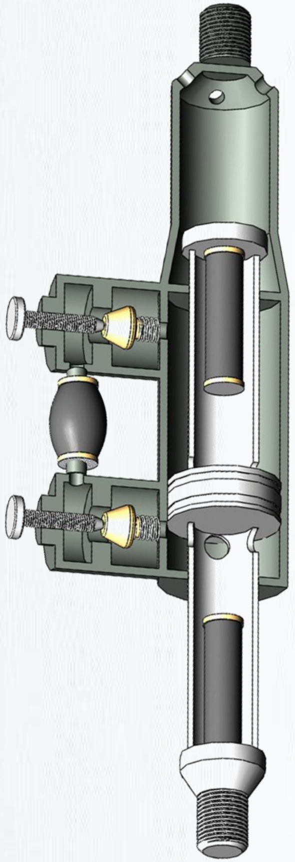






4. Electro-Intrusion project

Car shock-absorber prototype



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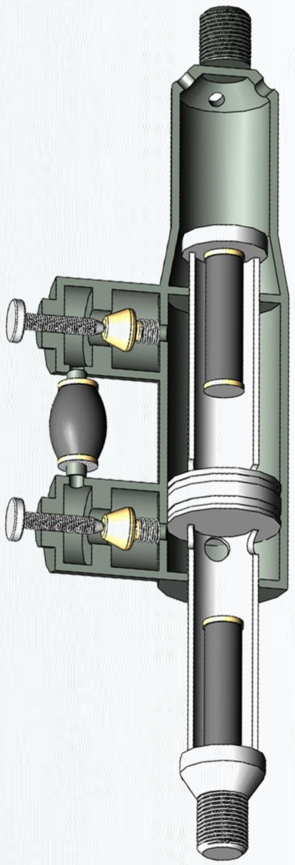
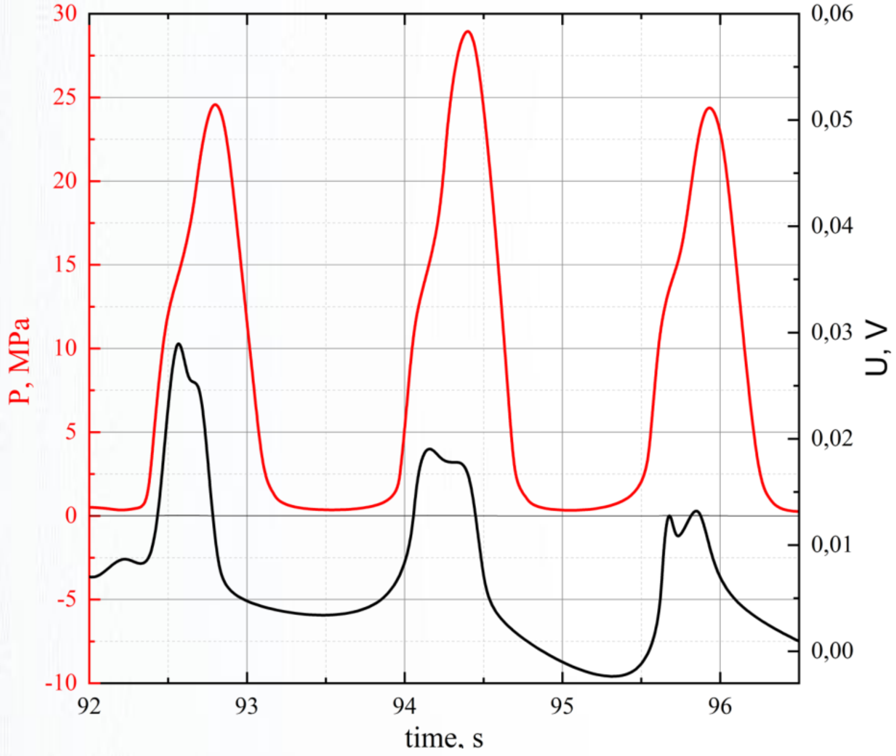
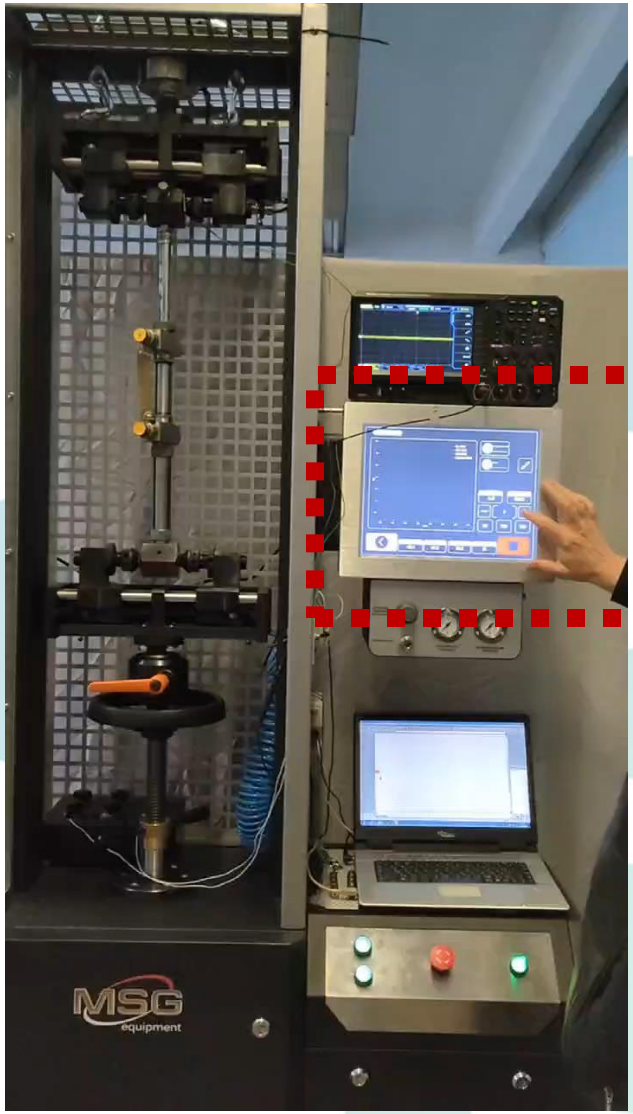
4. Electro-Intrusion project

Car shock-absorber prototype







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5. Conclusions

- Liquid intrusion-extrusion into-from nanopores is accompanied by electrification
- Intrusion-extrusion process allows TENGs with ~1000 m^2/g contact area
- Charge transfer in intrusion-extrusion TENGs is a challenge

Thanks for your attention!

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ELECTRO INTRUSION

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