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3D-PRINTED PIEZOELECTRETS BASED ON FOAMED PLA FOR ENERGY HARVESTING APPLICATIONS

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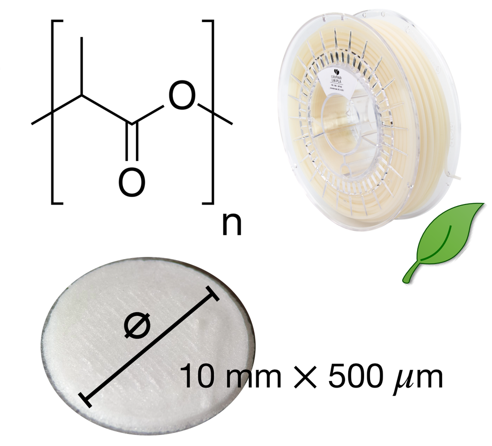
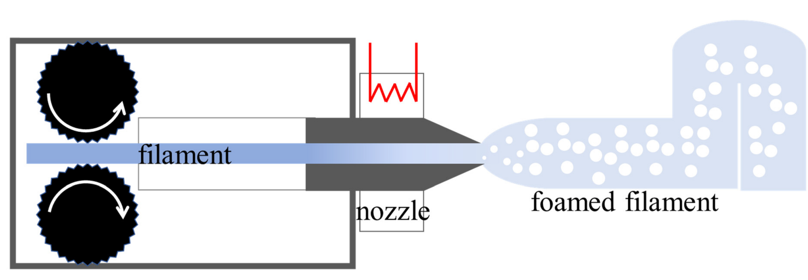
INTRODUCTION: Piezoelectrets are electroactive materials with an electrically charged cellular structure that can convert mechanical energy into electric energy and viceversa. They are mainly based on PP or PET polymers, showing sizable electromechanical and piezoelectric coefficients but they are carbon-based and fabricated from fossil fuels, so they do not comply eco-friendly policies. In this work the material used for the fabrication of the samples is an innovative and biodegradable polylactic acid (PLA) filament that can be foamed during printing due to the expansion of a blowing agent and controlled through the extrusion temperature. Afterwards the samples were polarized in a negative corona charging setup while heating and the surface potential was measured through an electrometer. We investigated the efficacy of the thermal treatment on charging efficiency and temporal stability of induced potential. We finally measured the effective piezoelectric d33 coefficient of foamed PLA samples as a function of porosity degree, and its temporal decay together with an estimate of the surface charge density. In conclusion, we present an innovative production of low-cost and sustainable electroactive material developed in a double-step process and a fully 3D-printed electrostatic energy harvester.

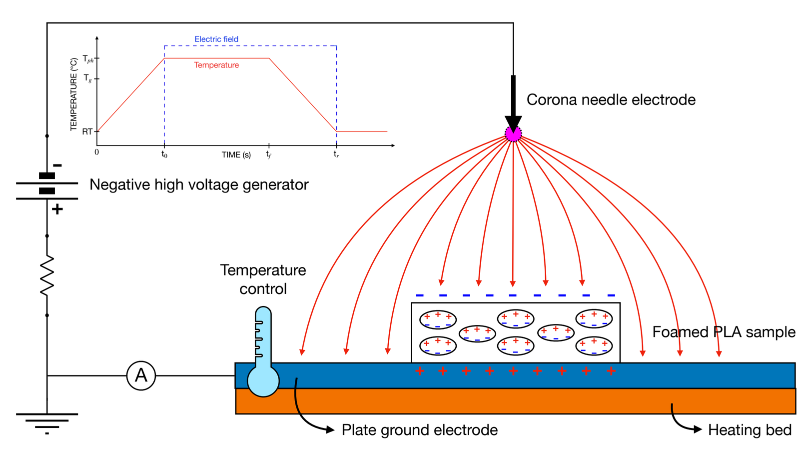


1. INSTRUMENTAL SETUP

2-step process implementation



Foam-controlled 3D-printing by varying extrusion temperature and flow rate



Simultaneous negative corona charging and thermal treatment of samples

2. MATERIAL CHARACTERIZATION

Commercial filament with active **foaming** technology (LW-PLA)

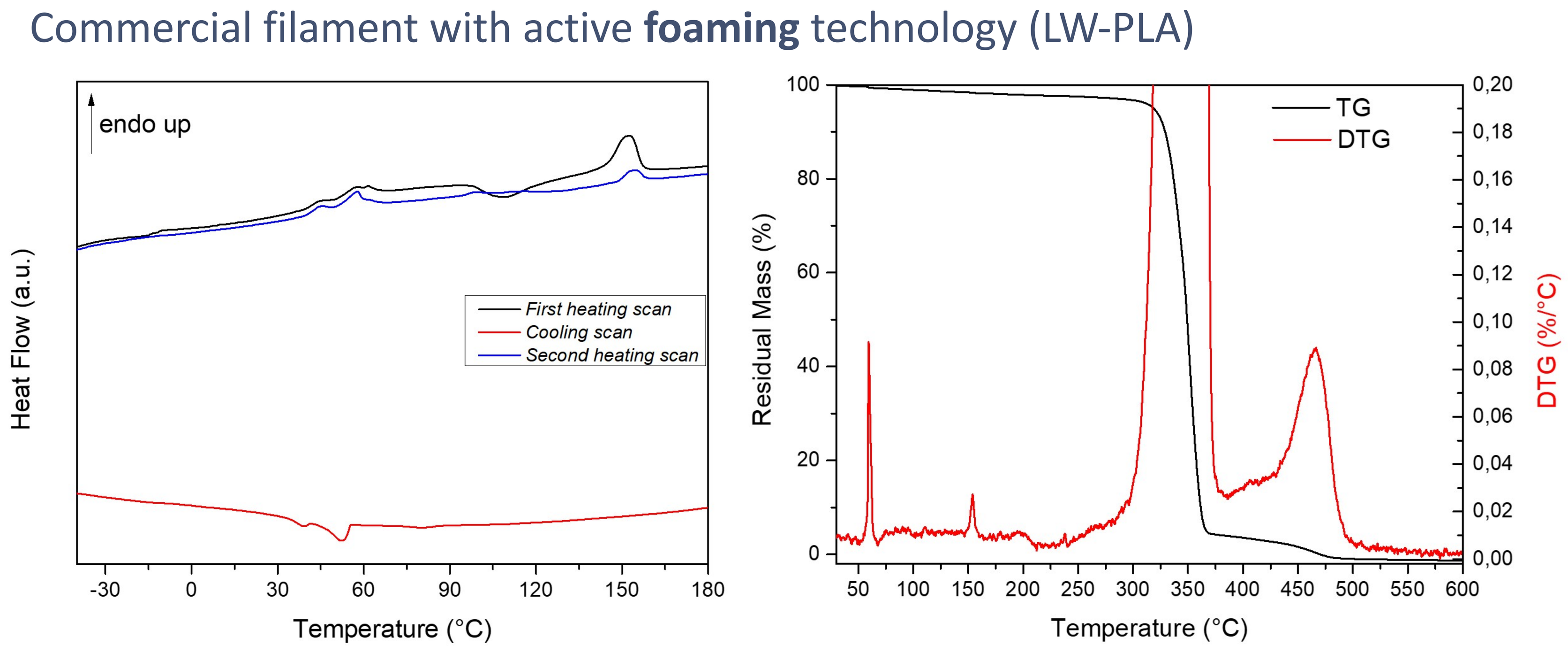
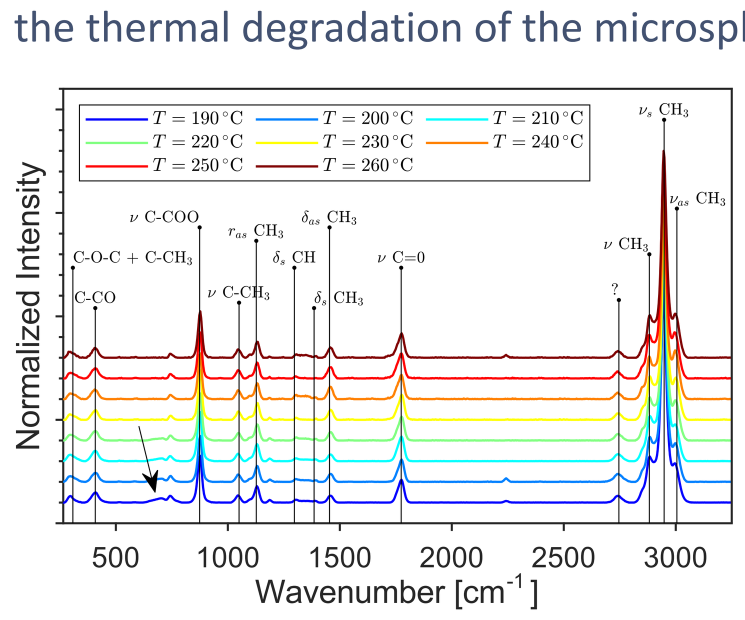


Figure 1 - Differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) of the filament

Plots indicate the presence of a low-melting polymeric blowing agent at 45.3°C and the thermal degradation of the microspheres is responsible for the material foaming



- The spectra show the most prominent peaks of PLA that preserves its molecular structure at increasing temperatures (the material is not degrading)
- A broad and shallow peak at 700 cm^{-1} found for lower-T samples gradually disappears (evaporation of blowing agent)

Figure 2 - Raman spectra acquired for different extrusion temperature of LW-PLA printed samples

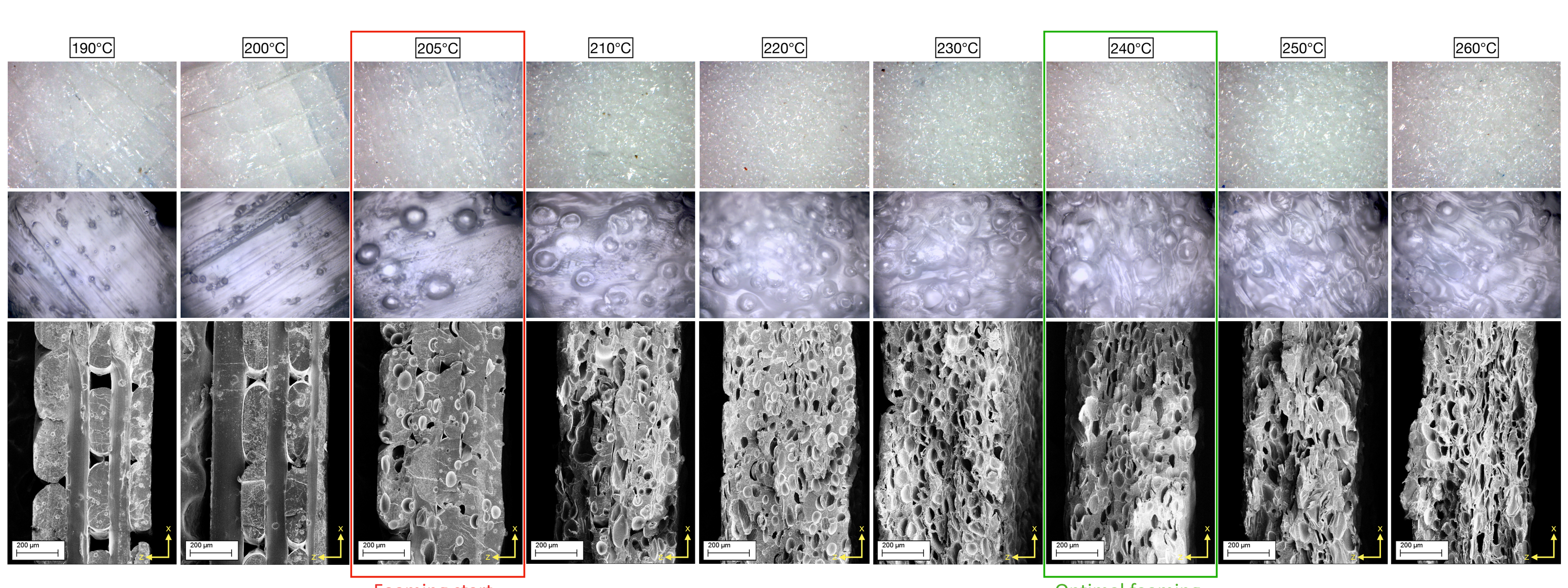
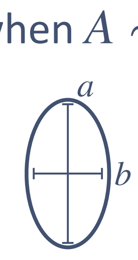


Figure 3 - Optical images of 3D-printed LW-PLA samples and relative SEM images of their cross sections

Extraction from cell dimension data of the asphericity parameter

- Spherical bubbles when $A \sim 0$
- Elongated bubbles when $A \sim 1$

$$A = 1 - \frac{4ab}{(a+b)^2}$$



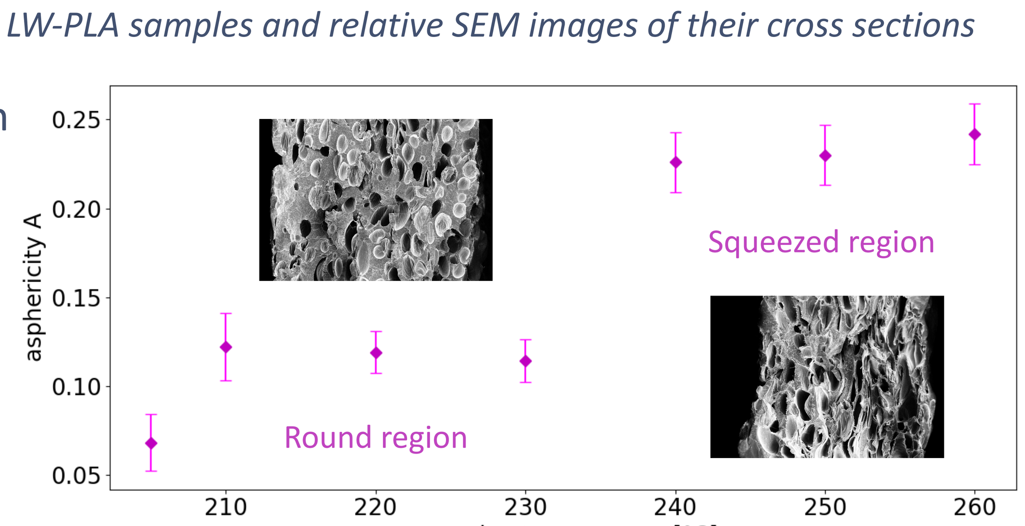


Figure 4 - Average asphericity of sample cells printed at different extrusion temperatures

3. MECHANICAL CHARACTERIZATION

Compression tests of cylindrical samples printed at different extrusion temperatures up to a load of 500 N

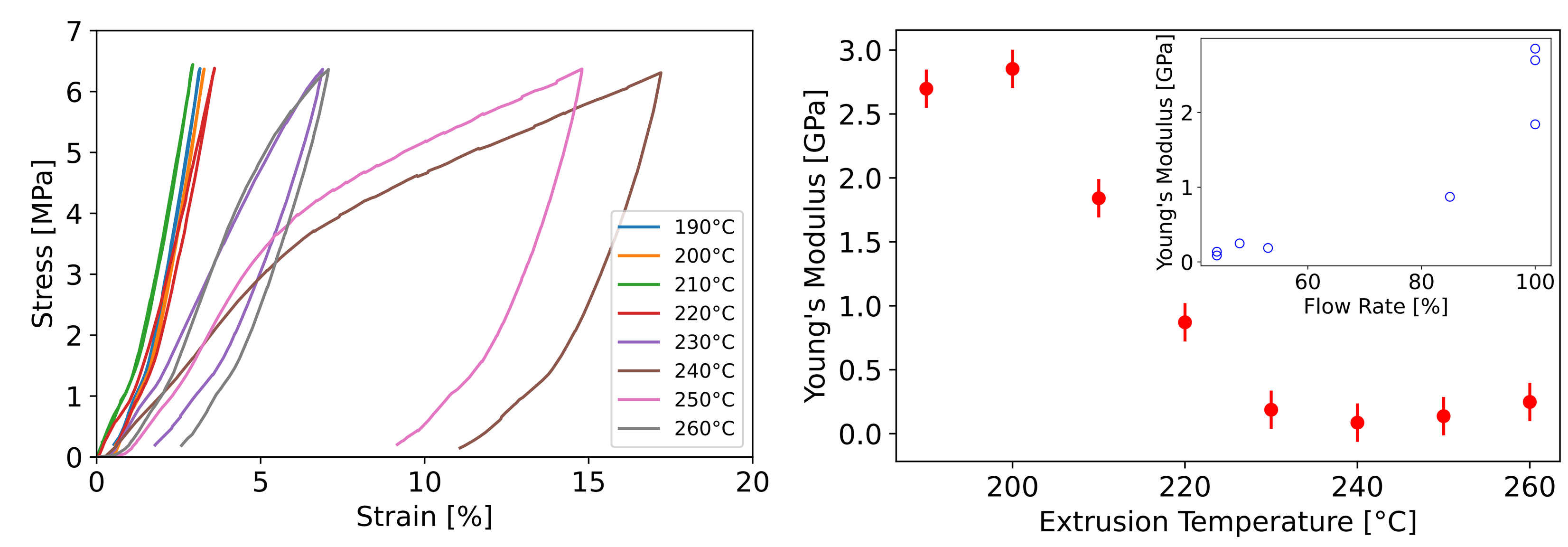


Figure 5 - Compressive stress as a function of percentage compressive strain and measured Young's modulus as a function of extrusion temperature and flow rate (inset)

- Foaming effect at low temperatures is negligible (constant Young's modulus of 2.7 GPa)
- Samples with higher foaming degree show a plastic deformation and a very reduced Young's modulus of 100 MPa

4. ELECTRET BEHAVIOR

Improvement of temporal stability of the electret surface potential values using the **thermal treatment** (85°C)

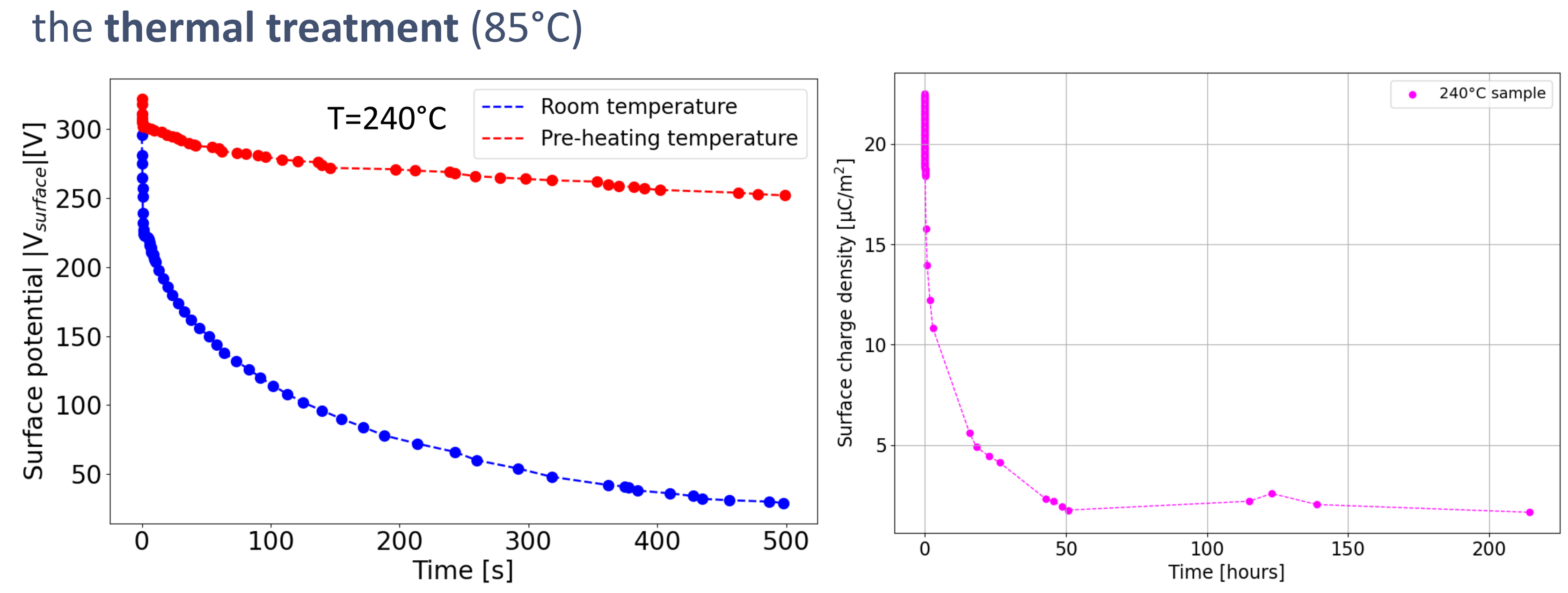


Figure 6 - Temporal decay of surface potential values and surface charge density of a 240°C-printed sample

- At RT a fast decay in a short time nullify the induced material charging while at 85°C the potential values remain stable up to 500 seconds for all the extrusion temperatures
- Surface charge density $\sigma = \frac{\varepsilon_0 \varepsilon_r V}{d}$ $(\varepsilon_r = 3.11)$ from 22.5 μC/m² to 1.65 μC/m²

5. PIEZOELECTRIC ACTIVITY

Indirect measure of the quasi-static d_{33} coefficient by integrating the short-circuit current generated by the sample subjected to a step-like compression force

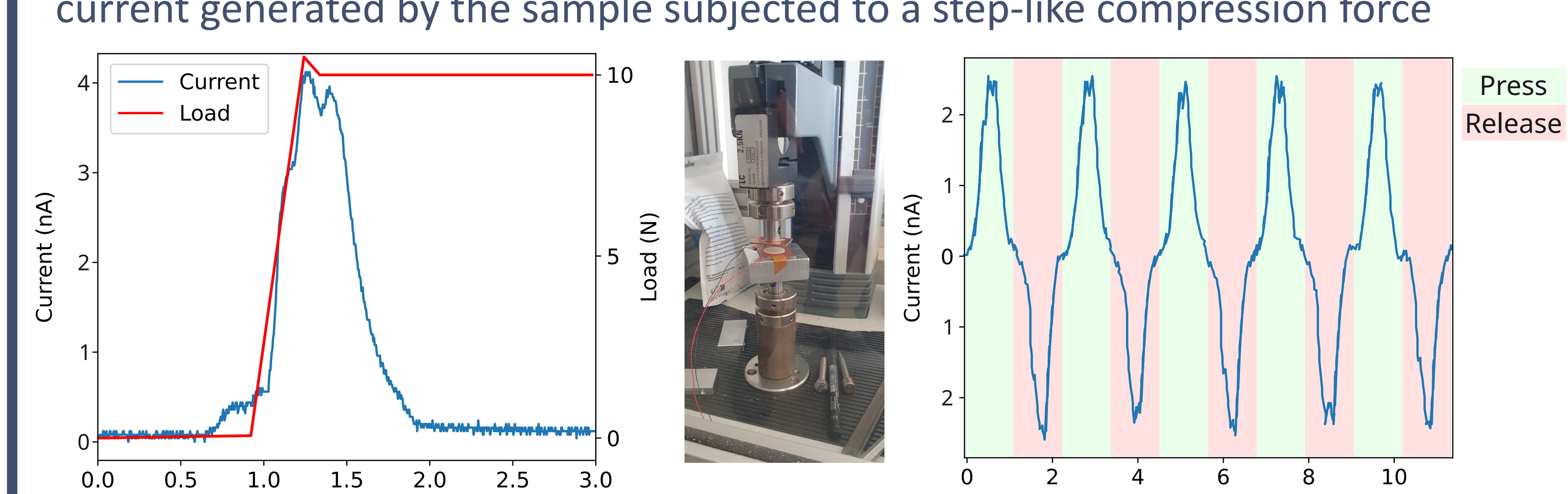


Figure 7 - Short-circuit current, the experimental setup and a series of compression and release cycles

Total generated charge $Q = \int I(t)dt = \sum_i I_i \cdot \Delta t_i \longrightarrow d_{33} = \frac{Q}{F} = \frac{\sigma_{surface}}{P} \simeq$ **212 pC/N**

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