Energy Harvesting from Human Gait by means of Electrostrictive Effect Exploiting Polymer Nanocomposites

Michele Zanoletti[1], Paolo Vitulo[1], Riccardo Morina[3], Daniele Callegari[2], Eliana Quartarone[2], Riccardo Viola[4], Davide Comoretto[5], Sergio Dulio[1], Piercarlo Mustarelli[3], and Maddalena Patrini[1]

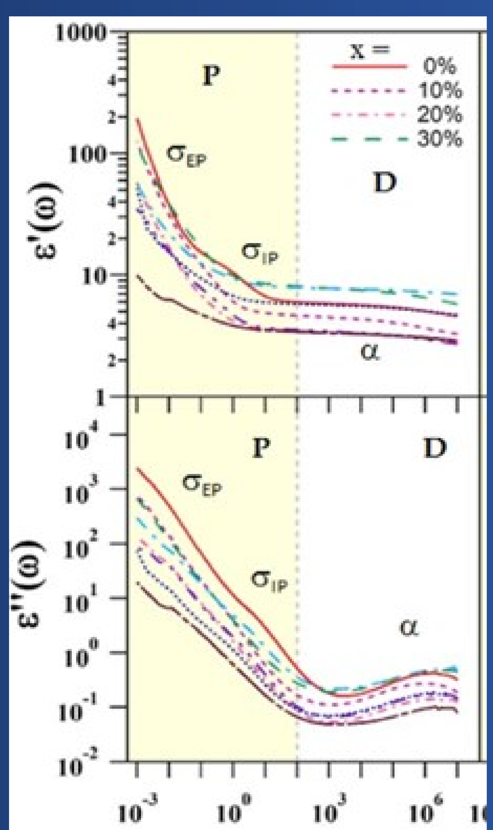
[1]CENTRO MADE - Dipartimento di Fisica, Università degli Studi di Pavia; [2]Dipartimento di Chimica, Università degli Studi di Pavia; [3]Dipartimento di Scienza dei Materiali, Università degli Studi di Milano Bicocca; [4]Atom S.p.A. Vigevano (PV); [5]Dipartimento di Chimica e Chimica Industriale, Università degli Studi di Genova

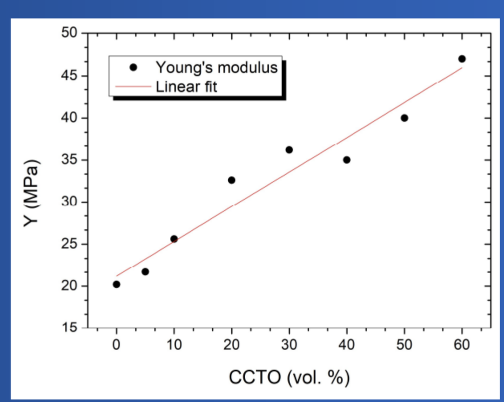
GIORNATE dell'ELETTROCHIMICA ITALIANA ORVIETO 2022

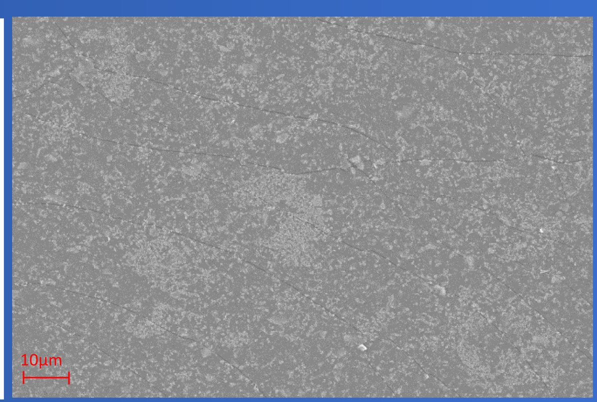
Abstract: Harvesting systems capable of transforming mechanical vibration into electrical energy have attracted considerable interest with particular focus on electroactive polymers. In this work, a composite material consisting of a polyurethane matrix filled with a high-k ceramic nanofiller ($CaCu_3Ti_4O_{12}$) is fabricated by doctor blade coating. Single strips, with sputtered electrodes, are electrically connected in parallel increasing electrical capacitance. The required bias voltage is provided by two alternative solutions, a rechargeable battery or a custom electret made by corona charging.

High-k electrostrictive material

Nanocomposites based on the incorporation of a high dielectric constant filler, calcium copper titanate $CaCu_3Ti_4O_{12}$, at different volume ratios in a commercial TPU elastomer.
Morphology investigated by SEM.







Dielectric spectroscopy at room temperature on different TPU-CCTO composites gives the profiles of complex permittivity $\varepsilon^*(\omega) = \varepsilon'(\omega) - i\,\varepsilon''(\omega)$.

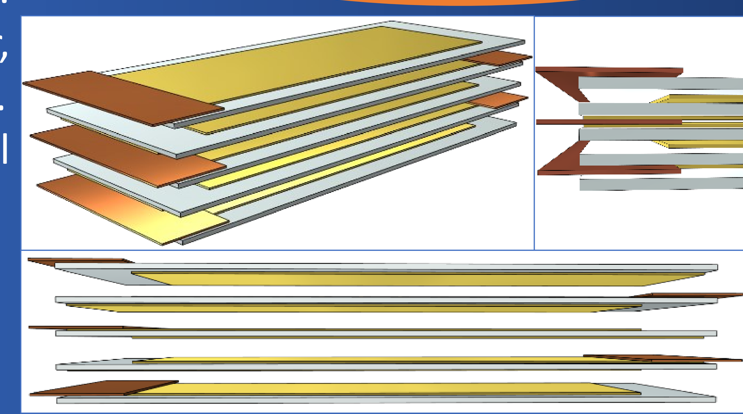
Invernizzi, F. et al. Journal of Physical Chemistry C 122 (2018) 21115

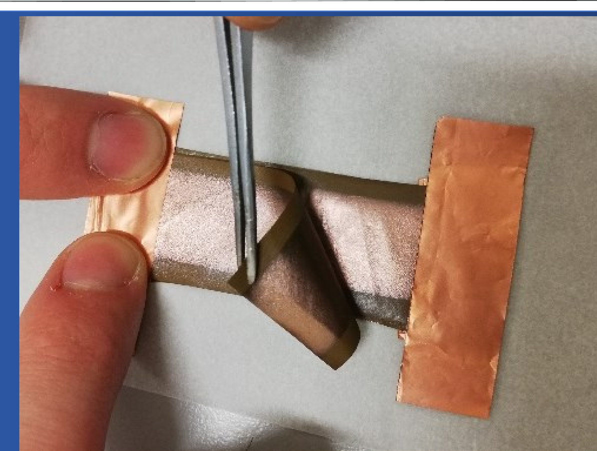
Multi-strip fabrication

Basic elements of the energy harvester (EH) are strips made of TPU-CCTO - high-R (~100s MΩ) and C (a few nF) tunable with strain (4-12%) - with sputtered Au electrodes on both sides. Multi-strips were assembled by pressing (14 bar, 90°C) the strips with alternated copper contacts. Pressure and temperature allow a functional coupling of the individual layers.

Inside the multi-strip the individual layers are electrically connected in parallel so as to increase C.

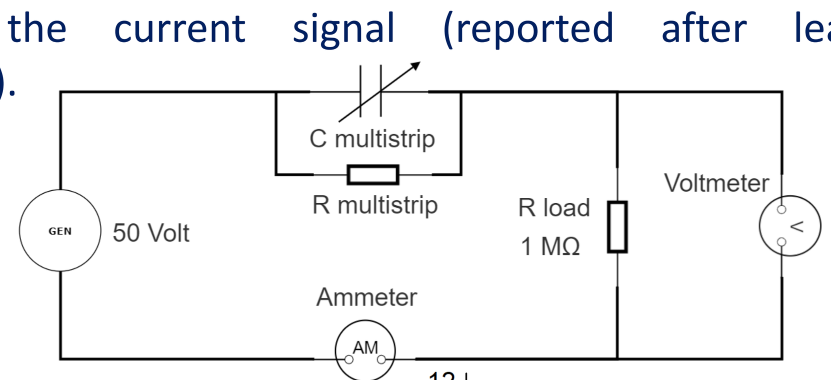
This configuration is designed to maximize electrostrictive energy generation, harvested from the mechanical motion
(f = 1-10 Hz).

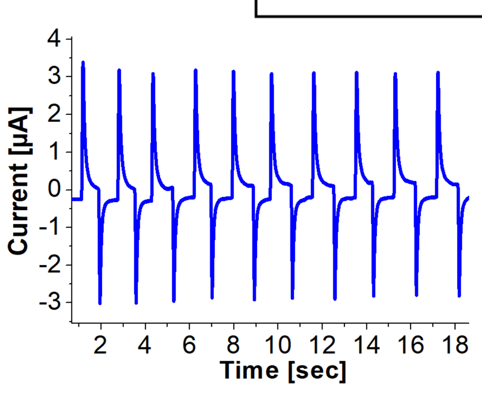


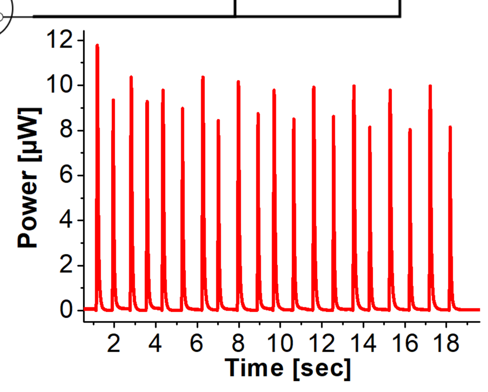


Energy harvesting

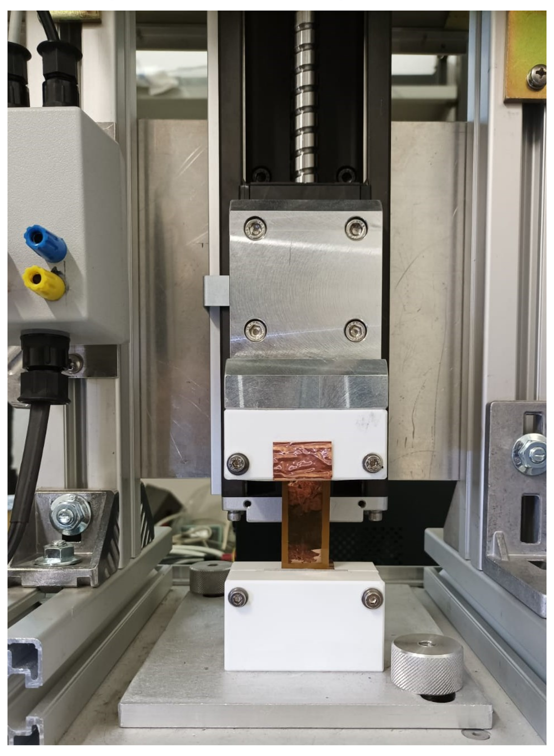
Multi-strips (*e.g.* of 10 strips) were subjected to elongation-release cycles at a frequency of 1 Hz. The test circuit consists of a generator supplying the bias voltage (50 V), the device under test, a load resistor, a voltmeter and a pico-ammeter that measures the current signal (reported after leakage subtraction).



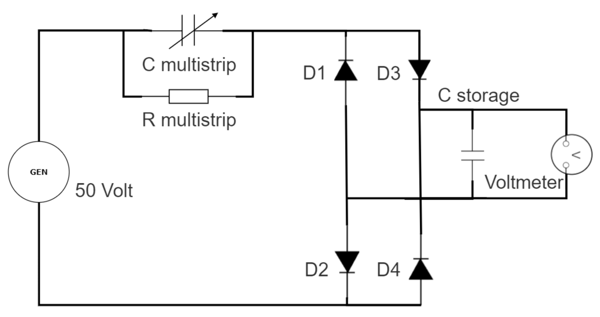


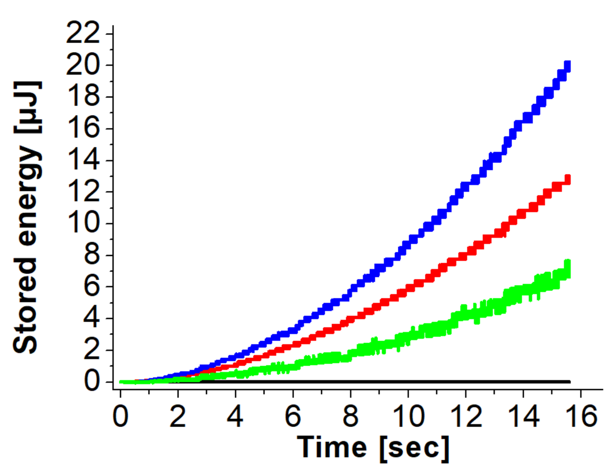


***f* = 1 Hz, Bias = 50 V, Strain = 12%**



Energy harvested is about 5µJ/cm³ per strip per cycle. In a typical human motion of a few hours, energy should be accumulated for use on demand. We have tested energy accumulation with a rectifier diode bridge and a capacitor.

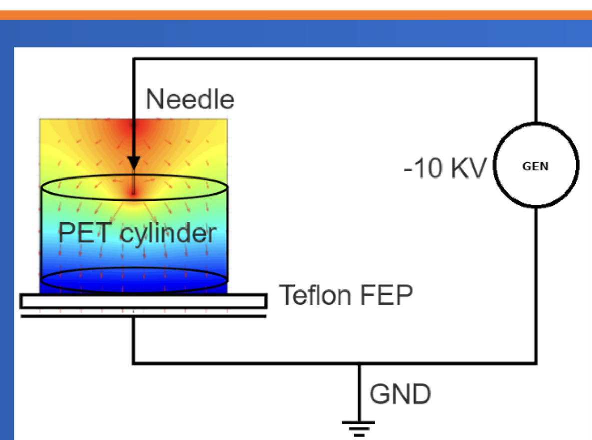


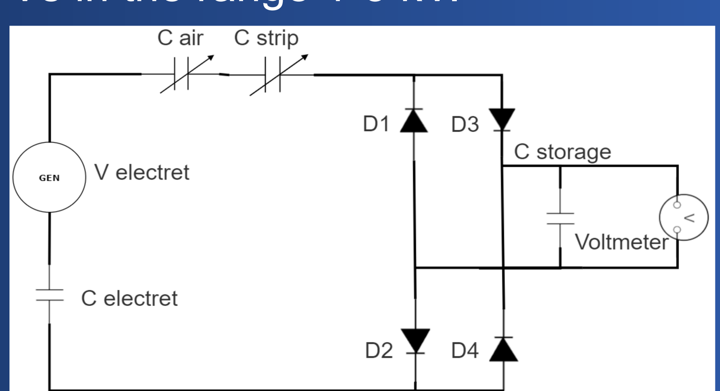


Energy stored on a 11 µF capacitor in different experimental configurations: EH disconnected, EH connected and not operating, EH connected and operating, net harvester energy.

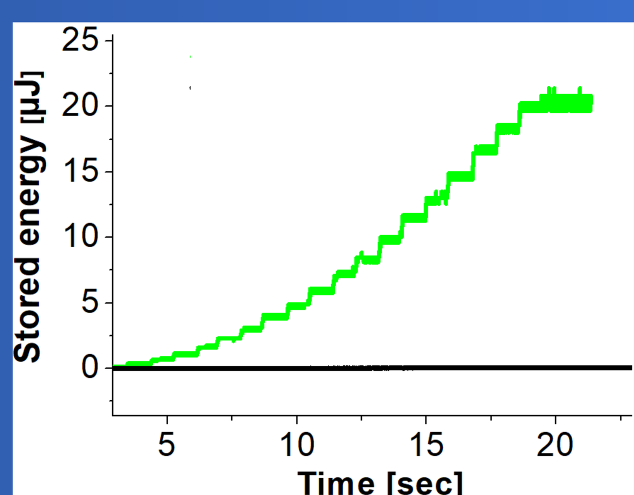
Electrets

Teflon (FEP, 50 µm) electrets were fabricated by the corona charging method resulting in implantation of charges at the surface and into the volume of the material. At the end of this process the electret presents a surface voltage Vs in the range 1-3 kV.





Energy accumulation tests with custom-made electrets were done with a diode bridge that rectifies the current to allow charging of a capacitor.

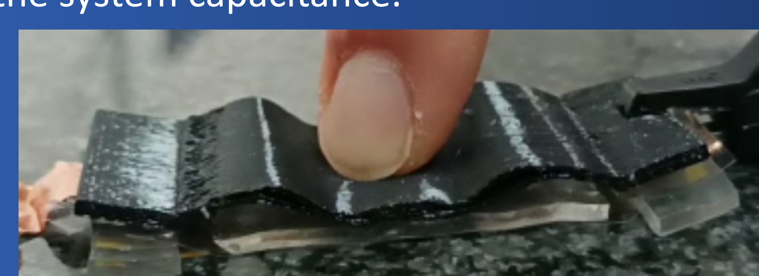


Energy stored in a 1 µF capacitor in different experimental configurations: harvester disconnected, net harvester energy.

Smart shoes

The multi-strip harvester will be immerged into a shoe sole at a position where maximum strain is impressed by the human gait (metatarsal region). Its bias voltage is provided by a rechargeable battery (limited to 48 V) or alternatively by the electret. The scavenged energy supplies a Printed Circuit Board placed into the shoe heel that manages the data acquisition and control of the acceleration, humidity, pressure and temperature sensors.

In the electret case a 3D TPU flexible arc structure allows to cyclically vary the electrostatic coupling strength on a multistrip plane, and then the system capacitance.



Conclusions and aims

An energy harvesting system is presented based on a hybrid electrostrictive elastomer used in different scavenging configurations. In the battery supply mode at about 50 V an energy density output of a few µJ/cm³ is obtained, while in the electret mode with surface voltages as high as 1 kV energy density output a factor 3 to 10 higher is measured. The biased EH plus electronic platform system is at prototypal level, while the electret mode EH needs structural optimization. Would an electret industrial processing be available with the needed properties, flexibility, durability, long term stability of the overall platform will be deeply investigated.