Pyroelectric device of ZnO ceramics as thermal energy harvesting

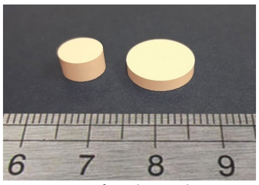
Amelia Montone (1*), Giuseppe De Santis (1), Francesco Cognini (1), Francesca Mazzanti (2), Selene Grilli (2), Elena Salernitano (2), Giuseppe Magnani (2)

(1) ENEA, Materials Technology Division, Casaccia Research Centre, Via Anguillarese 301, 00123 Rome, Italy
(2) ENEA, Laboratory of Material Technologies Faenza, Via Ravegnana 186, 48018 Faenza (RA), Italy

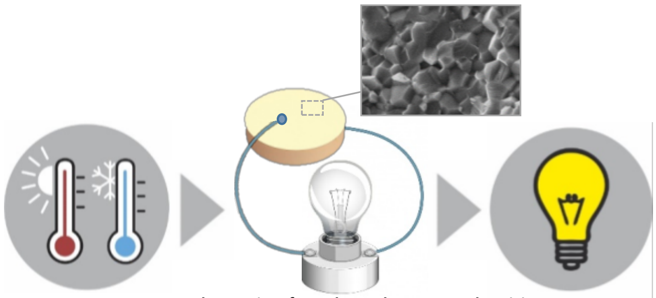
*Contact: amelia.montone@enea.it

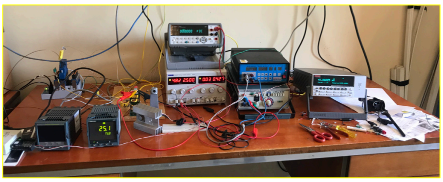
- Pyroelectric materials can convert thermal energy into electricity owing to the variation of internal spontaneous polarization.
- The electrical response to heat results from the oscillation of electric dipoles within pyroelectric materials induced by time-dependent temperature fluctuation.
- ZnO is a low cost, low toxicity and environmentally friendly pyroelectric material.
- Its pyroelectricity is attributable to non-centrosymmetrical crystals and so it has a specific polar axis along the direction of spontaneous polarization, without poling process
- When ZnO is subjected to temperature variations, its internal polarization produces an electric field [1].

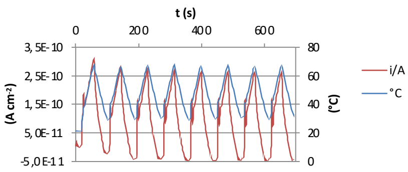
- ZnO ceramic specimens, with diameter ranging from 7 to 11 mm and thicknesses of 1.2-1.5 mm, were produced to be used in the pyroelectric device.
- Highly dense ceramics (about 98% T.D.) were obtained.
- Both commercial and synthesized nanopowder was used as starting material.
- The sintering was performed by a simple and easy to scale up pressureless process.



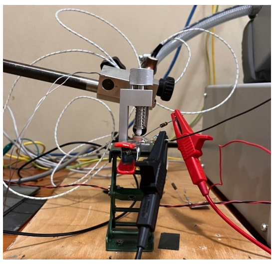
ZnO pyroelectric specimens

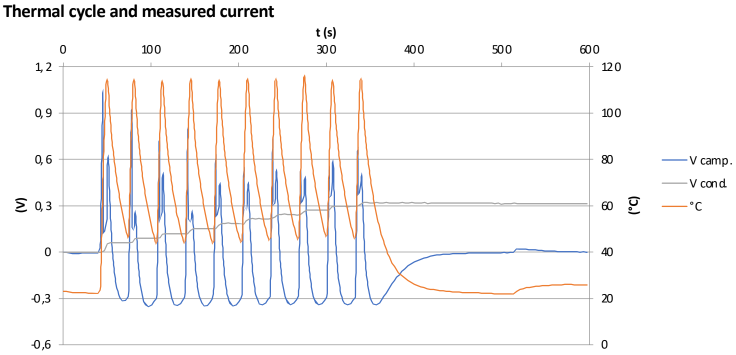

ZnO energy harvesting: from thermal energy to electricity


Experimental set up



Thermal cycle and measured current


Pyroelectrical device



Accumulated charge: trend of T and of the voltage at the sample and at the capacitor

- Specimens were used in the pyroelectric device [2], stable up to 180°C, after evaporation with Au of 150 nm thickness.
- Air heathing and cooling were used to probe the pyroelectric output.
- The average pyroelectric coefficient obtained is about 15 µ C m^{-2} K^{-1}.
- The samples showed pyroelectric behavior; the measured current values, for an area of the sample between 30 and 97 mm^2, are of the order of tens of pA, in particular 480 pA were reached at 150 ° C with linear ramp at 10 °C min^{-1}.
- Thermal cycles (T_{max} = 94 ± 12 °C, dT / dt | max = 8 ± 5 °C s^{-1}, dT /dt | min = -4 ± 2 °C s^{-1}) confirmed these results with maximum currents on average in the order of 0.1 nA (Imax = 91 ± 49 pA, Imin = -14 ± 15 pA). In terms of reproducibility of the measurements, the possibility of replicating dynamic thermal cycles with temperature and current deviations lower than 1 °C and 5% of the average current, respectively, has been demonstrated.
- The possibility of accumulating the charge produced by the pyroelectric effect has been verified, the accumulated energy at the end of the test is E = 528 nJ, the voltage remains significantly constant therefore the accumulated energy is conserved, it is foreseen for the future of optimize the storage system.

References:
[1] Hsiao C.C., Huang K.Y., Hu Y.C. Fabrication of a ZnO pyroelectric sensor. Sensors. 2008;8(1):185–192
[2] L.A. Chavez, F.O. Zayas Jimenez, B.R. Wilburn, L.C. Delfin, H. Kim, N. Love, Y. Lin, "Characterization of Thermal Energy Harvesting Using Pyroelectric Ceramics at Elevated Temperatures", Energy Harvesting and Systems, 5(1-2), 2018, 3–10.

Acknowledgement. This project has received funding by the Piano triennale di realizzazione 2019-2021 della ricerca di sistema elettrico nazionale – Progetto 1.3 Materiali di frontiera per usi energetici (C.U.P. code: I34I19005780001).