Innovative micro- and nano- structured piezoelectric materials for energy harvesting applications

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PON RICERCA E INNOVAZIONE 2014 - 2020

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My background

- Master's thesis work $\rightarrow$ relativistic nuclear theoretical physics
- my personal contribution to the article published on Physical Review C: "R. Alessandro, A. Del Dotto, E. Pace, G. Perna, G. Salmè, S. Scopetta, *Light-Front Transverse Momentum Distributions for* $\mathcal{J} = 1/2$ *Hadronic Systems in Valence Approximation*", arXiv:2107.10187 nucl-th

Light-Front Transverse Momentum Distributions for $\mathcal{J}$=1/2 Hadronic Systems in Valence Approximation.

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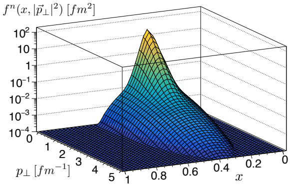
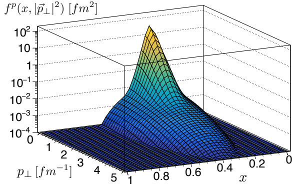
The semi-inclusive correlator for a $\mathcal{J}$=1/2 bound-system, composed by A spin-1/2 fermions, is linearly expressed in terms of the light-front Poincaré covariant spin-dependent spectral function, in valence approximation. The light-front spin-dependent spectral function is fully determined by six scalar functions that allow for a complete description of the six T-even transverse-momentum distributions, suitable for a detailed investigation of the dynamics inside the bound system. The application of the developed formalism to a case with a sophisticated dynamical content, like ^{3}He, reaches two goals: (i) to illustrate a prototype of an investigation path for gathering a rich wealth of information on the dynamics and also finding valuable constraints to be exploited from the phenomenological standpoint; (ii) to support for the three-nucleon system a dedicated experimental effort for obtaining a detailed 3D picture in momentum space. In particular, the orbital-angular momentum decomposition of the bound state can be studied through the assessment of relations among the transverse-momentum distributions, as well as the relevance of the relativistic effect generated by the implementation of macroscopic locality. A fresh evaluation of the longitudinal and transverse polarizations of the neutron and proton is also provided, confirming essentially the values used in the standard procedure for extracting the neutron structure functions from both deep-inelastic scattering and semi-inclusive reactions, in the same kinematical regime.

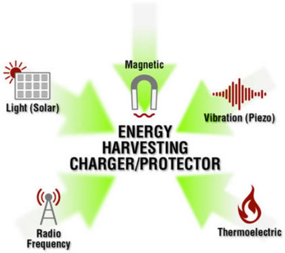




Overview

- **IoT (Internet of Things)**: universe of smart things interconnected (smart cars, smart homes, smart cities, industrial IoT) → nowadays they require power sources that are:
    1. miniaturized
    2. independent
    3. ecologically sustainable (green)

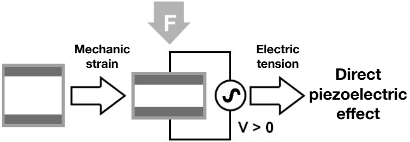
- **Energy harvesting**: process of collecting energy from external sources (solar, thermal, eolic, osmotic, kinetic, mechanic, electromagnetic, vibrational)
    1. conversion from environmental to electric energy
    2. storage in capacitors and batteries
    3. self-power supply of wireless devices (directly available energy)



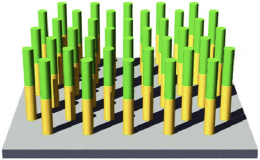
Innovative development

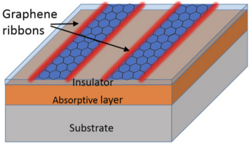
Exploration of new crystalline materials which exhibit piezoelectric properties:

- **direct** piezoelectric effect: the application of a force or a vibration on the crystal produces an electrical voltage (piezogenerator effect)



1. **lead-free** $\rightarrow$ biocompatibility
2. proof of concept of the device $\rightarrow$ use of **10 μm microcrystals** $\rightarrow$ energy conversion gain that increases one order of magnitude compared to cantilevers
   - matrix of pillars (forest)
   - matrix of ribbons (array)
3. piezoelectric characterization of the **single crystal** at microscales and nanoscales $\rightarrow$ calculation of d_{33} and k_{33} coefficients using a new measurement setup



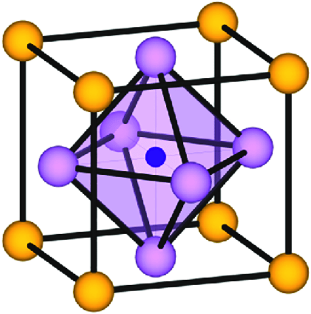


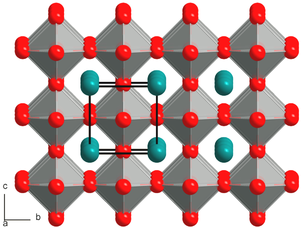
Advantages and drawbacks of PZT

Lead zirconate titanate

$Pb[Zr_x Ti_{1-x}]O_3 \quad 0 \leq x \leq 1$

- **Pb-based** ceramic piezoelectric material
- **perovskite** structure
- ferroelectric and pyroelectric properties
- advantages:
  1. high energy conversion gain
     $d_{33} = 650$ pC/N $\quad k_{33} = 0.75$
  2. extensive industrial use at macroscales
- drawbacks:
  1. pollutant for the environment
  2. toxic (non-biocompatible)
  3. need of a polarization process (poling)
  4. very fragile on micro- and nano- structures

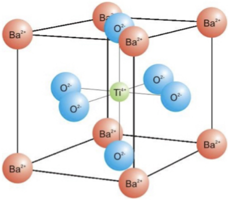


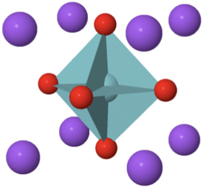


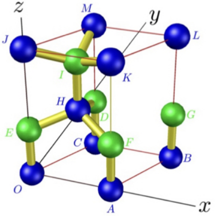
Alternative materials to PZT

1. Barium titanate: $BaTiO_3$
   - **perovskite** structure
   - $d_{33} = 190$ pC/N $\quad k_{33} = 0.5$
2. Sodium potassium niobate: $K_{1-x}Na_xNbO_3$
   - **perovskite** structure
   - $d_{33} = 190$ pC/N
3. Zinc oxide: ZnO
   - **wurtzite** structure
   - $d_{33} = 11$ pC/N $\quad k_{33} = 0.4$

- advantages:
  1. biocompatibility
  2. good piezoelectric performances
  3. low cost
  4. suitable for the creation of micro- and nano- structures

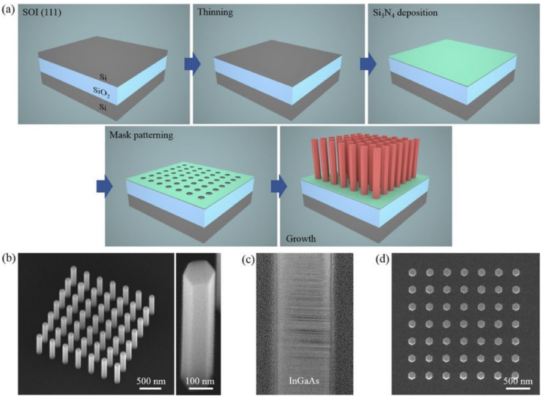


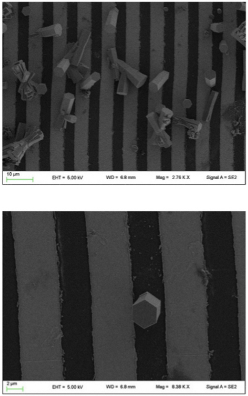


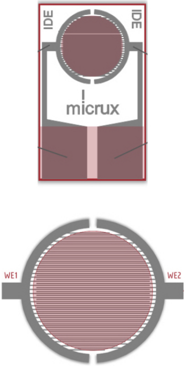


Main aim of the research project

- selection and synthesis of Pb-free piezoelectric materials
- realization of an innovative device at micro- and nano- scales which can transform efficiently the energy coming from environmental vibrations in electric energy
    1. pillars forest $\rightarrow$ piezoelectric crystals
    2. IDE Micrux integration $\rightarrow$ tracks of electrical contacts at the base $\rightarrow$ collection of the transverse **E** field when the pillar is stressed mechanically at the top

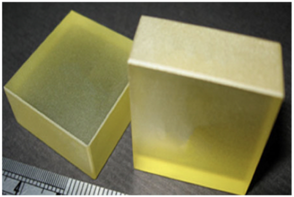


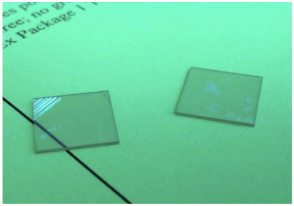


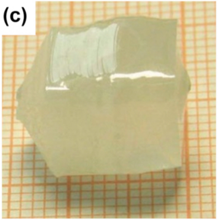


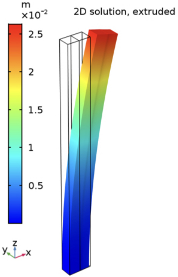
Methodology - I

1. theoretical study and comparison of various materials
2. comparison of the materials piezoelectric properties implemented in micro- and nano- structures
3. designing of the microstructured device on pillars or ribbons array
   - CAD software
4. study of the device electromechanic behaviour
   - numerical finite elements simulations (FEA)
   - Eulero-Bernoulli dynamics



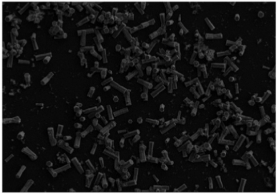


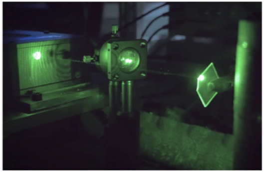




Methodology - II

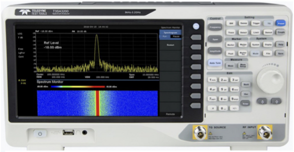
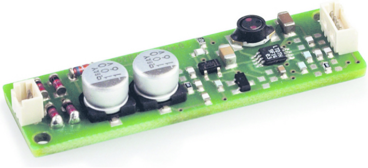
1. chemical synthesis of micro- and nano- piezoelectric crystals
   - bottom-up techniques: hydrothermal synthesis + ultrasonic sonication
2. physical and chemical characterization of the material
   - EDX spectroscopy
   - scanning electron microscopy (SEM)
   - Brillouin spectroscopy (BLS)
3. integration of the pillars forest on the substrate with electrical contacts
4. development of a measuring system of the crystalline materials piezoelectric coefficients and costants at micro- and nano- scales
   - atomic force microscopy (AFM)
   - Kelvin probe + micromanipulators




Methodology - III

1. characterization of the device performance in terms of the vibrational energy harvesting $\rightarrow$ laboratory setup:
   - shaker
   - accelerometers
   - spectrum analyzers
2. integration of the generator with the power management electronics + performance test at the company WISEPOWER s.r.l.
3. possibility of applying the idea and technology to an industrial setting (patent)

Thanks for the attention!

Essential bibliography

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