



# PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 39th cycle

**INTERDISCIPLINARY Research Field: TAILORED PIEZOELECTRIC MATERIALS AND  
OPTIMALLY DESIGNED METAMATERIALS FOR ENHANCED MECHANICAL ENERGY  
HARVESTING**

**Monthly net income of PhDscholarship (max 36 months)**

**€ 1400.0**

In case of a change of the welfare rates during the three-year period, the amount could be modified.

## Context of the research activity

**Motivation and objectives of the research  
in this field**

Interdisciplinary PhD Grant

The PhD research will be carried out in collaboration with research groups of the PhD programme in **"STRUCTURAL SEISMIC AND GEOTECHNICAL ENGINEERING"**.

It has been recently demonstrated that introducing controlled porosity into the piezoelectric ceramic allows gaining relevant advantages for energy harvesting, compared to dense piezoelectric materials, due to the beneficial ratio between the piezoelectric coefficients and the permittivity. According to the results of the ERC project NEMESIS, completed in 2018, even better energy harvesting performance can be achieved in the case of layered piezoelectric materials where dense outer layers surround a highly porous sandwich layer: the longitudinal piezoelectric strain coefficient ( $d_{33}$ ) increases as the thickness of the porous layer and total porosity level of the layered structure. These preliminary results open new and interesting perspectives for the application of energy harvesting devices in the MEMS field but, to be able to optimize the harvester for this specific purpose, thorough research in the multi-physics and multi-scale modeling of these new materials as well as in the analysis of the powder synthesis route and shaping technology is required. The piezoelectric features can be suitably designed, harnessing the capabilities of innovative



	<p>techniques of additive manufacturing. As a matter of fact, it is currently possible to create objects of complex shape, made of ceramic materials, both via binder jetting (powder-based additive manufacturing) and through inkjet printing. The research group has developed specific skills on such topics and may access to experimental equipment at the cutting edge of technology. The use of those machines, combined with a set of preliminary computational studies, may lead to the precise engineering of the porosity level, in order to achieve piezoelectric materials with unprecedented electro-mechanical features. The innovative piezoelectric materials can be applied to real devices for energy harvesting, also in view of recent research on the beneficial effect of metamaterials which are able to control the propagation of elastic waves. The research proposal aims at the optimal design of the metamaterial, so that the elastic energy can be focused on specific points, boosting the interaction with a piezoelectric resonator. The research group reached significant results in that field, but the shape optimization of the metamaterial is quite complicate. As a consequence, we plan to adopt the techniques of artificial intelligence, and more specifically of reinforcement learning, for the achievement of optimal metamaterials. In that way, the coupling of optimal metamaterials and innovative piezoelectric material may lead to interesting results in the ambit of vibration energy harvesting.</p>
<p><b>Methods and techniques that will be developed and used to carry out the research</b></p>	<p>The methods and techniques that will be used and further developed within this PhD are:</p> <ul style="list-style-type: none"> <li>- selection of the lead-free material, the composition and the geometry of the final components;</li> <li>- simulation of the production processes, in order to forecast the final properties of the ceramic materials;</li> <li>- engineering of the microstructure through modeling of the functional properties in relation to porosity amount and morphology;</li> <li>- design of new energy harvesting architectures, with special focus on the optimal design of metamaterials via reinforcement learning;</li> </ul>



	<ul style="list-style-type: none"> <li>- production of ceramic samples by synthesis of the piezoelectric powder, cold consolidation of the complex structure by binder jetting @Funtasma Lab. (to control pore distribution and morphology, or generate porosity graded structures), densification;</li> <li>- study of the dispersion of nanosized powders to produce inks suitable for ink jet printing of MEMS devices with controlled porosity @Polifab;</li> <li>- test of the piezoelectric properties and correlation with the microstructural parameters;</li> <li>- validation of the performance of the structures for mechanical energy harvesting and definition of the application parameters (frequency range, output energy etc).</li> </ul>
<b>Educational objectives</b>	At the end of the PhD cycle the candidate will be able to define, design and carry out original research programs by working in a team or leading a research group in the field of smart materials. Opportunities will be offered for spending visiting periods hosted by project partners for scientific cooperation.
<b>Job opportunities</b>	<p>All project activities are strongly connected to industrial needs and industrial and academic partners are directly participating to project tasks.</p> <p>Our last survey on MeccPhD Doctorates highlighted a <b>100% employment rate</b> within the first year and a <b>35% higher salary</b>, compared to Master of Science holders in the same field.</p>
<b>Composition of the research group</b>	0 Full Professors 2 Associated Professors 2 Assistant Professors 2 PhD Students
<b>Name of the research directors</b>	Prof. Nora Lecis, Prof. Raffaele Ardito

<b>Contacts</b>
<p><i>Email:</i> nora.lecis@polimi.it; raffaele.ardito@polimi.it</p> <p>For questions about scholarships/support phd-dmec@polimi.it</p>



Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents (more than 80Km out of Milano)	--

Scholarship Increase for a period abroad	
Amount monthly	700.0 €
By number of months	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information
<p>Financial aid is available for all PhD candidates (purchase of study books and materials, funding for participation in courses, summer schools, workshops and conferences) for a total amount of euro 5.707,13.</p> <p>Our candidates are strongly encouraged to spend a research period abroad, joining high-level research groups in the specific PhD research topic, selected in agreement with the Supervisor. An increase in the scholarship will be applied for periods up to 6 months (approx. 700 euro/month - net amount).</p> <p>Teaching assistantship: availability of funding in recognition of supporting teaching activities by the PhD candidate. There are various forms of financial aid for activities of support to the teaching practice. The PhD student is encouraged to take part in these activities, within the limits allowed by the regulations.</p>