

Project Periodic Report



Publishable Summary

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Project context and objectives

The NANOPOWER (“Nanoscale energy management for powering ICT devices”) project was conceived with the idea that a new generation of micro-to-nanoscale devices aimed at sensing, processing, actuating and communication will not be possible without solving the powering issue. Powering is relevant at least in two aspects: 1) too much power is currently dissipated into heat in the present generation of microelectronic devices. 2) Micro to nanoscale low-power autonomous devices of the next future will be powered by transforming energy available in the ambient. The scientific objective of this project is thus to study energy efficiency with the specific aim of identifying new directions for energy-harvesting technologies at the nanometre and molecular scale. Together with the scientific objective the project focuses also on an highly ambitious technological objective: to integrate such technologies into autonomous nanoscale systems to allow new, low-power ICT architectures to find their way into devices.

The NANOPOWER consortium has been very active in this first year devoting 103,6 person months (103,6 over 301 in total) to project activities organized in 23 Tasks (23 active over 30 total) distributed in 7 work packages. This work has generated a vast scientific activity that has involved universities, research centers, stockholders and the general public in more than one way with potential impact that will be evaluated in the years to come. The products of research generated in this year can be summarized in: 12 Deliverables (10 reports, 1 numerical code, 1 web site); 9 scientific articles on international ISI journals; 23 communications to international conferences; 2 Newsletter issues; 5 Board meetings; 4 Consortium meetings; 1 Summer School.

Work performed in year 1 and major achievements

Major progress was made in all tasks according to our work plan. However, the following achievements should be highlighted:

- **Task 1.1: Non-equilibrium fluctuations at the nanoscale** and **Task 2.1: Nanoscale energy transformation**

These Tasks deal with the description of non-equilibrium fluctuations with the methods of statistical mechanics and of energy management in the realm of nanoscales. In this ambit, under the leading activity of UNICAM we have developed an original approach to the implications and role of fluctuation theorems with the objective of reaching a comprehensive description of energy efficiency at nanoscale. For details see D1.1 and D2.1.

Other than a deeper understanding of the physical mechanisms at the bases of energy conversion at nanoscale, our NANOPOWER project deals with the study of three classes of potential nanoscale energy harvester devices. We have made significant progresses in all the three classes as detailed in the following.

Vibration energy harvesting

- **Task 2.2: Theory of nonlinear oscillators for vibration energy harvesting**

This Task is devoted to the development of a model for the description of optimized nonlinear oscillator for vibration energy harvesting. Under the leading activity of UNIPG we have developed a comprehensive modelling of nonlinear oscillator for energy harvesting that has soon become a reference for the vibration energy harvesting community. A review paper ("*There's plenty of energy at the bottom - Micro and nano scale nonlinear noise harvesting*", Luca Gammaitoni, to appear on Contemporary Physics, 2011) is presenting an overview of the topic. The work developed in this task has been presented in a number of international conferences during this year (e.g. "*Vibration energy harvesting with nonlinear oscillators*", L. Gammaitoni, Keynote speech at Euromech Colloquium at the University of Bristol (UK) devoted to *Structural Control and Energy Harvesting*, July 2011. For a complete list please see Report on Project Management - WP7). For details see also D2.2.

- **Task 4.2: Design of a vibration energy storage system**

This Task deals with the design of a kinetic energy storage system. In this topic UNIPG in collaboration with VTT has developed an original approach to local energy storage arising from vibrations: instead of converting kinetic energy from random fluctuation into electric energy and from this to chemical energy for storage, we propose to exploit the properties of low losses linear oscillators as temporary storage devices. The NANOPOWER partners are actively exploring the existing literature searching for patents on the subject and, at the same time, they are completing the design phase (as detailed in D4.2).

- **Task 4.3: Design of a prototype vibration harvester generator**

This Task is devoted to the design of a miniature energy harvester based on piezoelectric material. According to the results obtained in WP3 (see D3.1 - Material selected for nonlinear vibration harvester) Aluminum Nitride (AlN) has been selected as the piezoelectric material for the vibrational harvester. The geometry will be a buckled membrane or beam. The present activity has been focussed on the designing the test structure, fabricating the structures and investigate the properties. Tests are currently in progress in VTT and UNIPG.

Phonon rectification

- **Task 5.3: Design of a prototype heat rectification energy generator**

Phonon rectification through a spatially asymmetric medium (e.g, an ad hoc engineered meta-material) can also be used to establish controllable energy fluxes. The first and more ambitious idea consisted in studying phonon transmission through a membrane made of spatially asymmetric elements. The asymmetric diffusion of the phonons by such microscopic scatterers determines different phonon transmission rates across the membrane in opposite directions. This would result in a temperature difference on the two sides of the membrane, otherwise at equilibrium. Such effect was indeed numerically demonstrated for thin artificial membranes, which thus can be operated as phonon filters. The ICN partner in collaboration with VTT has presented the first design of a phononic-crystal membrane that allow in principle for rectification ratios larger than 20% (for details see D5.1 and M5.1 Report). Fabrication of first prototypes has just started.

Quantum harvesters

- **Task 2.4: Theory of quantum harvesters and Task 6.1: Definition of the principle of operation of the device class (Quantum harvester)**

These Tasks have been the recipient of a significant activity with high innovation potential. UNIGE has developed a novel concept where a quantum dot is coupled to two heat reservoirs via tunnel contacts which permit carrier exchange and is coupled capacitively to a gate such that there is only energy exchange between the conductor and the gate but remarkably no particle exchange. The gate is itself structured into a quantum dot that permits carrier exchange with its reservoir. What the Geneva group has found is that, under proper conditions, an electron that tunnels into the conductor quantum dot from left can only be transmitted to the right after absorbing a quantized amount of energy from the gate. This process allows a heat-to-charge current conversion, whose ratio is determined solely by the ratio of the charge to the energy quanta. For details see R. Sánchez and M. Büttiker, Phys. Rev. B 83, 085428 (2011). See also D6.1.

On this very topic UNI WUE has started a design activity (see Task 6.3).

- **Task 6.2: Design of a prototype quantum harvester I**

UNIWUE in collaboration with UNIGE has conceived an “integrated quantum harvester device” with an energy harvesting mechanism based on radiation absorption at nanoscale. The device consists of a Landauer-Büttiker motor (LBm) and an integrated resonant tunneling diode (RTD) (see Task 6.2). Herby, the LBm generates an electrical current by a

periodic and spatially symmetric electronic potential subject to an out of phase, but also periodic heating of the electron gas (or more general nonlinear noise). NANOPOWER partners are considering a possible activity of intellectual property protection aimed at depositing a patent on such device.

Consortium details

Consortium

No	Participating Institution	Short Name	Country
1	Dipartimento di Fisica Università degli Studi Perugia	UNIPG	Italy
2	Julius Maximilians Universität Würzburg	UNI WUE	Germany
3	Technical Research Centre Finland	VTT	Finland
4	Istituto Catalano de Nanotecnologia	ICN	Spain
5	University of Geneva	UNIGE	Switzerland
6	Università degli Studi di Camerino	UNICAM	Italy

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Project public website: www.nanopwr.eu

Project Logo:



Nanopower partners had 5 meetings during the first year: Kick-off in Perugia (1/8/2010); Consortium and Board in Wuerzburg (29-30/11/2010); Consortium and Board in Barcelona (28/2-1/3/2011); Board in Budapest (6/5/2011); Consortium and Board in Helsinki (6-7/6/2011).