ETTORE MAJORANA FOUNDATION AND CENTRE FOR SCIENTIFIC CULTURE

TO PAY A PERMANET TRIBUTE TO GALILEO GALILEI, FOUNDER OF MODERN SCIENCE AND TO ENRICO FERMI, "THE ITALIAN NAVIGATOR", FATHER OF THE WEAK FORCES

INTERNATIONAL SCHOOL ON STATISTICAL PHYSICS
Peter Hänggi and Fabio Marchesoni, Directors

1st COURSE

ENERGY HARVESTING AT MICRO AND NANOSCALES (NIPS2012)

ETTORE MAJORANA CENTRE
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July 23-28, 2012

NiPS Summer School 2012

July 23-28
Erice - Italy

Summer School "Energy harvesting at micro and nanoscales"

Workshop "Energy harvesting: models and applications"

NiPS Laboratory
Noise in Physical Systems

ZEROPOWER

NiPS Summer School 2012

NiPS Summer School 2012 is organized by NiPS Laboratory (Dipartimento di Fisica -University of Perugia - Italy) and is part of the European projects "**ZEROPOWER**: Co-ordinating Research Efforts Towards Zero-Power ICT" and “**NANOPOWER**: Nanoscale energy management for powering ICT devices”.

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Coordination and Support Action
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www.zero-power.eu

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www.nanopwr.eu

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NiPS Summer School 2012

Summer School "Energy harvesting at micro and nanoscales", July 23-26
Workshop "Energy harvesting: models and applications", July 27

General Program

Jul. 23: Arrival and registration

17.00 -18.00	Gammaitoni - Presentation of the school
18.00 -19.00	Alfonsi - Science communication training 1
19.00 -20:00	Welcome cocktail

Jul. 24:

9.00 -10.50	Marchesoni - Brownian transport at the nanoscales
11.10 -13.00	Venstra - Introduction to micro-electromechanical systems
15.30 -16.50	Cottone - Introduction to vibration harvesting
17.10 -18.30	Vocca - Non-linear vibration harvesting
18.30 -19.30	Alfonsi - Science communication training 2

Jul. 25:

9.00 -10.50	Buttiker - Current from hot spots
11.10 -13.00	Paul - Advances on thermoelectrics for energy harvesting
15.30 -16.50	Hartmann - Quantum energy harvesting in nanoelectronic devices
17.10 -18.30	Abadal - Energy harv. and storage from electromagnetic radiation sources
21.00 -23.00	Poster session

Jul. 26:

9.00 -10.50	Buttiker - Scattering theory of thermoelectric transport
11.10 -12.30	Baglio - Advances in nonlinear MEMS harvesters
Afternoon	Excursion

Jul. 27:

9.00 -13.00	Workshop: Energy harvesting: models and applications
15.30 -19.00	Workshop: Energy harvesting: models and applications
20.30	Gala dinner

Jul. 28: Departure

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Workshop Program - July 27th

Chair: **Douglas Paul**

9.00 – 9.30	**Teresa Emery**	Fabrication of bi-stable MEMS devices for energy harvesting
9.30 – 10.00	**Miquel López-Suárez**	MEMS based wide-band energy harvesting: a non linear approach
10.00 – 10.30	**Nima Tolou**	Carbon-nanotube-forest-based MEMS
10.30 – 11.00	**Eric Yeatman**	Miniature motion energy harvesters with rotating mechanisms
11.00 – 11.30	Coffee break	
11.30 – 12.00	**Chunyan Luan**	Hydrothermal growth of ZnO nanorods and their decoration with CdSe and CdS quantum dots for photovoltaic applications
12.00 – 12.30	**Mohsin Saleemi**	Synthesis of bulk nanostructured Bismuth Telluride (Bi2Te3) by co precipitation and sintered by spark plasma
12.30 – 13.00	**Igor Neri**	Real vibrations: a large, contributed vibration database
13.00 – 15.30	Lunch	
15.30 – 16.00	**Sergio P. Pellegrini**	Application of bond graph modeling to energy harvesting
16.00 – 16.30	**Sweta Bhansali**	Large thermoelectric figure of merit of lightly doped Nb: SrTiO3 thin films
16.30 – 17.00	**Loredana Latterini**	Preparation and characterization of colloidal nanoparticles interacting with visible light
17.00 – 17.30	Coffee break	
17.30 – 18.00	**Philipp Mensch**	Measurement of thermoelectric power of doped InAs nanowires
18.00 – 18.30	**Björn Sothmann**	Magnon-driven quantum-dot heat engine
18.30 – 19.00	**Vittorio Ferrari**	Bandwidth broadening in piezoelectric energy harvesting from vibrations

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Abstracts of the lectures

Gabriel Abadal Berini
Departament d'Enginyeria Electrònica, Universitat Autònoma de Barcelona (UAB), Spain

Energy harvesting and storage from electromagnetic radiation sources

Alternatives to phtotovoltaics have been explored in the last decades in order to extend the capabilities of the energy harvesting technology to other ranges of the electromagnetic radiation spectrum and, at the same time, to radically improve the conversion efficiency. Most of these alternatives are based on classical electromagnetic antennas as the core element that converts electromagnetic radiation energy into the electrical domain.

In this lecture we will review the schemes already proposed and proved in the literature and we will analyze their actual bottleneck that need to be improved. Novel state of the art technologies that include solutions to the storage of the harvested energy will be also presented and proposed in order to be discussed as possible new alternatives. Special emphasis will be given to those conversion strategies which are based on the combination of micro and nanoelectromechanical systems (M/NEMS) and optical components. The fabrication and characterization particularities of those special M/NOEMS devices will be presented in detail.

Leonardo Alfonsi
NiPS Laboratory, Dipartimento di Fisica, Università di Perugia, Italy

Talking Science

Over the last ten years many methods and techniques have been developed to present scientific contents to lay audiences. The *Talking Science* sessions will focus on the theoretical and practical features of a specific example developed within the context of the Cheltenham Science Festival (UK): the FameLab format. FameLab is an international competition for young researchers who present a scientific topic in 3 minutes to a general audience using only words and little objects; neither technical equipment nor pictures or slides are allowed during the presentations.

All these contraints in terms of time length and communication tools revealed to be useful to trigger creative and effective communication styles.

In the first session the FameLab competition and the rational behind it will be presented and some examples from FameLab international competition will be shown to reflect upon different communication styles. Some guidelines to prepare an effective FameLab presentation will also be discussed.

In the second session some summer school students will deliver a 3 minutes presentation following the FameLab competition rules. At the end of the presentations a discussion on contents and communication styles will follow.

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Markus Buttiker
University of Geneva, Switzerland

Current from hot spots

The lectrure discusses the generation of current from noise. We exmplify the phenomenon with a Brownian particle moving in centro-symmetric periodic potential and subject to non.equilibrium noise that is also centro-symmetric and periodic in space the same period but with a different phase. Our main interest is in quantum dot heat engines which are driven by a second hot dot that is only Coulomb coupled with the cold dot. We discuss the effciency, the bin which a second dot with We present a simple introduction The lecture introduces an approach to electrical transport in quantum coherent electrical conductors based on the scattering matrix. The basic expressions for two and multiterminal conductors are discussed. The theoretical results are compared with experiments. In addition to charge current I discuss the generalization of the approach to thermo-electrical phenomena. Thermopower, efficency, power and efficiency at maximum power are discussed for quantum dots. We address the role of inelastic scattering using probes which conserve both electrical and heat current.

Scattering theory of thermoelectric transport

The lecture introduces an approach to electrical transport in quantum coherent electrical conductors based on the scattering matrix. The basic expressions for two and multiterminal conductors are discussed. The theoretical results are compared with experiments. In addition to charge current I discuss the generalization of the approach to thermo-electrical phenomena. Thermopower, efficency, power and efficiency at maximum power are discussed for quantum dots. We address the role of inelastic scattering using probes which conserve both electrical and heat current.

The following publications provide useful reading:

"Coherent and Sequential Tunneling in Series Barriers",
M. Buttiker, IBM J. Res. Develop., 32, 63-75 (1988).

"Symmetry of Electrical Conduction",
M. Buttiker, IBM J. Res. Developm. 32, 317 (1988).

Salvatore Baglio
DIEEI, Università di Catania, Italy

Advances in nonlinear MEMS harvesters

Vibration energy harvesting will be addressed. Several different strategies will be explored and discussed in order to efficiently collect energy. Both magnetic and non magnetic approaches will be presented. Micro and nano systems for energy harvesting will result in low power and low output voltages, some considerations on the challenge of "storing" energy at very low voltage will be presented.

Francesco Cottone
ESIEE, Université Paris-Est, France

Introduction to vibration harvesting

Kinetic energy from vibrations is a reliable complementary resource to solar and thermal energy to power sub-milliwatts electronics like wireless sensor networks. This alternative is becoming a feasible perspective thanks to the parallel advancements of energy harvesting technologies and ultra-low power electronics. Vibrations sources are present almost everywhere: industrial machineries, bridges, buildings, transportations and human movements. Present mechanical-to-kinetic energy converters include piezoelectric, electromagnetics, electrostatic and magnetostrictive techniques. Moreover, most of the available vibration harvesting generators are based on resonant transducers which present a series of limitations such as narrow frequency response, frequency tuning issues and poor efficiency at small scale. In this seminar, an introduction to vibration energy harvesting will be presented. A general mathematical model will be introduced in order to derive all main characteristics of each transduction method, so to find the best environment and target application for each system. Finally, the main limitations of linear resonant versus nonlinear vibration harvesting systems will be briefly discussed.

Fabio Marchesoni
Università di Camerino, Italy

Brownian transport at the nanoscales

Diffusive transport of particles is a ubiquitous feature of physical and chemical reaction systems. In configurations containing confining walls or constrictions, transport is controlled both by the fluctuation statistics applied to the particles and the phase space available to their dynamics.
Consequently, the study of transport at the macro- and nanoscales must address both Brownian motion and entropic effects.
We report on recent advances in the theoretical and numerical investigation of stochastic transport occurring in narrow channels. The ensuing Brownian transport exhibits intriguing features such as a decrease in nonlinear mobility with increasing temperature or also a broad excess peak of the effective diffusion above the free diffusion limit. These paradoxical aspects can be understood in terms of entropic contributions resulting from the restricted dynamics in phase space. If, in addition, the diffusion properties of the suspension medium are subjected to external, space-dependent modulation, rectification or segregation of the diffusing Brownian particles becomes possible.

Douglas Paul
University of Glasgow, United Kingdom

Advances on thermoelectrics for energy harvesting

Thermoelectrics have been used to generate electricity for over a century although their mainstream use really started in the 1960s as BiTe generators became available. This set of lectures will overview the history of thermoelectrics and the background physics of the Seebeck, Peltier and Thomson effects. The major parameters of the Seebeck coefficient, electrical conductivity and thermal conductivity will be discussed including discussions on techniques to experimentally measure each effect in practical devices and materials along with the potential pitfalls. The figure of merit ZT will be introduced and used to allow a comparison between present demonstrated thermoelectric materials and generators. Techniques to enhance ZT values for future thermoelectric applications will be reviewed along with a comparison of demonstrated results in the literature. Finally a review of potential applications will be undertaking including a detailed assessment of the business case, limitations and requirements for thermoelectrics to penetrate some of the proposed new markets for energy harvesting.

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Warner J. Venstra
Kavli Institute of Nanoscience Delft The Netherlands

Introduction to micro-electromechanical systems

This lecture provides a general introduction to micro- and nano-electromechanical systems (MEMS, NEMS). First an overview of typical fabrication technologies and motion detection strategies is given. Downscaling of the dimensions results in ultra-floppy mechanics, in which nonlinearities are easily observed. Characteristic examples of nonlinear behaviour such as multi-stability, hysteresis, and coupled vibration modes are discussed.

Helios Vocca
NiPS Laboratory, Dipartimento di Fisica, Università di Perugia, Italy

Non-linear vibration harvesting

Ambient energy harvesting has been in recent years the recurring object of a number of research efforts aimed at providing an autonomous solution to the powering of small-scale electronic mobile devices.

The harvesting of kinetic energy present in the form of random vibrations (from non-equilibrium thermal noise up to machine vibrations) is an interesting option due to the almost universal presence of some kind of motion. Present working solutions for vibration energy harvesting are based on oscillating mechanical elements that convert kinetic energy via capacitive, inductive or piezoelectric methods. These oscillators are usually designed to be resonantly tuned to the ambient dominant frequency. However, in most cases the ambient random vibrations have their energy distributed over a wide spectrum of frequencies, especially at low frequency, and frequency tuning is not always possible due to geometrical/dynamical constraints.

A different method based on the exploitation of the dynamical features of stochastic nonlinear oscillators will be described. Such a method is shown to outperform standard linear oscillators and to overcome some of the most severe limitations of present approaches.

Lukas Worschech and Fabian Hartmann
Technische Physik, Universität Würzburg, Germany

Quantum devices for noise-induced switching, signal detection and energy harvesting

Advanced nanofabrication technologies are applied to realize quantum devices with distinct transport and optical properties such as resonant tunneling diodes and Y-branch switches. Such devices are characterized by nonlinear switching with steep thresholds tunable to intrinsic noise levels and show spike-like signal trains at the output similar to the operation of neurons. Logics gates, sensors and energy harvesting are discussed for different structures and device properties will be explained. Synchronization of small external signals and the system´s noise were also observed. A route for switching and programming externally logic stochastic resonance gates will be discussed.