Toward Zero-Power ICT

European initiative for efficient powering of micro and nanoscale autonomous devices

Luca Gammaitoni

NiPS Laboratory, Dipartimento di Fisica

Università degli Studi di Perugia and INFN Perugia, Italy

GUARDIAN ANGELS Workshop – Helsinki 15-16 Sept 2011

N.i.P.S Laboratory
Noise in Physical Systems

www.nipslab.org

WISEPOWER

Conclusions

From A. Ionesco's talk,
15-9-2011

The zero-power platform vision of Guardian Angels is essential to enable the economy of scale and the future success of WSN.

Energy efficiency gain is obtained by:

- Fundamental research into the limits of computation, communication, sensing, energy harvesting.

- …

Toward zero-power ICT

This is part of an ongoing EC (ICT – FET Proactive) effort

- Jan 2008, Brussels. Expert Consultation on “Molecular-scale Information Systems”
- July 2009, Call FP7-ICT-2009-5 - ICT 2009.8.6 Towards Zero-Power ICT
- Feb 2010, Brussels. Consultation workshop on "Disruptive Solutions for Energy Efficient ICT"
- Aug.1st 2010 three project started (SiNAPS, GREEN SILICON, NANOPOWER)
- Jan 1st 2011 ZEROPOWER C.A. started
- 26 July 2011 FP7 CALL 8, ICT 9.8 FET Proactive: Minimising Energy Consumption of Computing to the Limit (MINECC) (deadline 17 January 2012)
- 12 Oct 2011 FET Proactive Information Day - Brussels

Toward zero-power ICT

This is NOT the only initiative but shows an interesting peculiarity

1) Addresses the problem of PORTABLE POWER for Autonomous ICT Devices
2) Addresses the problem of ENERGY EFFICIENCY in ICT

To date these two problems we considered independetly by different communities

Toward zero-power ICT

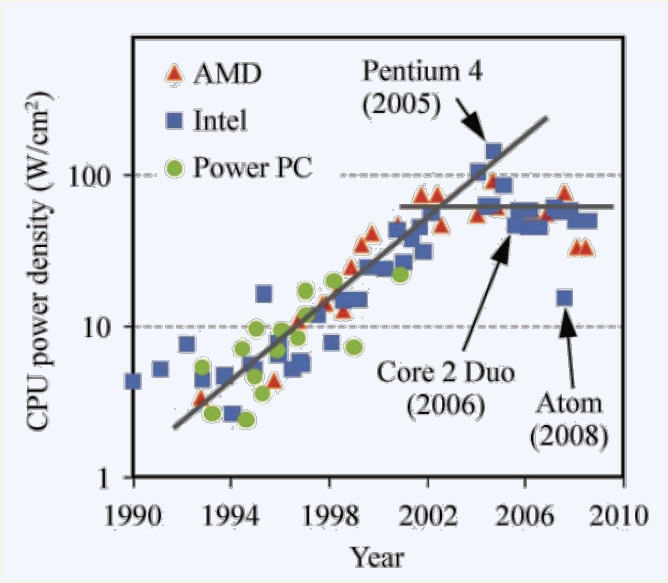
This is NOT the only initiative but shows an interesting peculiarity

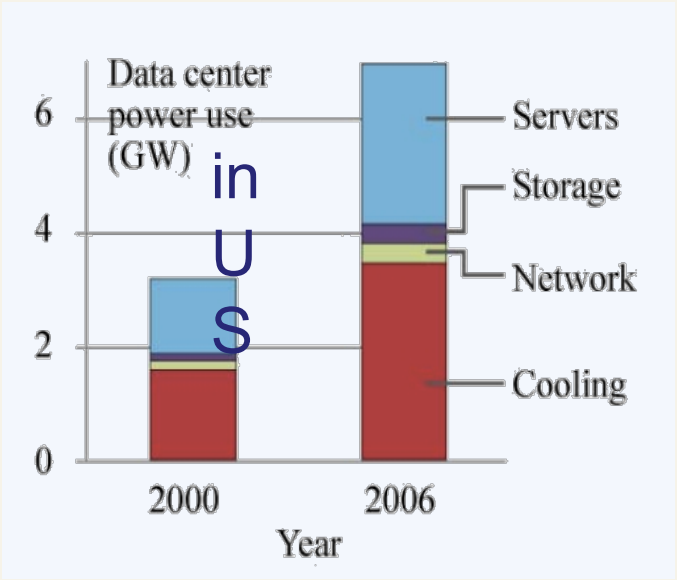
1) Addresses the problem of PORTABLE POWER for Autonomous ICT Devices
2) Addresses the problem of ENERGY EFFICIENCY in ICT

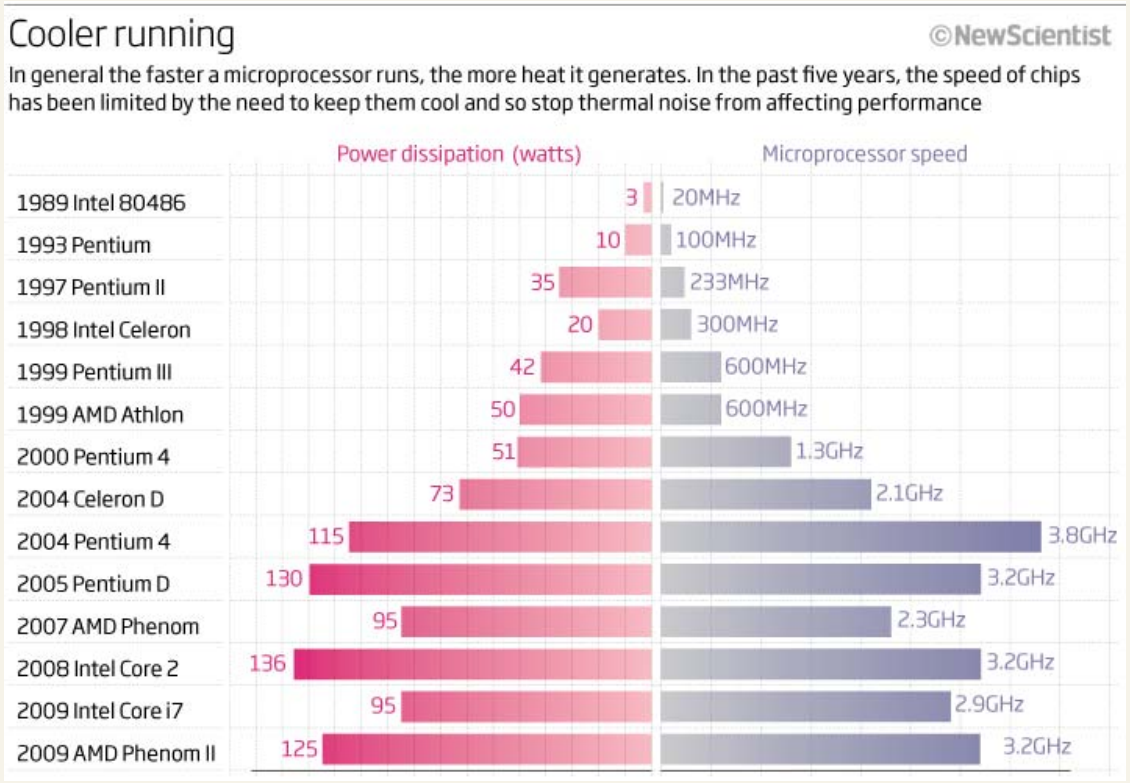
To date these two problems we considered independently by different communities

Few hints on these topics…

Heat dissipation in computing devices is a serious problem







E. Pop, *Energy Dissipation and Transport in Nanoscale Devices*, Nano Res (2010) 3: 147–169

Energy inpact of ICT is under discussion

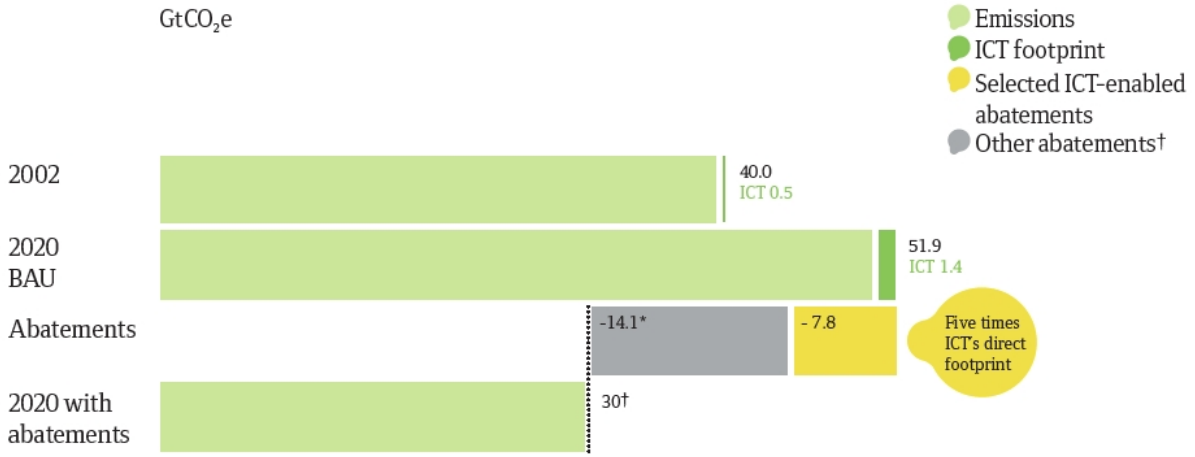
Objectives of the Consultation Workshop (Brussels, 8-9 February 2010**):**
Disruptive Solutions for Energy Efficient ICT

It will be **a clear future priority** world wide to decrease mankind's carbon footprint.

According to the SMART2020 study, the share of ICT on the world wide energy consumption today is in the range of 2-5%.

Hence, it becomes more and more important to consider and improve the energy efficiency of ICT.
On the **short term**, it will be an obvious and practical solution to exploit better the potential of technologies that already exist or are currently in the making. On the **long term**, new and disruptive ideas will be needed, and **we must start to search for those ideas already now**.

Fig. 1 ICT impact: The global footprint and the enabling effect



* For example, avoided deforestation, wind power or biofuels.
† 21.9 $GtCO_2e$ abatements were identified in the McKinsey abatement cost curve and from estimates in this study. Source: Enkvist P., T. Naucler and J. Rosander (2007), *'A Cost Curve for Greenhouse Gas Reduction'*, The McKinsey Quarterly, Number 1.

http://cordis.europa.eu/fp7/ict/fet-proactive/docs/shapefetip-wp2011-12-10_en.pdf

There are fundamental physics **LIMITS** that are relevant

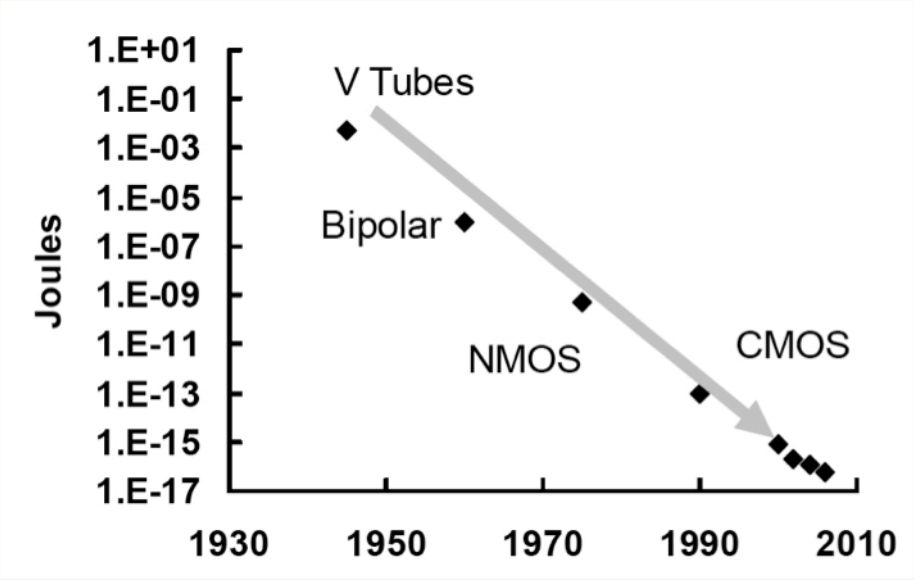
1. Landauer limit to minimum energy for logically irreversible operation

$$E_{min} = KT \log 2 = 10^{-21} \text{ J}$$

2. Quantum limit from Energy/time uncertainity relation

$$\Delta t = \pi\hbar/2E$$

Margolus, N. & Levitin, L. B.
The maximum speed of dynamical evolution.
Physica D 120, 188–195 (1998)



Energy per elementary logic operation. From: Shekhar Borkar, Electronics beyond nano-scale CMOS, Proceedings of the 43rd annual Design Automation Conference, p. 807, San Francisco, CA, USA, 2006

Noise will become increasingly important in ICT

INSTITUTE OF PHYSICS PUBLISHING — REPORTS ON PROGRESS IN PHYSICS
Rep. Prog. Phys. **68** (2005) 2701–2746 — doi:10.1088/0034-4885/68/12/R01

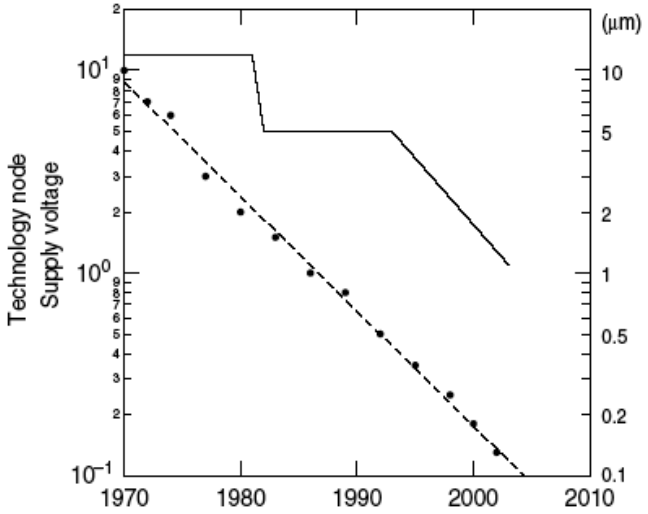
Physical limits of silicon transistors and circuits

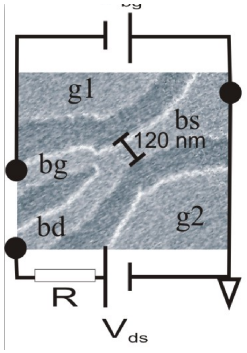
Robert W Keyes

IBM Research Division, Yorktown, NY 10598, USA

Received 27 April 2005, in final form 11 August 2005
Published 19 September 2005
Online at stacks.iop.org/RoPP/68/2701

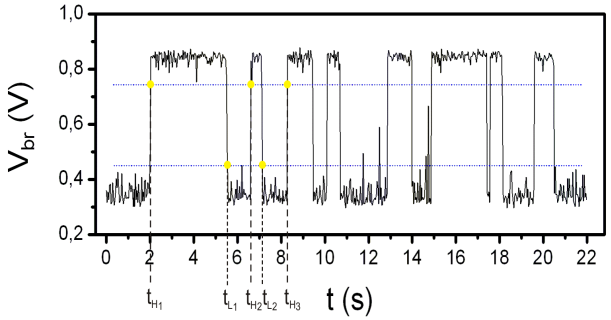
Progressive decrease in supply voltage requires noise tollerance



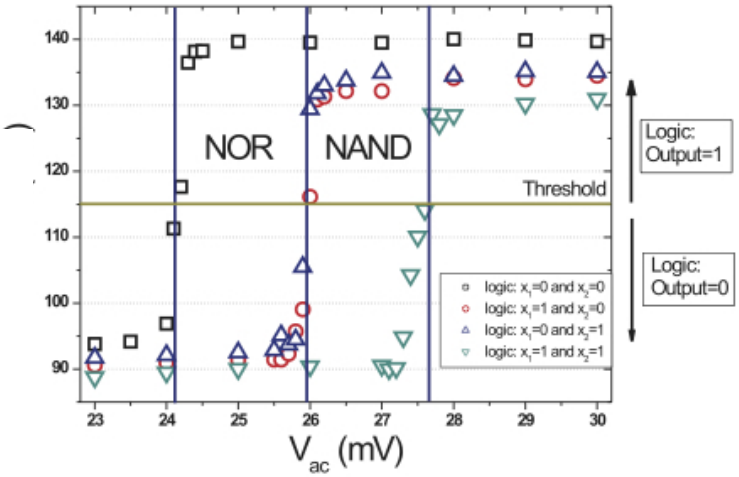


Nanoscale architecture

Bistable stochastic dynamics

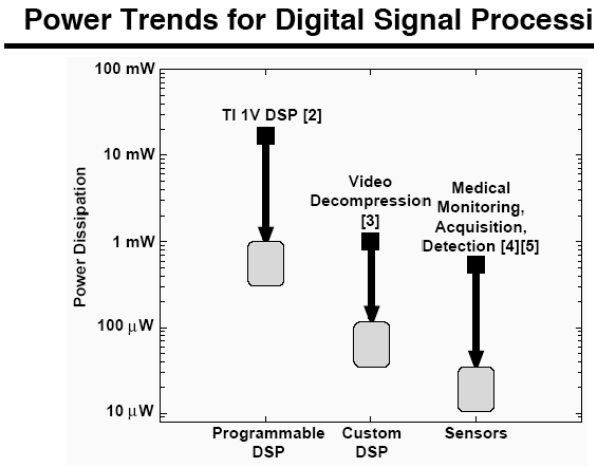


Noise operated universal logic gates



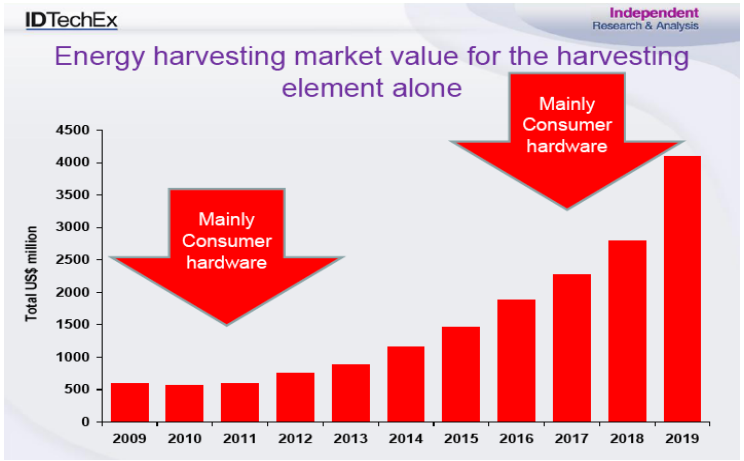
Universal and reconfigurable logic gates in a compact three-terminal resonant tunneling diode, L. Worschech; F. Hartmann; T. Y. Kim; S. Hofling; M. Kamp; A. Forchel; J. Ahopelto; I. Neri; A. Dari; L. Gammaitoni , APL 96, 042112, (2010)

Future ICT will be characterized by pervasive computing



Decreses the power demand for ICT devices

Increases the market for portable micro-to-nano power generators



Guardian Angels (GA's) are zero-power smart autonomous systems featuring sensing, computation and communication. They can harvest different kinds of energy.

From Florin Udrea presentation at Scientific Session
Sustainable ICT: Micro and Nanoscale Energy Management
Budapest, May 2011

Toward zero-power ICT

We would like to address all these topics within one unifying frame:

Energy efficiency in micro and nanoscale devices

Coordinating this research effort is the purpose of our C.A. ZEROPOWER (www.zero-power.eu)

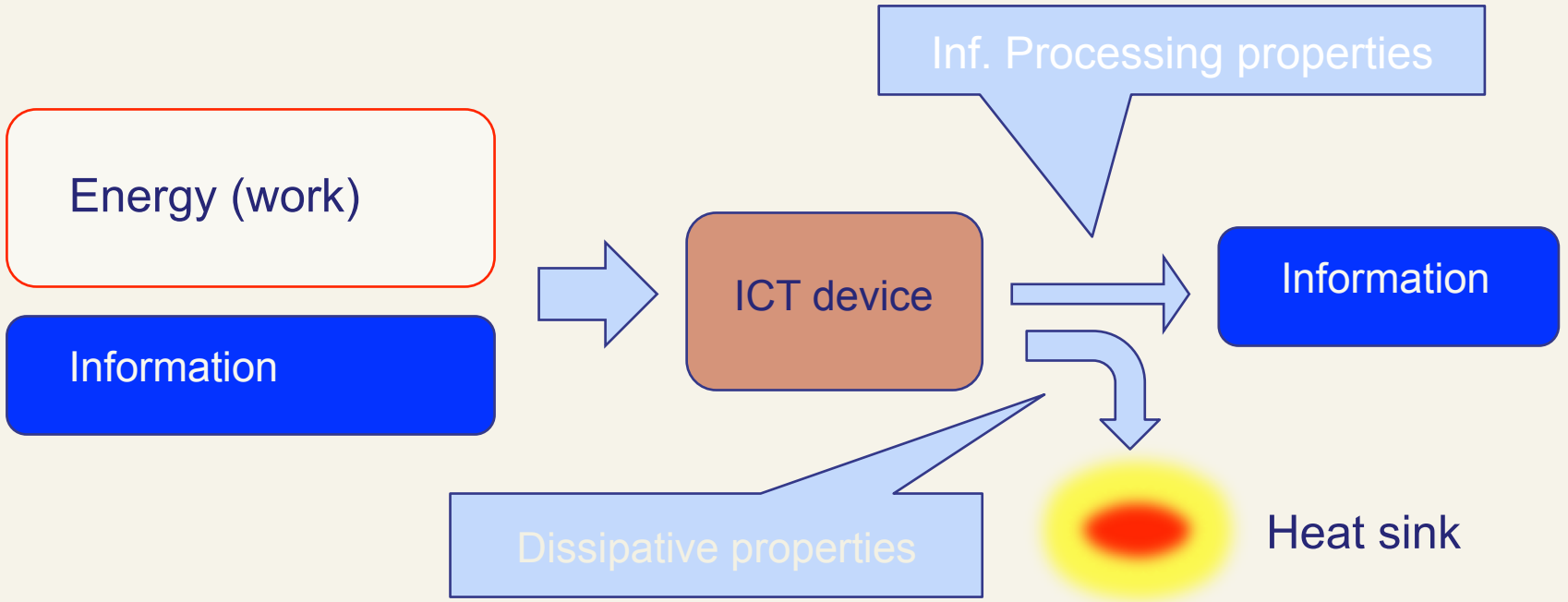
ZERØPOWER

4 partners:
NiPS Lab (IT), UAB (Sp), Tyndal (Ir),
Univ Glasgow (UK)
0.6 M€, 3 years, lead by NiPS

www.zero-power.eu

Key-point in our effort:
A general approach to ICT devices as micro/nano machines

An **ICT device** is a machine that inputs information and energy (under the form of work), processes both and outputs information and energy (mostly under the form of heat).



Energy efficiency is usually defined as the percentage of energy input to a device that is consumed in useful work and not wasted as useless heat, **however ...**

… however this definition **does not apply** when we have to deal with processes taking place at nanoscale.

The well-known laws of heat and work transformation that lie at the base of the classical thermodynamics are going to **need a rethinking**. The very basic mechanism behind energy dissipation requires a new definition when non-equilibrium processes involving only few degrees of freedom are considered.

CHALLENGE:

the description of **energy transformation processes at the nanoscale** aimed at unveiling new mechanisms for powering next generations of ICT devices.

European Commission policy toward these issues in FPVII

ICT – FET (Future and Emerging Technologies)

FET proactive initiative: Towards Zero-Power ICT

(http://cordis.europa.eu/fp7/ict/fet-proactive/2zerop_en.html)

Extract from ICT Work programme 2009-2010 - Objective ICT-2009 8.6 – Call 5:
New disruptive directions are needed for energy-harvesting technologies at the nanometre and molecular scale, and their integration with low-power ICT into autonomous nano-scale devices for sensing, processing, actuating and communication.

Three projects have been funded with a budget of 7 M€.
- **SINAPS** will employ semiconductor nanowires both for energy harvesting of electromagnetic radiation and for (bio-) chemical sensing.
- **GREEN SILICON** will harvest energy from temperature gradients with zero-, one- and two-dimensional silicon silicon-germanium superlattices.
- **NANOPOWER** will investigate the fundamentals of energy harvesting at the nano-scale.

Starting date is 1st of August, 2010, end date 31th July 2013.

NANOPOWER

Nanoscale energy management for powering ICT devices

www.nanopwr.eu

6 partners:
Wurzburg (Ger), ICN (Sp), VTT (Fi), Univ Geneva (Ch), Unicam (It)
2.6 M€, 3 years, lead by NiPS

NANOPOWER is an EC funded project (Objective ICT-2009 8.6 – Call 5, GA no: 256959) under the **FET proactive initiative "Toward Zero-Power ICT" (2zeroP)**

what

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.

The technological objective of the project is to integrate such technologies into autonomous nanoscale systems to allow new, low-power ICT architectures to find their way into devices.

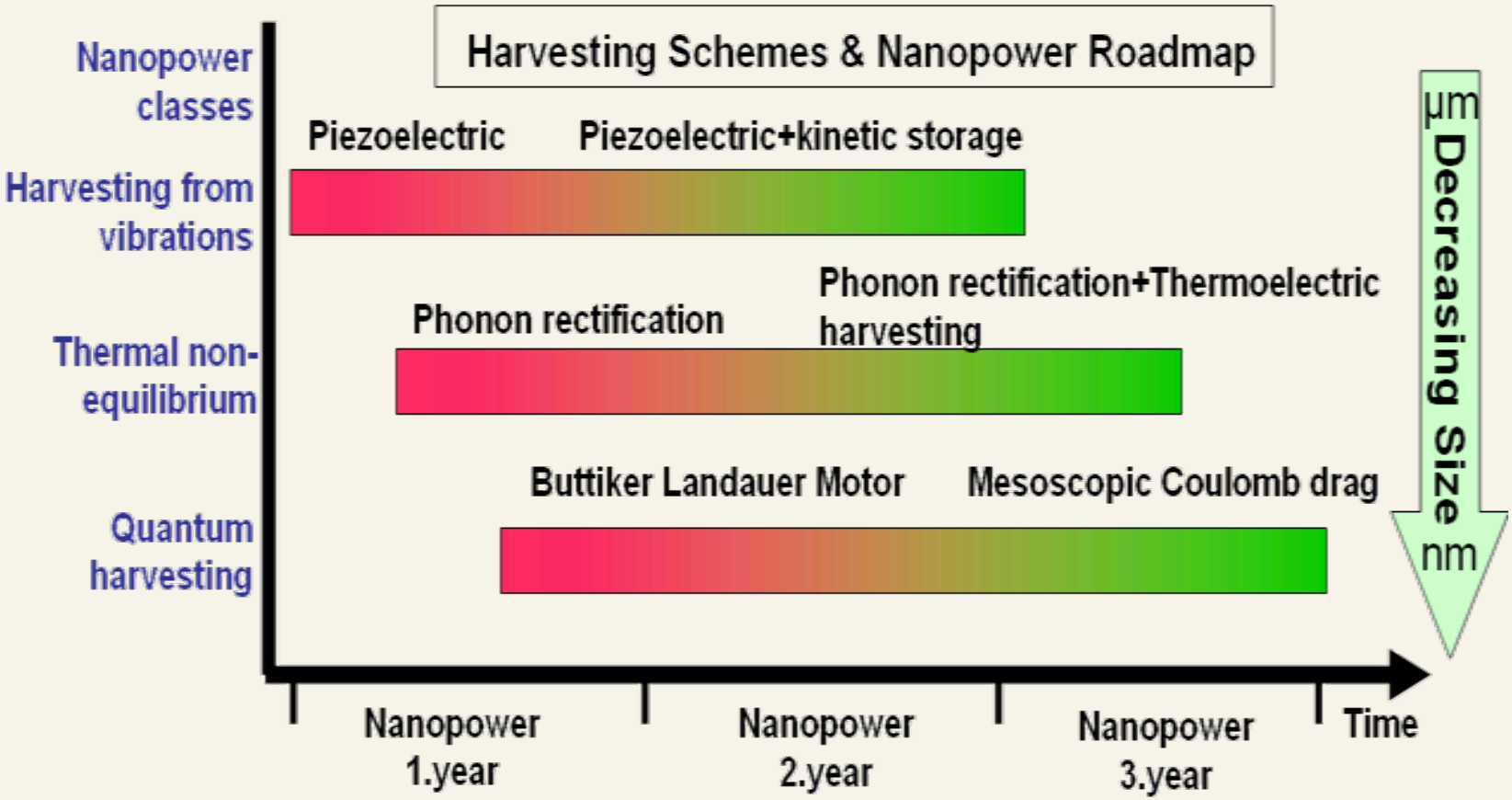
In a joint effort, the NANOPOWER consortium composed by word leading experts in the fabrication of Si and III-V semiconductor nanodevices, fundamental and applied modelling as well as design and integration of ICT architectures will fabricate, test and evaluate new challenging prototype devices:

- ✓ *Nanomechanical nonlinear oscillators*
- ✓ *Phonon rectifiers*
- ✓ *quantum harvesters*

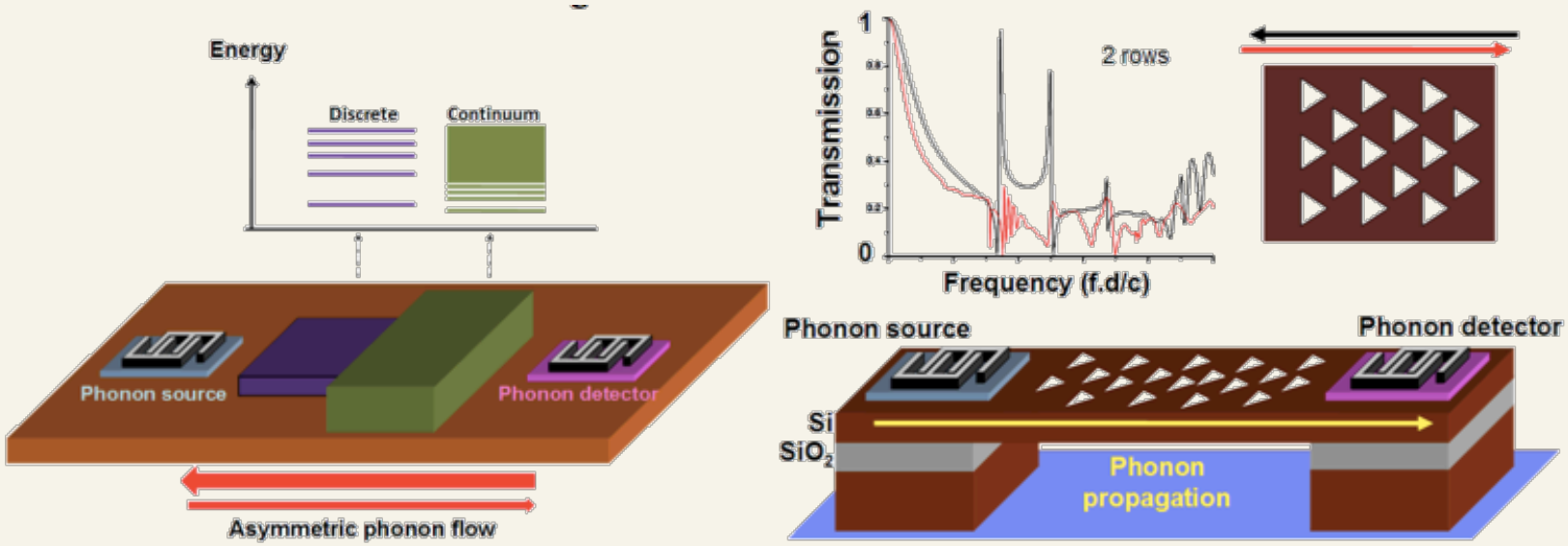
addressing applied prototypes and non-equilibrium processes down to the quantum level.

when

2010 - 2013



Phonon rectification



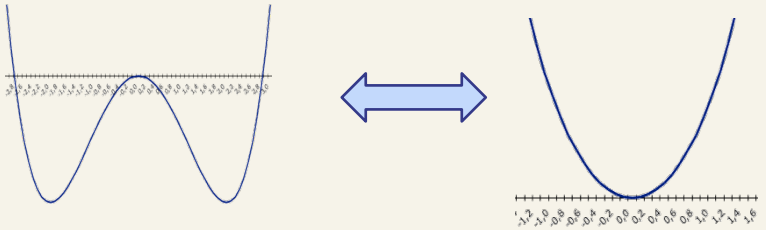
Two classes of phonon rectifiers will be studied.
Left*: Phonon cavities with discrete unmatched phonon modes rectify the phonon propagation (e.g.* inorganic quantum wires or nanorods, such as those of Indium Tin Oxide*).*
Right*: Phononic crystals will help to control phonon transmission and storage*

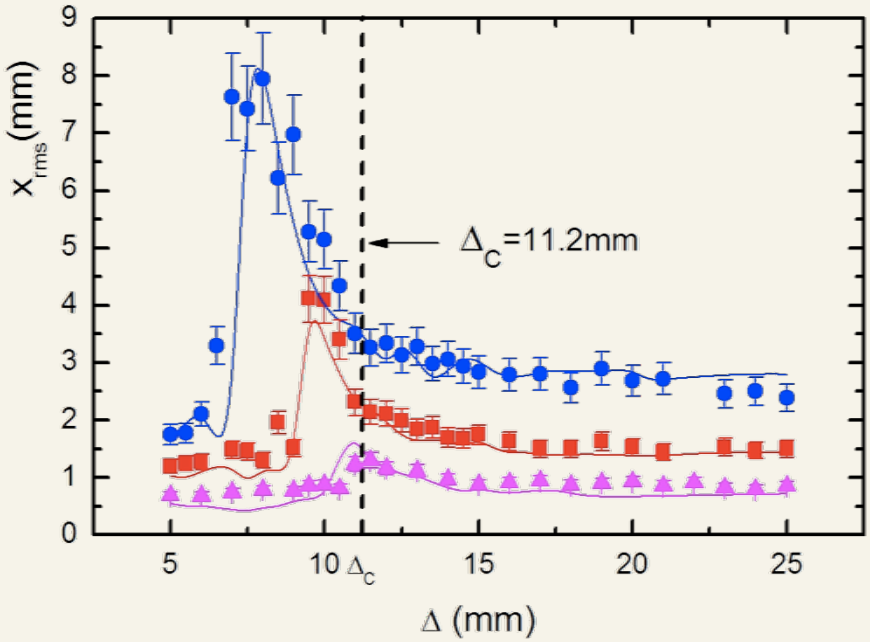
Ref. C O'Dwyer et al, Nature Nanotechnology **4** 239 (2009); R Krishna et al., Solid State Commun **144** 194 (2007).

Noises energy harvesting

NON-Linear mechanical oscillators

$$U(x) = \frac{1}{2}k_e x^2 + (Ax^2 + B\Delta^2)^{-3/2}$$





Available on the App Store

http://itunes.apple.com/app/wisepower

Nonlinear Energy Harvesting, F. Cottone; H. Vocca; L. Gammaitoni, Physical Review Letters, 102, 080601 (2009)

Dissemination activity

Scientific Sessions

"Energy efficient ICT: toward zero-power devices for a greener planet" ICT2010 - 28th September 2010 Brussels

"Sustainable ICT: Micro and Nanoscale Energy Management " FET11 - 6th May 2011 Budapest


NANOENERGY
L E T T E R S

NANOENERGY LETTERS is a newsletter created in order to help the circulation of news and thoughts about micro and nano energies.

But... what are micro and nano energies? With these terms we intend to address the many different tiny energies present in micro and nanoscale physical systems. The role of micro-energies, indeed is more and more frequently evoked in fields as diverse as nano-electronics, computer science, micro-robotics, wireless telecommunications and it is believed that in general they could play a role in powering the future generations of Information and Communication Technology (ICT) devices. In this newsletter we would like to discuss about these energies, about their role and potential applications together with the physical foundation of this discipline. This newsletter is open to the contribution of all the interested readers and is specially aimed at reaching those readers involved in industry and innovative SMEs as an humble attempt to bridge the gap between Academia and Industry.

With your help we will try to keep it twice a year. LG

Newsletter

A digital newsletter specifically oriented for people interested in nanoscale energy harvesting technology.

www.zero-power.eu

Micro-Energy day
14 april 2011

Events

Micro Energy Day: a public awarness event
www.microenergyday.eu

Educational activity: Summer school

www.nipslab.org/summerschool

2010

2011

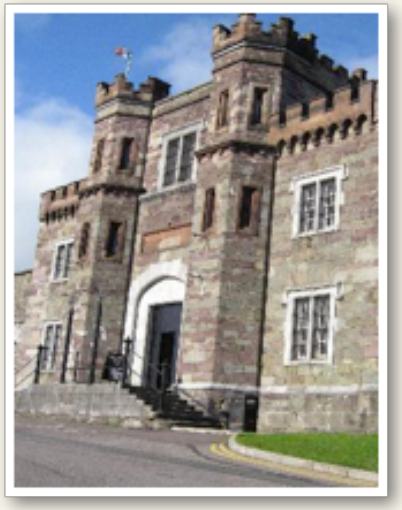
Future events

- **ZEROPOWER Workshop**

Cork, Oct 25-27 2011

Finalized to build the emerging ICT-Energy related community, at networking existing “energy efficiency” national, regional or international activities/ programmes in view of exploiting synergies, maximizing impact and contributing to the definition of international cooperation strategies and/or the development of research collaborations.

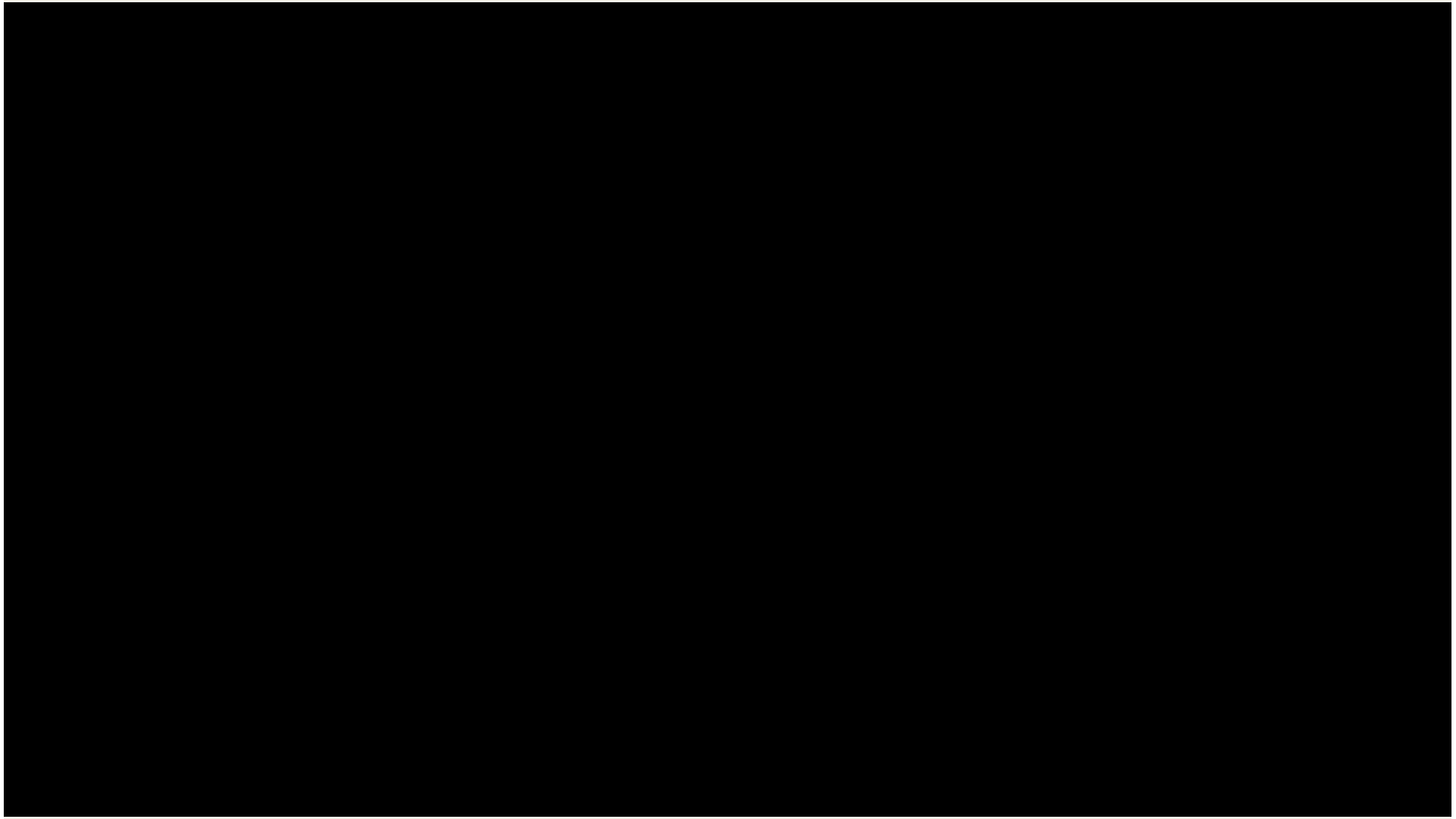
Infos on: www.zero-power.eu



River Lee Hotel,
Cork (IR)
Oct. 25-27 2011

www.zero-power.eu

NANOPOWER ZEROPOWER WISEPOWER



Video available on: http://youtu.be/GrKDnEhK130

SEVENTH FRAMEWORK PROGRAMME