NANOENERGY LETTERS number three.

The field of micro and nano energies is expanding and its role and importance is increasing. Societies reliance and use of Information Communications Technology (ICT) is increasing with 2% of all energy consumption now the result of ICT use. The SMART2020 report foresees that this percentage will increase up to 5% by the end of this decade. The energy consumption and carbon dioxide emission from the expanding ICT use, however, is unsustainable and will impact heavily on future climate change. Methods are required to make ICT technology more energy efficient but also the development of new self-harvesting technologies and nano-scale systems ZEROPOWER through the harvesting of waste energy from the environment are also required. Such technologies provide an opportunity for Europe to lead and generate significant economic benefit whilst simultaneously addressing climate change, healthcare and manufacturing efficiency benefits. Developing ZEROPOWER energy harvesting technology will be key for Europe to meet many of the Europe 2020 targets. To achieve such goals, Europe needs to invest in research and development programmes to be first to deliver these technologies to market. Therefore the potential for positive return on investment for developing ZEROPOWER technology is enormous. To address this challenge we promoted the ZEROPOWER community and this newsletter is one of the instruments that we are putting in place. Another instrument is the organisation of community workshops and meetings. If you are interested in joining our efforts save the date for the next ZEROPOWER workshop: Glasgow, 3-4 July, 2012.

We are looking forward to meeting you there! (LG)
MicroEnergy Day 2012

For the third year the NiPS laboratory (www.nipslab.org) from University of Perugia (Italy) launches the “MicroEnergy day” project to raise the awareness on micro-energies among the general public. The MicroEnergy day will take place on the 21st of June during the European Sustainable Energy Week 2012 (www.esew.eu) and is included among the dissemination actions that the EC funded Nanopower and Zeropower projects have been developing for the last two years to communicate what micro-energies are and how relevant they can be for the future of ICT.

The main feature of the MicroEnergy day is the creativity to be used to imagine an event that can engage, interest, entertain and inform on micro-energies. The event should be addressed to both non-expert audience interested on energy issues and experts in the energy research field. The main goal is to widen the set of information that the general audience have about sustainable energies. Along with the classical sustainable macroscopic energies such as solar and wind power general public should start conceiving micro-energy as a crucial tile of the energy jigsaw.

Last year the Nanerg Lab of the Universitat Autònoma de Barcelona organised a Science Café moderated by Gabriel Abadal Berini, while the NiPS Laboratory in Perugia organised the first battery free party, an evening event where people where invited to come with and electronic equipment that can work without battery to enter the competition for the best battery free device. The presentation of an Italian book about sustainability “Manuale di sopravvivenza energetica” was combined with the competition.

The MicroEnergy day can be also addressed to schools as you might find out checking the website to join the project and read some suggestions to organise your own event www.microenergycday.eu. For further information do not hesitate to contact Leonardo Alfonsi at comunicazione@nipslab.org.

Future and Emerging Technologies (FET) is the ICT incubator and pathfinder for new ideas and themes for long-term research in the area of information and communication technologies. Its mission is to promote high risk research, offset by potential breakthrough with high technological or societal impact.

The FET11 Conference proceedings are published online at: http://www.sciencedirect.com/science/journal/18770509

Do not forget... the new issue of FET NEWSLETTER !!!
Innovative energy

The Europe’s next frontier is just around the corner and the year 2020 is an horizon not too far away to transform Europe in a continent where innovative ideas shape the everyday life. President José Manuel Barroso of the European Commission stressed these concepts opening the first Innovation Convention, a showcase of innovative ideas, projects and prototypes, held in Brussels on the 5th and the 6th of December 2011. Barroso highlighted how the current crisis obliges to conceive a new approach both in terms of financial rules and of motors for a stronger economy. Research will be one of these motors as the budget for the next framework programme “Horizon 2020” seems to prove: 80 billion euros are planned to be invested on research and innovation by the European Commission within a seven years programme from 2014 to 2020 a 46% increase in this field compared to the FP7. Barroso also said to the over 1000 delegates attending the conference that more flexible procedures will be developed to access these budget and a unique procedure for European patents will be introduced to allow smart ideas entering quickly the market worldwide. You won’t be surprised by the role that energy will play in the “Innovative Union” context but you might be astonished by the importance that micro energies will have among the others as stressed during the talk of the European Commissioner for Research, Innovation and Science Máire Geoghegan-Quinn who opened the exhibition area where the Nanopower and Zeropower stand was. The Nanopower proposal to present the state of the art in microenergy fields was accepted among 450 proposals submitted from all over Europe and presented the only over 50 stands to present micro energy topics and research within the exhibition area at the Square Centre in Brussels where the conference took place. Nanopower and Zeropower research and goals were presented by a delegation of the NiPS Laboratory from Perugia to journalists, general public, stakeholders and politicians through interactive exhibits and printed material about the European projects. During the first day a live connection with one of the most popular national radio programme in Italy was realized talking about microenergies and on the second day the Italian Minister for Research Francesco Profumo visited the stand congratulating with Luca Gammaitoni, the NiPS Laboratory director, for the brilliant development in this field and for the European dimension of these two projects.

Leonardo Alfonsi
Nips Laboratory - Università di Perugia (IT)

ZEROPOWER Workshop

The ZEROPOWER Coordination and Support Action aims to create a coordination activity among consortia involved in “Toward Zero-Power ICT” research projects (FET proactive call FP7-ICT-2009-5, Objective 8.6) and communities of scientists interested in energy harvesting and low power, energy efficient ICT.

The project organized a workshop in Cork on 26-27 Oct 2011, with the aim to build the emerging ICT-Energy related community by networking existing national, regional or international activities and programmes in “energy efficiency” with a view to exploiting synergies, maximizing impact and contributing to the definition of international cooperation strategies and the development of research collaboration.

More information on: http://www.zero-power.eu/
SUMMER SCHOOL: Micro and nanoscale Energy Harvesting

The Noise in Physical System Laboratory (NiPS Lab) at University of Perugia (Italy) organizes the third edition of NiPS Summer School and Workshop devoted to "Energy Harvesting at micro and nanoscale" to be held in Erice (Sicily, IT) on 23-27 July 2012.

NiPS Summer School 2012, supported by European Commission under the Coordination and Support Action ZEROPOWER, is open to all scientists interested in the physical foundations and practical applications of energy harvesting at micro and nanoscale. As part of the school there is a workshop where students and external participants can present the result of their research.

Topics covered at the school:

- Introduction to Energy Harvesting (EH)
- Linear and non-linear vibration H.
- Thermoelectric efficiency
- Noise rectification
- Phonon engineering for EH
- MEMS/NEMS design and realization
- Micro/Nano devices for EH
- ICT applications of EH
- Future technological trends: Beyond CMOS technology and Energy Efficiency.

TO REMEMBER

School location: Erice (Sicily), IT

Important dates:

July 23-28 2012: SUMMER SCHOOL
- March 1 2012: Student registration opens
- July 1 2012: Student registration closes

Website: www.nipslab.org/summerschool

Images from 2011 NiPS Summer School held at Hotel Colle della Trinità in Perugia (IT) on 1-5 August 2011.

The Noise in Physical System Laboratory organized the 2011 NiPS Summer School on “Energy Harvesting at micro and nanoscale”. The school, supported by the EC Fet Proactive project NANOPOWER and the Coordination and Support Action ZEROPOWER, and by the Office of Naval Research Europe, has seen the participation of more than 30 graduate students, post-docs and young researchers coming from 9 different countries. Attached to the school there was a two days workshop where the students and external participants presented the result of their research. The workshop covered a wider range of subjects under the title of “Energy management at micro and nanoscale”.

The program of the school, pictures of the participants and PDFs of the slides presented at the lectures are available at www.nipslab.org/summerschool2011.

This has been the second edition of the school. The 2011 NiPS Summer School has seen the participation of more than 35 participants (www.nipslab.org/summerschool2010).

Luca Gammaitoni, director of the School, lecturing at the NiPS Summer School 2011, in Perugia (IT).
Accurate Thermoelectric Measurements

The EC GREEN Silicon project is investigating how to produce thermoelectric energy harvesters using microfabrication techniques that could potentially power autonomous sensors systems. Present thermoelectric devices that convert thermal energy into electricity use bismuth telluride and antimony telluride but since tellurium is the 8th rarest element on the planet, large scale market penetration of thermoelectrics would be difficult and expensive with present technology. The GREEN Silicon project is pioneering silicon germanium heterostructures on top of silicon wafers so that the energy harvesters are not just made from more abundant and sustainable materials but also the harvesters can be integrated with microelectronic circuits and sensors to enable integrated autonomous sensors. The partners are: the University of Glasgow, U.K. who are fabricating and charactering the thermoelectric materials and generators; the L-NESS laboratory of the Politecnico di Milano, Italy, who are growing the SiGe materials; ETH Zurich, Switzerland, who are undertaking electron microscopy characterisation of the materials and devices; and the University of Linz, Austria, who are undertaking x-ray diffraction characterisation.

The Seebeck effect where a temperature gradient across a semiconductor results in a voltage proportional to the temperature difference was originally discovered in 1822 and while many thermoelectric and Peltier cooling devices are in the market place, the efficiency and cost means that the harvesters can be integrated with microelectronic circuits and sensors to enable integrated autonomous sensors. The partners are:- the University of Glasgow, U.K. who are fabricating and charactering the thermoelectric materials and generators; the L-NESS laboratory of the Politecnico di Milano, Italy, who are growing the SiGe materials; ETH Zurich, Switzerland, who are undertaking electron microscopy characterisation of the materials and devices; and the University of Linz, Austria, who are undertaking x-ray diffraction characterisation.

The Seebeck effect where a temperature gradient across a semiconductor results in a voltage proportional to the temperature difference was originally discovered in 1822 and while many thermoelectric and Peltier cooling devices are in the market place, the efficiency and cost means that thermoelectrics are still an expensive source of electricity. GREEN Silicon is aiming to improve thermoelectrics through the use of low dimensional structures that help increase the Seebeck coefficient (the rate of change of voltage with temperature) through the increase of the change of the density of states across the Fermi energy. The figures of merit for thermoelectric materials and devices is ZT which equals the square of the Seebeck coefficient times the electrical conductivity times the temperature divided by the thermal conductivity. Measuring temperature and electrical conductivity can be achieved routinely with high accuracy (uncertainties well below 0.1%) but the measurement of thermal conductivity even in standards laboratories on the macroscale can have uncertainties up to 50%.

Fig. 1: An electron microscope image of the metal tracks for a thermocouple going up the side of a Si pyramid AFM tip that is about 200 µm high and forms a thermocouple at the end of the AFM tip.

In the GREEN Silicon project we are pioneering a new method at the microscale for the accurate measurement of thermal conductivity. Standard methods use a heater at one end of a rod like sample with thermometers at both ends to measure the temperature gradient down the sample. The major problems with such an approach is knowing exactly how much thermal energy as heat enters and leaves the sample at each end and also one has to assume a linear temperature gradient down the sample. The second approach is the $3\omega$ technique which uses a heater on top of a bulk sample with an applied current at $2\omega$ which produces Joule heating at $2\omega$, a resistance at $2\omega$ and so measuring the voltage at $3\omega$ on the same 4 terminal metal heater can be used to extract a thermal conductivity. This scheme uses a trucated series to extract the thermal conductivity but this approximation is only valid for uniform and homogenous materials. For the GREEN Silicon project we are using superlattices, nanowires and quantum dots to deliberately make non-uniform structures that enhance the scattering of phonons so the $3\omega$ technique even in the differential form is not valid for our materials.

Fig. 2: A free standing Hall bar with heaters at each end, electrical contacts and thermometers to allow the accurate measurement of electrical conductivity, thermal conductivity and Seebeck coefficient.

In GREEN Silicon we are using microfabricated thermocouples on the end of an atomic force microscope (AFM) tip (Fig. 1) that can be scanned down the sample. The thermocouples are calibrated using a heater which heats a resistor on top of which is placed the AFM tip. By measuring the Johnson noise in the resistor, an absolute calibration of the temperature can be achieved to around 0.1 K accuracy [Dobson et al.]. This measurement of temperature through the whole sample allows much more accurate determination of the heat flow and therefore thermal conductivity when the temperature is modelled. As the tip of the AFM can always remove or add some heat from the samples thereby perturbing the measurement, a number of measurements are taken with the sample and tip at thermal equilibrium so that the amount of perturbation can be quantitatively determined.

For these thermal measurements of around 10 µm thick heterostructure material which should have a low thermal conductivity grown on top of a 400 µm thick silicon wafer with a high thermal conductivity, the substrate needs to be removed from the measurement. To achieve this we grow the heterolayers on top of a silicon-on-insulator wafer where we have a thin SiO2 layer. This layer helps with the fabrication of devices where we make a free standing Hall bar with electrical contacts so that the electrical conductivity, Seebeck coefficient and (using the AFM technique) thermal conductivity can be obtained on a single sample (Fig. 2). Initial measurements with the thermal AFM have produced thermal conductivity values on SiGe heterostructure samples which are a factor of 100 different from the differential $3\omega$ technique. The GREEN Silicon project is now working with the National Physical Laboratory (NPL), the U.K.’s standards laboratory, to help improve the accuracy of thermal conductivity and thermoelectric measurements to allow more accurate comparisons of different results and materials in the future.


Douglas Paul
for GREEN Silicon
Nanoscale energy harvesting with graphene

Energy harvesting, energy storing and energy conversion are attracting a considerable interest in many fields. The main driving force is the pursuit of clean energy sources compatible with a sustainable development, but the search of efficient schemes for power supplying of increasingly small electronic devices, is equally important.

Advantages and drawbacks of several energy scavenging strategies have been discussed in several studies. The bottom line is that, although facing some limitations, energy harvesting appears to be feasible. Efforts are now being made to transfer some of these harvesting schemes to the nanoscale or —more excitingly—to devise new ones. Now, the relevant questions are two: “Can we do it?” on the one hand, and “Do we want to do it?”, implying: is there any intrinsic advantage or if it is just a matter to do things smaller? In a recent publication [1] we have explored these two points.

It is well established and intuitive that using linear resonators to convert vibrations to other forms of energy is not an efficient approach. Linear resonators are the best solution one can think of to respond to a specific frequency —the resonant frequency—, but out of such narrow frequency interval they behave poorly. This is exactly what must be avoided when dealing with the broad spectra typical of ambient energy sources that one aims at harvesting. An interesting workaround, a proof-of-principle of which has been recently presented [2], consists in engineering a non-linearity in an otherwise linear system. In our study [1] we have shown that such an approach can be implemented at the nanoscale by applying a moderate compressive strain to a graphene sheet or any other exfoliable material. The idea is very simple: a slightly compressed sheet favors two symmetric and equivalent buckled configurations (shown in the Figure). These minima are separated by a barrier of tunable height (tunable because it depends on the compression), whose saddle point corresponds to the flat, strained sheet. In this way, if the barrier is high, but not too high, motion in one of the potential wells will be combined with large excursions from one well to the other, maximizing the mean root mean square of the displacement and the response to a broader frequency range.

This answers the first of our two questions: yes, we can in principle do it. Now it is matter of deciding if it is worth it. The answer, we believe, is again yes. The barrier that can be tuned by controlling the compressive strain is commensurate to the scale of system. In other words, it can be made small enough for the system to respond to energy sources that are freely available, but poses a very low power density, such as thermal fluctuations. The prototype of Cottone et al. [2] will harvest efficiently ambient vibrations such as low frequency seismic waves, but will not respond to room temperature fluctuations. This is where nanoscale harvesting comes into play! A nanoelectronics circuit has very moderate power requirements, then energy can be harvested from equally moderate waste sources, such as thermal fluctuations, Joule heating of nanoscale components... sources that have a too low power density to be transduced by micro or macroscopic devices.

Finally, it is remarkable that on top of the applications that can be envisaged—a science fiction world of batteryless nanodevices—these study brings us to a new an exciting place where ab initio electronic structure modeling meets statistical physics, two fields that have been evolving in parallel, at a large extent, and are now coming together.

Riccardo Rurali
Institut de Ciència de Materials de Barcelona (ICMAB–CSIC), Spain

Real vibrations database

Many efforts to power micro electronic devices by pumping energy from the environment have been attempted in the recent years. Among the renewable energy sources, kinetic energy is undoubtedly the most widely studied for applications to the micro energy generation. Kinetic energy harvesting requires a transduction mechanism to generate electrical energy from motion like piezoelectric, electromagnetic, magnetostrictive or inductive. This can happen via a mechanical coupling between the moving body and a physical device capable of generating electricity.

In real world applications it is important to test such energy harvesters on the field, with the real environmental vibrations, in order to improve, tune and set up all the parameters at best. During the R&D phase, this is not always possible and so laboratory tests are performed using artificial noises. However, such signals are a good approximation of real world vibrations only in a few specific cases, e.g. in linear systems. For nonlinear oscillators the use of signals reproducing the characteristics of real vibrations is all the more crucial to understand how to match the dynamics of the harvesters to the noise sources.

For these reasons we decided to develop a database, to store time series of heterogeneous vibration sources that could be used to reproduce in laboratory the operating conditions of the harvesters.

The interface to the database access is offered by a web interface that provides navigation, search and download capabilities. By selecting an entry it is possible to view the information associated with it like title, description, sampling rate, duration, acquisition conditions, RMS, standard deviation and mean for each orthogonal component. Using the search box it is possible to search through the database by keywords present on title or description. The records in the database can also be sorted out to help locate specific data more quickly. By default, the database is ordered by creation date. It is possible to sort the entries even by name or magnitude of acceleration. It is also possible to attach free tags to each entry and filter the signals by tags associated with...
The entries are not classified a priori. Thanks to this approach and the tags associated with the entry the use of the database results more flexible. The vibration signals contained on the database are acquired using two different acquisition systems. These systems differ by portability, maximum resolution in frequency and maximum acceleration. The portable one is a commercial device, the SlamStick™, produced by Midé Technology Corporation (USA). It is a high-speed ultra-portable rechargeable data logger capable of measuring acceleration in all the three axes. The device uses a USB port to transfer data to a computer. The second acquisition system is composed by a tri-axial accelerometer, a data acquisition system (DAQ) and a laptop. Due to volume of the components this systems results less portable but it provides data more accurate. The quality of the data depend also by the acquisition methodology followed, in fact there are few common parameters to take into account during the acquisition: the expected frequency content, the expected acceleration, mass ratio between accelerometer and vibration source and the mechanical coupling. By the first two parameters depend the chose of the acquisition system to be used. The mechanical coupling between the accelerometer and the vibrating source is the most crucial parameter to take into account. In fact it may affect the accuracy, limits and usable frequency range of the accelerometer. The interface between the accelerometer and the vibrating source, used to mount the sensor, can create a mechanical filtering effect by isolating and damping high-frequency transferability. In the acquisition campaign we followed all the best practices to ensure that the acceleration data provided are as close as possible to the real vibrations. The database is available at the following web address: http://realvibrations.nipslab.org. While a free access to a subset of the data will be available to all, the access to the full set of data present on the database (approx. 150 entry at this time) will be available upon approbation. To request access to the database please write to realvibrations@nipslab.org.

Igor Neri
Nips Laboratory
Dipartimento di Fisica
Università di Perugia (IT)

Updates on the first year of NANOPOWER

The project “NANOPOWER: Nanoscale energy management for powering ICT devices”, funded under Future and Emerging Technologies (FET) within the ICT theme of the Seventh Framework Programme for Research of the European Commission, has come to its second year. The ambitious objective of this project is the introduction of a new class of nanoscale devices capable of harvesting energy from the environment and transforming it into electric energy, available for powering the next generation of autonomous Information and Communication Technology (ICT) devices. The NANOPOWER consortium, composed by six world leading experts in the fabrication of semiconductor nanodevices, fundamental and applied modelling, as well as design and integration of ICT architectures, is joining the efforts to fabricate, test and evaluate new conception devices (nanomechanical nonlinear oscillators, heat rectification harvesters and quantum harvesters), addressing applied prototypes and non-equilibrium processes down to the quantum level.

The NANOPOWER consortium has been very active in the first year, devoting 103.6 person months (103.6 over 301 in total) to project activities, generating a vast scientific activity that has involved universities, research centers, stockholders and the general public. The first year review meeting of the project was held in Cork (IR) on Oct 25th 2011. A European Commission representative and two external reviewers have determined that “excellent progress has been achieved”. More information on NANOPOWER activities can be found in the project web site: www.nanopwr.eu.

Silvia Lombardi
for NANOPOWER
University of Würzburg (UNIWUE) is a partner within the Nanopower consortium especially engaged with device and fabrication technologies. One topic within the Nanopower project is related to quantum harvesters on the basis of so called Landauer-Büttiker motors and heat-to-current conversion in coupled quantum dots. UNIWUE has a long standing tradition in fabrication of low dimensional III-IV based semiconductor heterostructures.

**Current generation from local hot spots at the micro- and nanoscale**

The main goal of the Nanopower project is energy harvesting for different classes of devices with feature sizes down to the nanoscale.

One emphasis of the project is related to devices, where the energy which has to be harvested is provided from the ambient noise, e.g. fluctuations and random excitations of electron gases. In this regard the question arises, whether or not it is possible to harvest and transduce the otherwise “wasted” amount of energy in such a way that another (low dimensional) electronic devices can be powered.

In solar cells, junctions between p- and n-doped semiconductors lead to a built-in potential serving as slide for charged carriers and as a result a net current is achieved. Usually, it is indeed a distinct geometrical asymmetry in the design of the harvester junction which is fundament for rectification of excited carriers, however, within the framework of the Nanopower project we are also interested in novel class of energy harvesters without such a geometrical asymmetry.

Such devices were proposed by works trading back to the pioneering works of Landauer and Büttiker [1,2], where a Brownian particle can move in a sinusoidal and geometrically symmetric potential. It has been shown that such a particle additionally subject to non-equilibrium noise, where the spatial modulation of the noise has the same period as the periodic potential but a different phase, can contribute to a net particle current. The heat-dependent diffusion is responsible for such a mechanism: it is easier for the particles to overcome a “hot” than a “cold” barrier. For clarity in Figure 1A) a double well potential is sketched. The potential is slightly tilted, e.g. due to an external bias.

Let us now consider two different temperatures at the site of the slopes of the potential, with $T_{cold}$ and $T_{hot}$ (as sketched) and $T_{cold} > T_{hot}$. Due to the higher temperature $T_{hot}$, the activation rate for a particle initially at point D traversing to point A is enhanced. Thus more particles will populate the minimum at A, for a particle initially at point D traversing to point A is

$$I = \frac{\gamma^2}{2m}\exp\left(-\frac{E_0}{T_0}\sin(\phi)\right)$$

$T_0$ is the low and $T_1$ the high temperature, $\gamma$ the damping constant, $m$ the mass of the particles and $\phi$ the phase shift between the periodic heating and electronic potential with barrier height $E_0$. Thus the current output is linear in $T_1$. The net current can also be calculated in the overdamped limit (see also Refs. [4]) with

$$I_{ov} = \frac{\pi^2E_0^2T_1^2}{12E_0^2T_0^2}\exp\left(-\frac{E_0}{T_0}\sin(\phi)\right)$$

and a critical damping constant $\gamma_c$ between the over and underdamped regime can be found by

$$\gamma_c \sim \langle E_0/L \rangle(m/T_0)^{1/2}$$

**Stochastic resonance in nanoelectronic devices**

The nanoelectronic group at UNIWUE is especially interested in noise induced and enhanced signal detection and processing in low dimensional III-IV based semiconductor devices. When decreasing the feature size of electronic devices, fluctuations can reach values in the order of typical device currents. Closely spaced wires can lead to feedback mechanisms which in turn create bistable switching. Subthreshold signals, steep thresholds and noise are basic ingredients for stochastic resonance (SR). SR, originally introduced at the macro scale as a model to explain periodicities in our earth’s climate changes, is a synchronization process of noise with a weak periodic signal. It manifest itself in an optimum output quantity, e.g. spectral response, for noise levels unequal to zero. Thus noise can enhance output signals instead of destroying it. In Figure 2 an example of SR measurements conducted at UNIWUE is shown. For a more detailed discussion on that topic we refer interested readers also to Ref. [5]. In the following, spectral response of bistable-driven resonant-tunneling diodes (RTDs) at room temperature is discussed. In the experiment a periodic modulated, weak light signal with power $P$ was focused on the light active part of the structures, the entrance slit, and by the aid of noise bistable crossing events were triggered to occur. In Figure 2A) a sketch of the layer sequence and an electron microscopy image of a three terminal RTD are shown. The RTDs are based on the GaAs system with a bistable transfer
characteristic. Noise induces transitions from one stable state to the other, which can be synchronized by a weak periodic signal. In Figure 2B) stochastic resonance under weak light excitation is shown. Here the spectral component $<V>$ reaches a maximum for noise powers $P_{\text{noise}}$ unequal to zero.

**Figure 2:** A) Sketch of layer sequence of a GaAs based and trench-etched RTD. Also shown are electron microscopy images of RTD mesas together with the electronic circuit diagram. The RTD is biased with a static dc voltage $V_{\text{dc}}$ superimposed by a stochastic $V_{\text{noise}}$ and periodic $V_{\text{ac}}$ component. On the light active trench of the RTD a periodic chopped laser light is focused. B) The spectral component $<V>$ shows stochastic resonance for an RTD at room temperature under a weak external periodic light modulation with light powers $P_{\text{light}} = 160$ and $400 \text{ nW}$.

**Noise-activated nonlinear dynamic sensors**

As a second class of noise-enhanced transport properties in nanoelectronic systems represent bistable driven, Y-branch junctions. In Figure 3A) an electron microscopy image of a Y-branch is shown. The junction consists of two branches, one stem and respective side gates to control the operation condition. The devices are based on a GaAs/AlGaAs modulation doped heterostructures with a high mobility two dimensional electron gas located 80 nm below the surface. E-beam lithography and dry chemical etching is applied to define the three terminal device. The Y-branch switch can be operated in a bistable condition exploiting the selfgating effect of Y-branches [6]. This is based on a capacitive coupling between the branches. Also in Y-branches noise can lead to transitions between the two possible stable states. It was found that transition rates can be sensitively controlled by external parameters e.g. an external magnetic field. Dependent on the strength of the applied magnetic field the residence times of the switch in each of the two stable states vary. As an output signal of this noise activated nonlinear dynamic sensor the residence time difference $\Delta T$ can be chosen. This is the time difference of the high $T_H$ and the low $T_L$ state. As shown in Figure 3B) $\Delta T$ is sensitive to the applied magnetic field.

**Figure 3:** A) Electron microscopy image of a three-terminal junction together with the electronic circuit diagram. B) Residence time difference $\Delta T$ versus $B$. Within $10 \text{ mT} < B < 45 \text{ mT}$ $\Delta T$ is a linear function of the applied magnetic field.

Interestingly the residence time difference is a linear function around the initial symmetric condition with $\Delta T = 0$ corresponding to a magnetic field strength of $B = 26 \text{ mT}$, which reflects a desired property of any sensors.

**Fabian Hartmann** and **Lukas Worschech**, University of Würzburg (Germany)

---

**SAVE THE DATE**

<table>
<thead>
<tr>
<th>DATE</th>
<th>EVENT</th>
<th>WEBSITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 3-4, 2012 - Glasgow</td>
<td>ZEROPOWER Workshop</td>
<td><a href="http://www.zero-power.eu">www.zero-power.eu</a></td>
</tr>
</tbody>
</table>

**NANOENERGY LETTERS** is realized with the contribution of **NANOPOWER project and ZEROPOWER Coordination and Support Action**, funded under the **Future and Emerging Technologies (FET)** programme within the **ICT theme** of the **Seventh Framework Programme for Research** of the European Commission.