NANOENERGY LETTERS

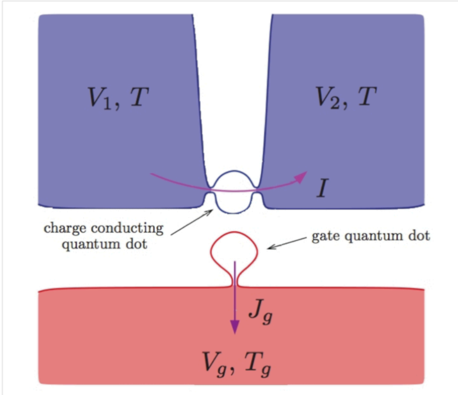
Hot quantum dots

The search for new efficient ways to power small autonomous electronic devices records an important achievement. In the framework of NANOPOWER, a novel class of energy harvesters based on purely quantum effects has been developed.

These "quantum harvesters", as they have been called, are based on the exploitation of strong interaction between charge fluctuations in small, coupled conductors that are at different temperatures in order to create a finite current in one of them. Specifically, the converter consists of a hot quantum dot that acts as the driver of current through a second quantum dot that is electrically isolated from the driver. The energy level structure in the two dots can be engineered to find configurations for which the efficiency of the heat-into-charge-current conversion reaches the Carnot limit. An important novel aspect of this method is the spatial separation of heat and charge current, while in ordinary thermoelectric converters an electric current flows between electrodes at different temperatures and these flows are along the same direction.

In the scheme proposed by the NANOPOWER partner group, led by Markus Buttiker (in photo), at the University of Geneva, a quantum dot is coupled to two 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 (see Figure). The gate is itself structured into a quantum dot that permits carrier exchange with its reservoir. One of the quantum dots is connected to two terminals (at voltages V1 = V2) in order to support an electric current, I. The other quantum dot is connected to a single terminal (at voltage Vg) which is at a higher temperature than the other two. Thus, the charge fluctuations in this dot are increased with respect to those in the other two terminals. The hot terminal supports a heat current, Jg, but no charge transport.

The study realized in Geneva explores the non-equilibrium states of this system and investigate the relation between the charge current flowing through the two terminals of the conductor, and the heat current flowing through the gate terminal at temperature Tg > T.



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. These results allow the design of a new class of solid-state environmental energy to current converters of high efficiency. Exporting these ideas to other mesoscopic systems opens new possibilities for highly efficient solid-state thermoelectric devices: a long-sought dream of energy harvesting.

R. Sánchez and M. Büttiker, Phys. Rev. B 83, 085428 (2011)

Nanoelectromechanical systems for energy harvesting

NOEMS for Energy Laboratory (NANERG LAB), the Catalan partner, in the FET funded Coordination Action ZEROPOWER is an emerging research group that since 2009 explores the possibilities of nano-electro-mechanical devices as transducers in the energy harvesting processes at the nanoscale. Past recent activity on the monolithic and heterogeneous integration of electrostatic (figure 1) and piezoelectric vibrational energy scavengers, has been during last two years redirected and focused to the study of nano-optoelectromechanical systems (NOEMS) as energy harvesters.

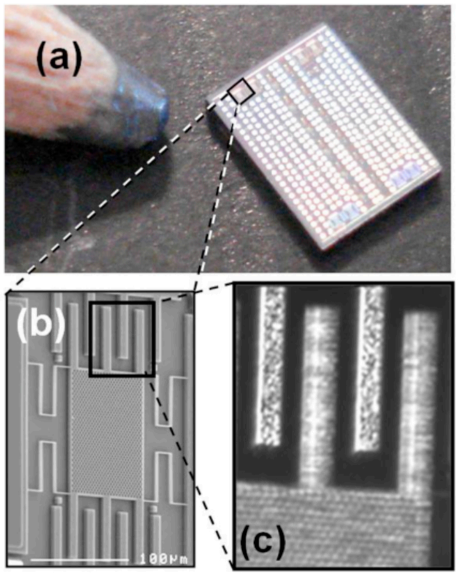


Figure 1: Images of a Harvester on Chip (HoC) prototype. Cells containing the inertial mass and the comb-drive electrostatic transducer (b) are integrated in a CMOS substrate (a). The in-plane resonance (c) is excited with an external vibration of 20.4 kHz.

New concepts as the NEMSTENNA, emerged from the combination of a rectenna with a NEMS resonator, or the OPACMEMS, arisen from the integration of a MEMS resonator with an Optical Antenna, are being developed in collaboration with the group of Prof. Javier Alda from Universidad Complutense de Madrid (UCM). Both concepts aim at extracting energy from electromagnetic radiations in the RF bands (NEMSTENNA) and in the optical regions (OPACMEMS) with special emphasis at wavelengths of λ=1.55 um and λ =10.6 um in the IR sub-region. In the NEMSTENNA (figure 2.a), a NEMS resonator with an embedded permanent electrical charge is excited by the electric field of a RF electromagnetic wave. The mechanical vibration at the resonance is converted to useful electrical power by means of a piezoelectric layer integrated in the NEMSTENNA element. Alternatively, the energy from an IR radiation is selectively adsorbed by a tailored optical antenna composed by an array of nano-dipoles, which has been integrated on a MEMS resonator (figure 2.b). A positive feedback loop established in the phenomenological chain: IR-adsorption, temperature change, stress induced deflection, IR-adsorption dependence on the deflection, will produce a self-