Multisource Nanoenergy Harvesting and Storage in the Mechanical Domain

F. Torres, O. Súchil, P. Bramon, M. López, J. Agustí and G. Abadal

Departament Enginyeria Electrònica, Universitat Autònoma de Barcelona, Edifici Q, Campus Bellaterra, 08193 Bellaterra, Spain
Francesc.Torres@uab.cat

Abstract

Introduction

The research regarding green and sustainable micro and nanosystems has experimented an important increase from few years ago until now. Our work is directly related with this kind of research, specifically with two important parts of it, the generation of the energy to feed the micro/nanoelectronic systems and its storage. The main motivation is the study of new challenges in the energy harvesting research: the needs for new sources, mechanisms and technologies at the nanoscale.

For the energy generation, our research follows two energy harvesting strategies based on non-linear bistable approach and on MEMSTENNA concept. Both strategies could be merged onto one system only, as it is shown below.

For the energy storage, our work is based on a non-classical way, different from which is used by standard batteries which consists on the mechanical energy storage, and follows different ways, but the main one is based in pressing/bending an array of fine wires system [1]. The common denominator of our mechanical storage approach is to load some kind of spring and maintaining this load with a ratchet potential. This approach could maintain the storage energy unlike the batteries based on charge stored, which suffer a certain discharge during time.

Energy Harvesting: Bistable Approach

Based on the research done by the group of professor Gammaitoni [2] our work uses a cantilevers system subjected to a bistable potential which, using ambient vibrations as noise, the cantilevers could jump from one of the potential minimum to the another one and due to this generates energy useful for the system to be powered. This bistable approach has the important advantage that does not need to be designed specifically for one ambient vibration frequency due to the fact that movement of the cantilever does not depends on an excitation at its natural frequency but only on the “noise” of the ambient vibrations.

We have used a commercial AFM cantilever near to a fixed tip at a certain distance [3]. The bistable potential is got putting an electrical charge of the same sign just in the tip of both the AFM cantilever and the fixed part (see figure 1.A).

Using an optical measurement system and changing the distance between the tips, we can measure the jumps between potential minima as is showed in figure 1.B for three different distances. The shorter distance maintains the tip on one of the two minimums of the potential and the longest one has not two minimums of the potential.

MEMSTENNA

MEMSTENNA is a MEMS based rectenna energy harvester that converts a RF signal into direct current electricity. We have used the same AFM tip presented in the previous section as a MEMSTENNA and a dipole antenna to excite it. We have worked in near field conditions, placing the MEMSTENNA near to dipole antenna. Using an optical detection system (the same system used in previous section), we have measured the vibration of the MEMSTENNA and also we have used a piezoelectric vibrometer to excite it in order to compare both excitations.

As we can see in figure 2.A and 2.B the response of the MEMSTENNA follows perfectly the mechanical excitation if the frequency of the dipole antenna is matched with the natural frequency of the AFM tip, but the response of the MEMSTENNA is a convolution between mechanical and RF excitations if the frequency of the emitter dipole antenna is a little bit different than the natural frequency. It is important to point out that our approach for bistable potential and MEMSTENNA uses the same system and thus, we can use both energy harvesting approximations at the same time.

Mechanical Battery

Related with energy harvesting, the researchers look for energy storage systems compatible with the small dimensions. Our purpose is a battery based on mechanical storage rather than electrical storage with the advantage of durability of the energy stored (ideally the battery do not suffer any discharge process) and, depending on the material, it can store a great amount of energy per unit volume or mass

[4]. We are working on two ways: batteries based on mechanical press or bend of a system of fine wires and the other one we are working on the charging process using thermoactuated or photoactuated materials, which change their dimensions through applying thermal energy or light.

For the fine wire based battery, we have chosen ZnO fine wires due to the fact that they could be grown using a simple and cheap process, so called hydrothermal process [1]. We have done a lot of experiments changing the variables of the growth in order to achieve the best way to produce the best fine wires for our purposes (high density, good adhesion to the base of the battery, width and length) [5]. We have worked on changing the temperature, solvent concentrations and initial pH of the solution.

We have calculated the maximum stored energy and we have fixed as the maximum value for the load we can apply to the system the one that produces the linear buckling and also using a young modulus of 16.2 GPa taken from the literature [6]. We obtain values from the low capability of energy storage limit: a critical strain of ε_c = 0.0034 and energy per unit volume U = 95 kJ/m^3; to the high capability of energy storage limit: ε_c = 0.09 and U = 91 MJ/m^3. In order to calculate critical strain and maximum storage energy, we have taken statistical values of length and width from each experiment and we have applied linear elastic theory and also we have compared our calculations with the results using Finite Elements Methods commercial software (Comsol Multiphysics [7]). This work was financed by ZEROPOWER project FP7-ICT-2009-6, EXPLORA project TEC2010-10459-E and with a collaboration of CONACYT coordinated by the Mexican government.

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Figures

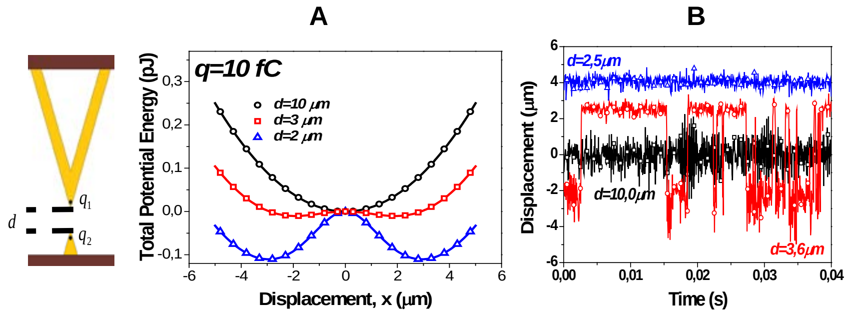

Figure 1. A) Sketch of the system used (the left image) and calculation of the bistable potential at different distances between both tips. **B)** Measurement of tip jumps.

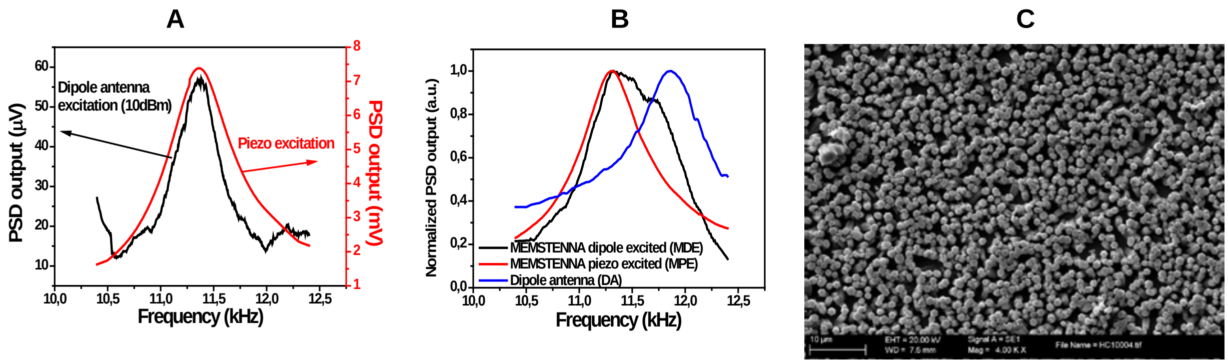

Figure 2: A) Comparison between piezo excitation and antenna excitation tuned at the same frequency. **B)** Example of detuning between antenna frequency and cantilever natural frequency. **C)** SEM image of a detail of the forest of ZnO fine wires.