Project III. 1B ENERGY HARVESTING MATERIALS AND DEVICES

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Objectives:

- Design and optimization of Energy Scavengers for autonomous Microsystems
- Novel materials for high efficiency energy conversion (mechanical, thermal, etc)
- Development of single and dual-transduction mechanical harvesters for improved power characteristics
- Device fabrication and characterization

Funding:

- MEMSENSE”, Corralia, National Funds and European Regional Development Funds, NSRF 2007–2013, contract no. 45 (5/2009 - 4/2012)

MAIN RESULTS IN 2009

Energy Scavenging from the ambient has been actively explored using several methods such as solar power, electromagnetic fields, thermal gradients, fluid flow, energy produced by the human body, and the action of gravitational fields. Most of all, mechanical vibration is a potential power source which is easily accessible through Microelectromechanical Systems (MEMS) technology for conversion to electrical energy. The reported examples use a mass–spring system which resonates when the frame of the device is vibrated. The motion of the mass relative to the frame is damped by one of several energy conversion mechanisms, namely electromagnetic force, electrostatic force, or piezoelectric force.

From these scavenger types, the ones based on electromagnetic and piezoelectric principle appear to be the most promising ones and has been the main target of our activities. Furthermore our research effort focuses on an innovative concept and design approach, targeting to a novel energy scavenger, capable of harvesting mechanical vibration energy with the aid of two transduction mechanisms.

ZnO nanorod growth for efficient energy conversion

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Over the past few years, ZnO has been the center of attention for a variety of applications, mostly due to its unique set of properties. Apart from its use in electronic and optoelectronic devices such as field-effect transistors, gas sensors, solar cells and UV emitting diodes, ZnO has showed a great potential for energy harvesting applications. Due to its coupled piezoelectric and semiconducting properties, ZnO in the form of nanostructures such as wires, rods or helices has exhibited a remarkable efficiency in the conversion of mechanical energy to electrical energy, becoming thus an excellent candidate for energy scavengers and innovative nanopiezotronic applications.

During this year, we continued our research effort on the growth of ZnO nanorods on patterned substrates using a low temperature, silicon-compatible, solution-based approach. Since accurate control of the dimensions and sizes of the resulting nanostructures was achieved by employing the ZnO seeding layer, lithographically patterned substrates were the next step towards exhibiting the potential of the ACG process to become a low-cost, environmental-friendly method for large-scale mass production. Vertically aligned nanorods were grown with high cover density and uniformity (Figures 1a,1b) onto the various patterns where the vertical alignment seemed to be further enhanced by the physical confinement of the photoresist side-walls. It is worth noting that the growth follows even the lithographic imperfections and the undercuts of the photoresist.

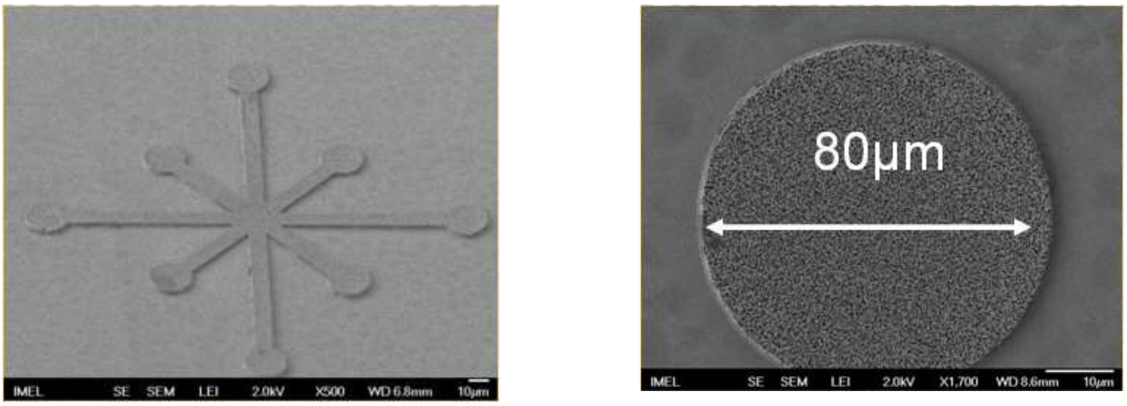

Fig. 1 *SEM images of patterned areas where ZnO nanorods have be grown using the hydrothermal technique.*

As can be seen from Figure 2a, ZnO nanorods can be classified into four different types: I) Regular Hexagonal-shaped, II) Elongated Hexagonal-shaped, III) Asymmetric Hexagonal-shaped and IV) Irregular (non-hexagonal) shaped nanorods. Statistical analysis shows that the number of hexagonal-shaped (Type I, II and III) nanorods is significantly larger (80-85%) compared to non-hexagonal (type IV) ones, indicating that the process conditions favour the growth of hexagonal based structures. The distribution between the various types of nanorods does not depend on the concentration of the aqueous solution. Further analysis reveal that as we decrease the concentration of the aqueous solution from 10mM to 5mM the percentage of regular hexagonal nanorods (Type I) decreases, while the number of enlongated (Type II) and asymmetric (Type III) nanorods increases.

Besides the shape distribution, it is important to know the size distribution of the nanorods. We observed that, increased concentrations (10mM) allow for the production of more uniform and denser arrays but with a compromise on the precision of the size control. On the other hand, however, lower concentration nutrient solutions (5mM) provide a better control over the size dispersion of the produced nanorods (Fig 2b). Knowledge of size distribution in combination with FEM modelling can provide a useful methodology for the optimization of process parameters for the fabrication of patterned nanorod arrays to be implemented in nanogenerators with improved energy conversion efficiency.

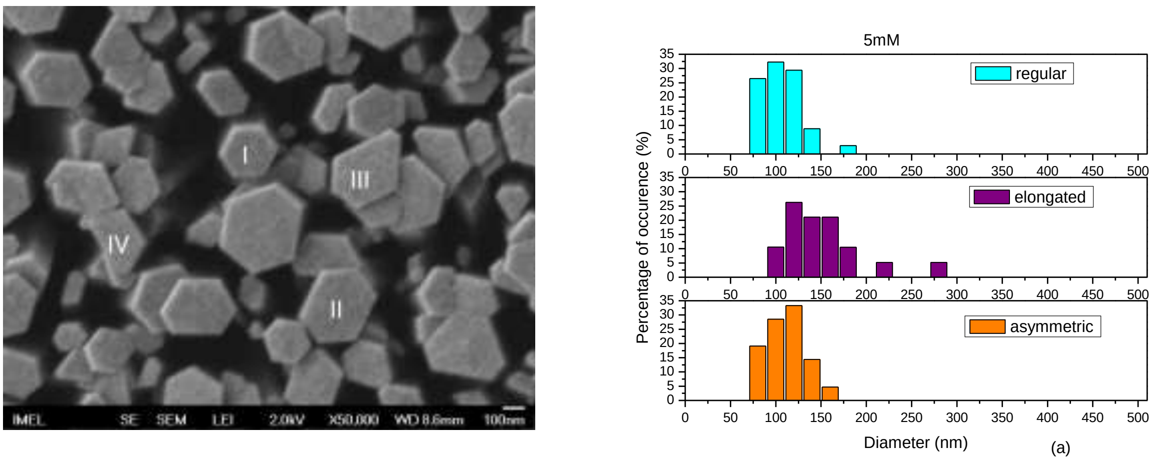

Fig. 2 (a) *SEM images of ZnO nanorods. Various shapes of hexagonal (I), (II), (III) and non-hexagonal (IV) nanorods can be identified* ***(b)*** *Size distribution of hexagonal-shaped nanorods.*

PROJECT OUTPUT in 2009

Publications in International Journals

1. “Growth of ZnO nanorods on patterned templates for efficient, large-area energy scavengers”, G. Niarchos, E. Makarona and C. Tsamis , To appear in Journal of Microsystems Technology.

Publications in International Conference Proceedings

1. “Growth of ZnO nanorods on patterned templates for energy harvesting applications” , “Niarchos G., Makarona E. and Tsamis C., Proc. of SPIE Vol. 7362:73621L-1, (2009)

Conference Presentations

1. “Modeling and optimization of ZnO nanostructure arrays for improved energy conversion efficiency”, G. Niarchos, E. Makarona, C. Tsamis, Third International Conference on One-dimensional Nanomaterials (ICON), 7-9 December 2009, Atlanta, Georgia (Oral)
2. “Growth of ZnO nanorods on patterned templates for energy harvesting applications”, Niarchos G., Makarona E. and Tsamis C., Microtechnologies for the New Millennium 2009, 4-6 May 2009, Dresden, Germany (Poster)