Type of presentation: Poster

IT-14-P-1878 Thermal conductivity reduction measurement on Si and P3HT nanowires : diameter size effect

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Nanostructuration has induced a renewed interest for thermoelectric materials whose performance can be evaluated through their figure of merit $ZT=(S^2\sigma T)/\lambda$ where S is the Seebeck coefficient, σ the electrical conductivity and λ the thermal conductivity. Indeed, in a nanostructured material, the dimension reduction could possibly induce a thermal conductivity reduction and consequently an increase of their figure of merit. This can be partially ascribed to phonon boundary scattering appearing when one dimension of the nanostructured material becomes smaller than the phonon mean free path. The nanomaterial behaves than as a phonon glass and an electron crystal.

The work presented here deals with the study of the variation of the thermal conductivity of nanowires when reducing their diameter size due to confinement effects. The thermoelectric device is actually made of nanowires embedded in a matrix. We have studied two different kinds of nanowires with varying diameters: on one hand inorganic semiconductor Si nanowires in a SiO_2 silica matrix, on the other hand poly(3-hexylthiophene) (P3HT) nanowires, an organic semiconductor polymer, which have been proven to have good thermoelectric properties[1], in an alumina matrix.

Measuring the thermal conductivity of individual nanowires embedded in a matrix is still challenging and nowadays there are not many techniques able do it[2]. Nevertheless, we have developed a technique based on an AFM associated to a thermoresistive tip and called 3ω-Scanning Thermal Microscopy (3ω-SThM). The thermoresistive tip is used both as a heater and a sensor. A current passing through it heats the tip. Depending on the thermal conductivity of the scanned material, the heat flux passing from the tip to the scanned sample varies, inducing a tip temperature variation. Then, the tip resistance changes, which induces a tip voltage variation. As a consequence, measuring the tip voltage variation enables to deduce the material thermal conductivity[3]. This mode enables to simultaneously obtain a topographical image and a thermal conductivity contrast image.

We show that a thermal conductivity reduction is observed when reducing the diameter of the nanowires for both silicon and P3HT nanowires. The thermal conductivity is reduced by 4 for P3HT nanowires when their mean diameter is reduced from 350nm to 120nm and up to a factor 10 for silicon nanowires when the mean diameter is reduced from 300nm to 50nm.

References:

1. C. Bounioux et al, Energy & Environmental Science, 2013, 6, 918-925.

2. M. Muñoz Rojo et al, Nanoscale, 2013.

3. E. Puyoo et al, J. Appl.Phys., 2011, 109, 024302-024309.

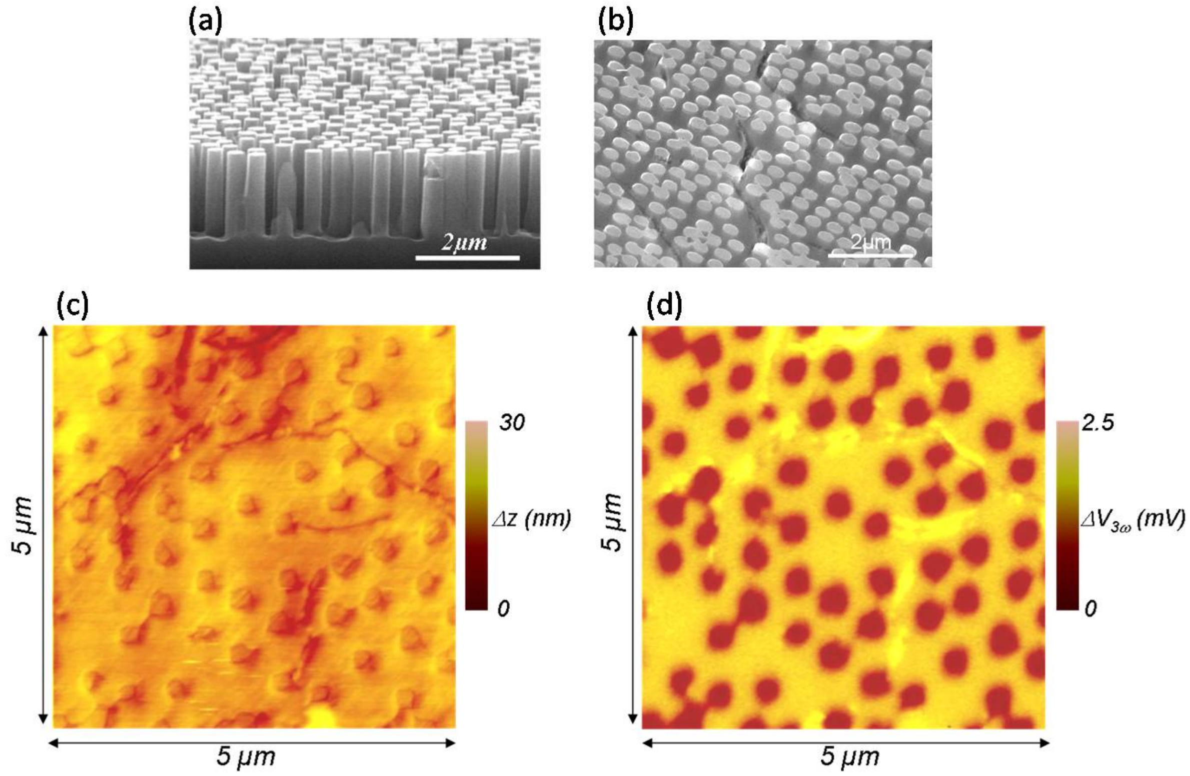

Fig. 1: Si nanowires: Scanning Electron Microscopy images respectively before (a) and after (b) encapsulation in the SiO_2 matrix; 5μmx5μm 3ω-SThM images (c) topographical image, and (d) thermal conductivity contrast image.