Nanowire Based Flexible Piezoelectric Sensor for Structural Health Monitoring Applications

A. El Kacimi[1], E. Pauliac-Vaujour[1], J. Eymery[2]

[1]University Grenoble Alpes, CEA, LETI, MINATEC Campus, Grenoble, France
[2]University Grenoble Alpes, CEA, Grenoble, France

Abstract

Gallium nitride (GaN) wires are used to build up capacitive flexible piezoelectric sensors dedicated to structural health monitoring applications. These slightly cone-shaped nanowires with a hexagonal cross section are grown on sapphire substrate by Metal Organic Vapor Phase Epitaxy (MOVPE); their length (L) can vary from few microns up to hundreds of microns, while the conicity angle (alpha) evolves in the 0.1-1.2° range for 300[nm]-2[µm] diameters [1]. Nanowires are assembled into a capacitive structure on a flexible substrate using the Langmuir-Blodgett method [2]. As the nanowire geometry (i.e. L and alpha) depends on the growth conditions, the response of the device with embedded nanowires may vary accordingly. In this work, we investigate in depth the impact of these two parameters on the potential generated by single hexagonal wire embedded in a dielectric (parylene). Based on such studies, our aim is to figure out the best-suited geometry for the targeted application.
COMSOL was used to build up a new model from scratch as no pre-existent model has been used. The structure is obtained from a hexagon section extruded along a certain axis with a fully parametrized extrusion ratio properly calculated in order to achieve realistic conical shapes. The software was used to simulate the electrical behavior of the piezoelectric nanowires under bending using MEMS and piezoelectric modules. Piezoelectric module allows the calculations of the piezo response of the nanowires in terms of piezo-potential and polarization. Deformation is applied under structural mechanics section as a prescribed displacement, which is function of a curvature radius. Geometry and constraint are parametrized to be able to perform parametric studies on L and alpha and to quantify their impact on the piezo response, hence on the overall flexible sensor response. Studies have been conducted taking into account both surface and volume effects, since the physical phenomena behind potential generation are strongly related to these quantities as well as the crystallographic orientation of the wire facets and growth direction.
Simulations have shown the importance of the conical shape for potential generation. The piezo potential vanishes for non-conical nanowires (i.e. alpha ~ 0) due to the disappearance of internal field that separate charges. Conicity is therefore mandatory for potential generation and a quantitative evaluation is provided. Besides, short nanowires are much more sensible to conicity variations than longer ones. Consequently, high conicity is not needed when length exceeds one hundred microns. Nevertheless, length is critical to minimize the impact of the extremity effects (at the top and bottom) on the overall potential along the wire. At a fixed conicity angle, we observed a decrease of the generated potential as the length of the nanowires gets higher,

regardless the nanowire volume and surface.
Relying on these results, we were able to figure out appropriate nanowire geometry for integration within the sensor. The fabrication methods will be subsequently adapted so as to obtain suitable shapes. Depending on the targeted properties of the sensors, we would either go for short nanowires with high conicity or ultra-long nanowires with moderate conicity angles.

Reference

[1] J. Eymery et al, Self-organized and self-catalyst growth of semiconductor and metal wires by vapour phase epitaxy: GaN rods versus Cu whiskers, C. R. Physique 14, pp 221/227 (2013)
[2] S. Salomon et al, GaN wire-based Langmuir-Blodgett films for self-powered flexible strain sensors, Nanotechnology 25, pp 375502(2014)

Figures used in the abstract

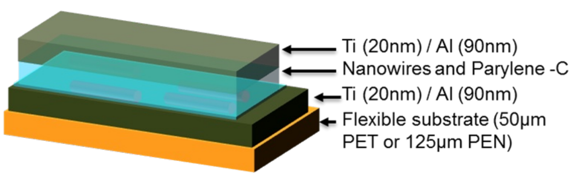

Figure 1: Schematic view of the final device illustrating the whole stack of the sensor.

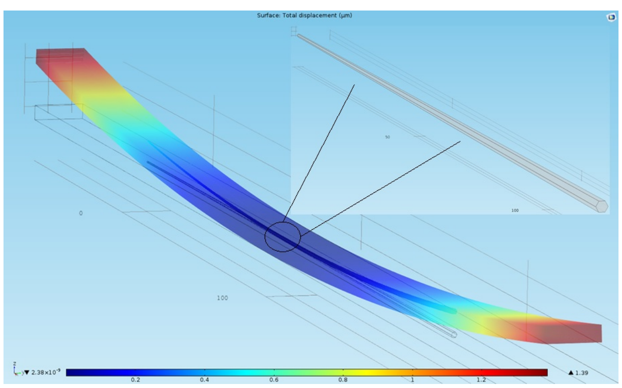

Figure 2: Figure showing a single nanowire embedded into a parylene layer under bending with a zoom on the wire structure.

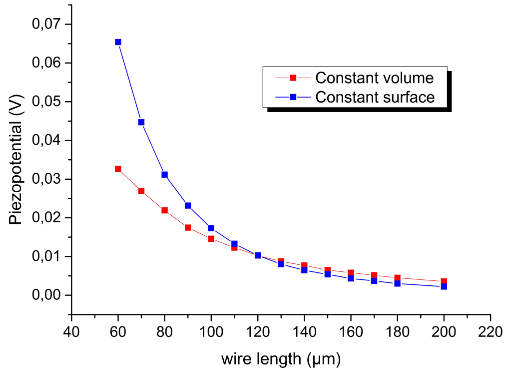

Figure 3: Potential evolution, taken on the upper facet at middle distance from the nanowire extremities, as a function of the wire length for constant surface and constant volume for a conicity angle fixed at alpha = 1°.

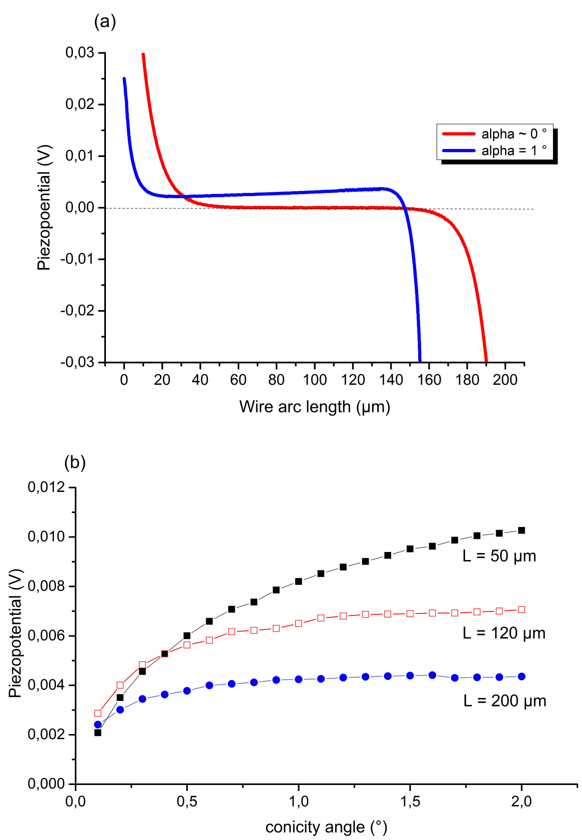

Figure 4: Study of the effect of conicity : (a) piezopotential after bending for a nanowire of alpha = 0° and alpha =1° and L = 200 µm. (b) Potential evolution as a function of the the wire conicity angle (alpha) for L = 50µm, L= 120 µm and L = 200µm.