Characterization of piezo-generation performances of GaN nanowires: contribution of conductive probe AFM

T. Sodhi1,2, P. Chrétien1, N. Jamond1, N. Jegenyés1, N. Gogneau1, F. Houzé2
1 Centre de Nanosciences et de Nanotechnologies - CNRS-UMR9001, Université Paris-Saclay, Boulevard T. Gobert, 91120 Palaiseau, France
2 Laboratoire de Génie Électrique et Électronique de Paris, UMR 8507 CNRS-CentraleSupélec, Paris-Sud and Sorbonne Université, 11 rue Joliot-Curie, 91192 Gif-sur-Yvette, France

Context and Challenges

Piezoelectric nanowires (NWs) have emerged as excellent candidates to fabricate novel ultra-compact and efficient power sources for micro-electronic devices. New generation of III-N nanowires based piezo-generators are required for more efficient and higher energy conversion.

Improvement of the energy conversion efficiency and of the power density while reducing the dimensions and weight of piezoelectric generators
- Careful assessment of the piezoelectric conversion, in order to assess the optimum parameters for maximizing the mechanical-electrical conversion capacity
- A fundamental understanding of the piezoelectric mechanisms and a prediction of the piezoelectric potential as a function of the NW characteristics
- Establishment of a synthesis-characterization-piezoelectric potential relation

Studies of Piezo-conversion mechanism in GaN NWs

Strong correlation between
- The structural and electrical properties of the NWs;
- The deformation of the nanostructure;
- The establishment of the piezoelectric potential inside the nanostructure

Measurement of electrical properties of GaN nanowires
Adaptation of GeePs’s Resiscope structure for parallel measurements:
- Obtain the voltage peaks by solicitation using the AFM tip (Generation mode)
- Studying electrical properties of the NWs (Resiscope mode)

Electrical profiles in harvesting situation for two types of GaN nanowires

(Generation Mode)


- Lateral bending of doped NWs using conductive AFM tip in contact mode induces piezo-electric effect
- Piezoelectric potential distribution depends on polarity and nanowire doping
- Energy harvesting depends on the Schottky behaviour

Influence of the Schottky nano-contact on the energy harvesting efficiency

(a, b, c) Resiscope mode, (d) Generation mode.

Nanoscale 9,4610 (2017)

For different normal constant forces:
- I-V characteristics of single n-doped GaN NW by using (a) p-type doped diamond, (b) PbI and (c) Pd/V conductive.
- (d) Correlated output voltages in generation mode.
- Schottky barrier height is function of diode size
- Nanometric contact lowers barrier height – Tunneling effect
- Nano contact size : Pd-based tip + Diamond based tip, hence effective charge collection for a min. applied constant force

Piezo-conversion of n-doped GaN NWs

The piezoelectric properties of GaN NWs have been characterized by atomic force microscopy equipped with a modified Resiscope module

PSS-BRL, A. 414 (2014)

3D output voltages collected by AFM-Resiscope on partially encapsulated GaN NWs for different constant normal force applied
Our n-doped GaN NWs can generate an average output voltage about -74mV, with the largest value reaching -443 mV.
A maximum power density of 5.9 mW/cm²

Piezo-conversion of p-doped InGaN/GaN NWs

Nanoscale 5, 367 (2018)

First demonstration of the piezo-conversion from InGaN NWs !!!
The piezoelectric properties of InGaN/GaN NWs have been characterized by atomic force microscopy equipped with a modified Resiscope module

3 Types of InxGa1-xN/GaN NW tested
The NWs are deformed under lateral bending (deformation applied via a conductive AFM tip)
The piezo-generated voltage was detected when the AFM tip is in contact with the NW compressed side

Piezo-conversion capacity and efficiency

Influence of the InGaN insertion

A significant improvement on the piezo-conversion capacity and efficiency of NWs was observed by introducing InGaN heterostructures in GaN NW volume
By NW with 70 nm-thick InGaN insertion:
Average outputs up to 330mV + 70mV with max of 472 mV

3D mapping of piezo-generated energy
At each Output Voltage peak corresponds the localization of a single free-standing NW

The piezo-conversion of InGaN/GaN NWs is 30% more efficient than pure GaN NWs

Conclusion

Development of a new nanoscale tool based on AFM-Resiscope for piezo-conversion characterization of single nanowires
Establishment of the piezo-conversion mechanisms in play in III-N NWs
First demonstration of the piezo-conversion from InGaN/GaN NWs
Twice state-of-the-art for energy piezo-generated from 1D-nanostructure

Future / Perspectives

- Increasing piezo-conversion efficiency by optimizing NW doping
- Optimization of the surface charge effects by adjusting the NW diameter and doping