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

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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

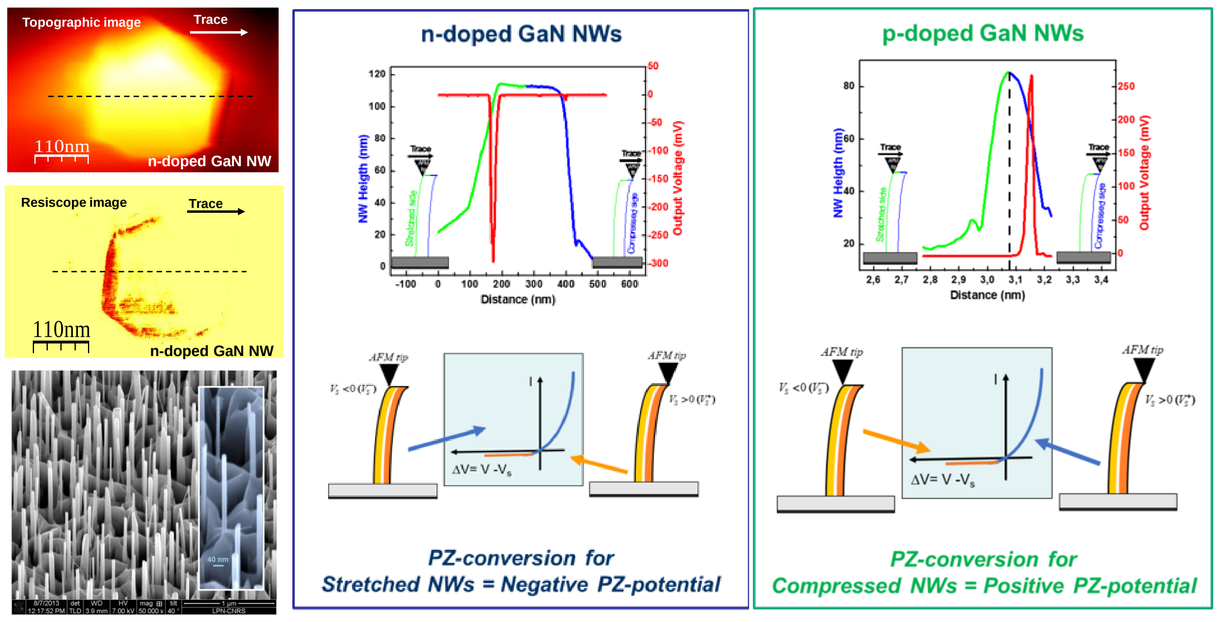
Measurement of electrical properties of GaN nanowires

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)*

APL 104, 213105 (2014); Semicond. Sci. Technol. 31, 103002 (2016)

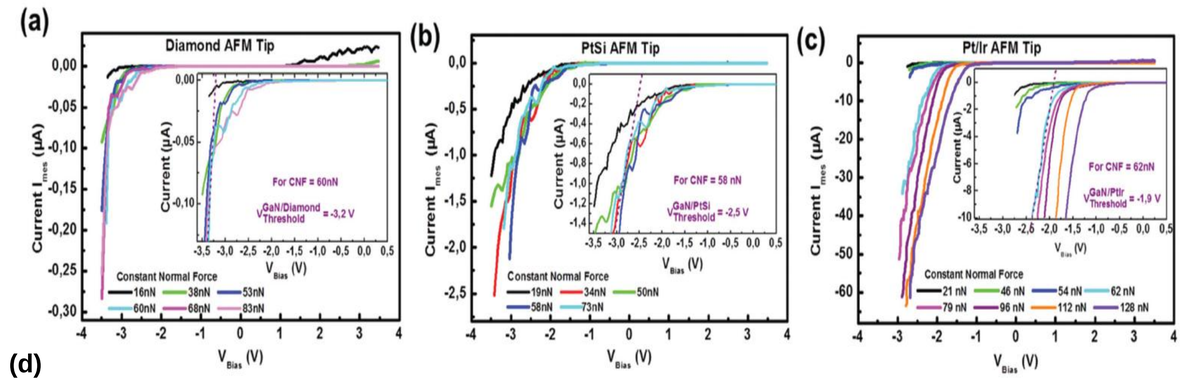


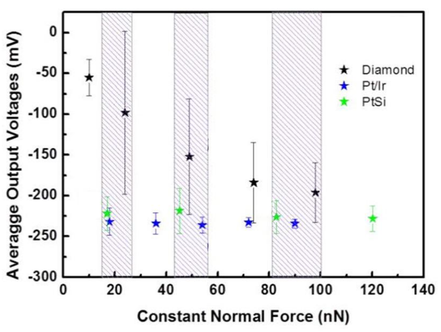
- ***Lateral bending of doped NWs using conductive AFM tip in contact mode induces piezo-electric effect***
- ***Piezoelectric potential distribution depends on polarity and nanowire doping***
- ***Energy harvesting depends on the Schottky behaviour***

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

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

Nanoscale 9,4610 (2017)





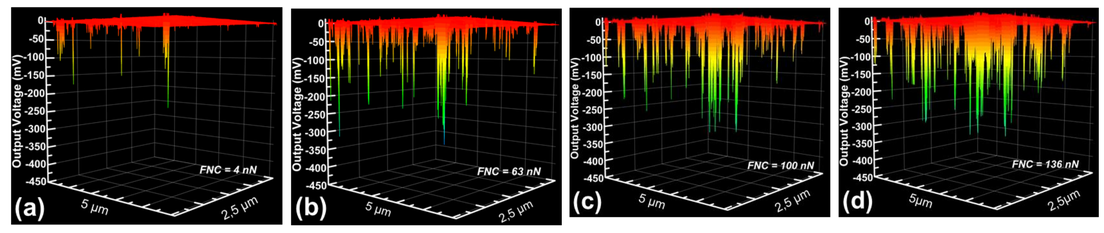
For different normal constant forces:
I–V characteristics of single n-doped GaN NW by using (a) p-type doped diamond, (b) PtSi and (c) Pt/Ir conductive.
(d) Correlated output voltages in generation mode.

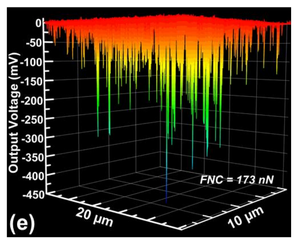
- Schottky barrier height is function of diode size
- Nanometric contact lowers barrier height – Tunneling effect
- Nano contact size : Pt-based tip < Diamond based tip, hence effective charge collection for a min. applied constant force

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-RRL 8, 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

Nanomaterials 8, 367 (2018)

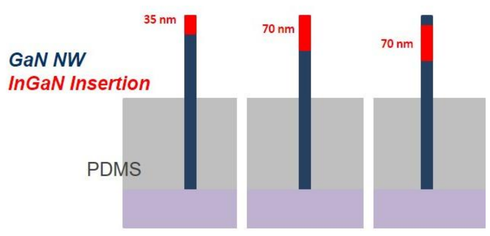
First demonstration of the piezo-conversion from InGaN NWs !!!

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

3 Types of $In_{0,4}Ga_{0,6}N$/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

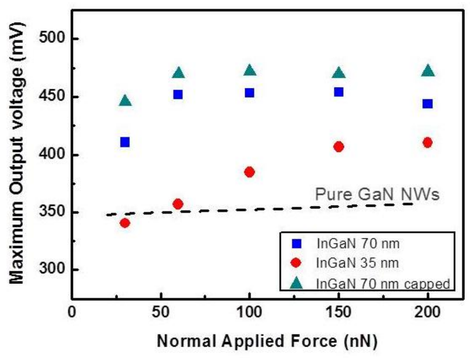


Piezo-conversion capacity and efficiency

Influence of the InGaN insertion

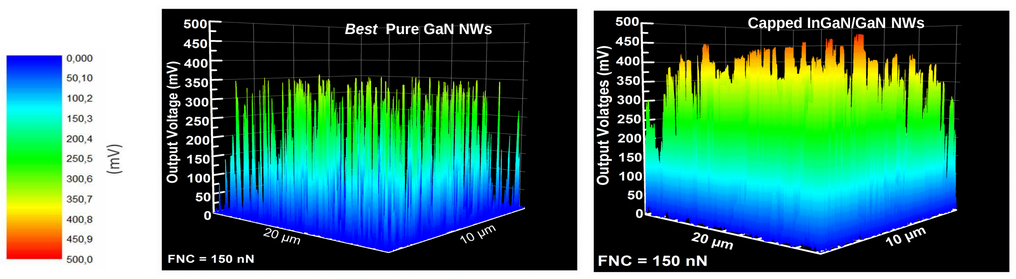
A significant improvement on the piezo-conversion capacity and efficiency of NWs was observed by introducing InGaN heterostructures in GaN NW volume

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**