DE LA RECHERCHE À L'INDUSTRIE

NANOWIRE BASED FLEXIBLE PIEZOELECTRIC SENSOR

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What materials for piezoelectricity?

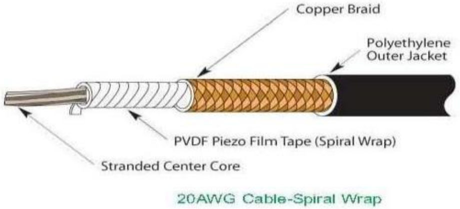
Usual commercial solutions:

- ✓ Ceramics : PZT

(fragile)

- ✓ Polymers

  PVDF (polyvinylidene fluoride)



(need ext. Polar.)

Nanowire based solutions :

- ✓ Vertically grown GaN nanowires [1].
- ✓ ZnO nanogenerators [2]

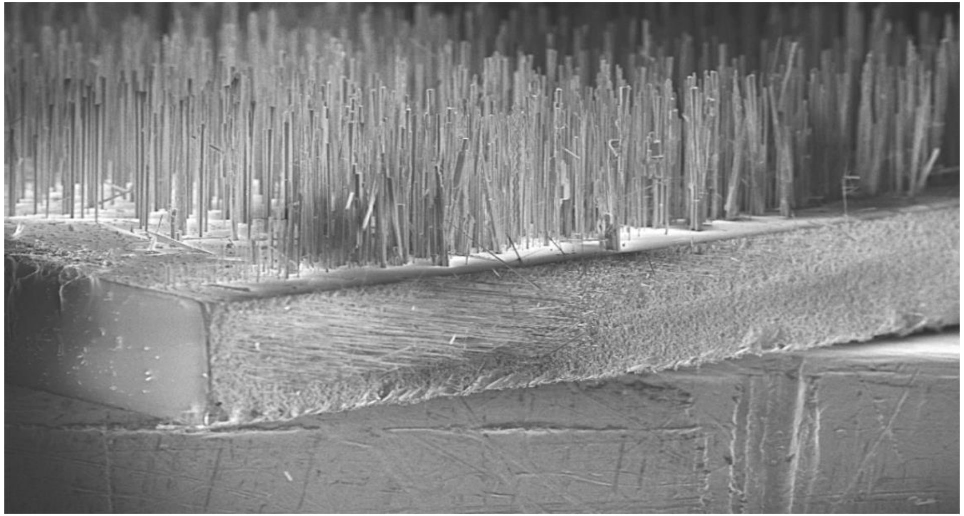
Exploiting intrinsic piezoelectric properties

[1] J. Eymery et al., C.R Physique **14** (2013) 221
[2] Z.L. Wang, *Piezotronics and Piezo-Phototronics*, Microtechnology and MEMS, Springer-Verlag 2012

How are the GaN wires fabricated?

Top-down approach :

- ✓ Lithography and patterning
- ✓ Etching
- ✓ Sacrificial layers

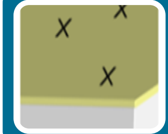


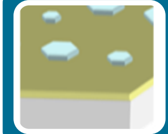
Bottom-up processes :

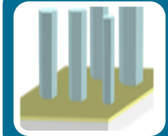
- ✓ Hybrid vapor phase epitaxy
- ✓ Molecular Beam Epitaxy
- ✓ <u>Metal organic Vapor Phase Deposition</u>

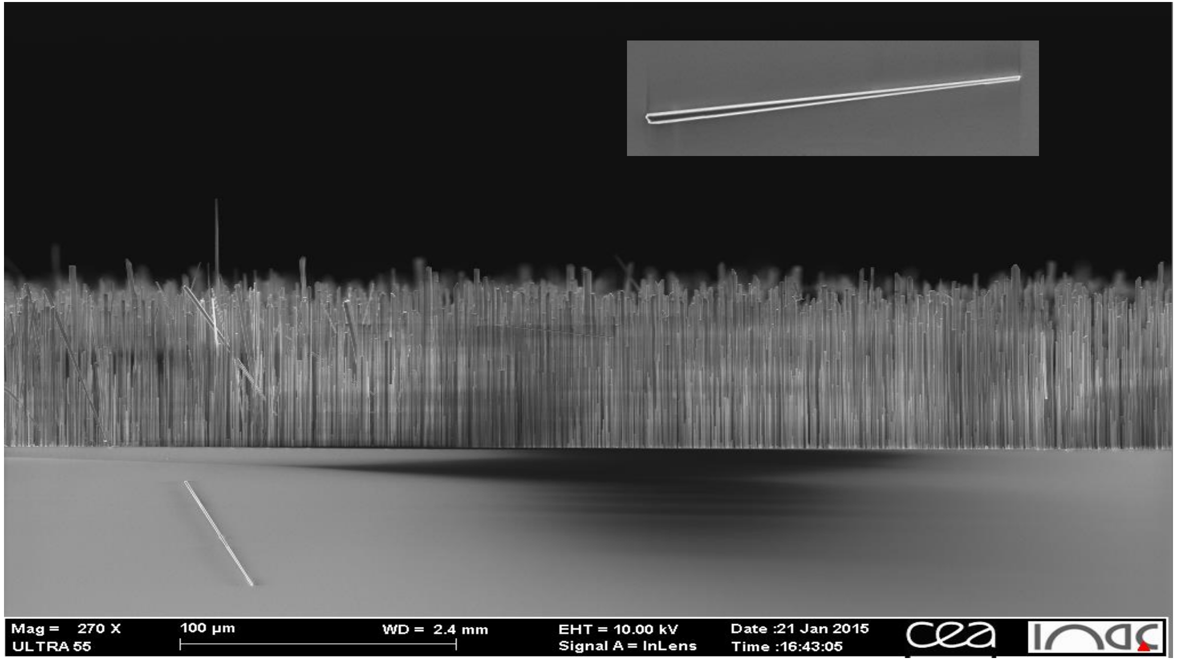
MOVPE growth technique: simplest solution


Sapphire substrate


SiNx layer deposition


Nucleation


Wire growth



J. Eymery et al., Compte Rendu Physique 14 (2013) 221

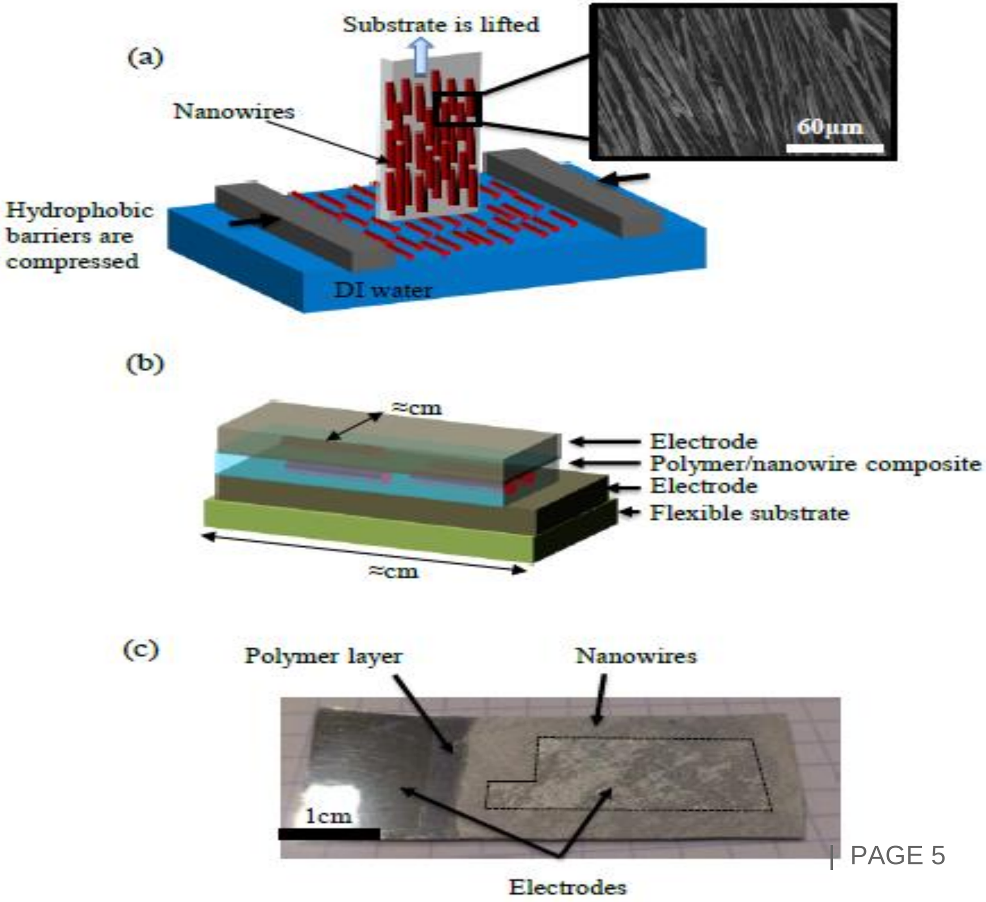
R. Koester et al., Nanotechnology 21 (2010) 015602

Assembling the wires and device realization

- Langmuir-Blodgett method

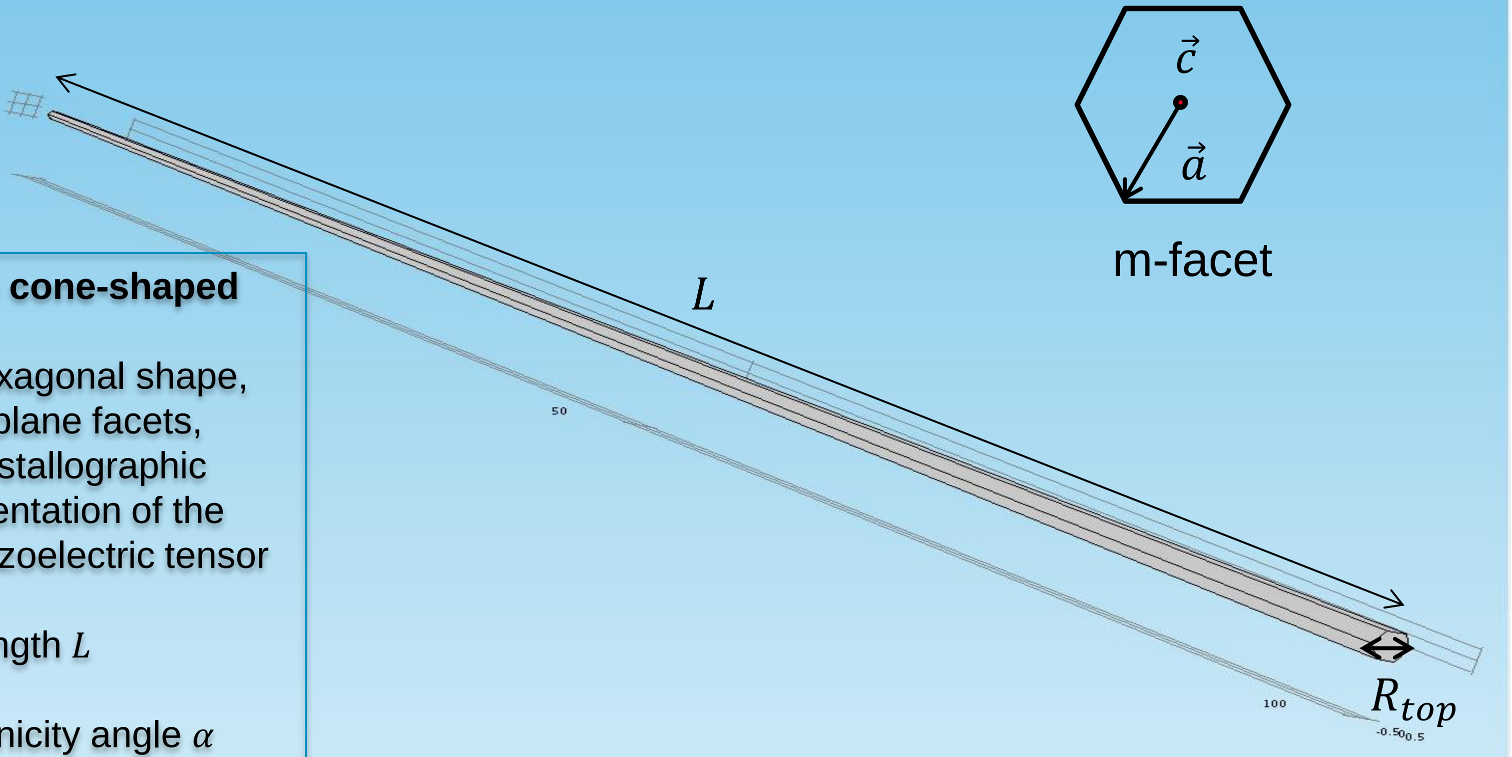
- Capacitive structure

- Device integration



S. Salomon et al., Nanotechnology **25** (2014) 375502.

GaN wire as active material

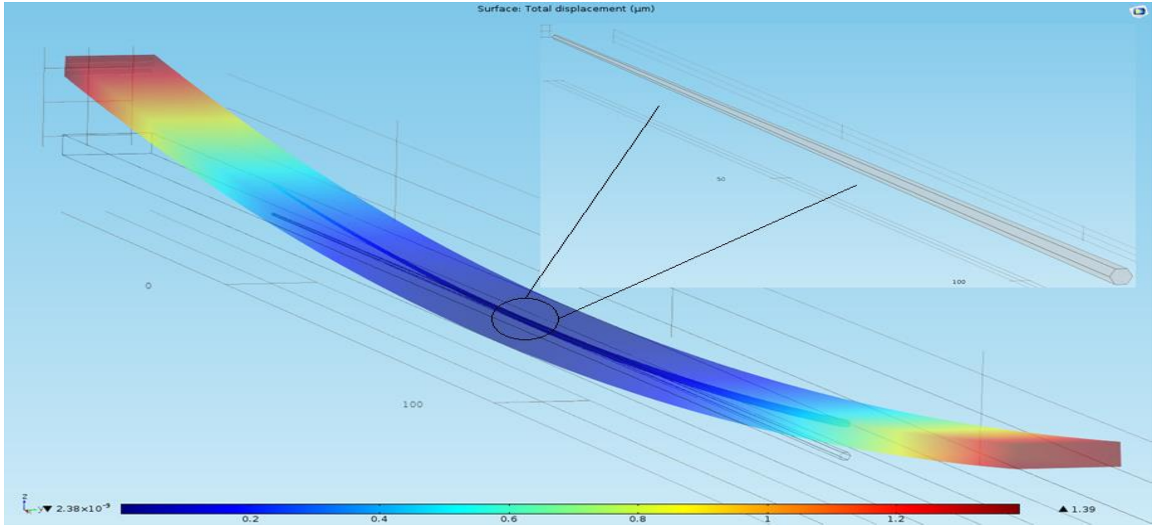


Single cone-shaped wire:

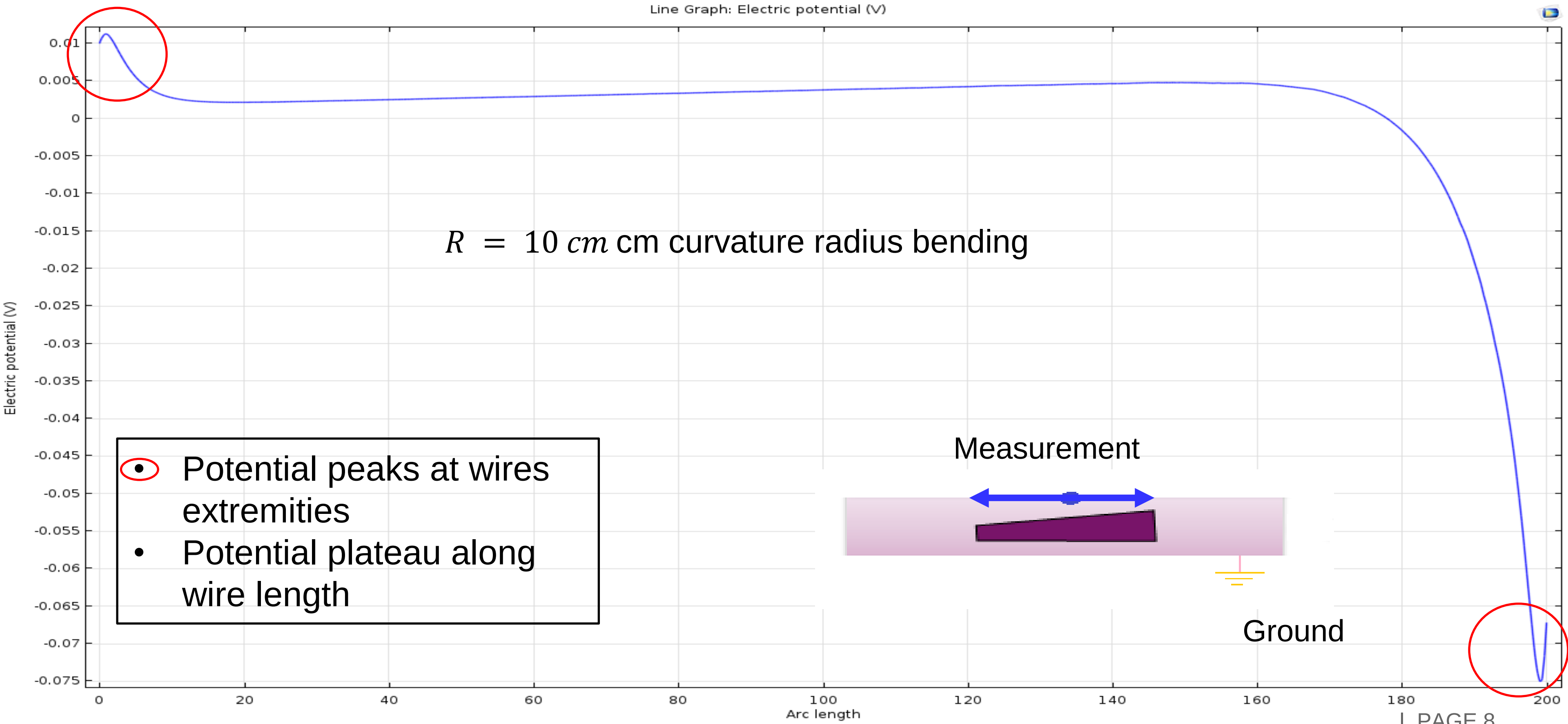
- ✓ Hexagonal shape, m-plane facets, crystallographic orientation of the piezoelectric tensor
- ✓ Length L
- ✓ Conicity angle α

Finite element modelling : simplified structure

- ✓ Embedded into dielectric layer: parylene
- ✓ Bending constraint : $10\ cm$ curvature radius



Understanding the potential generated by single wire

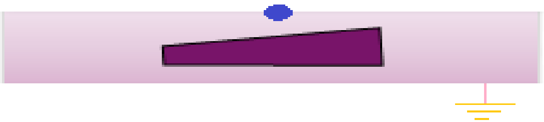


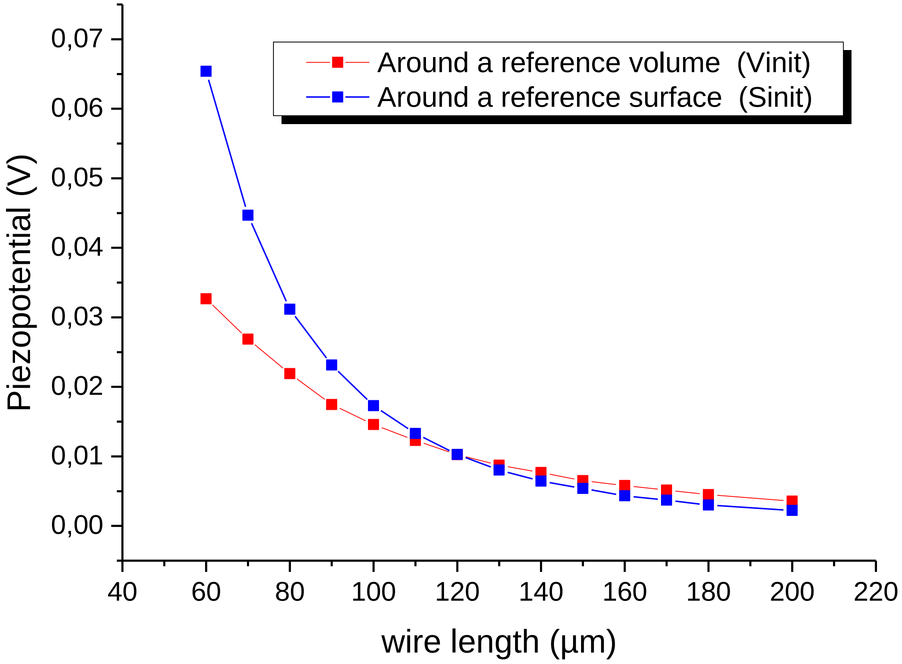
$R = 10\ cm$ cm curvature radius bending

- Potential peaks at wires extremities
- Potential plateau along wire length

Effect of the length on the generated potential

- *Fixed*:
  - conicity angle $\alpha = 1°$
- Parametric sweep around reference value :
  - Volume $V_{init} = 66\ \mu m^3$
  - Surface $S_{init} = 330\ \mu m^2$.
- Potential is measured at one point



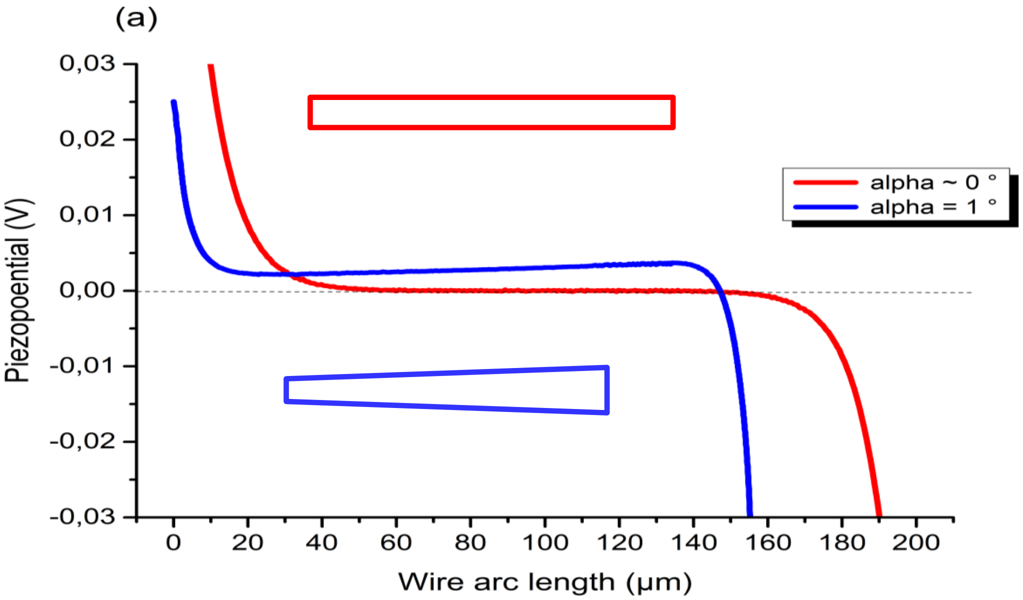


- Shorter wires are prefered

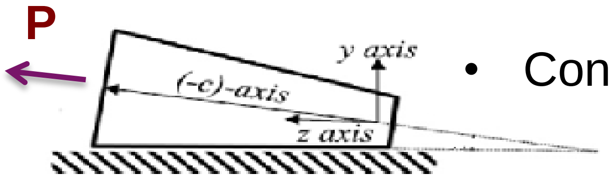
Conicity mandatory for potential generation

- *Fixed :*
  - $\alpha = 0 \; and \; 1\,°$
  - Top diameter $R_{top} = \; 700 \; nm$
  - curvature radius of deformation = $10 \; cm$

- Potential is measured along the wire length



- Conicity mandatory for charge separation onto the wire facets.

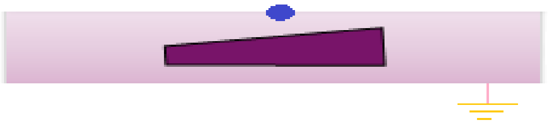


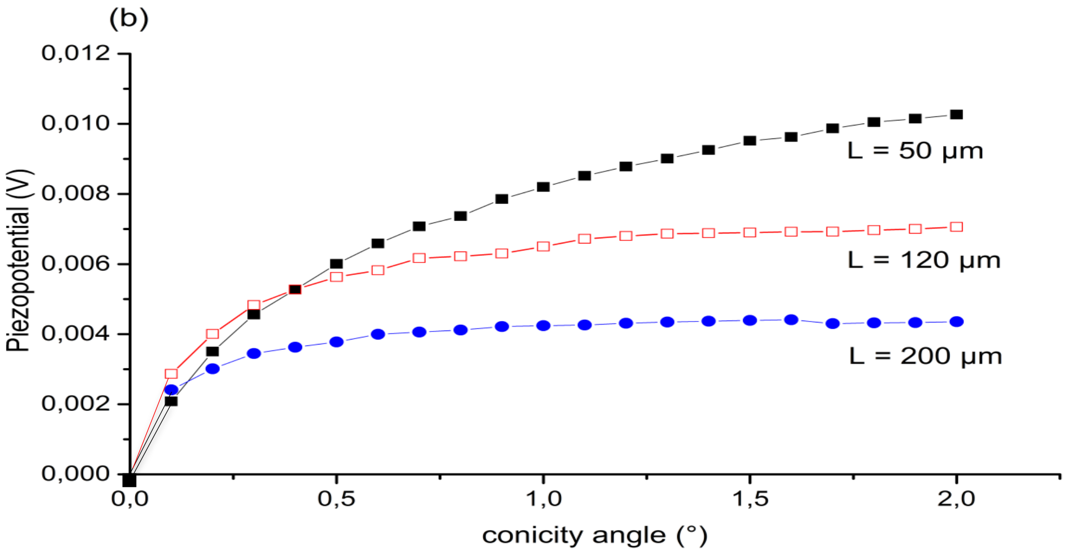
- Condition: $P_y \neq 0$

Effect of the conicity on the generated potential

- *Fixed*:
  - Wire lengths : $50, \ 120, \ 200 \ \mu m$
  - Top diameter : $R\_top = 700 \ nm$
- Potential is measured at one point

Measurement





- Shorter wires are more sensitive to conicity variations.
- Larger conicity is not mandatory for potential generation.

Conclusion

- COMSOL Simulation helped :
  - Optimal wire geometry : $L\ and\ \alpha$.
  - Insight about growth recipes improvements to reach optimal geometry.
- Further works : Compare different crystallographic shapes and orientations.
- Open points : Taking into account spontaneous polarization and dopant concentration (free carriers).

Thank you for your attention

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Conclusion

- Comsol has been used to :
  - Guide the design of the wire geometry :
    - Growth target : $120\ \mu m$
    - Conicity of about 1°

- Further works : Compate different crystallographic shapes and orientations.

- Open points : Taking into account spontaneous polarization and dopant concentration (free carriers)

MOVPE growth technique: simplest solution

Sapphire substrate

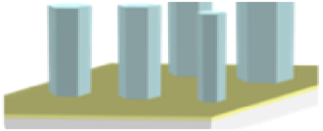
- Substrate cleaning under H_2
- Substrate nitruration under NH_3 : additional Al(O)N polar layer

SiNx layer deposition

- Simultaneous injection of Silane and NH_3 at high temperature.
- SiN_x layer as a mask for GaN nucleation.

Nucleation

- Injection of TMGa AND NH_3 precursors for short time to form nucleii.
- Relatively high V/III molar ratio.



Wire growth

- Injection of TMGa, NH_3 and silane under N_2 flux at high temperature (1000°C).
- Low V/III molar ratio.

J. Eymery et al., Compte Rendu Physique **14** (2013) 221

R. Koester et al., Nanotechnology 21 (2010) 015602

GEOMETRY EQUATIONS

$$fv = \frac{R_{top}}{2 \cdot L \cdot \tan\left(\frac{\alpha}{2}\right) + R_{top}}$$

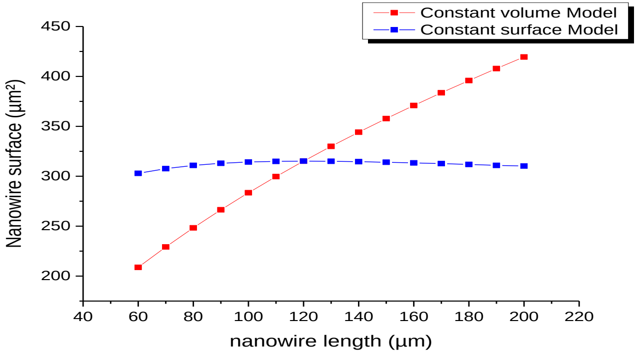
$$R_{top} = \frac{R_{top_{init}}}{\sqrt{a}}$$

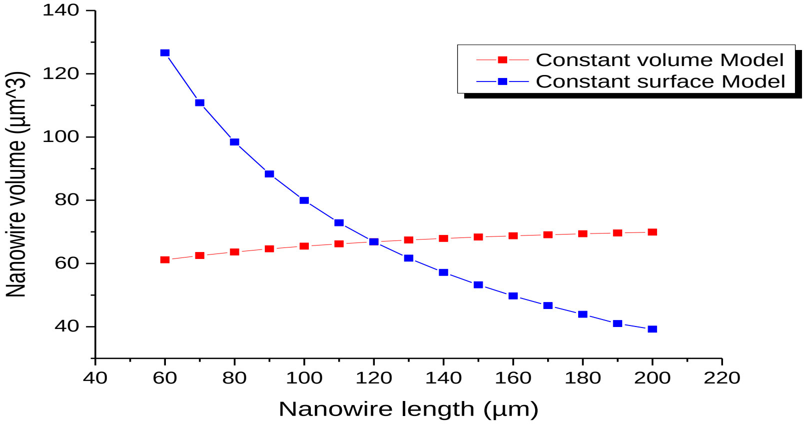
$$a = \frac{L}{L_{init}}$$

$$fs = \frac{R_{top}}{2 * L * \tan\left(\frac{\alpha}{2}\right) + R_{top}}$$

$$with \quad R_{top} = \frac{R_{top_{init}}}{a}$$

SURFACE AND VOLUME DURING SWEEP





$$6 * Surface_{facet} + surface\ top + surface\ bottom$$

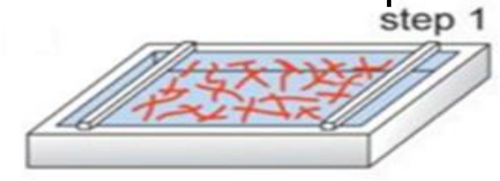
Tapez une équation ici.

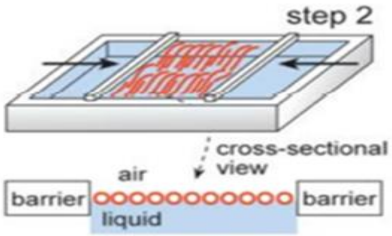
Langmuir-Blodgett method

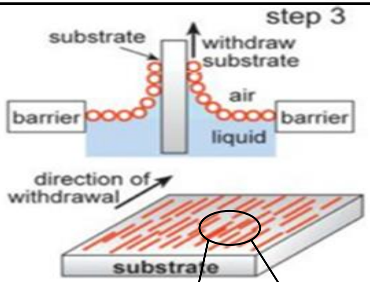
1. Pre-processing wire functionalization :

3 times 4 hours in incubation Isooctane and 2-propanol solution containing 1-octadecylamine diluted in hexane.

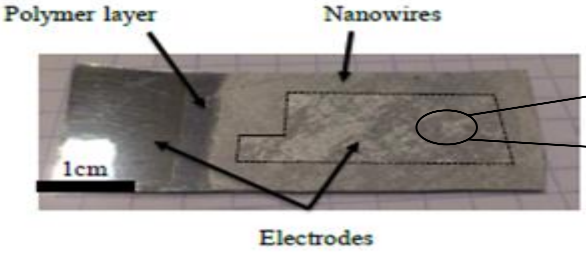
2. Process steps :

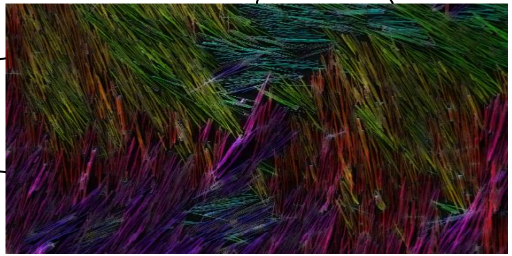




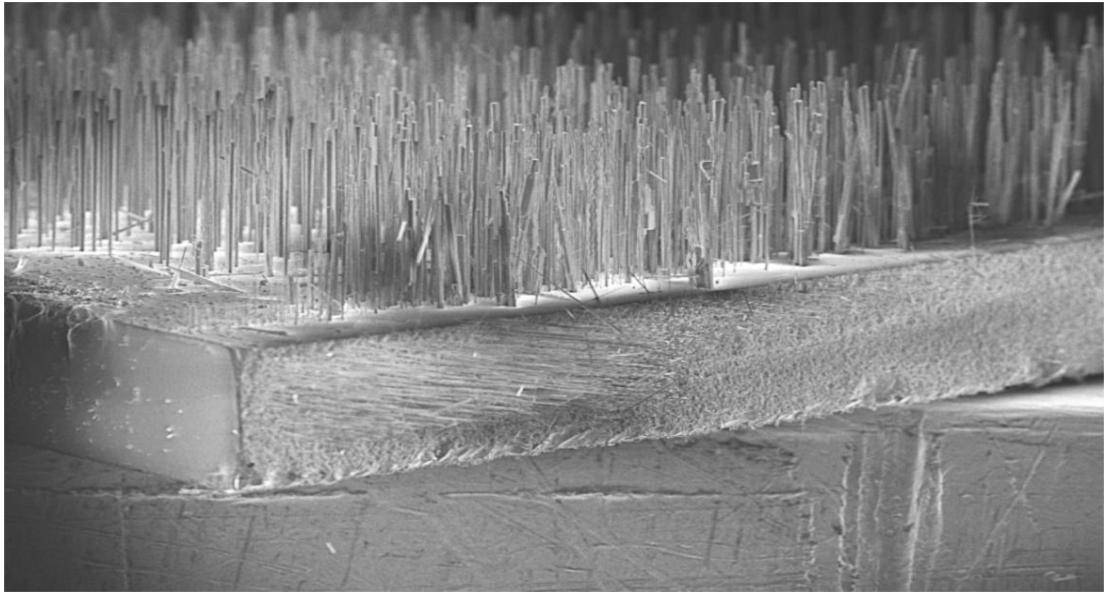


Final device





Target orientation



Assembling the wires and device realization

Langmuir-Blodgett method

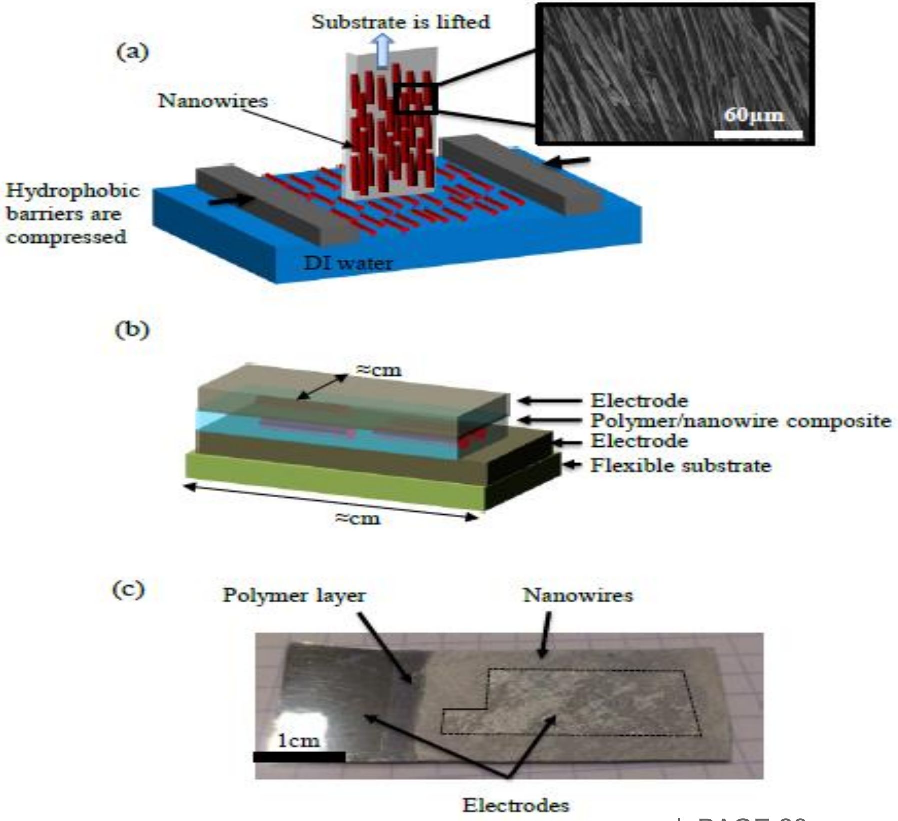
Iso-octane and 2-propanol
containing 1-octadecylamine in hexane .
12h incubation
Rinsed with IPA / isooctane solution

Capacitive structure

125 µm flexible polyethylene naphthalate (PEN) film
Evaporation of parylene-C under vacuum
Ti (20 nm) / Al (90 nm) electrodes

Device integration

0.5 mm plastic substrate covered
with an adhesive (holder)



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