E-MRS 2016
Spring Meeting

Selective growth of ZnO nanosheets and their application in piezoelectric and triboelectric energy harvesting devices

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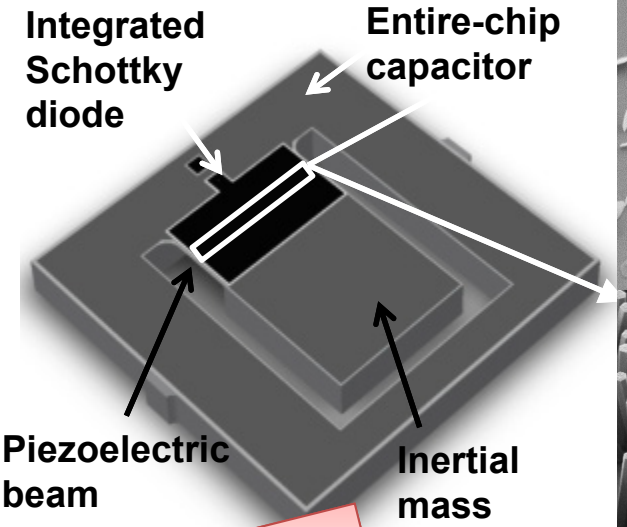
sinergy-project.eu

Introduction

Piezoelectric Energy Harvesting: nano & micro

- Piezoelectric Energy Harvesters: our final target
  - Silicon mass and cantilever beam based on DRIE of an SOI wafer
  - **ZnO nanostructures** (nanowire and nanosheet) as piezoelectric material
  - Polymer encapsulation of NW/NS network
  - **Monolithically integrated Schottky diode and capacitor**



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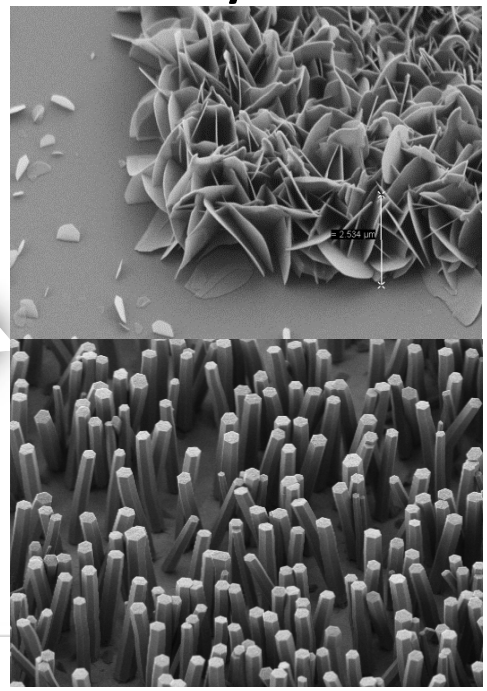
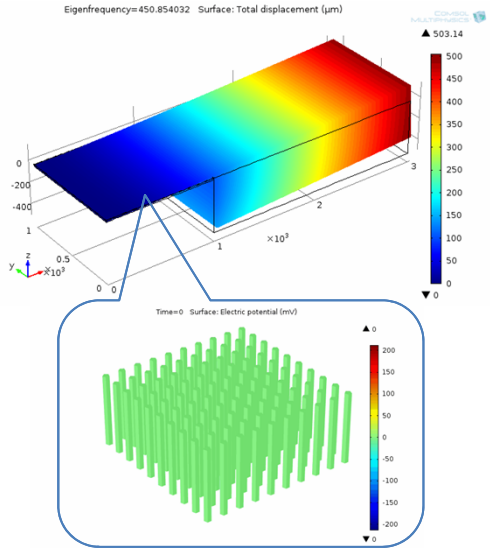




Piezoelectric Energy Harvesting

- Why ZnO nanostructures?

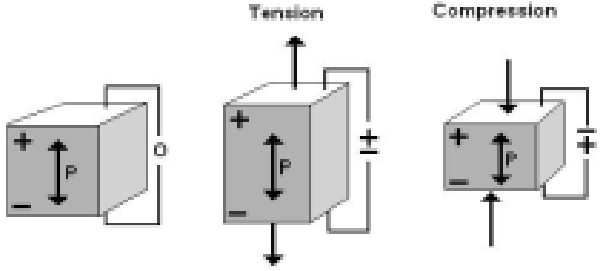
➢ ZnO is a semiconductor that presents a piezoelectric behavior and direct band-gap

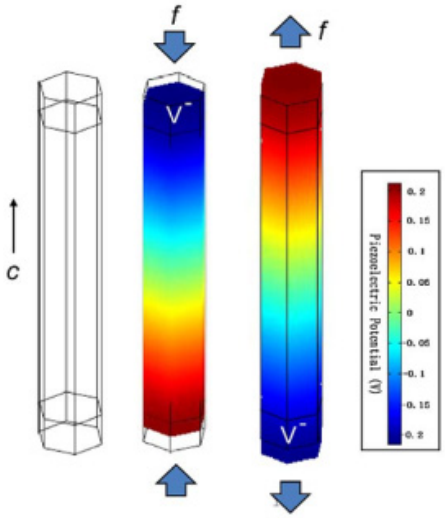
➢ ZnO nanostructures are easy to grow and integrate with silicon

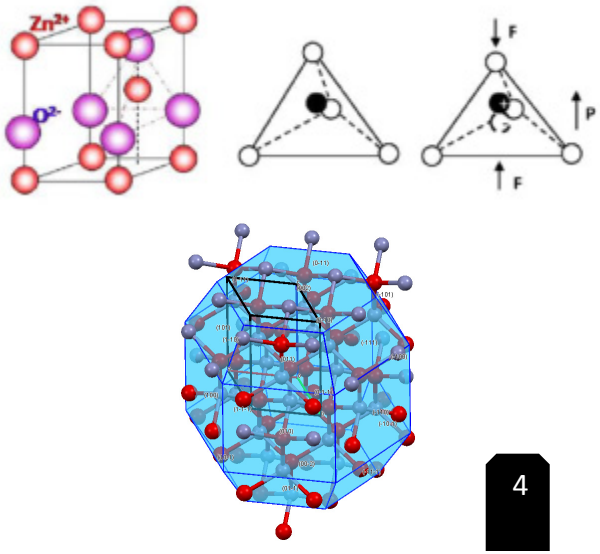
➢ More flexible and robust than thin-films

➢ Compatible with VLS silicon technologies

➢ ZnO is also a hot-topic and low-cost solution to grow nanostructures



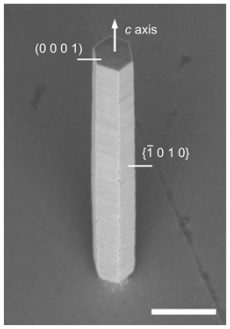




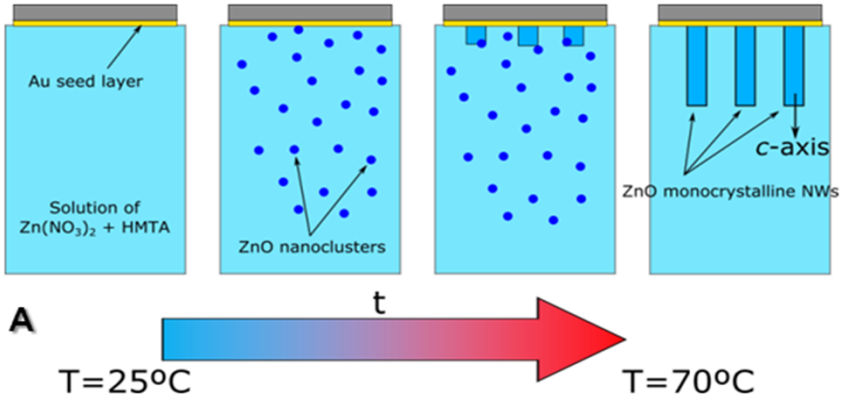
Growth of ZnO nanosheets (NSs) and nanowires (NWs)

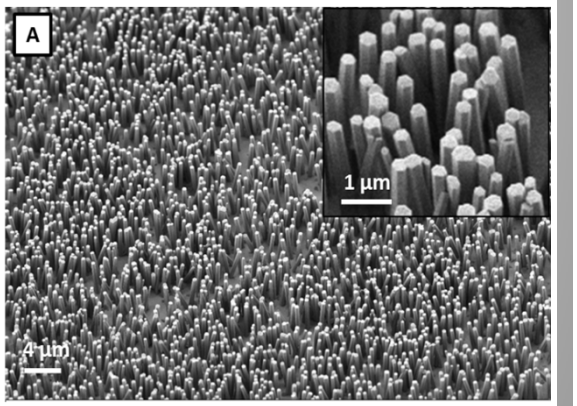
Hydrothermal method for ZnO nanostructures

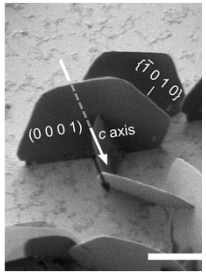
Hydrothermal process (cheap, low T, wafer level and selective)



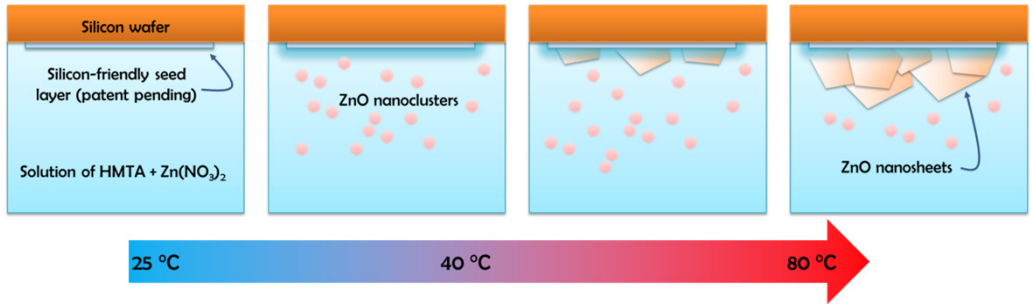
NW

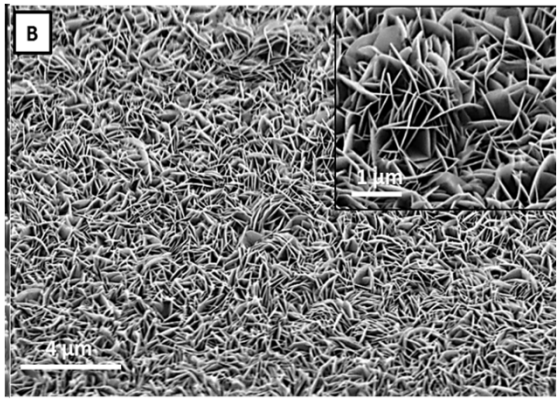






NS





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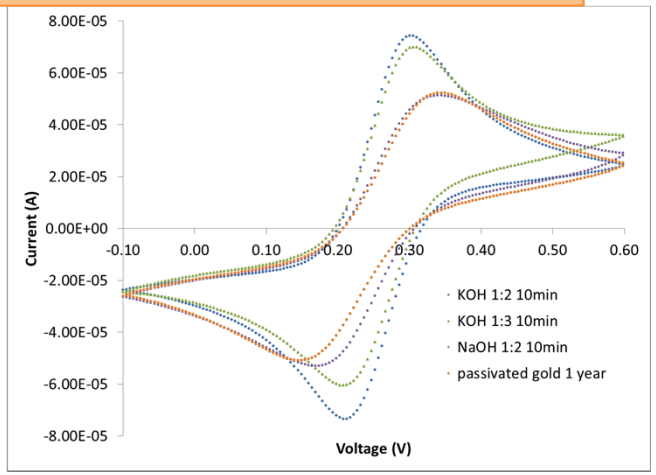
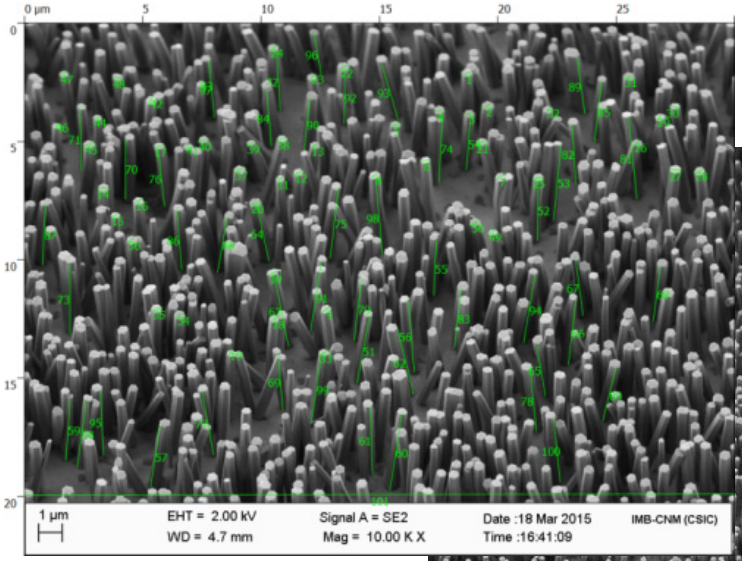
ZnO NW synthesis: activation method

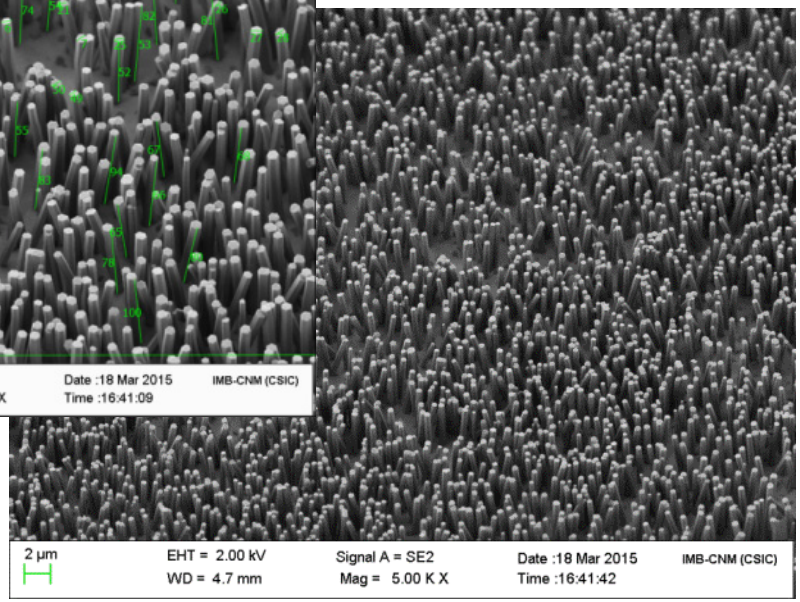
Growth Characterization of NW over gold seed layer

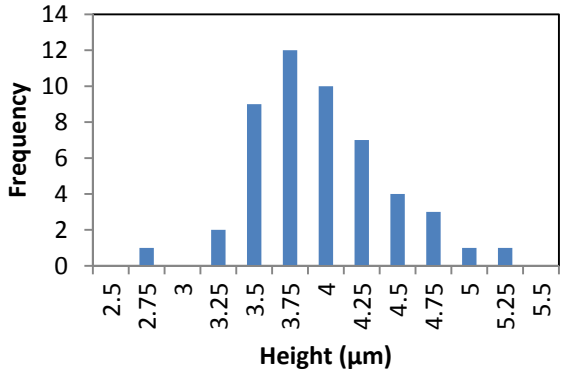
Density = 124 NW/100µm²

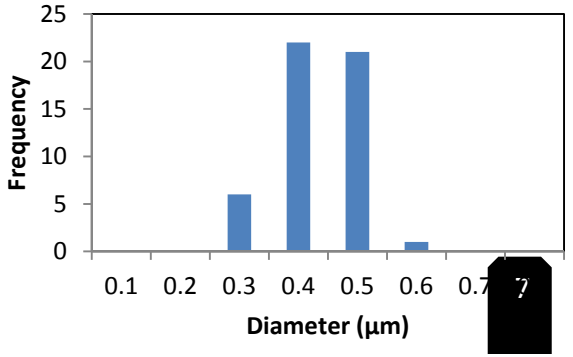
- Activation process developed with H_2O_2:KOH (1:3 and 1:2), H_2O_2:NaOH (1:3 and 1:2) or HNO_3.
- **Relationship between cyclic voltammetry and surface cleanness and quality**



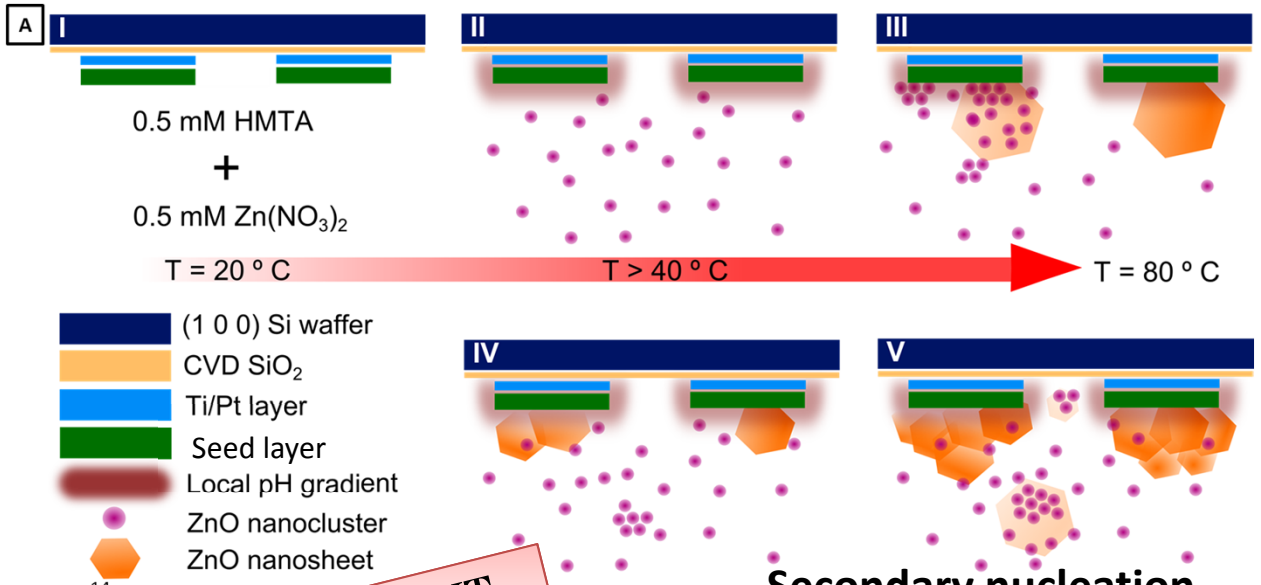








ZnO NS synthesis: working principle



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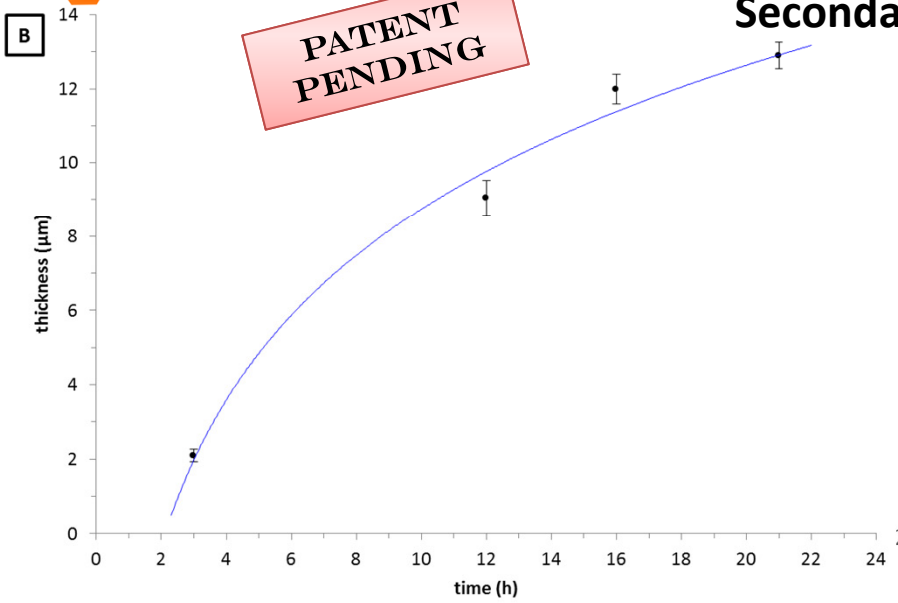

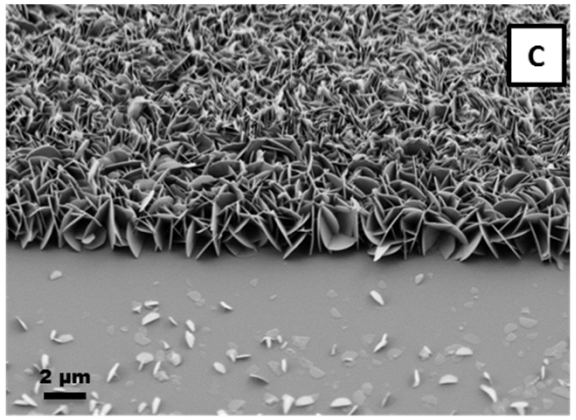

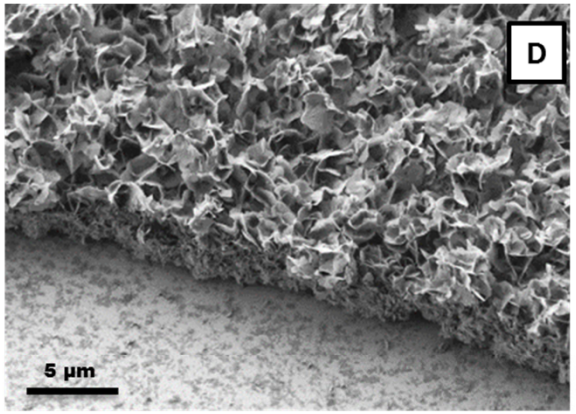

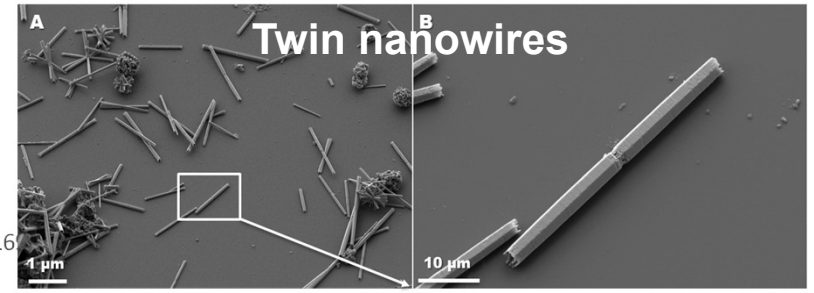

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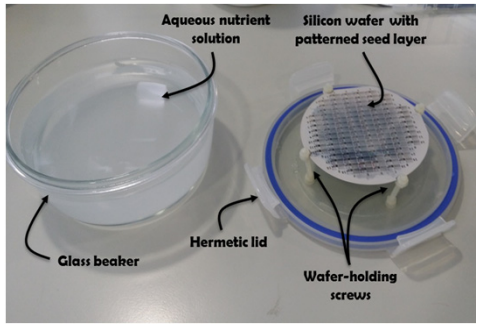
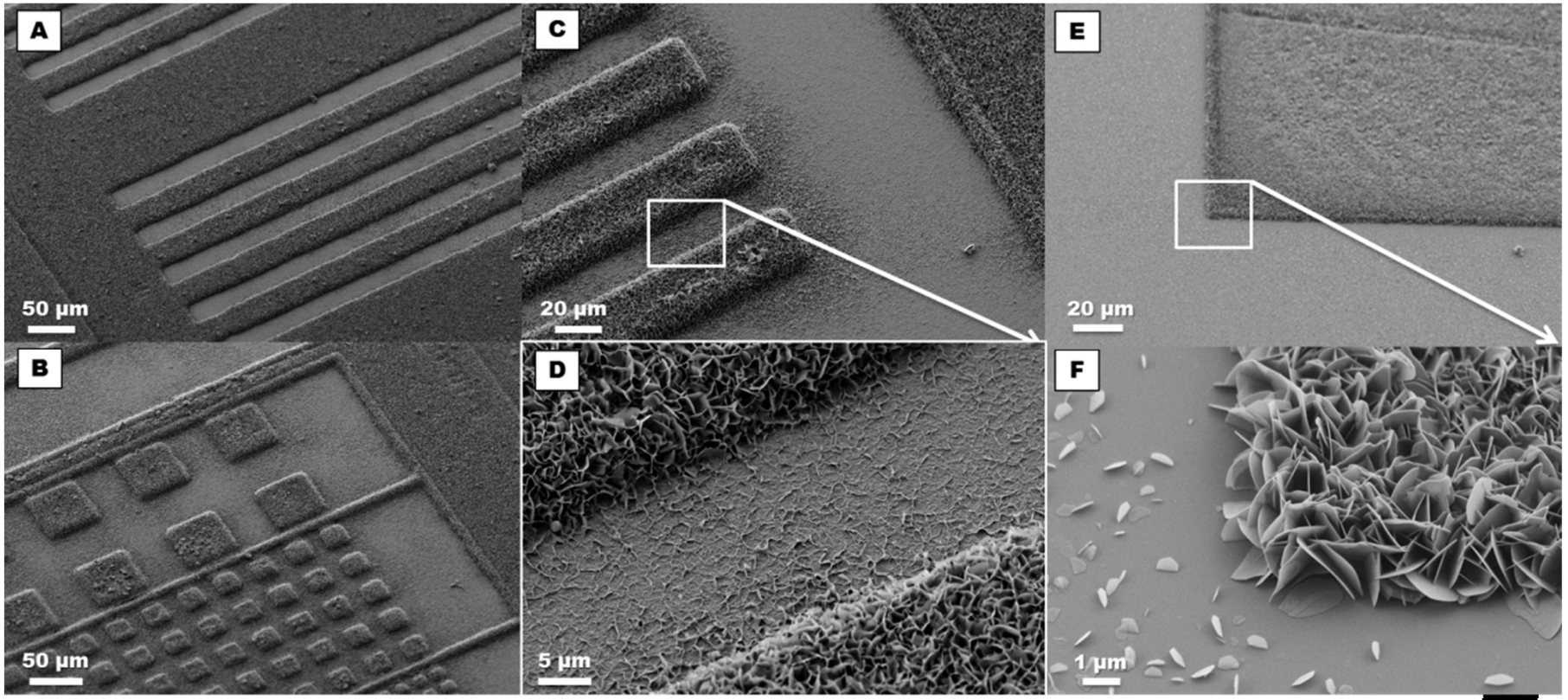
Selective area ZnO NS synthesis at wafer level

Selective area growth on silicon wafers

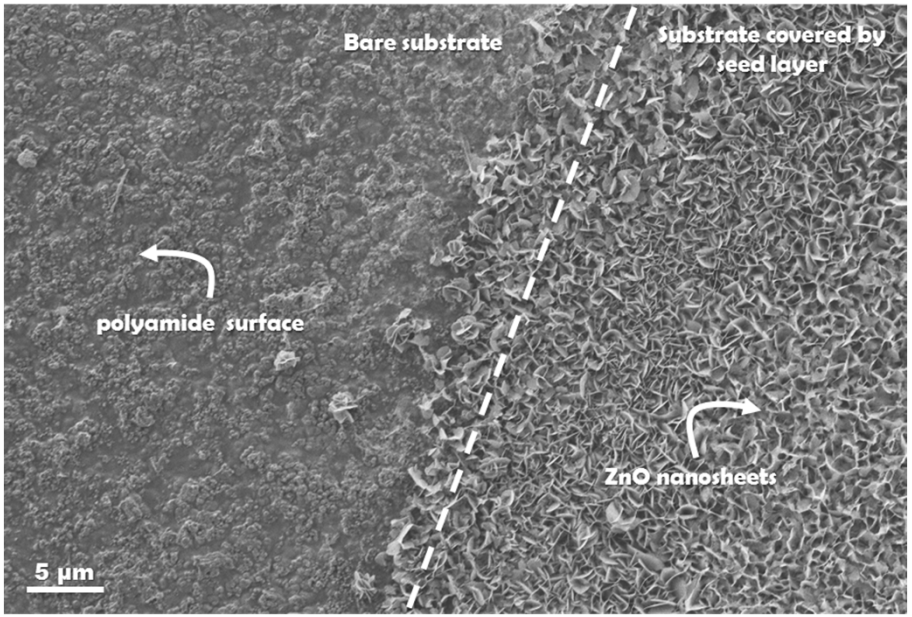
- Micrometric features can be obtained with high selectivity at wafer level.

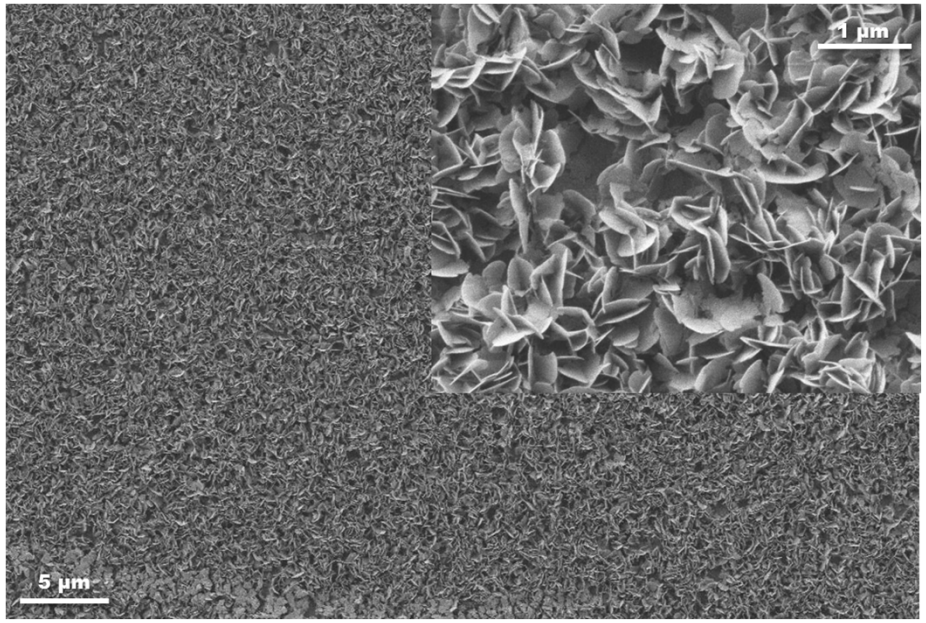




ZnO NS synthesis on other substrates

- Performed in flexible substrates such as polyimide
- It can be grown on top of glass (transparent device)
- Wafer-level synthesis





polyimide **glass**

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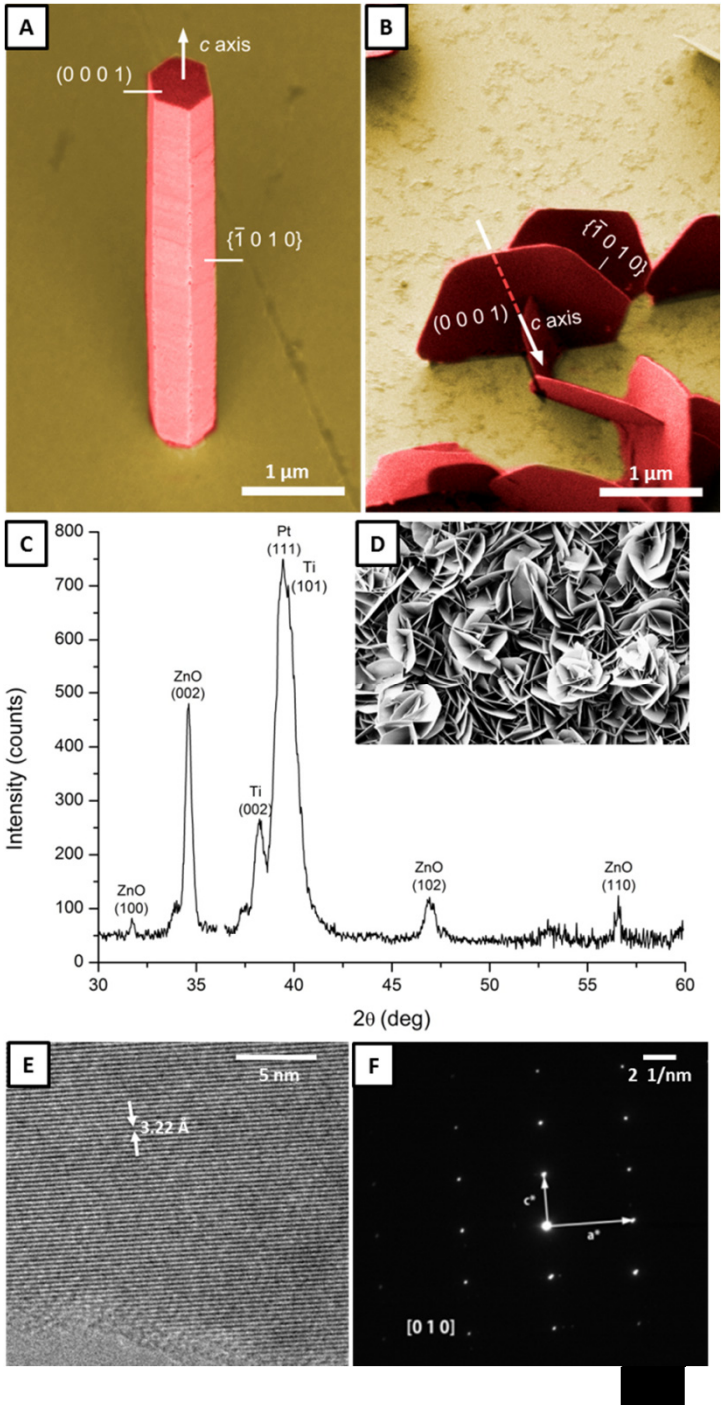
Material characterization

ZnO NS vs. NW

Characterization by HRTEM, SEM and XRD:

- ZnO NWs & NWs show a **good crystalline** structure.
- NS: Thickness < 20 nm, several µm long; **high aspect ratio**
- NS: Extremely high-density, **reproducible and fast**
- Growth along (0001) face is inhibited by the local pH gradient around seed layer
- **Seed layer is an insulator** which **avoid screening effect** of external carriers going into the ZnO



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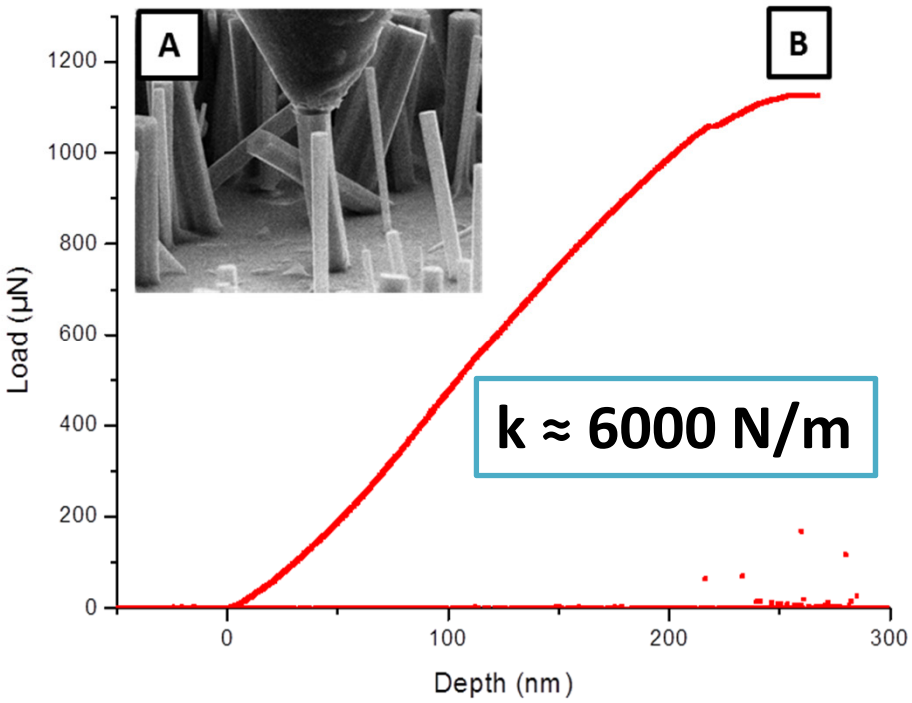
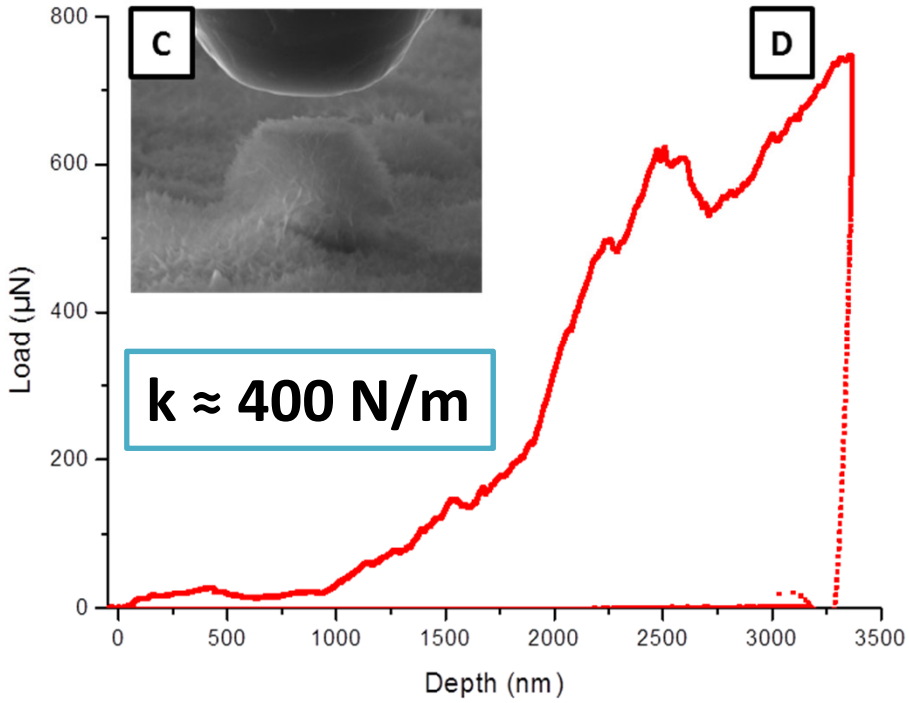
In-situ picoindentation

- ZnO nanostructures allow higher compression without fracture.
- It has been demonstrated that a single ZnO NW can stand for a compressing force of more than 1mN!

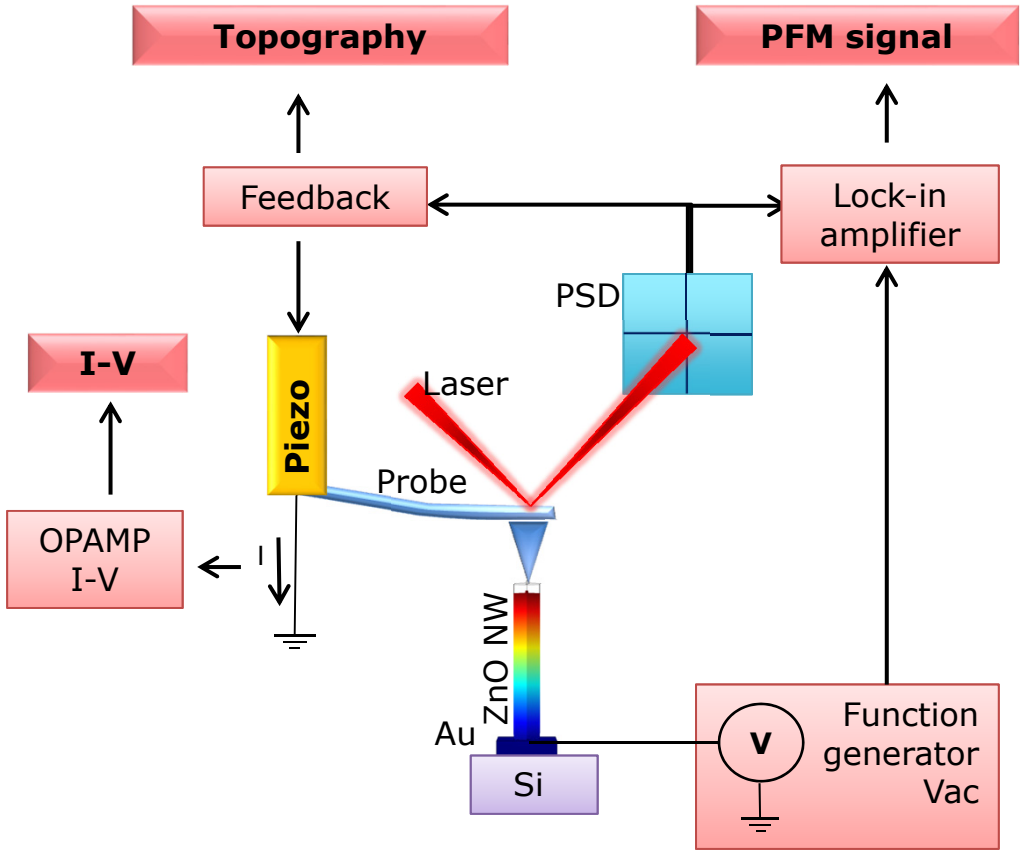




Piezoresponse measurement (PFM)

Piezoresponse Force Microscopy (PFM):

- AFM technique based on the converse piezoelectric effect
- Conductive tip used to measure the mechanical response when an electrical voltage (usually ac-voltage) is applied to the surface

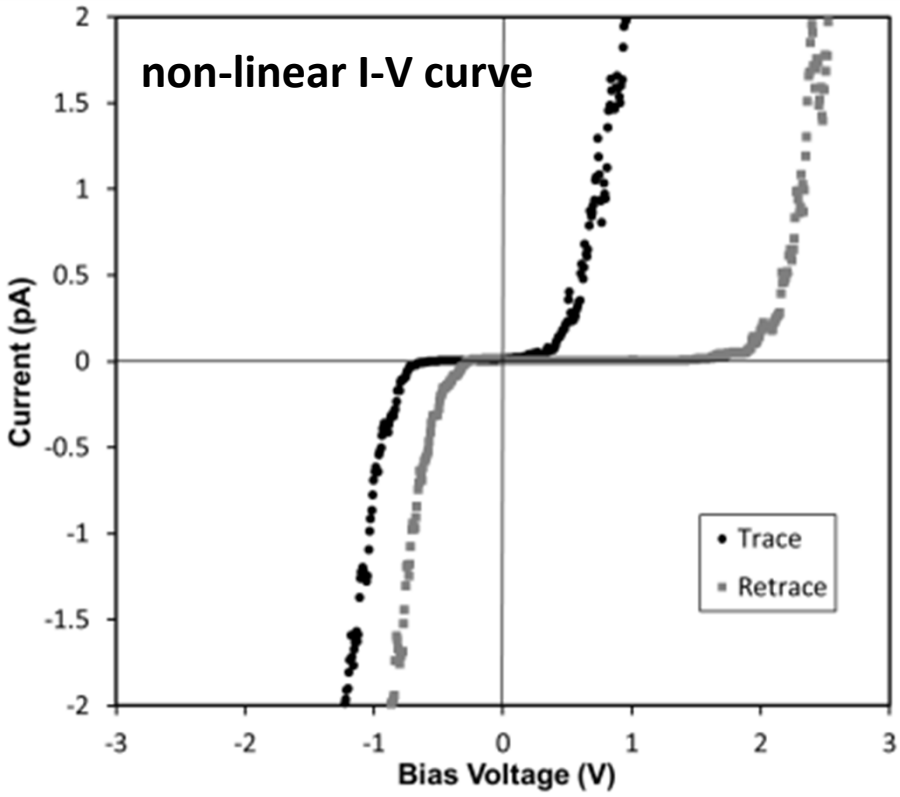


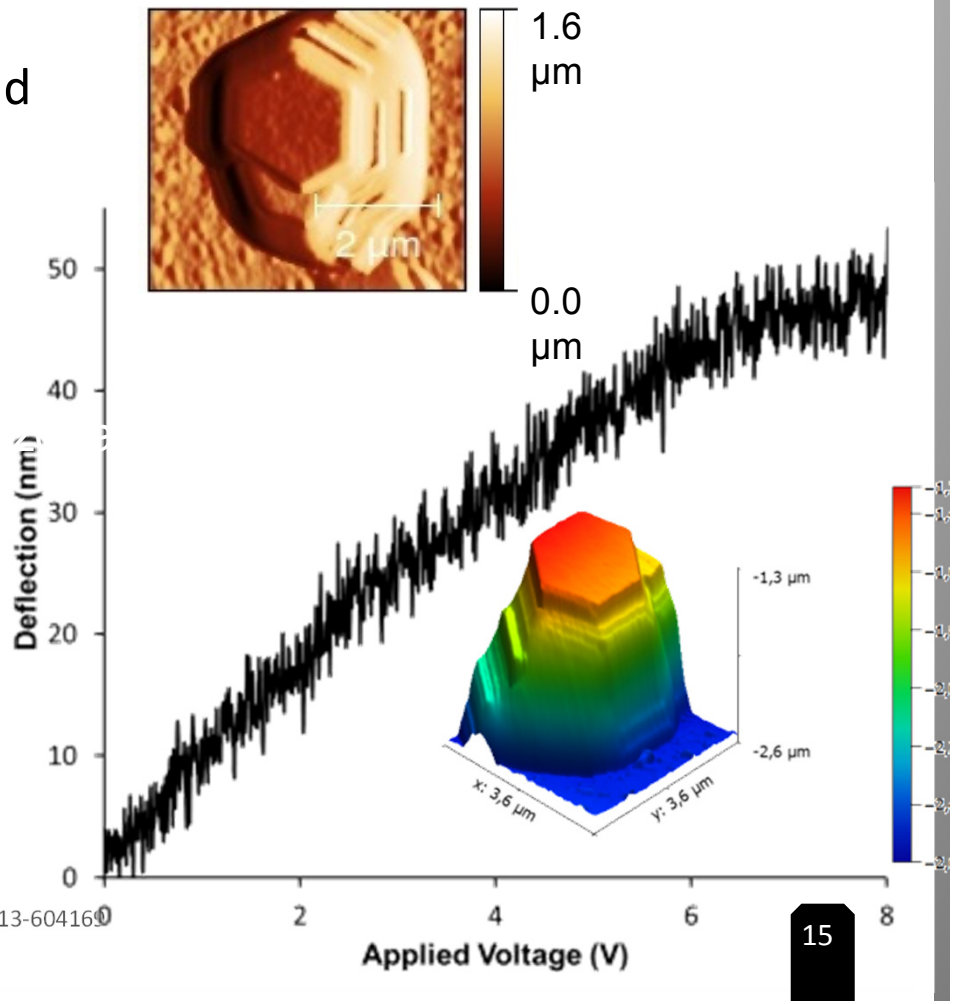
Piezoresponse measurement (PFM)

- I-V and piezoresponse characterization

ZnO nanowire: d33 ≈ 8.6 pm/V

Piezoresponse AFM (PFM) measurement of ZnO nanowires and nanosheets at 37kHz.

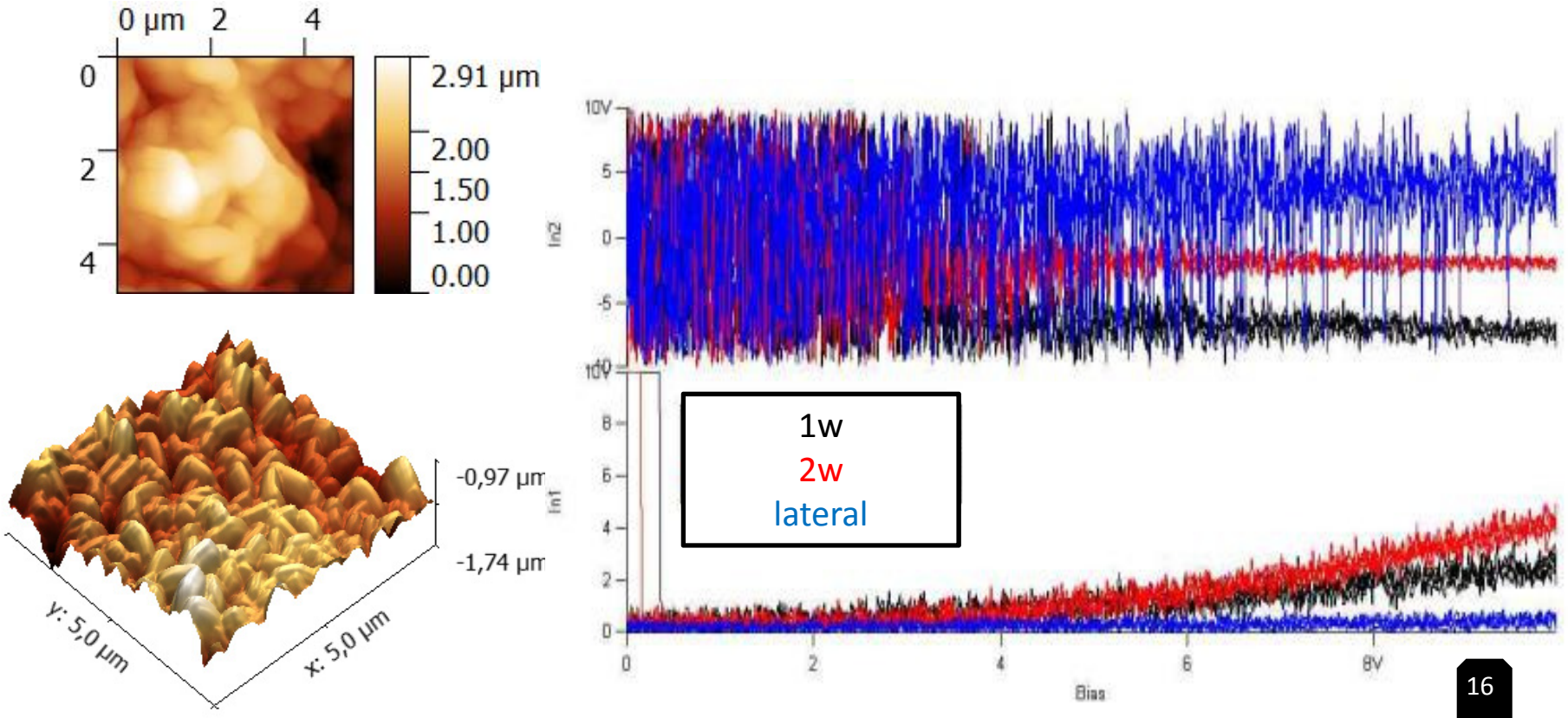




Piezoresponse measurement (PFM)

- PFM characterization
  - Piezoresponse of ZnO nanowires and nanosheets at 37kHz.

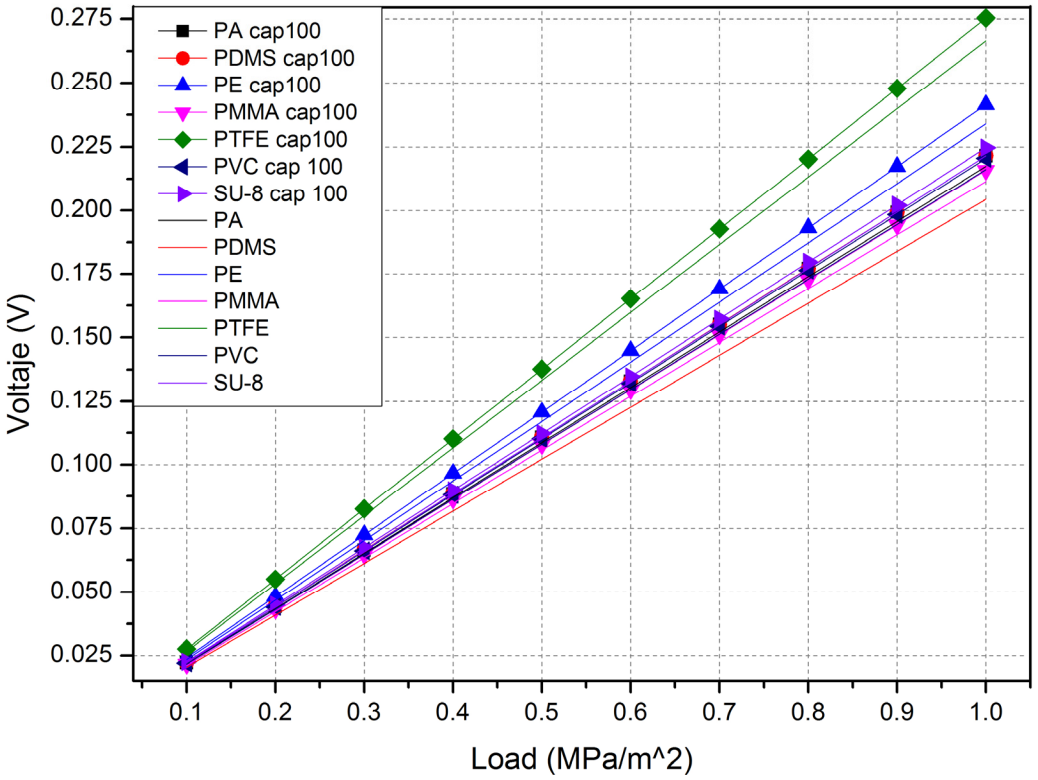
ZnO nanosheet: d31 ≈ 6 pm/V

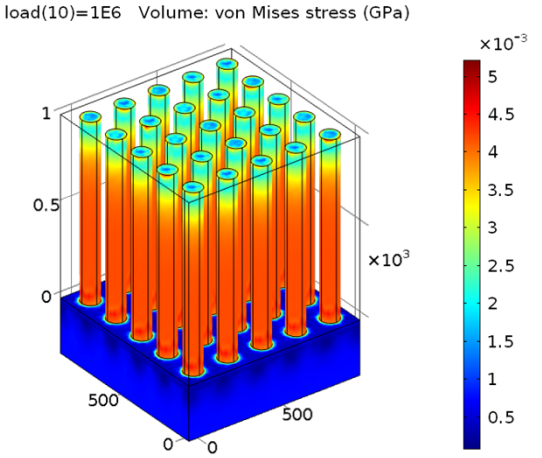


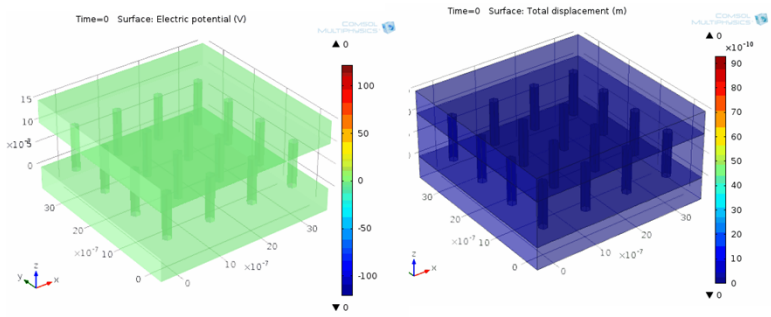
Piezoelectric and triboelectric applications: preliminary results

FEM simulations of embedded ZnO nanostructures

- ZnO nanowires
  - Study of more suitable polymer to encapsulate ZnO NWs in terms of open circuit voltage:

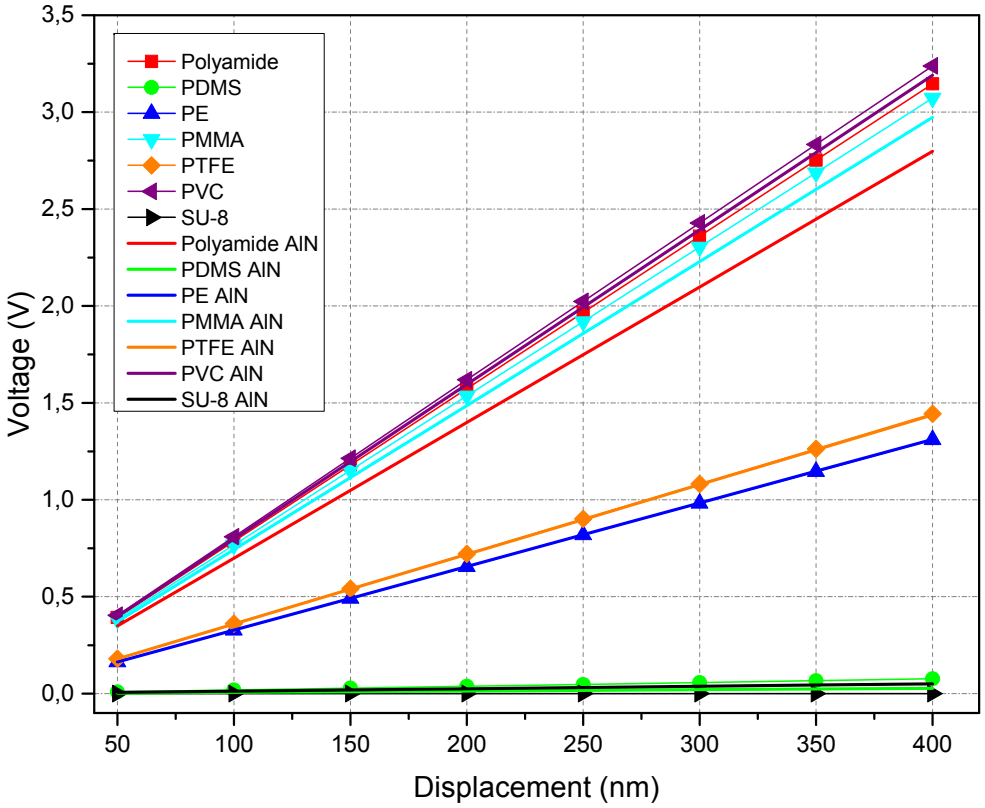


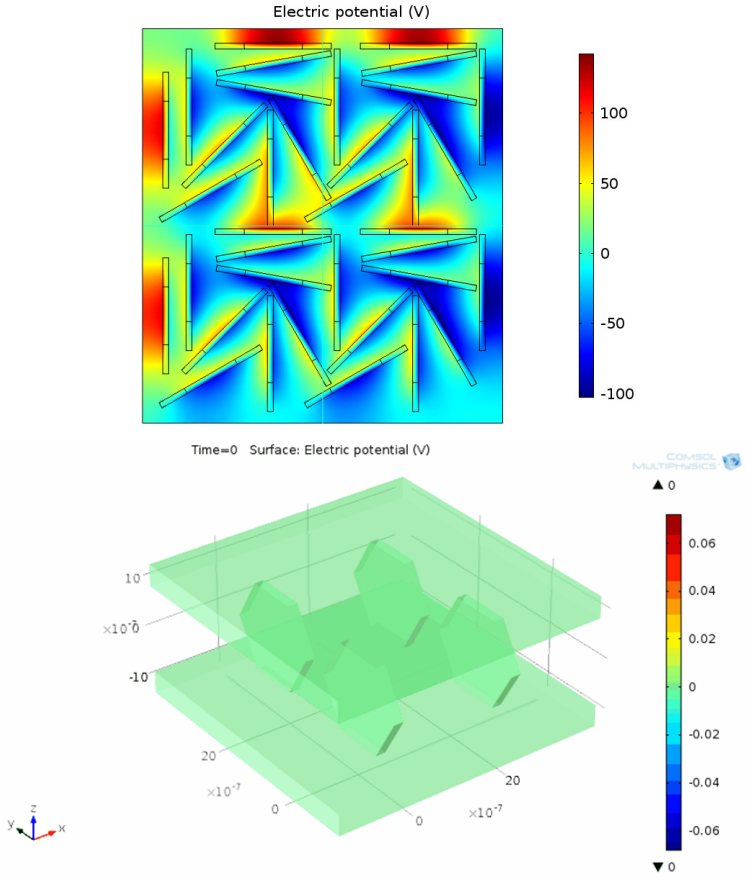




FEM simulations of embedded ZnO nanostructures

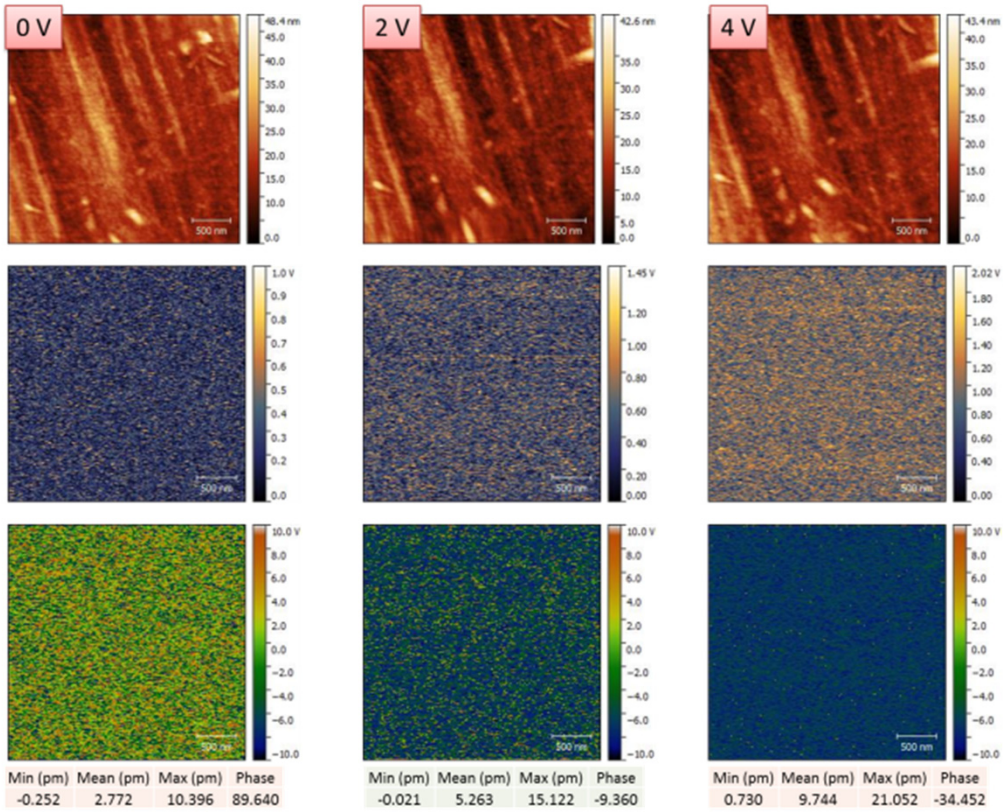
- ZnO nanosheets:
  - Study of more suitable polymer to encapsulate ZnO NSs in terms of open circuit voltage:

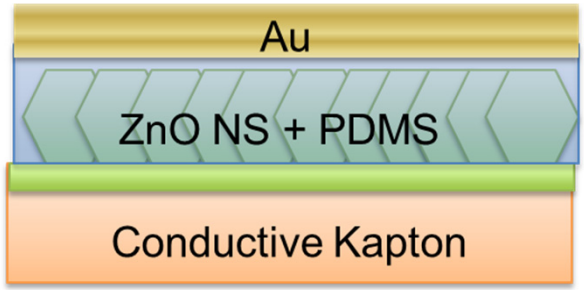


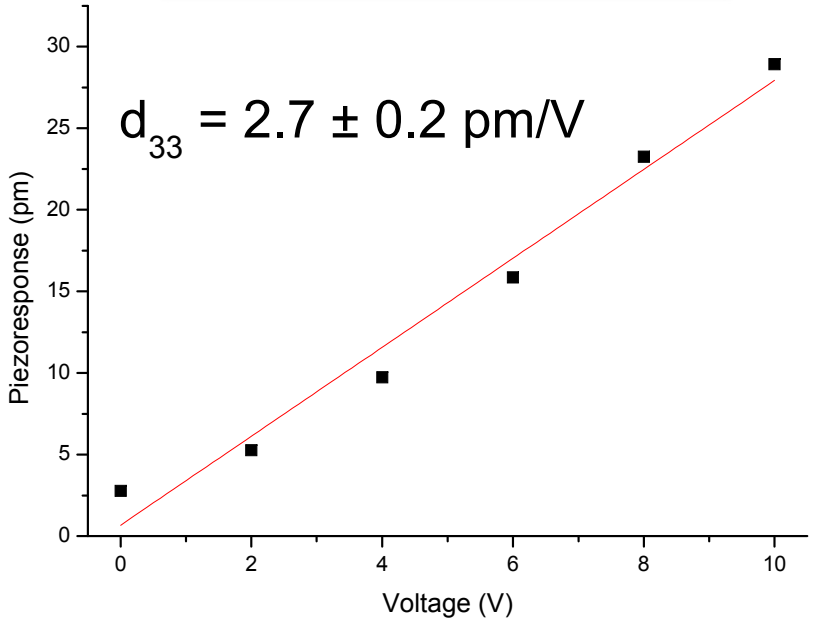


Flexible ZnO NS EH

PFM of Flexible generator based on ZnO NS + PDMS

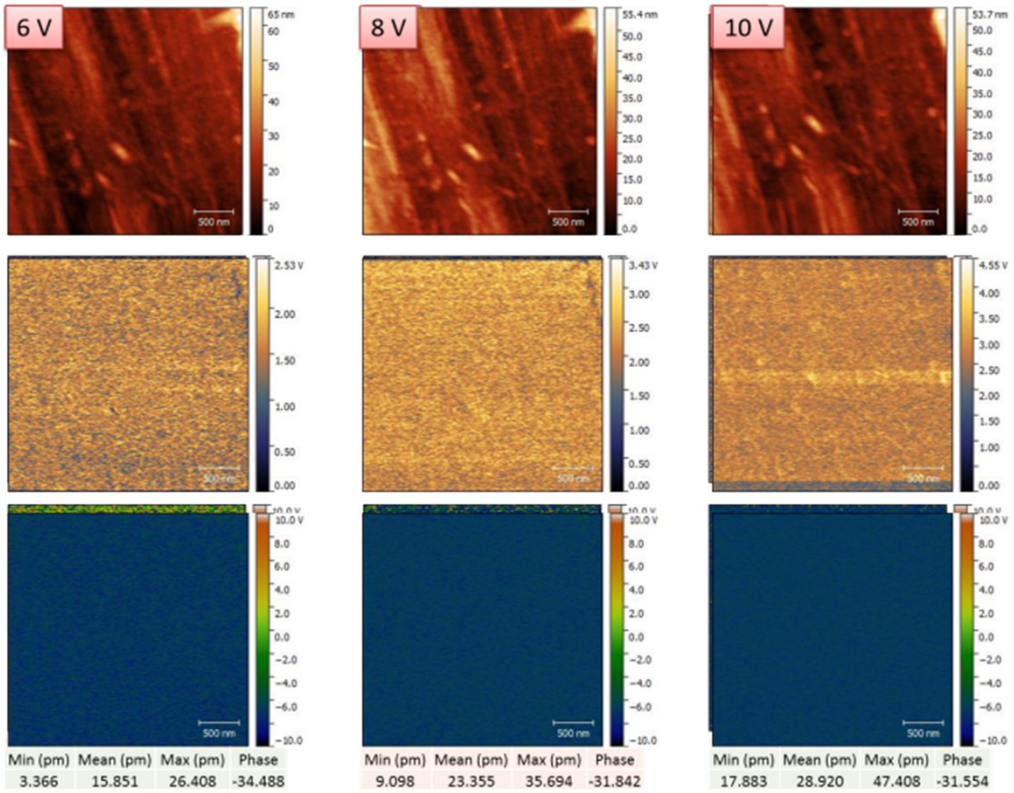


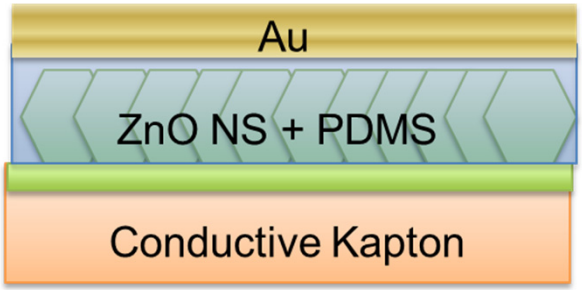


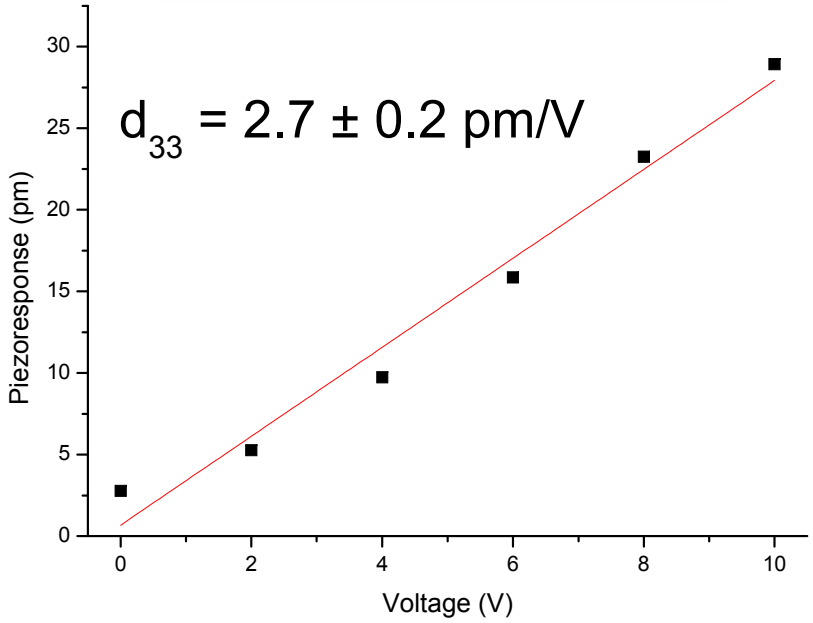


Flexible ZnO NS EH

PFM of Flexible generator based on ZnO NS + PDMS

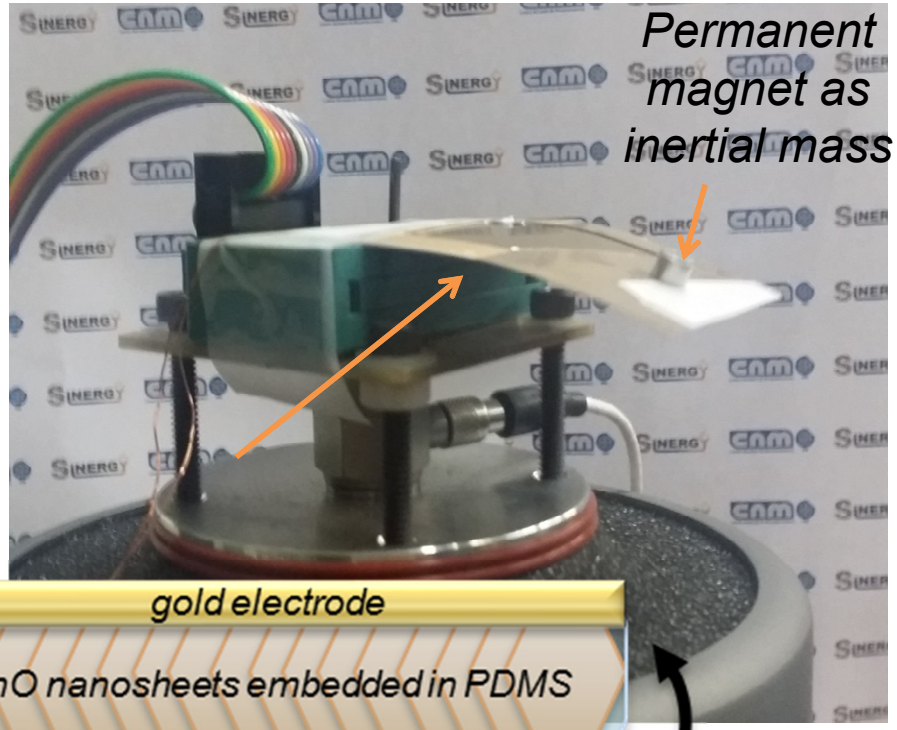


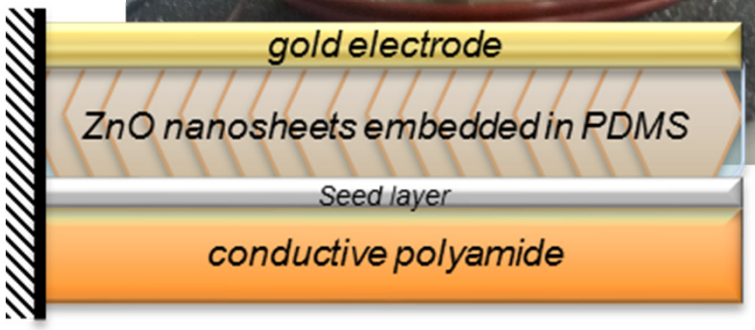


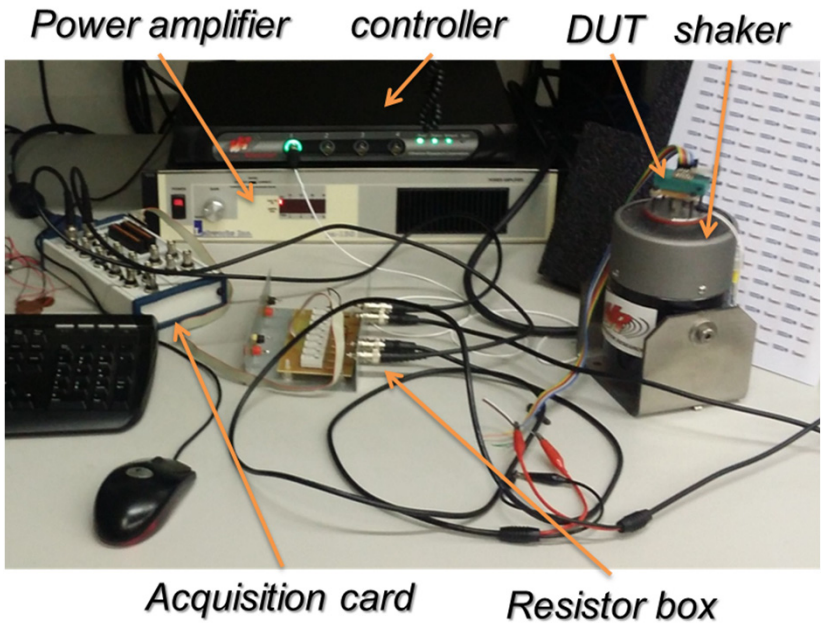


Flexible NS-based prototype

- Flexible energy harvester
  - **Vibrational device characterisation**
  - Tip mass made with two magnets



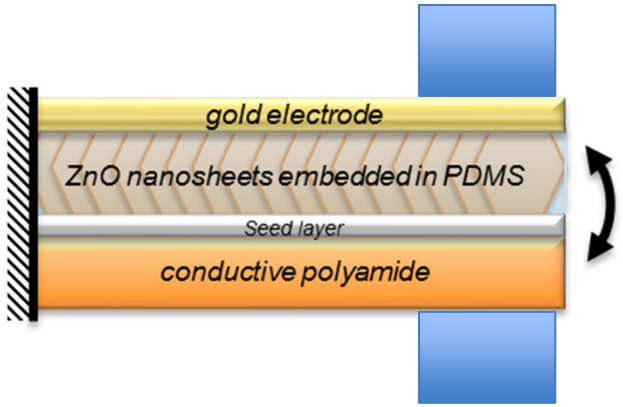


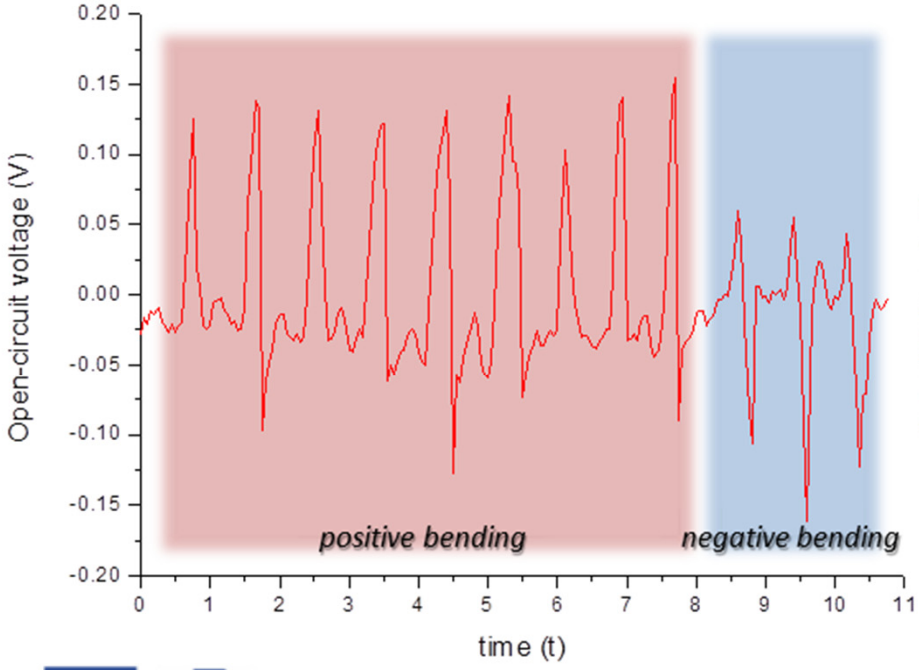


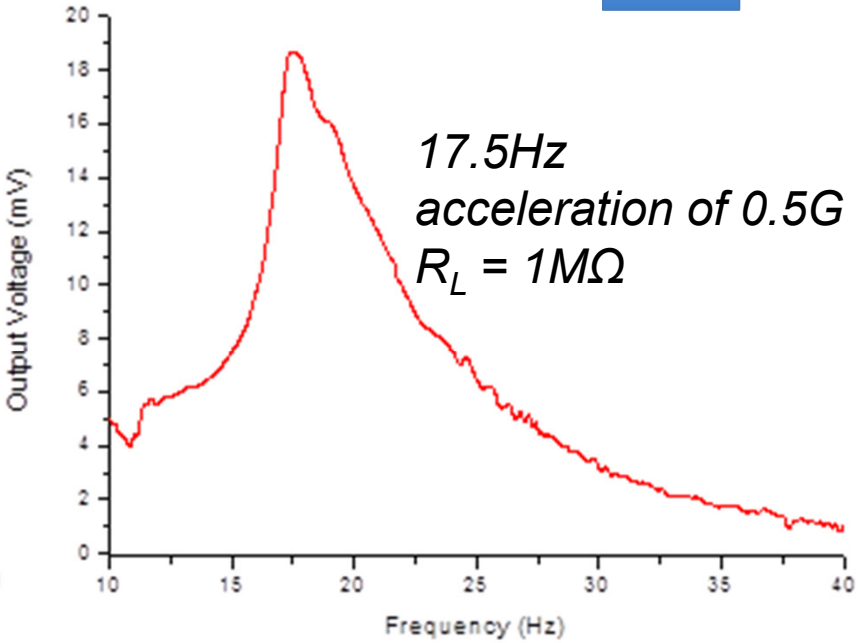
Flexible NS-based prototype

- Piezoelectric effect

Flexible device mounted on top of an electromagnetical shaker to be tested at a controlled vibration at a certain frequency and acceleration



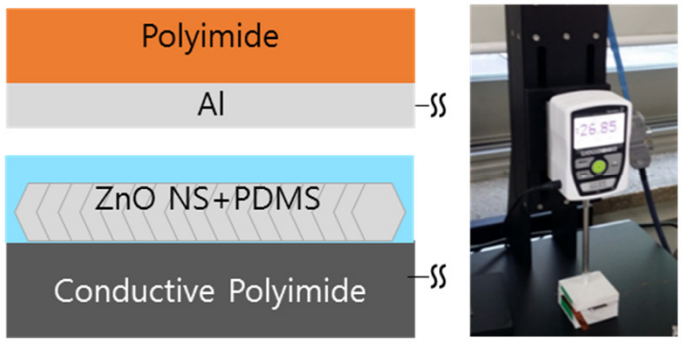




Flexible NS-based prototype

- Triboelectric effect:

a



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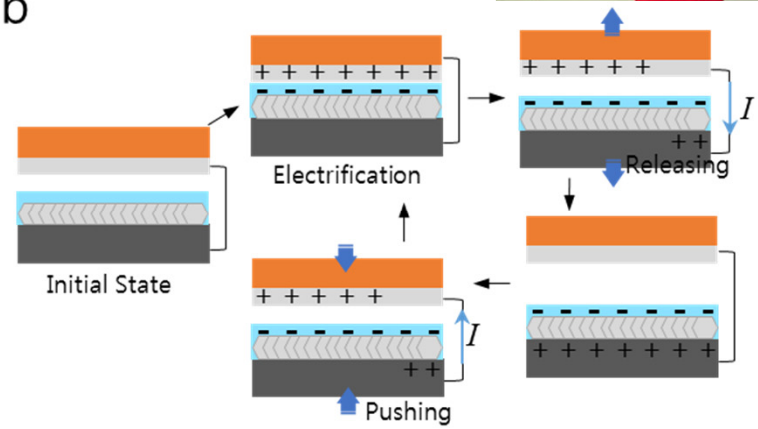
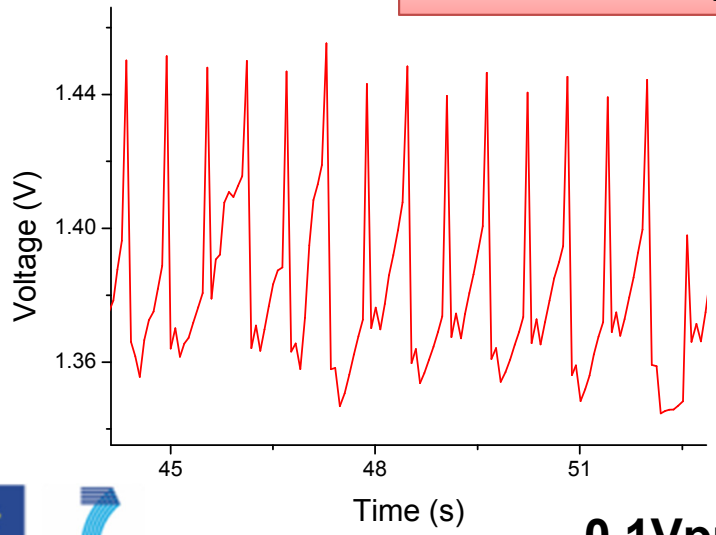
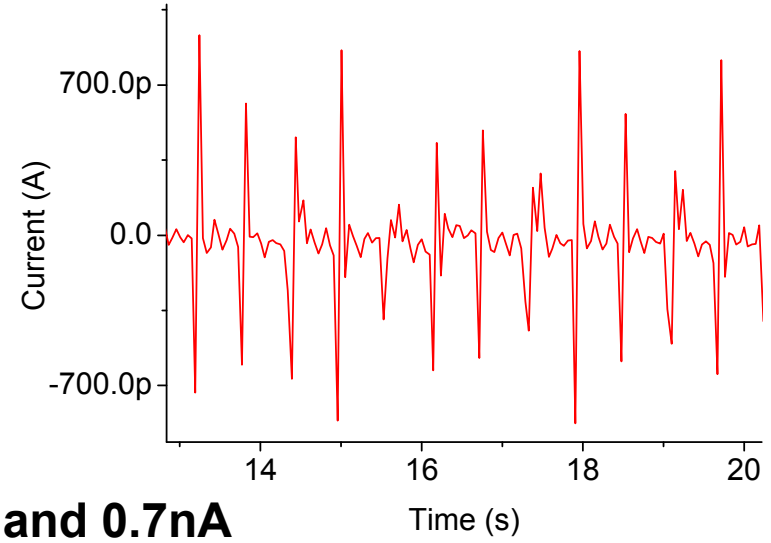


Close contact: piezoelectric contribution



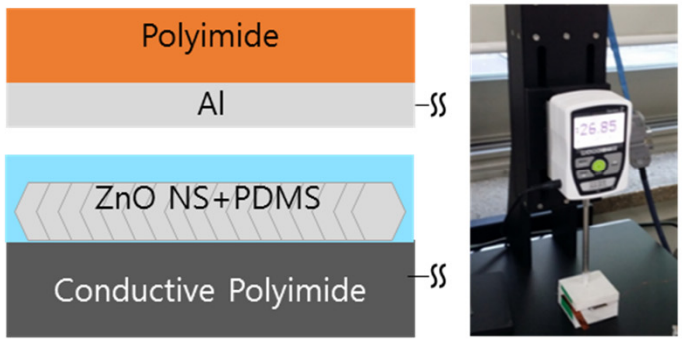


0.1Vpp and 0.7nA

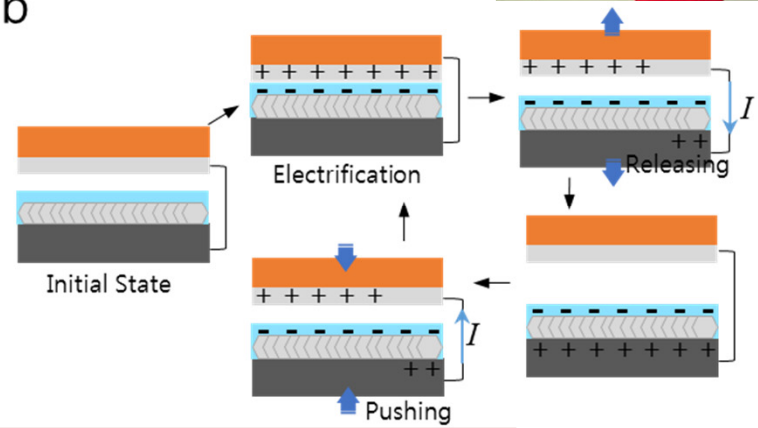
Flexible NS-based prototype

- Triboelectric effect:

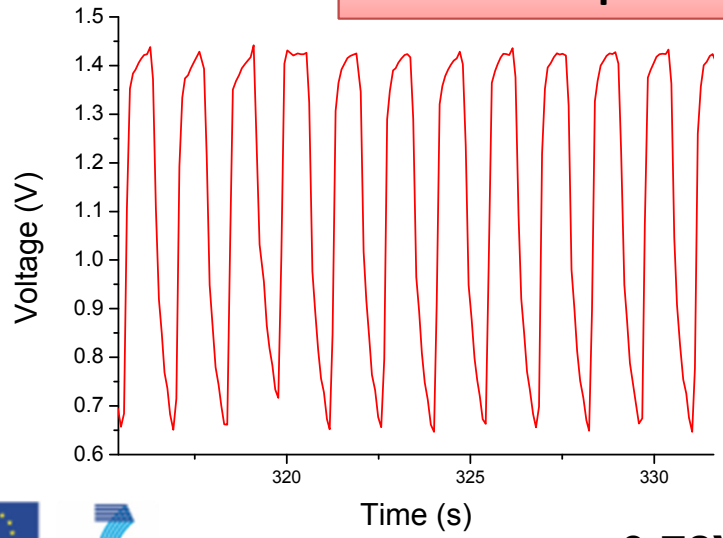
a

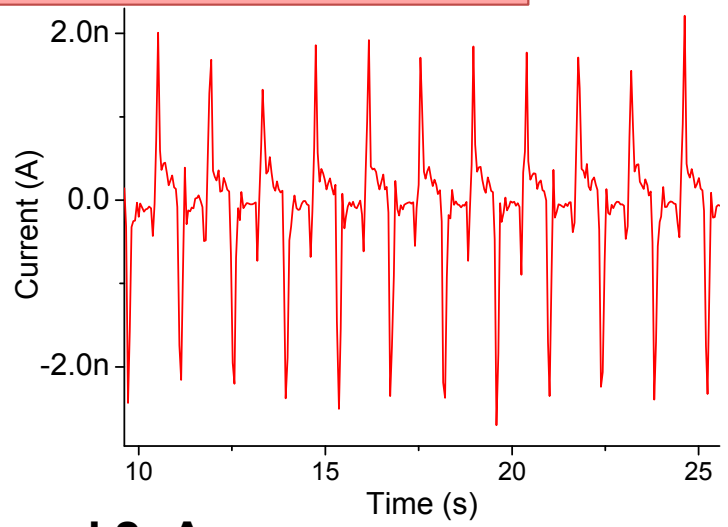


b



5 mm of separation: triboelectric contribution





0.78Vpp and 2nA

Conclusions

Conclusions

- Our novel seed layer allows **selective area growth of ZnO NSs**
- This growth is **inexpensive, fast, reproducible, at wafer level** and over transparent, flexible and silicon substrates
- Piezoelectric coefficients of ZnO NWs and NSs have been measured
- A **flexible NS-based prototype** has been fabricated and electrically characterized
- Some preliminary results show a promising application of ZnO NSs in **triboelectric and piezoelectric devices**

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Thank you! Any question?

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