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Context

GaN nanowires (NWs) are promising candidates for piezoelectric nano-generators thanks to their advantages:

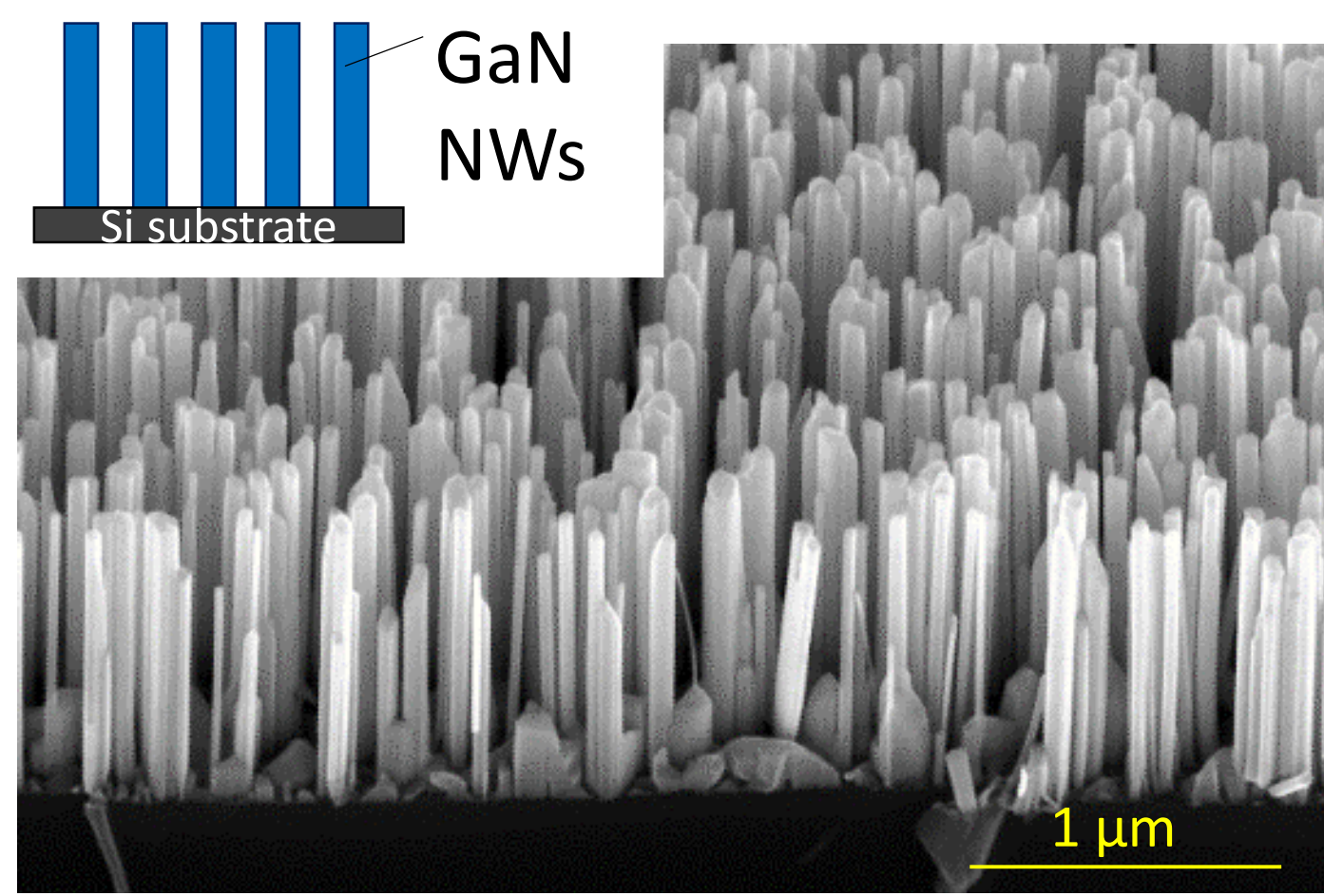
- Lead-free material
- High thermal, chemical stability and radiation hardness
- High force sensitivity thanks to large degree of elastic deformation
- Surface charge effect¹ potentially enhance piezoelectric efficiency

However, the piezoelectric properties of NW are not fully investigated due to the challenge of performing characterizations at the nanoscale

→ **In this work:** Study the piezoelectric properties of each individual GaN NWs using AFM (direct and inverse piezoelectric methods)

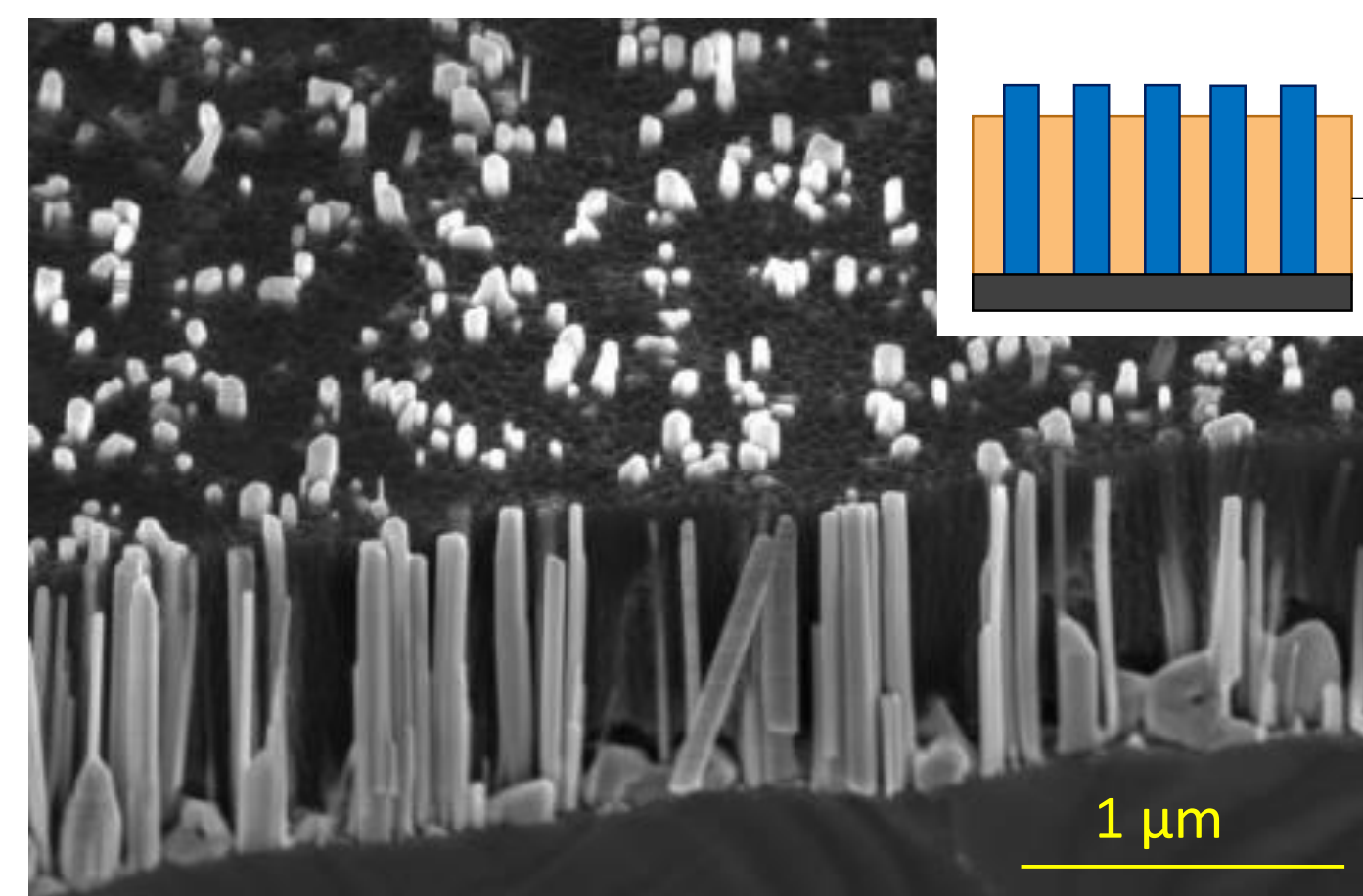
Our objective: Identify NWs with optimal piezoelectric properties to integrate into a polymer matrix for piezoelectric applications

GaN NWs for AFM characterizations



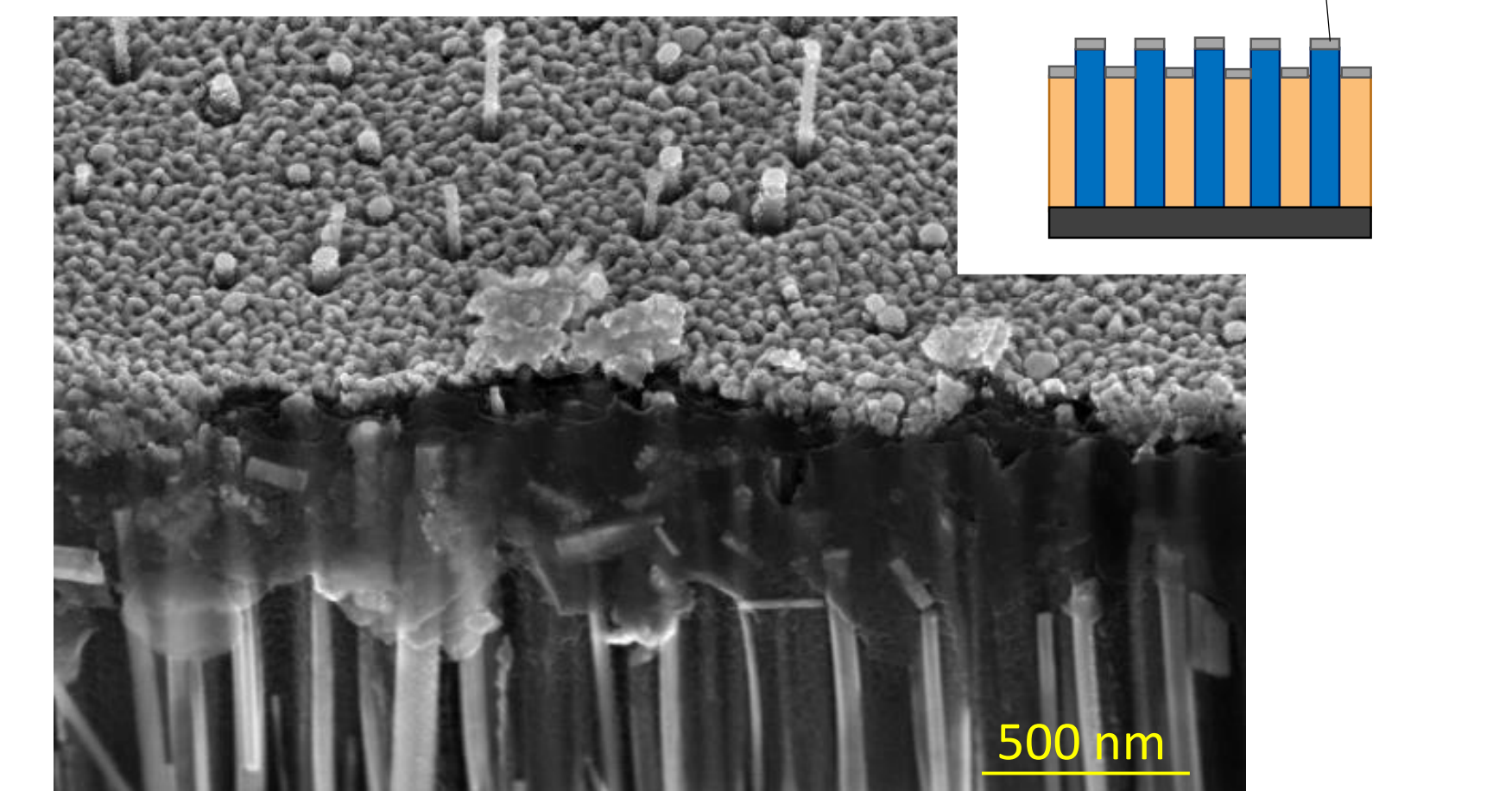
GaN NWs grown by PA-MBE

Spin coating following by RIE etching



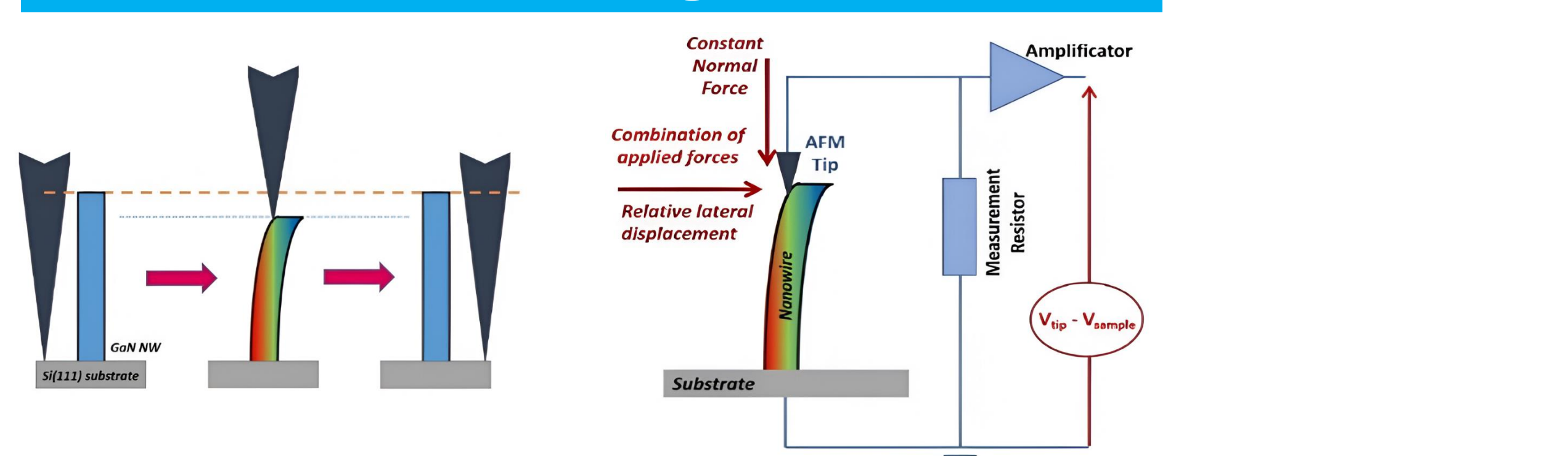
GaN NWs encapsulated in BCB

Thermal evaporation deposition

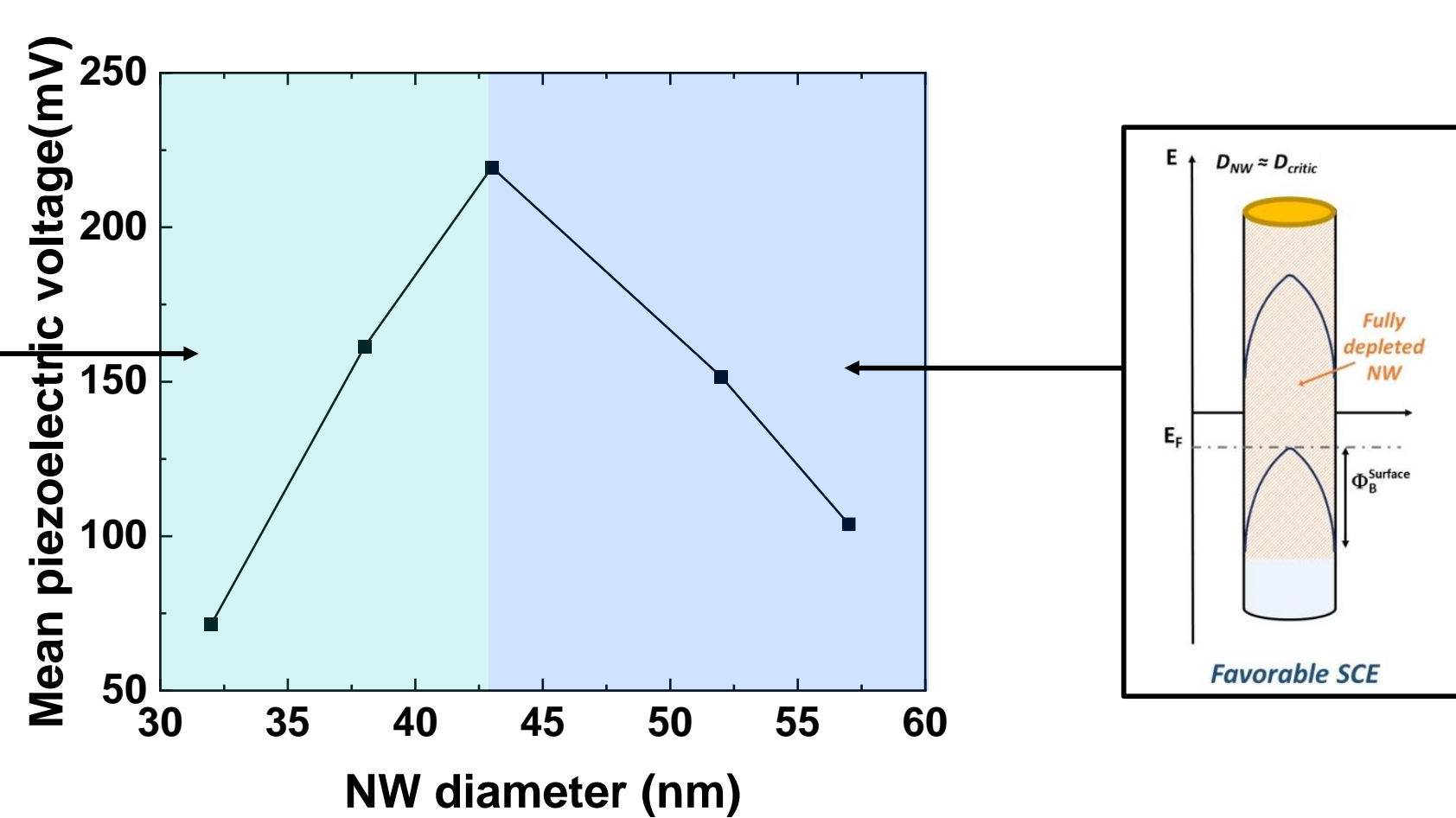
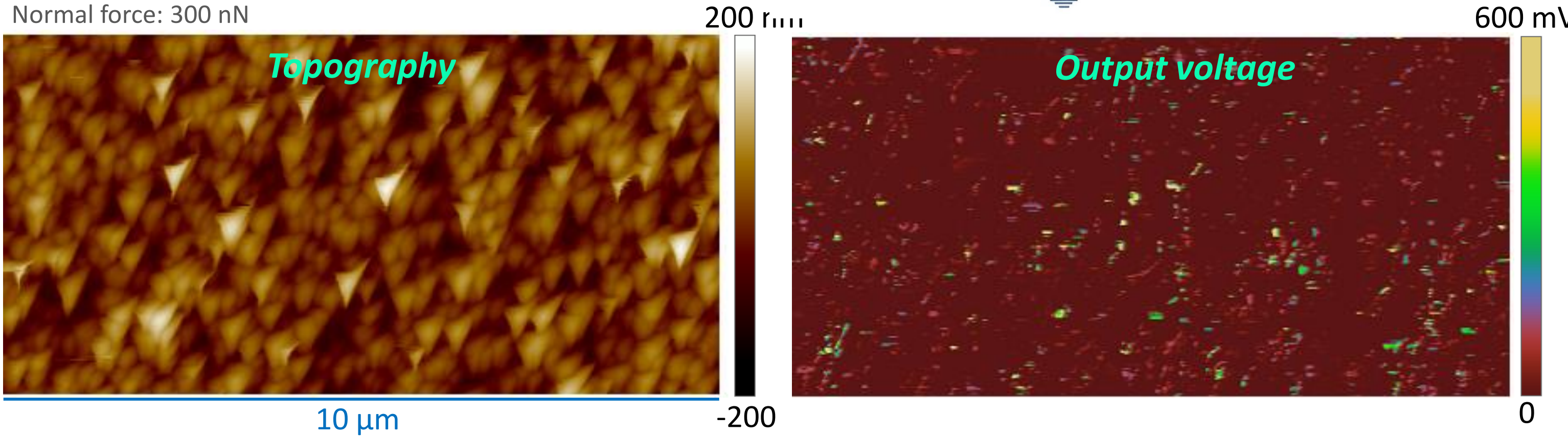


Metal electrode deposited on top of NWs

AFM bending mode

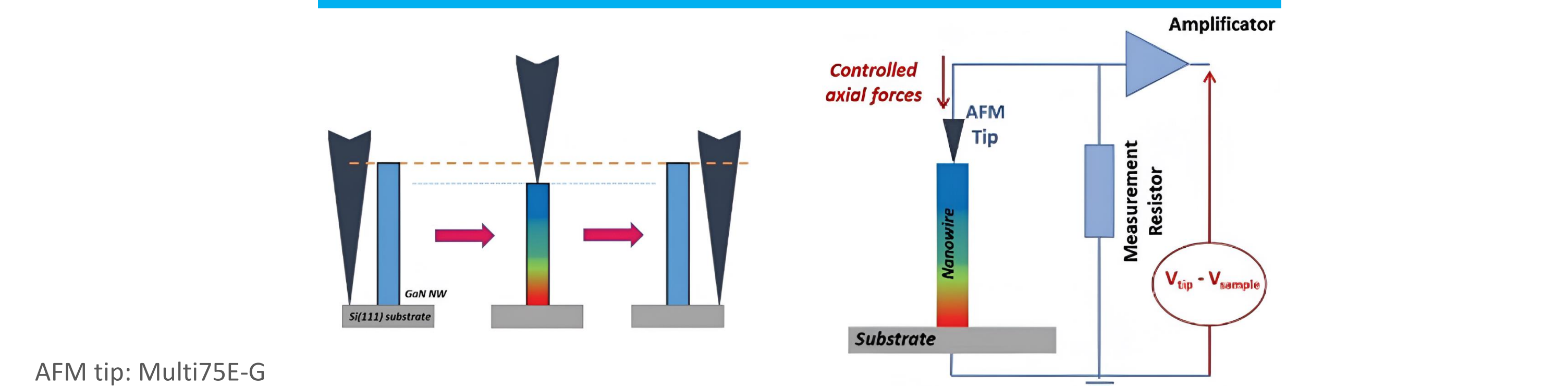


AFM tip: Multi75E-G
Normal force: 300 nN

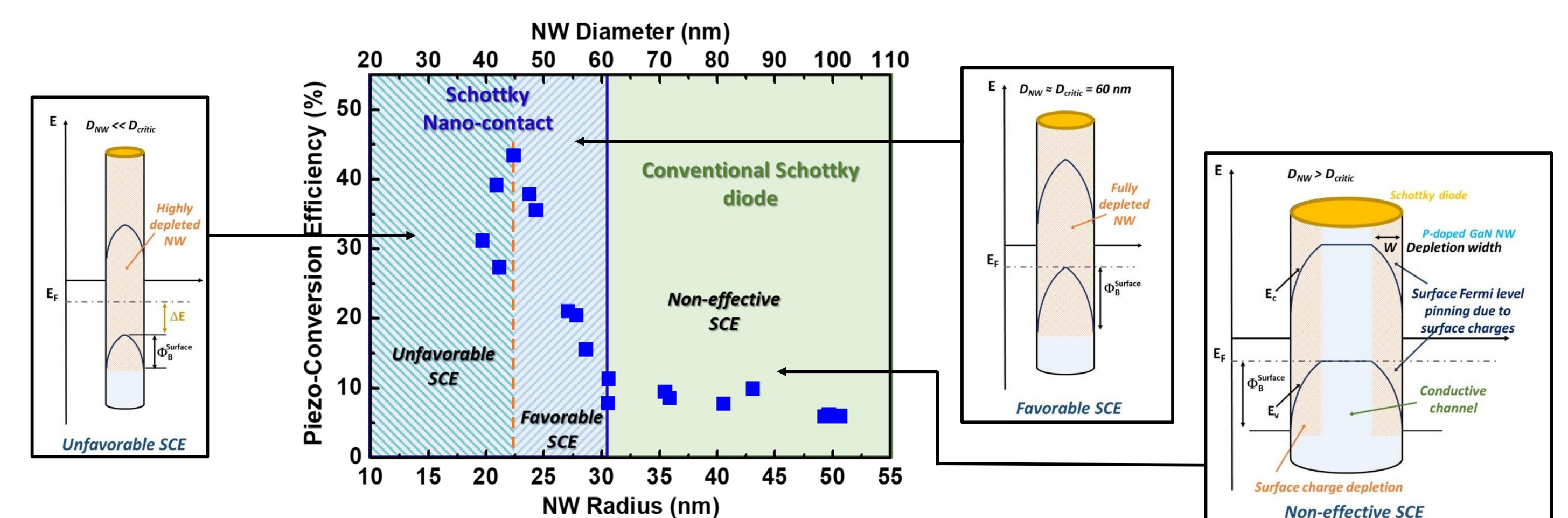
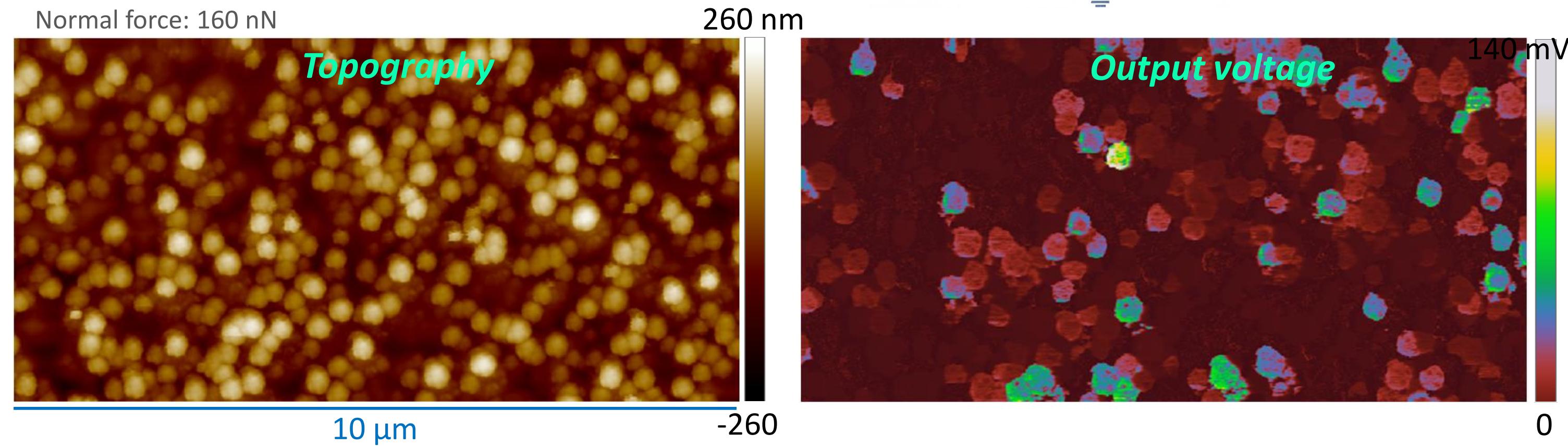


Evolution of piezoelectric output voltage as function of NW diameter.

AFM compression mode



AFM tip: Multi75E-G
Normal force: 160 nN

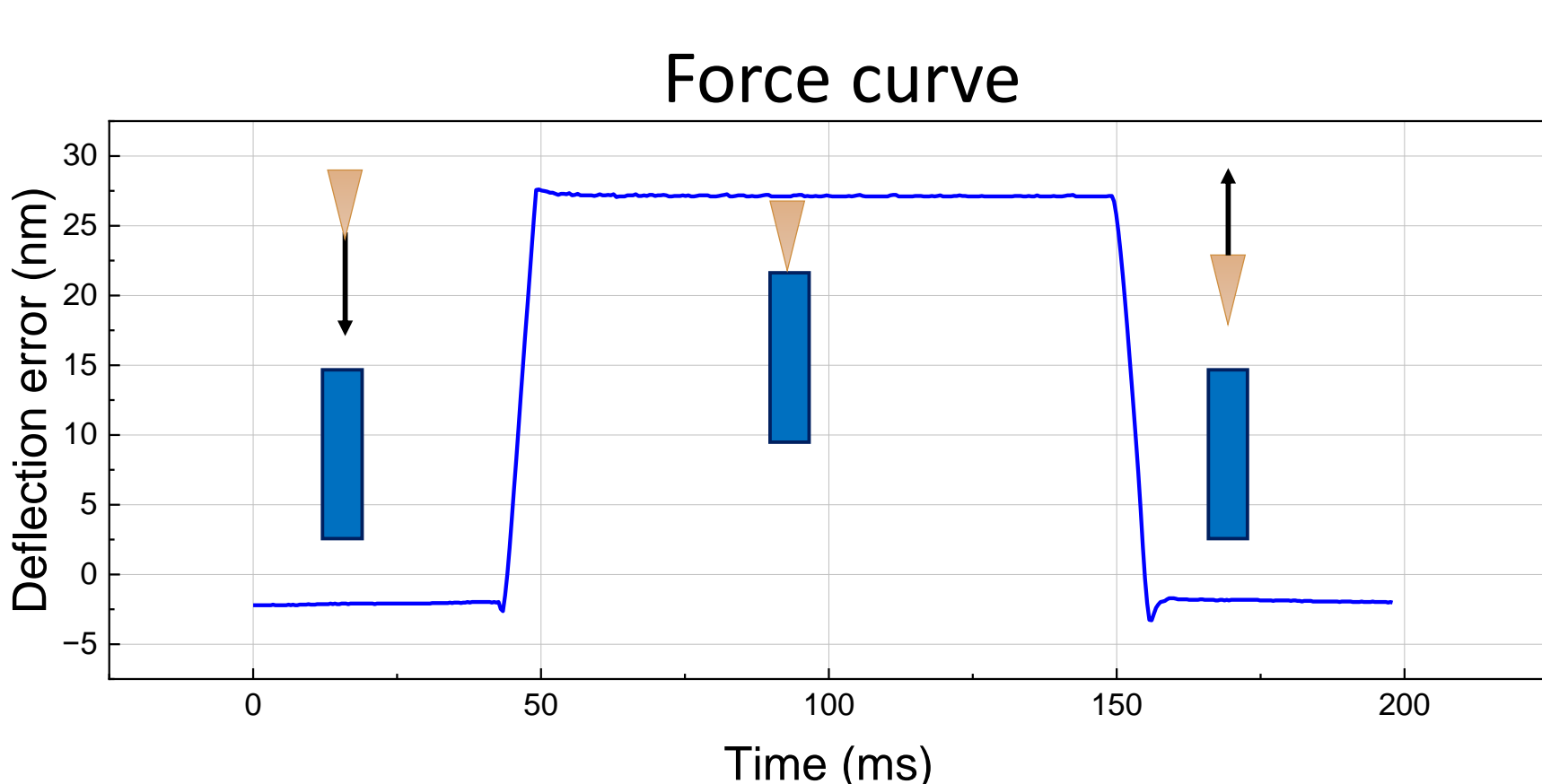
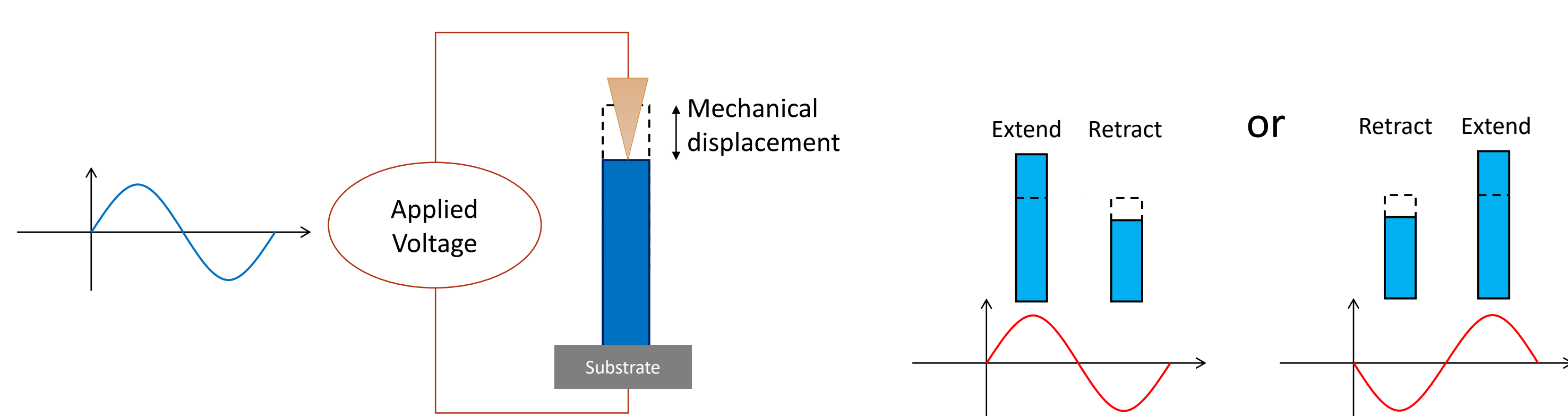


Evolution of piezo-conversion efficiency as function of NW diameter.²

Best piezoelectric Response for a NW diameter of around 45 nm thanks to the surface charge effects

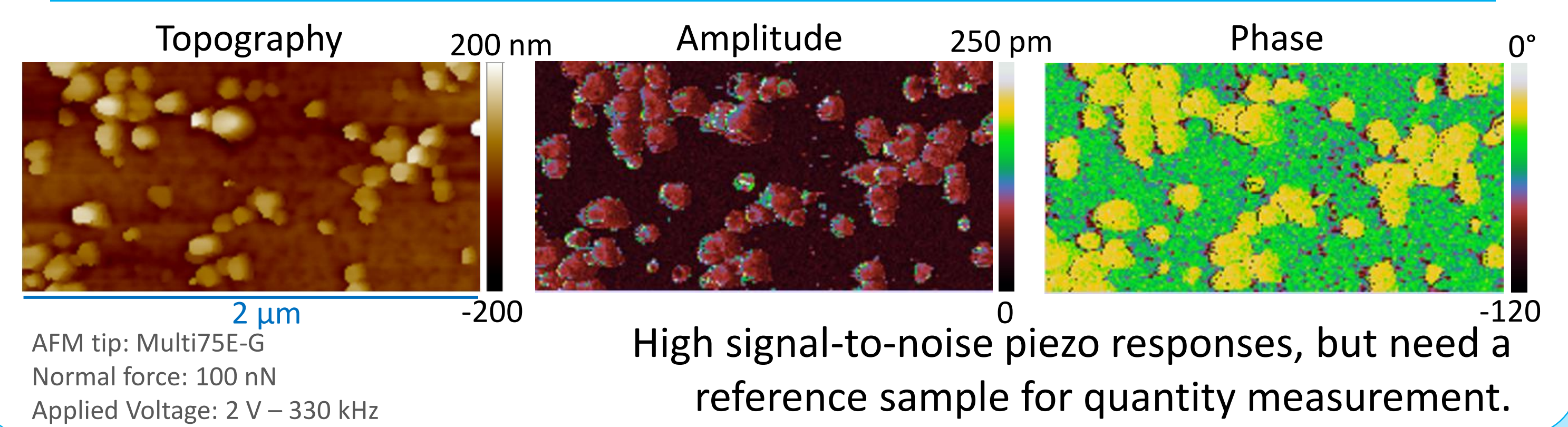
How are evolving the piezoelectric coefficient as a function of the NW diameter? Which influence of the surface charge effects?

Datacube Piezoelectric Force Microscopy (PFM)



- Piezoresponse amplitude is proportional to the piezoelectric coefficient d_{33}
- Piezoresponse phase is attributed to the piezoelectric polarity

Datacube PFM measurement on GaN NWs



AFM tip: Multi75E-G
Normal force: 100 nN
Applied Voltage: 2 V - 330 kHz

High signal-to-noise piezo responses, but need a reference sample for quantity measurement.

Conclusion

- Measured directly the piezoelectric voltage of individual NWs
 - Bending and compression modes show the same optimal diameter
 - Measured piezoelectric responses of individual NWs by datacube PFM
- Perspective:** Establish a protocol for PFM measurements and piezoelectric coefficient evaluation

References: [1] R. Calarco et al., J. Mater. Res. 26, 2157 (2011);
[2] N. Gogneau et al., Nanoscale 14, 4965 (2022).