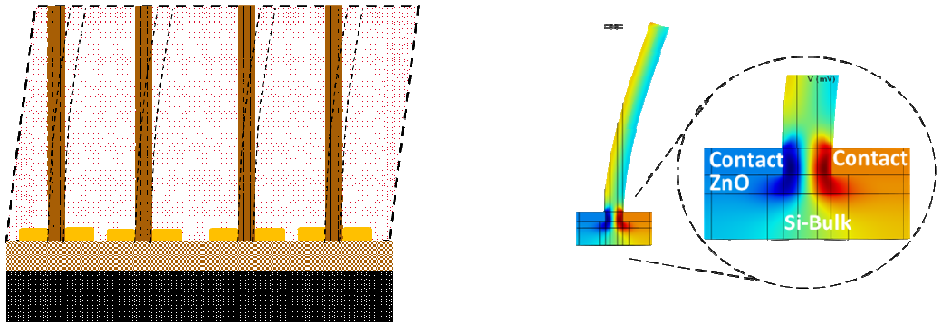
Unit-Cell Design of a Force Sensor Based on Vertical Piezoelectric Nanowires



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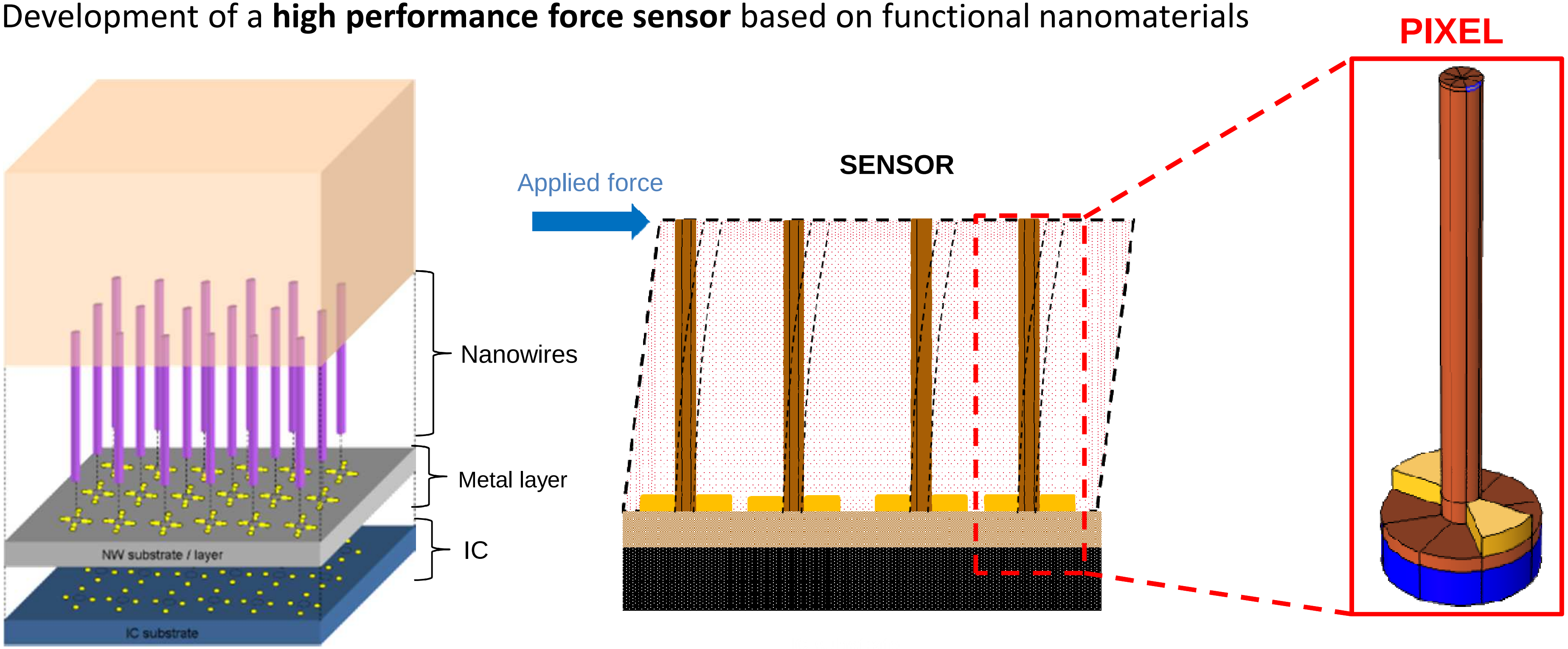
Summary

PART I:
INTRODUCTION

Large-scale integration of nano-objects

Context: Systems Integration and miniaturization

Development of a **high performance force sensor** based on functional nanomaterials



Piezoelectric response impacted by nanowires characteristics (Hinchet et al., IEDM 2012)

3D reconstruction of the force / deformation applied on the sensor via strain-stress field mapping

PART I:
STARTING POINT

Starting Point

Static FEM simulation

NW Dimensions: **R=25nm, L=600nm**

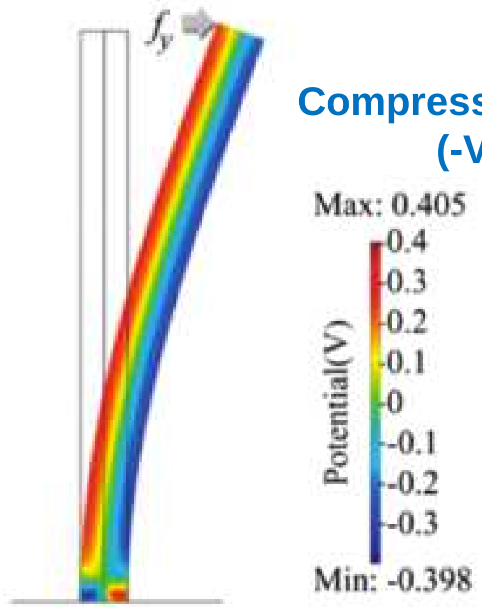
Applied force: **Fy=80 nN**

ZnO

Tensile-side (+V)

Compressive-side (-V)

Bottom reverse region



V_{max}≈300 mV

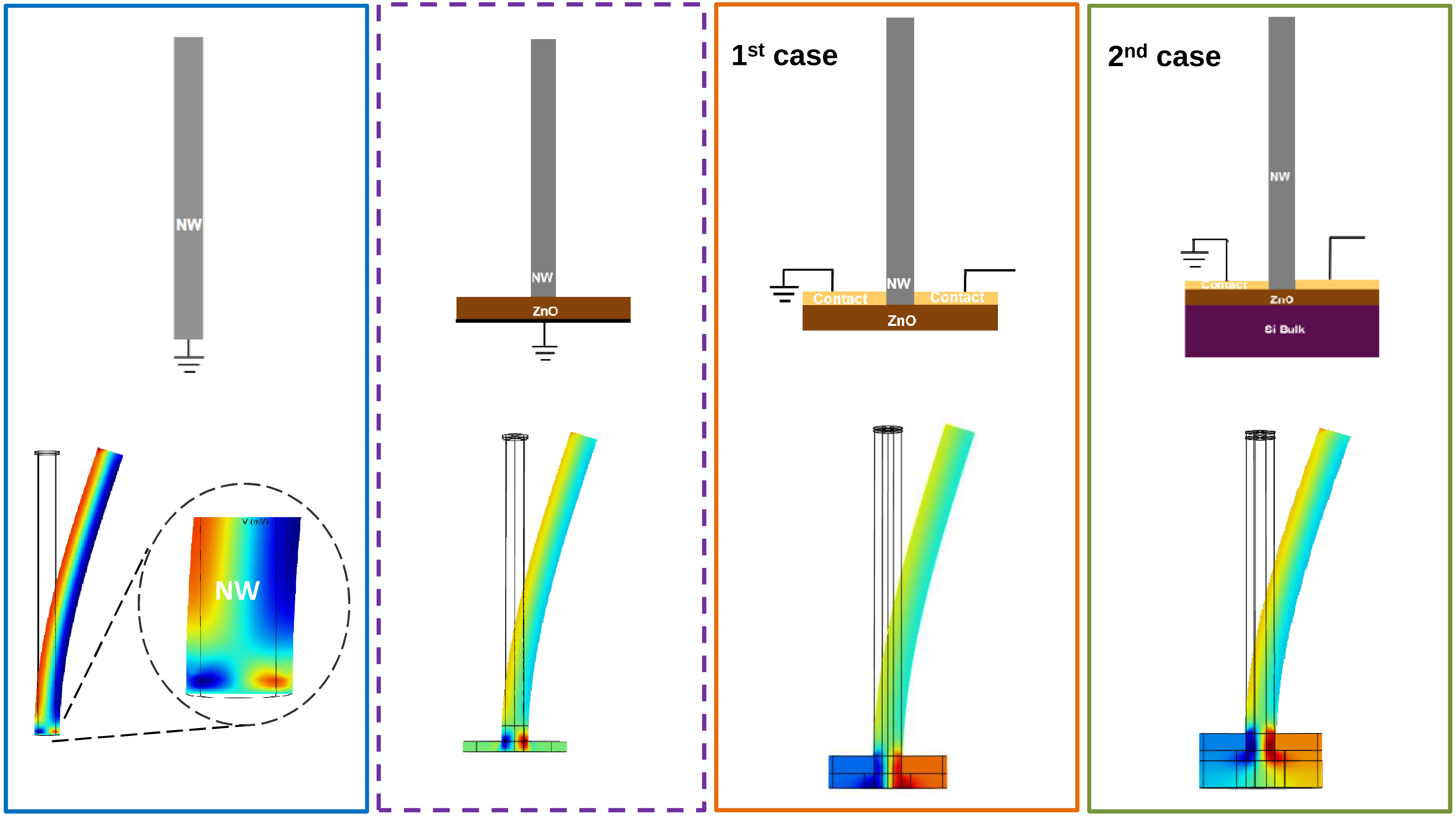
(Y. Gao *et al.*, Nano Letters 2007)

- **Enables electrical contact positioning**
- **Missing surrounding environment of NW (pixel)**

PART II:
STATIC FEM SIMULATIONS OF A PIXEL

FEM approach for sensing-device design

Multi-physics static finite element simulations: exploit the **piezopotential reverse region** for contacting



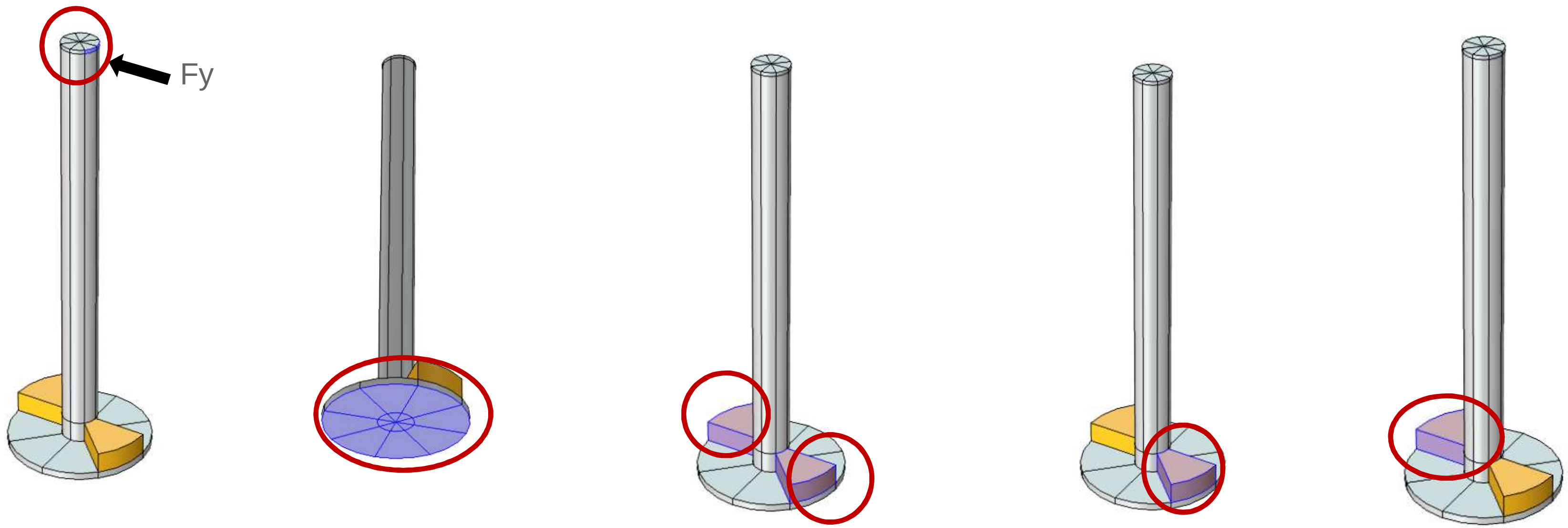
The piezopotential inversion region hosts the highest values in our configurations

FEM approach for device design: 1^{st} case

Boundary Conditions:

MECHANICAL conditions

ELECTRICAL conditions



External force

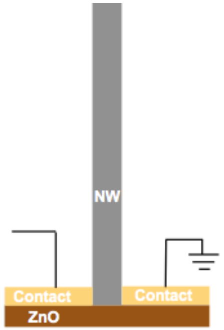
Clamped base

Elastic-electric metal contacts

Grounded-contact

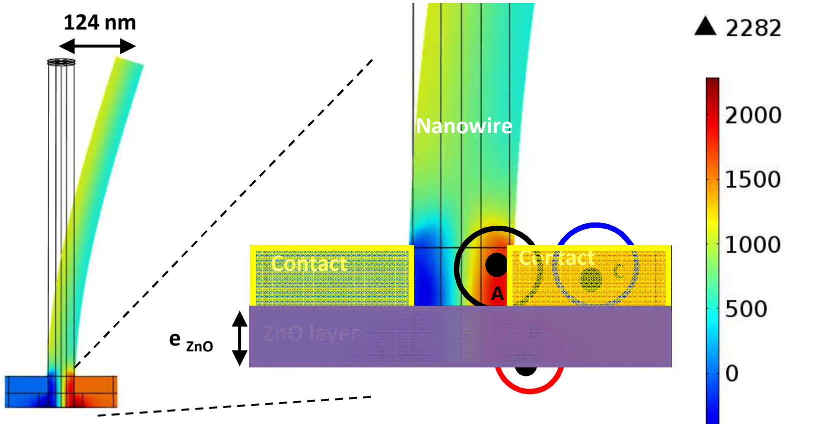
Floating potential

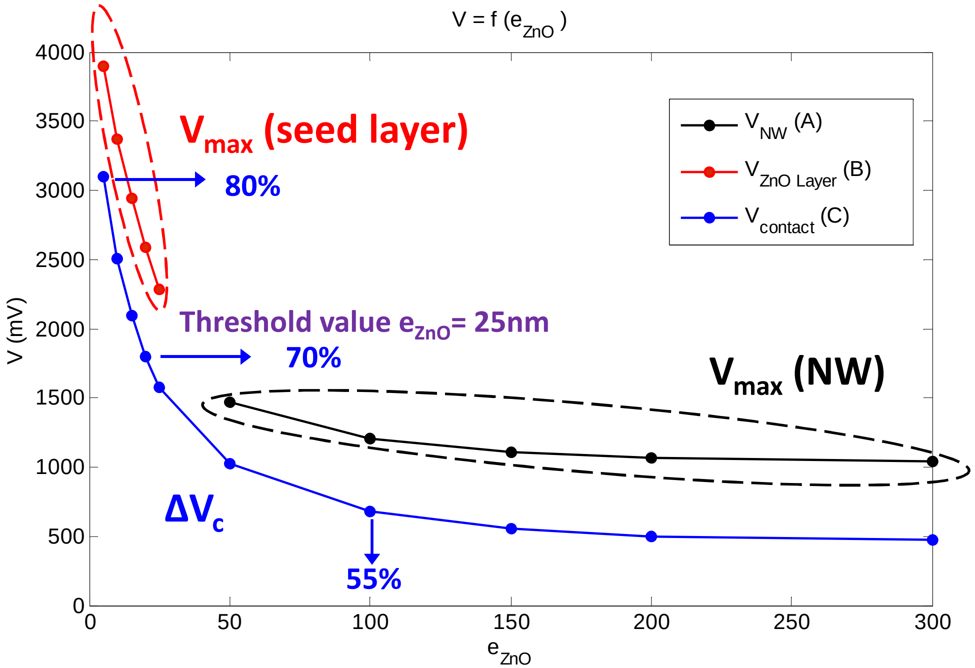
FEM approach for device design 1st case



Parametric study

Parameter: **ZnO layer thickness (e_{ZnO})**

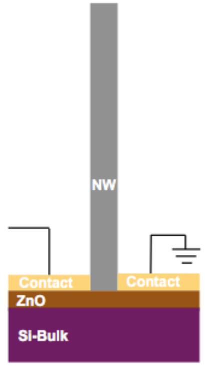




Collection efficiency = $\Delta V_c / V_{max}$

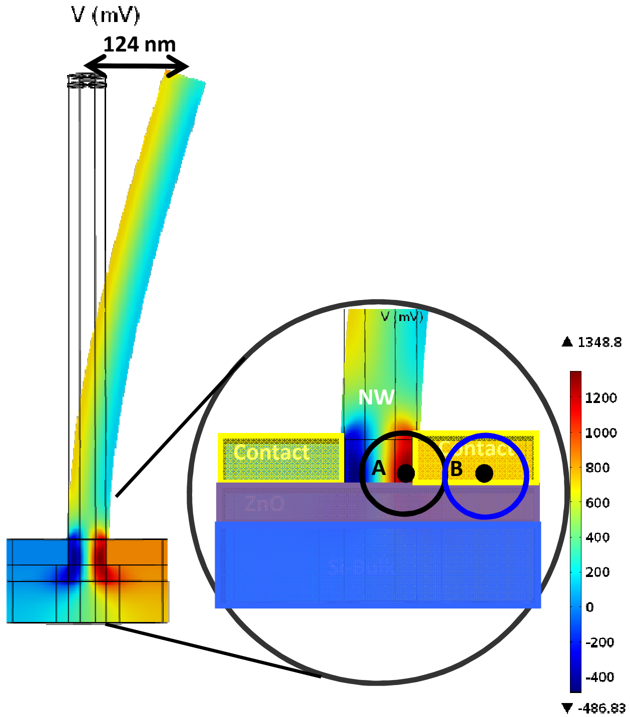
The location of the piezopotential maximum depends on the ZnO thickness
Thinner seed layer is preferred

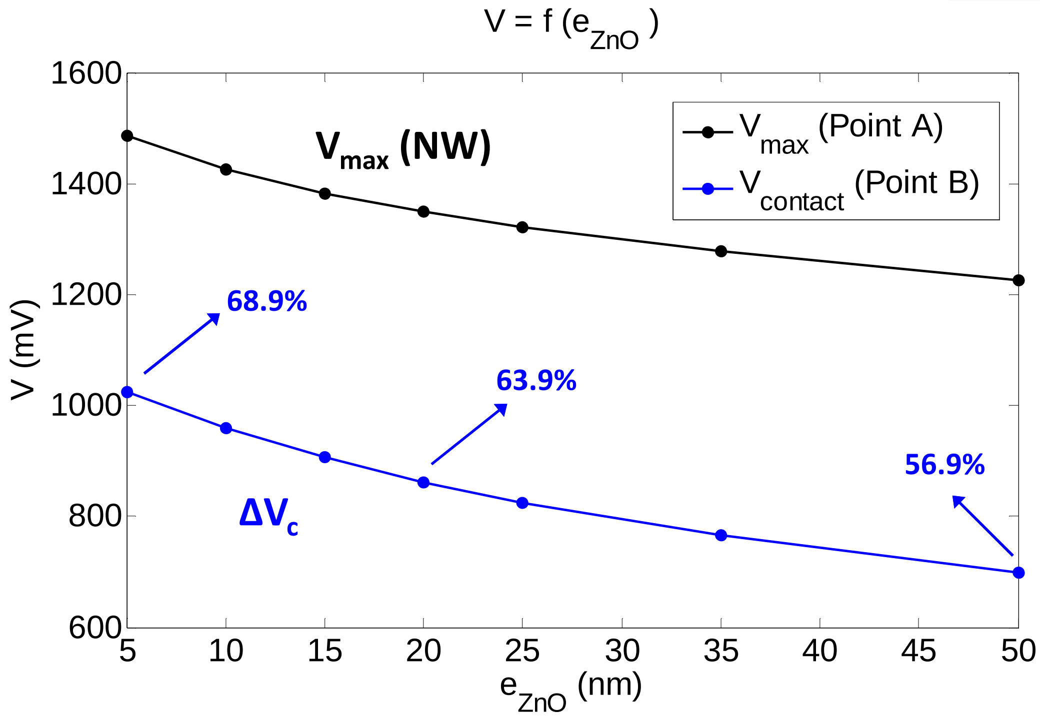
FEM approach for device design 2nd case



Parametric study

Parameter: **ZnO layer thickness (e_{ZnO})**



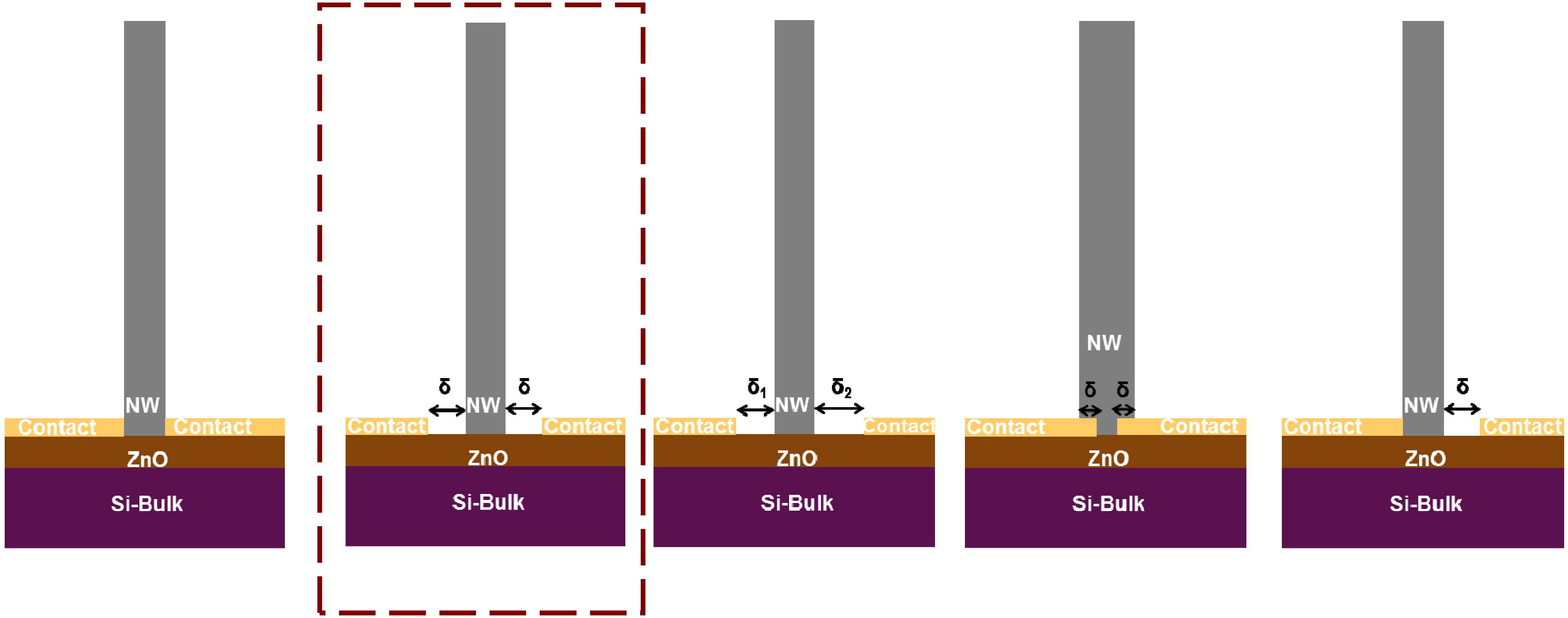


Collection efficiency = $\Delta V_c / V_{max}$

Better potential outputs with thinner ZnO layers

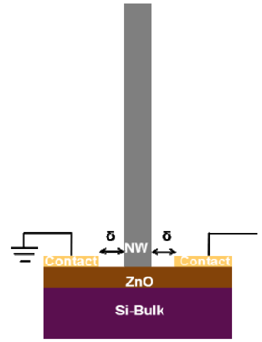
Realistic cases: issues inherent to fabrication

Possible misalignment of contacts and NW



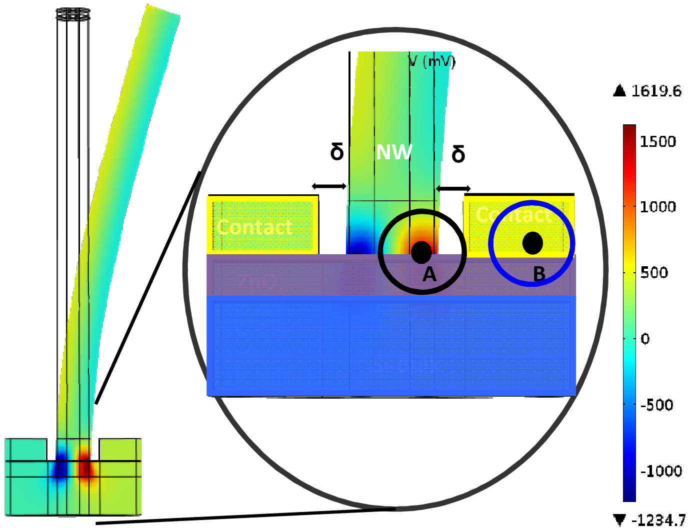
Inherent to device fabrication (contact deposition and NW growth) which introduce strong variability.

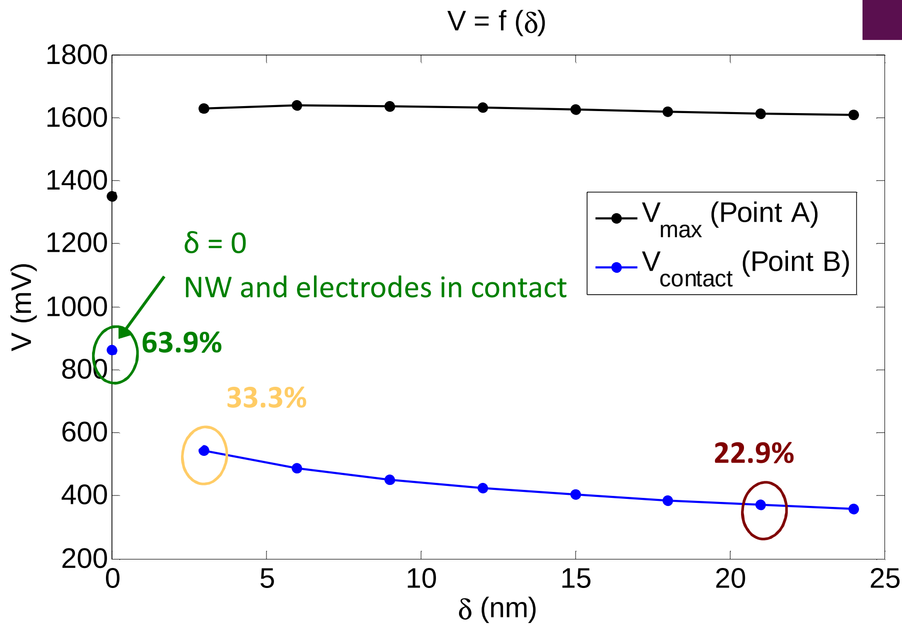
Investigation of technologically realistic parameters



Parametric study

Parameter: **spacing δ** (e_{ZnO}=20nm)





Configuration (e_{ZnO}=20nm)	Displacement at free end (nm)	V_{max} (mV)	ΔV_c (mV)	$\Delta V_c/V_{NW}$ (%)
δ=0	**124**	1349	862	63.9
δ=3 nm	**136**	1630	544	33.3
δ=12 nm	136	1631	424	25.9
δ=18 nm	136	1619	384	23.7
δ=21 nm	136	1613	370	22.9

Significant drop of ΔV_c when physical contact is lost
But stabilization of ΔV_c for δ > 5 nm.

Investigation of technologically realistic parameters

Influence of the electrode height ($h_{contact}$)

δ = 0

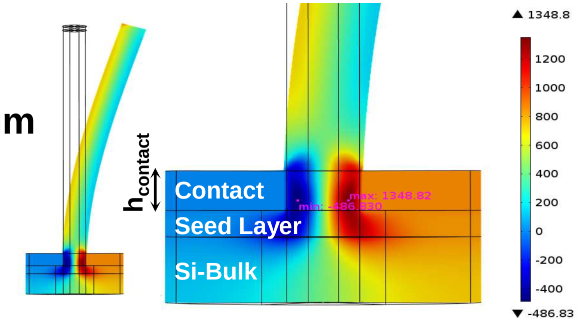
δ ≠ 0 (18 nm)

Investigation of technologically realistic parameters

Influence of the electrode height ($h_{contact}$)

δ = 0

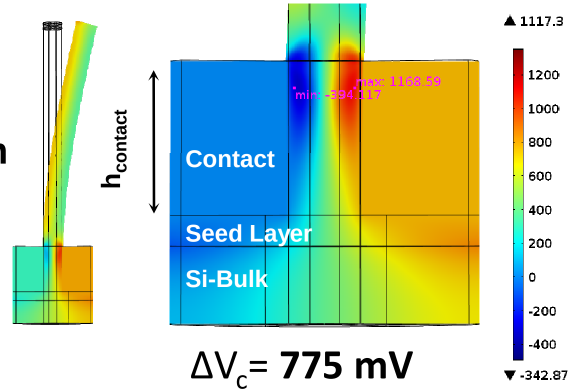
h $_{contact}$= **30 nm**



ΔV_c= **862 mV**

V_{max}= 1349 mV

h $_{contact}$= **100 nm**

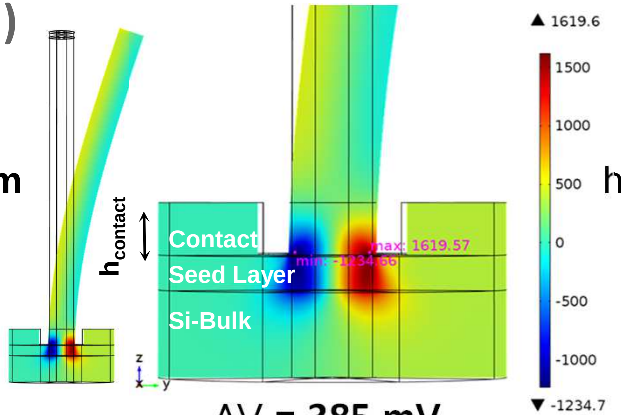


ΔV_c= **775 mV**

V_{NW}= 1169 mV

δ ≠ 0 (18 nm)

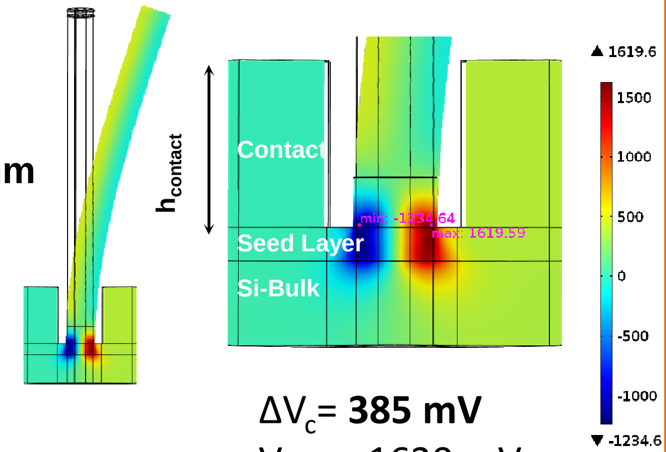
h $_{contact}$= **30 nm**



ΔV_c= **385 mV**

V_{NW}= 1620 mV

h $_{contact}$= **100 nm**



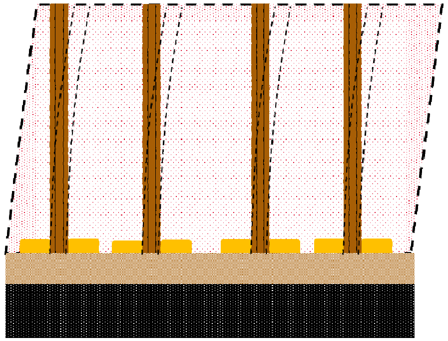
ΔV_c= **385 mV**

V_{NW}= 1620 mV

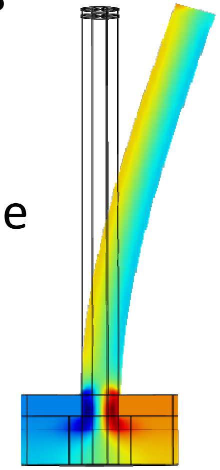
➡ For δ > 0 nm there is no influence of $h_{contact}$

CONCLUSIONS

Conclusions



FEM simulations provide valuable insight for device design:



- The inversion region hosts the highest values of piezopotential, this is where the contacts should be placed
- Piezopotential spreads continuously from the inversion region into the seed layer and (to a smaller extend) into the electrodes
- Thinner seed layers are preferred
- Although the piezopotential values drops dramatically when **δ > 0nm**, it is still exploitable

→ **Microfabrication can be anticipated by studying the influence of different parameters that are inherent to device fabrication**

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Thank you for your attention

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SEVENTH FRAMEWORK PROGRAMME