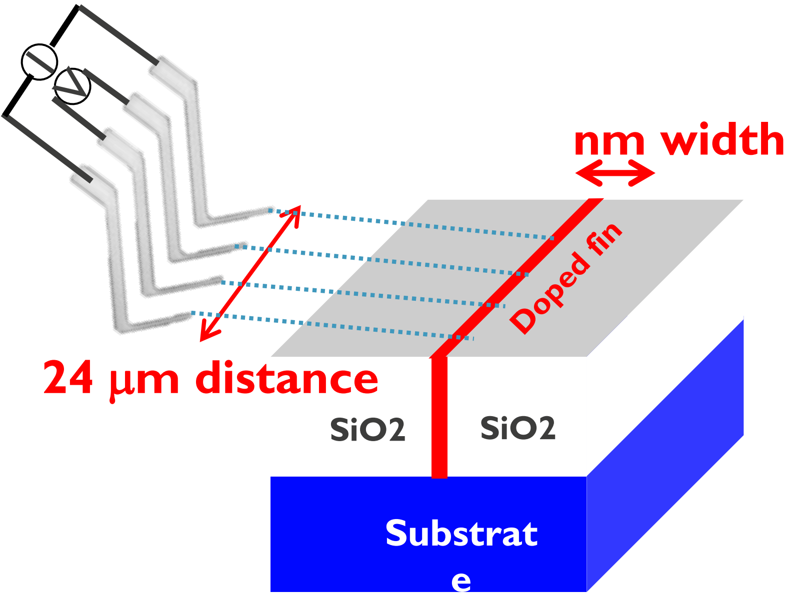

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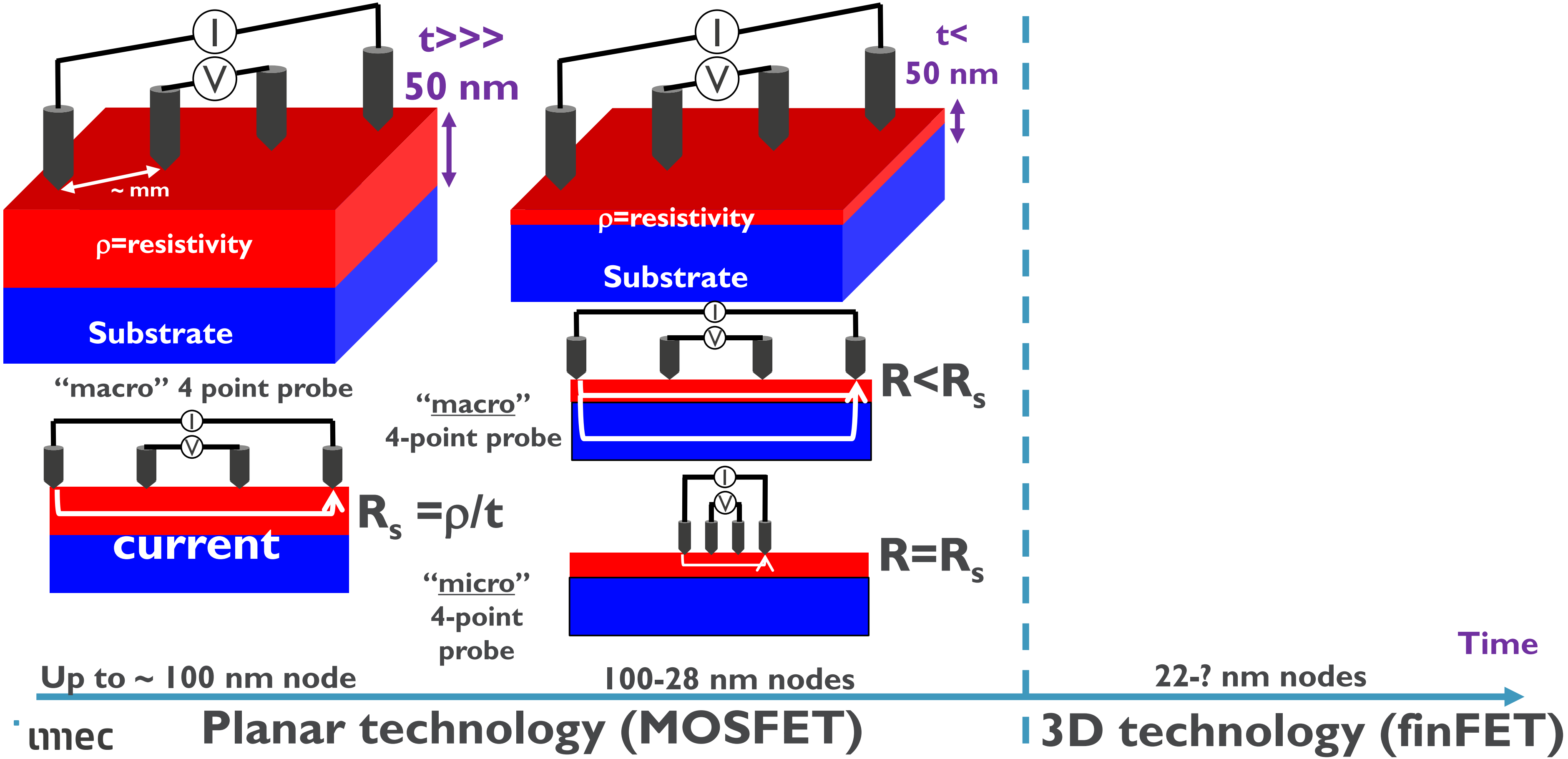
SIZE-DEPENDENT RESISTIVITY IN NARROW FINS AS PROBED WITH MICRO-FOUR-POINT PROBE

J. BOGDANOWICZ, S. FOLKERSMA, S. SERGEANT, A. SCHULZE, A. MOUSSA, C. MERCKLING, B. KUNERT
W. GUO, Y. MOLS, D. H. PETERSEN, M.-L. WITTHØFT, O. HANSEN, H. H. HENRICHSEN,
P. F. NIELSEN AND W. VANDERVORST

CAPRES A/S
COPENHAGEN APPLIED RESEARCH

DTU Nanotech
Department of Micro- and Nanotechnology

PARADIGM SHIFTS IN THE ELECTRICAL CHARACTERIZATION OF SOURCE/DRAIN REGIONS AND EXTENSIONS



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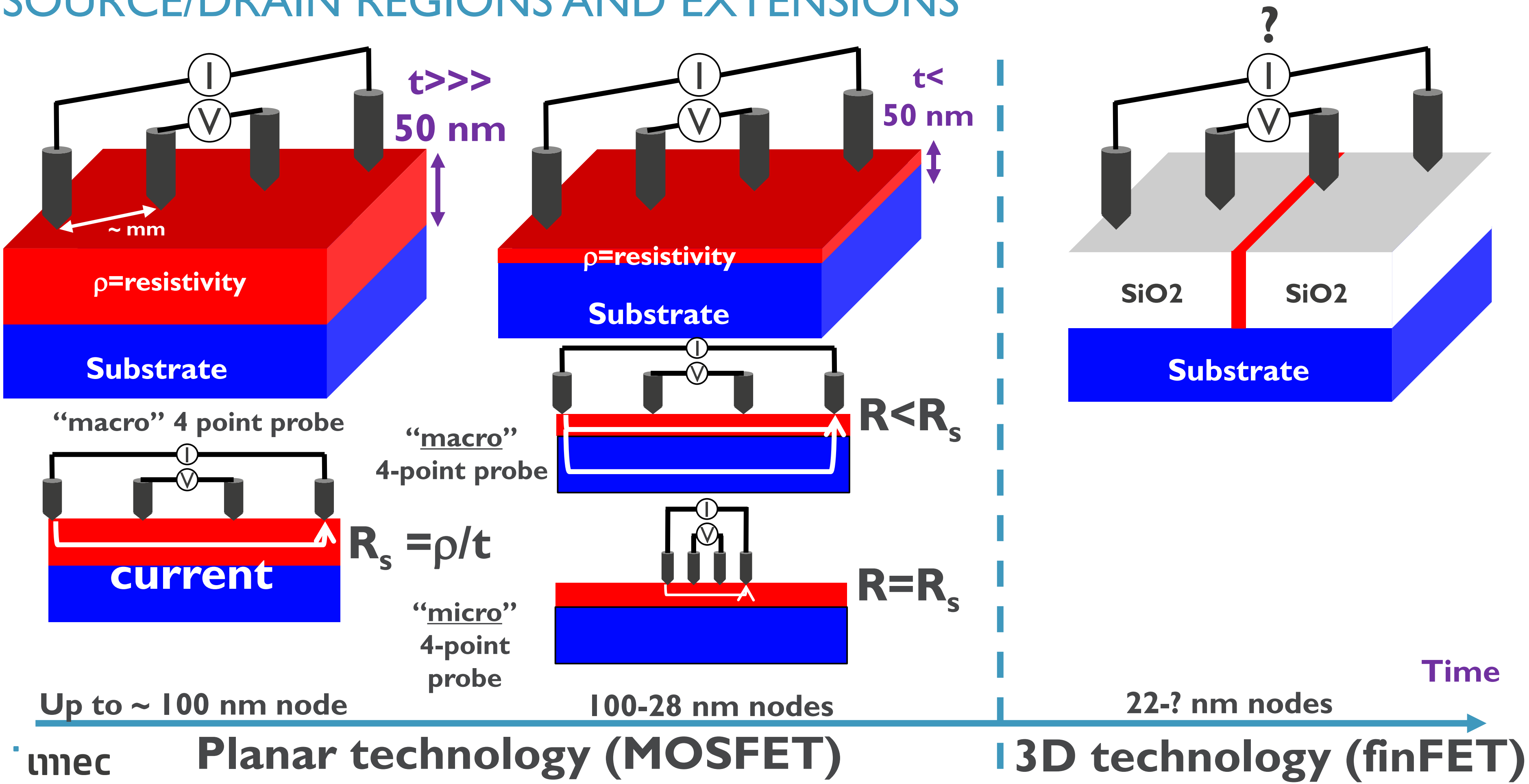
PARADIGM SHIFTS IN THE ELECTRICAL CHARACTERIZATION OF SOURCE/DRAIN REGIONS AND EXTENSIONS



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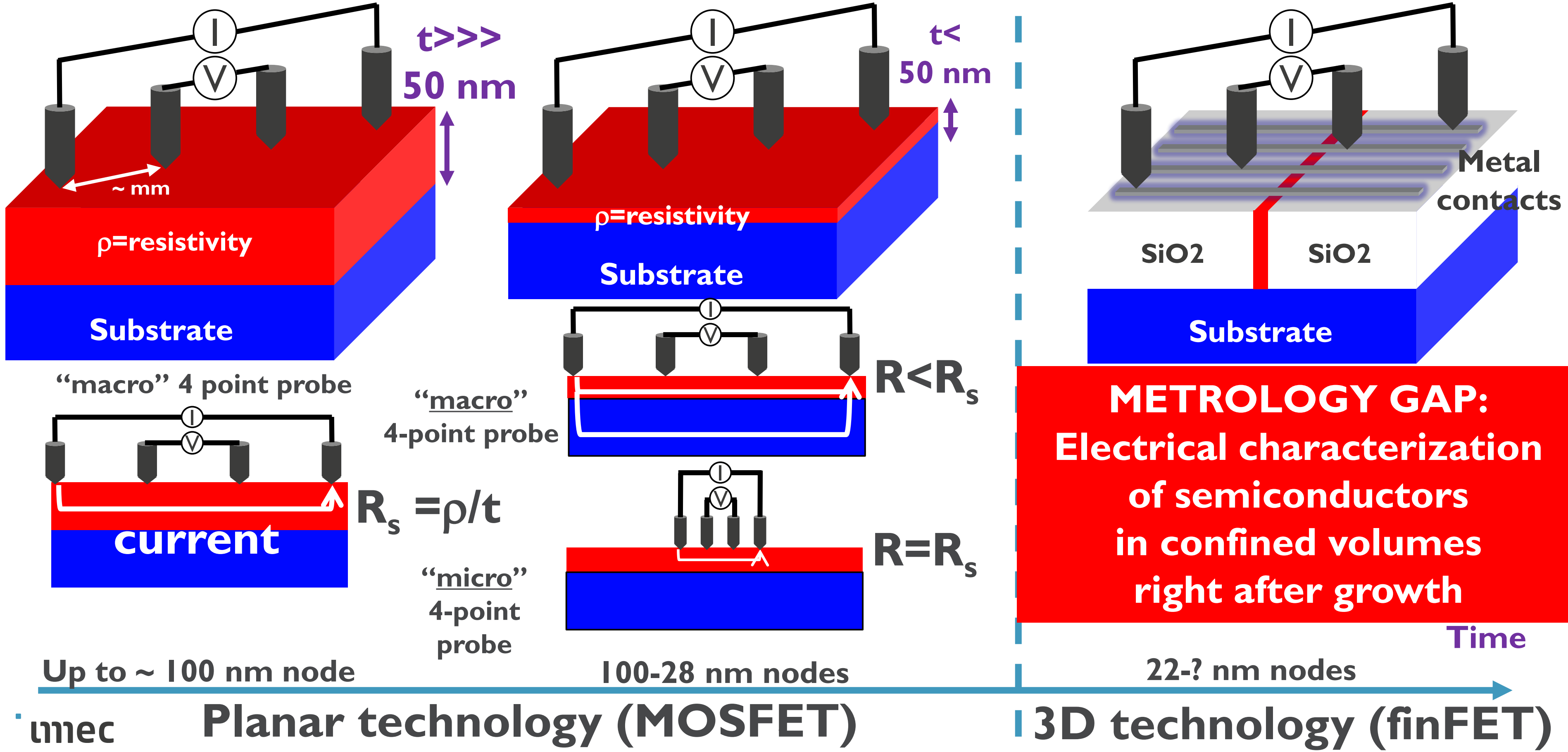

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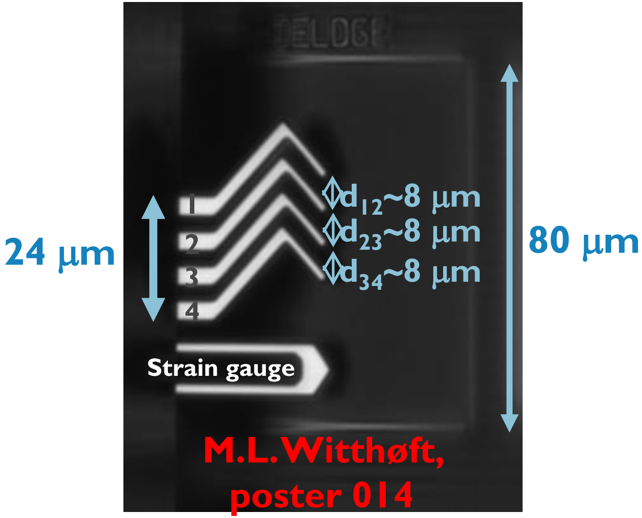
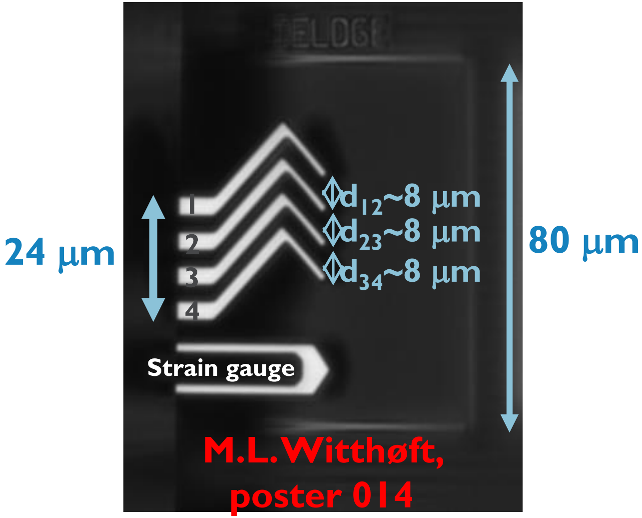
MICROHALL-A300 TOOL OF CAPRES:
FULLY AUTOMATED IN-LINE <u>MICRO</u> FOUR-POINT PROBE



<u>Advantages of micro-probes:</u>

- **Better accuracy on ultra-shallow layers (reduced leakage)**
- **Measurements on blanket but also in pads (> 20x35 μm²)**

MICROHALL-A300 TOOL OF CAPRES: FULLY AUTOMATED IN-LINE MICRO FOUR-POINT PROBE



Advantages of micro-probes:

- **Better accuracy on ultra-shallow layers (less leakage)**
- **Measurements on blanket but also in pads (> 20x35 µm^2)**
- **Microprobes can be aligned to a nm-wide conductive line**

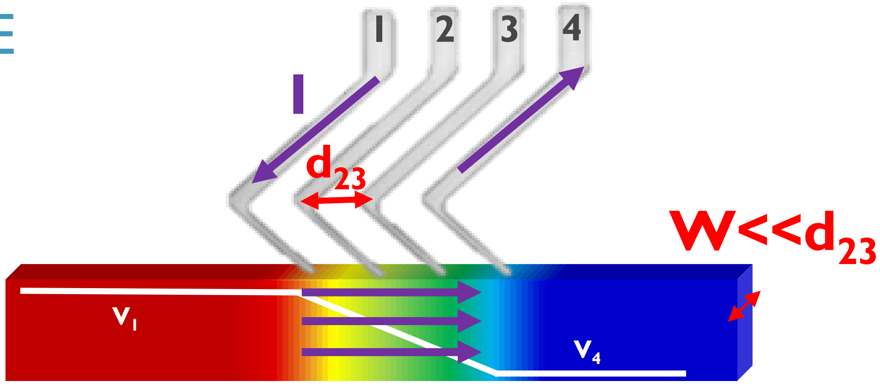
OUTLINE

- **Basics**
- Proof of concept : P+N Si fins
- leakage information : P+P Si fins
- III-V fins

MICRO FOUR-POINT PROBE MEASUREMENT IN CONFINED VOLUME

D.H. Petersen et al.,
J. Appl. Phys. 104, 013710 (2008)

Configuration A:



Potential distribution inside the fin

- **fin resistance between pins 2 and 3 is measured**

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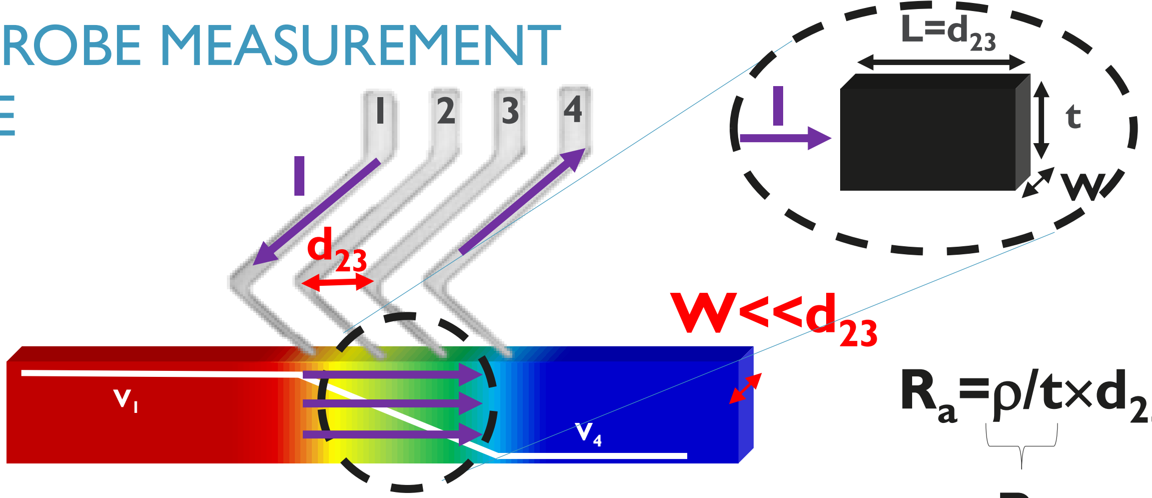

$R_a = \rho/t \times d_{23}/W$

R_s

Potential distribution inside the fin

- fin resistance between pins 2 and 3 is measured

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MICRO FOUR-POINT PROBE MEASUREMENT IN CONFINED VOLUME

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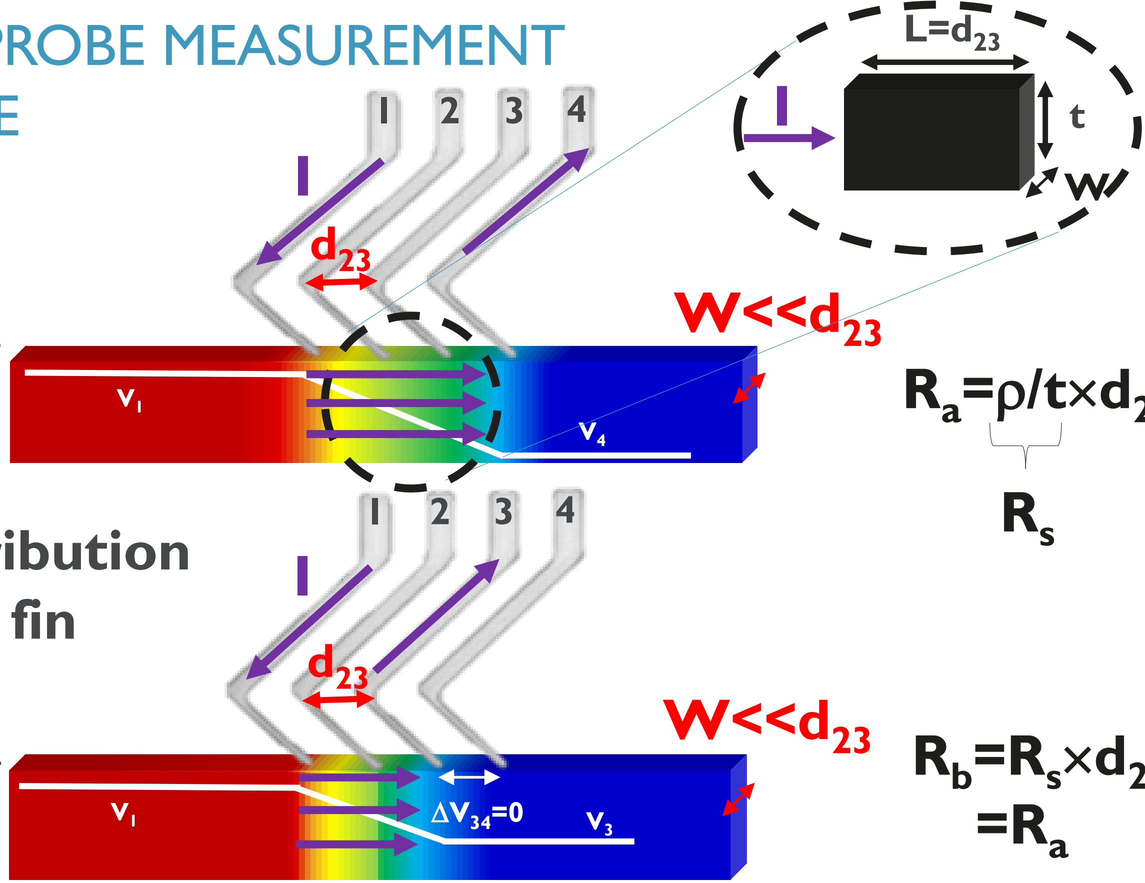
Configuration A:



$R_a=\rho/t \times d_{23}/W$

R_s

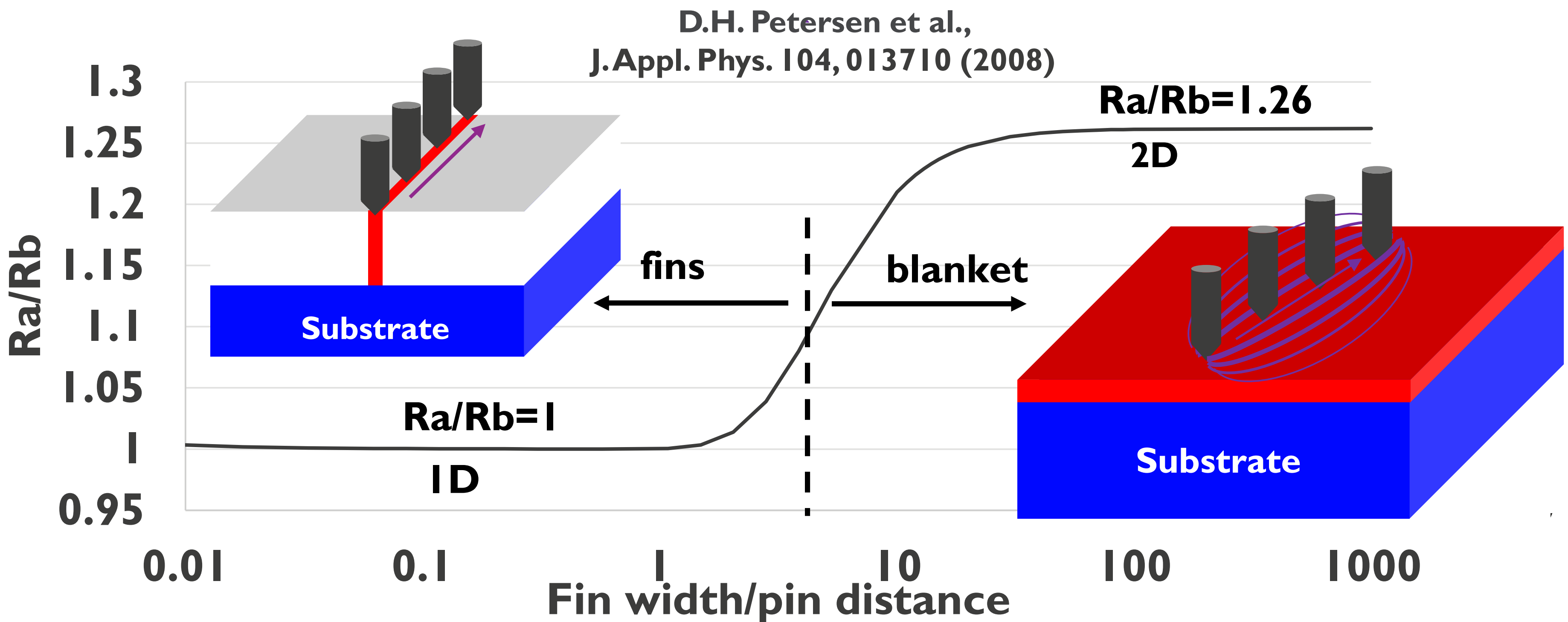
Potential distribution inside the fin

Configuration B:

$R_b=R_s \times d_{23}/W$
$=R_a$

- fin resistance between pins 2 and 3 is measured
- Same resistance measured in a and b configurations (Ra/Rb=1)

R_a/R_b RATIO AND DIMENSIONALITY OF THE CURRENT FLOW

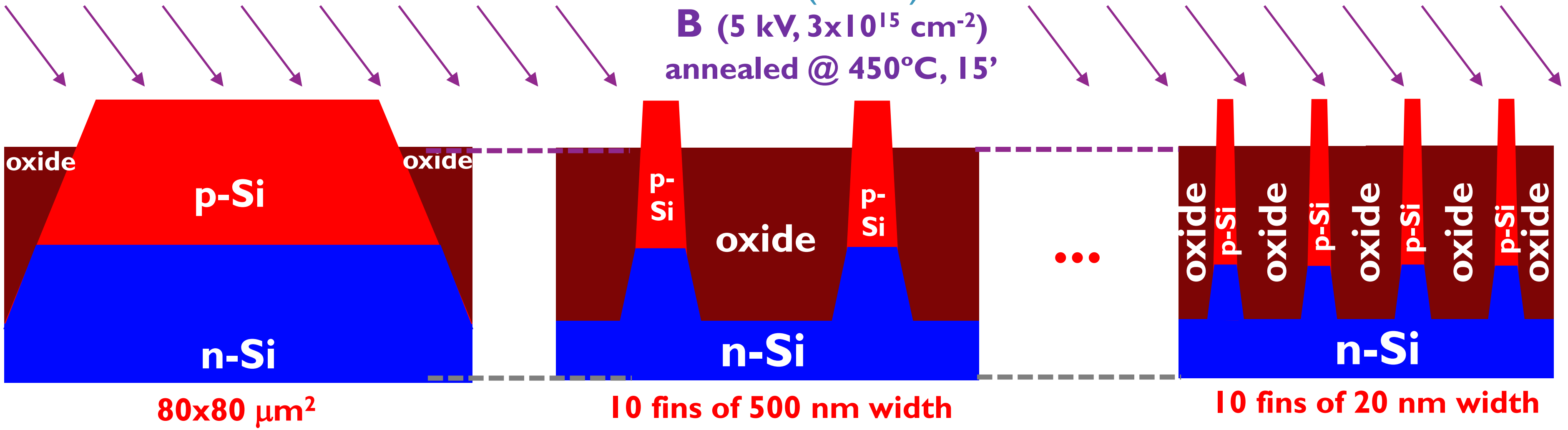


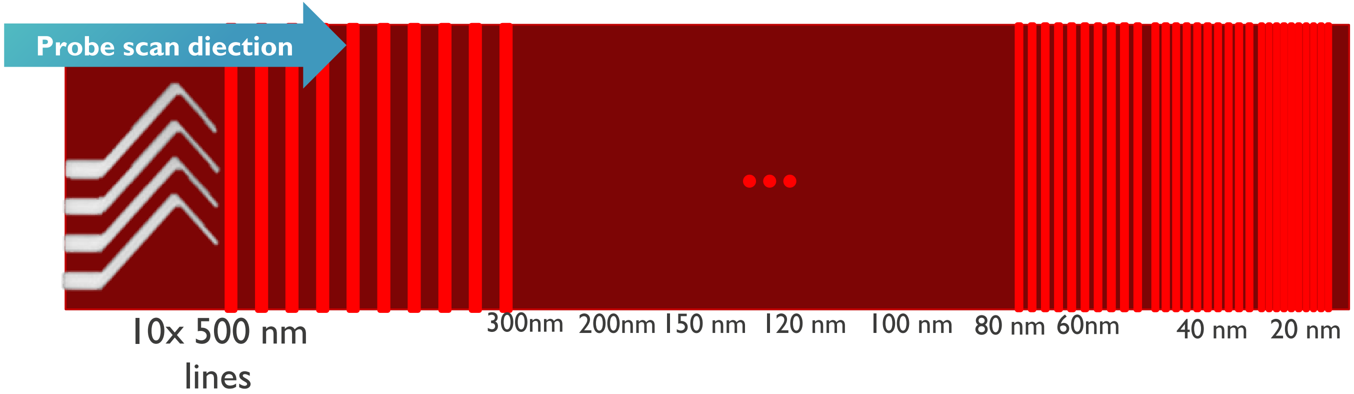
- Ra/Rb=1.00 → 1D current flow (fin)
- Ra/Rb=1.26 → 2D current flow (blanket)
- Information about leakage can be extracted based on Ra/Rb>1

OUTLINE

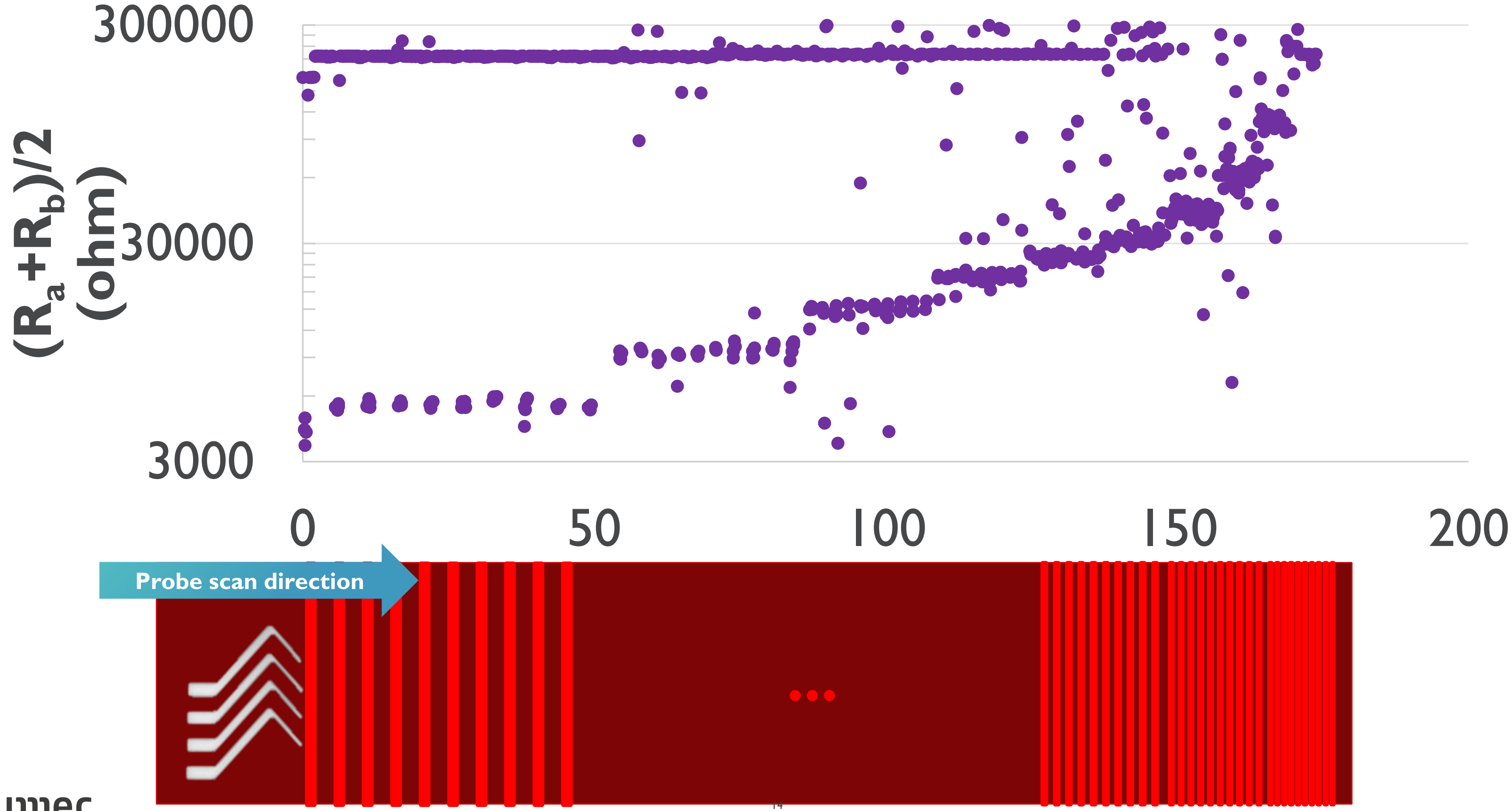
- Basics
- **Proof of concept : P+N Si fins**
- leakage information : P+P Si fins
- III-V fins

TEST SAMPLE: B-IMPLANTED SI FINS (P+N)





B-IMPLANTED FINS : EXPERIMENTAL



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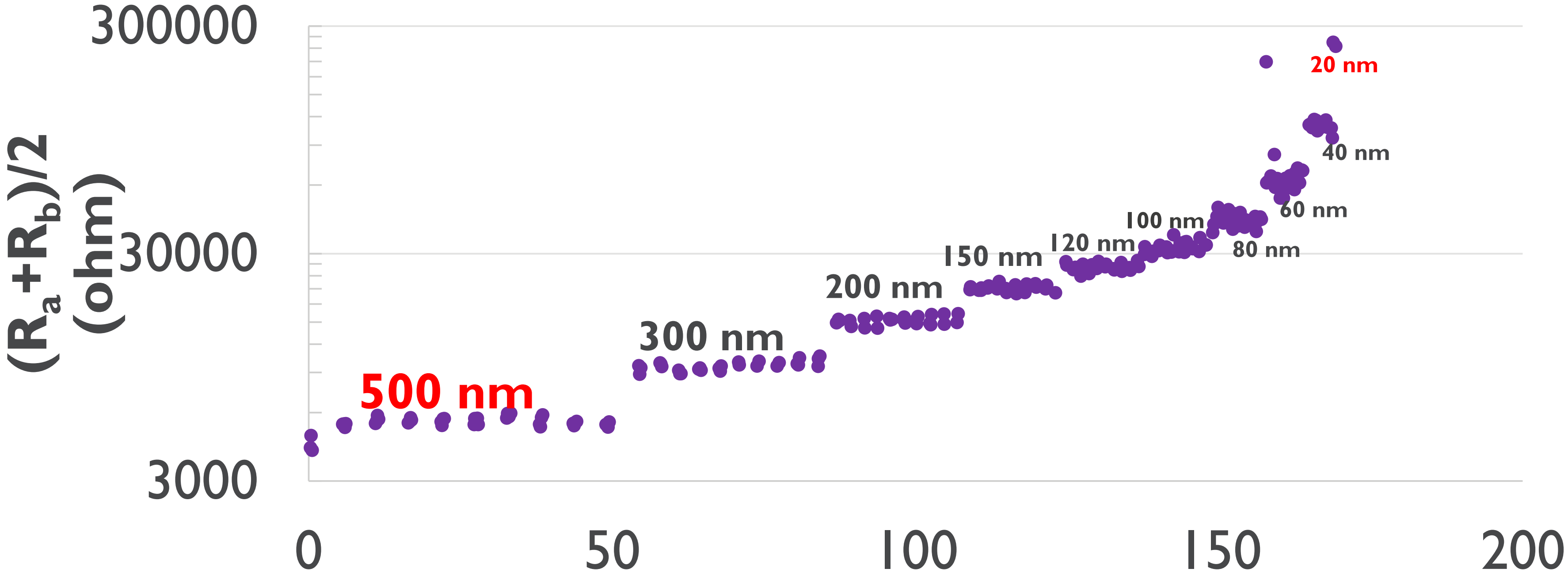
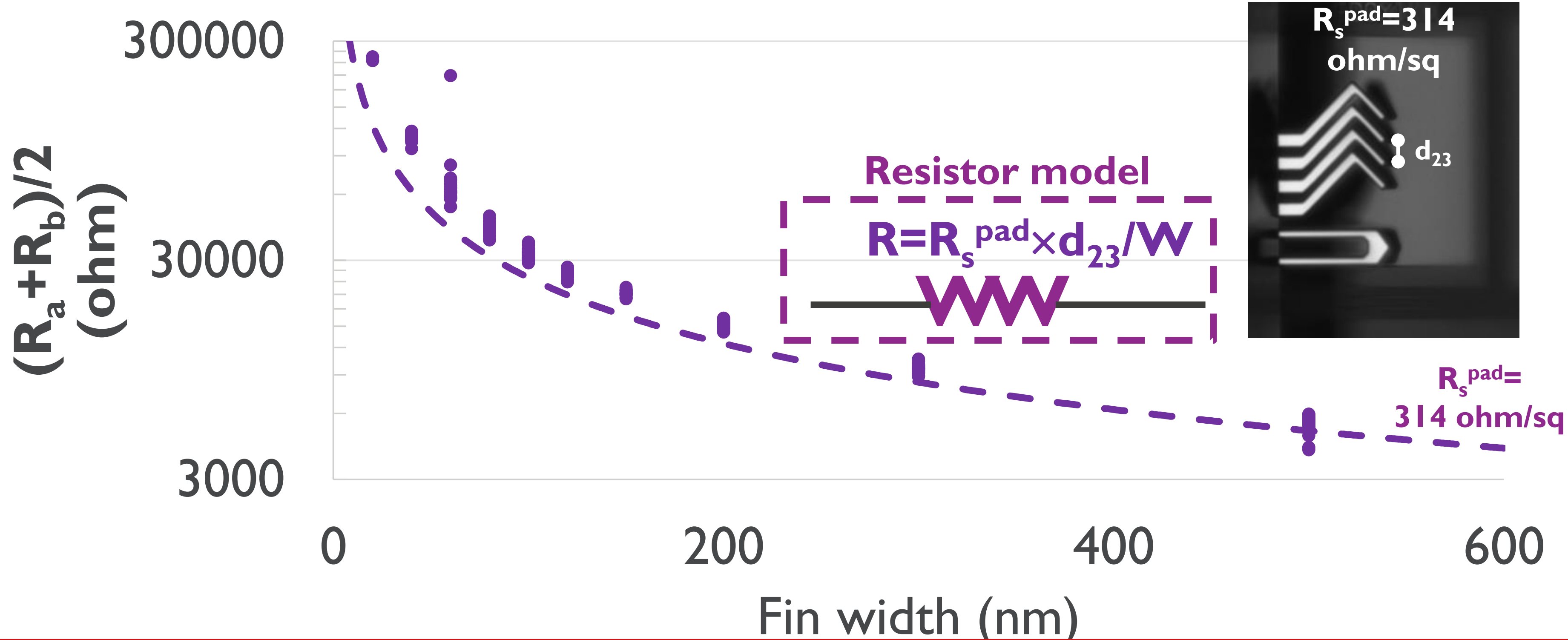
B-IMPLANTED FINS : EXPERIMENTAL



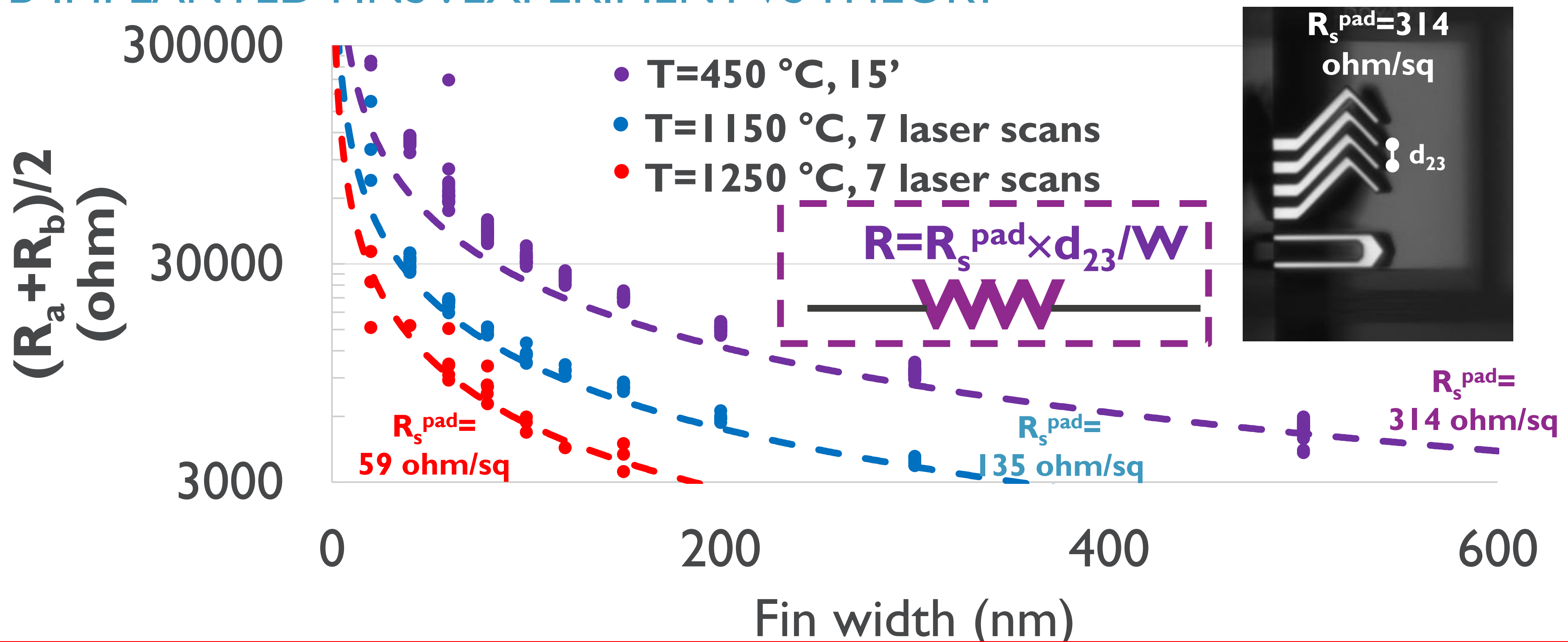
- **All widths captured**
- **Measured resistance increases with decreasing width**

B-IMPLANTED FINS : EXPERIMENT VS THEORY



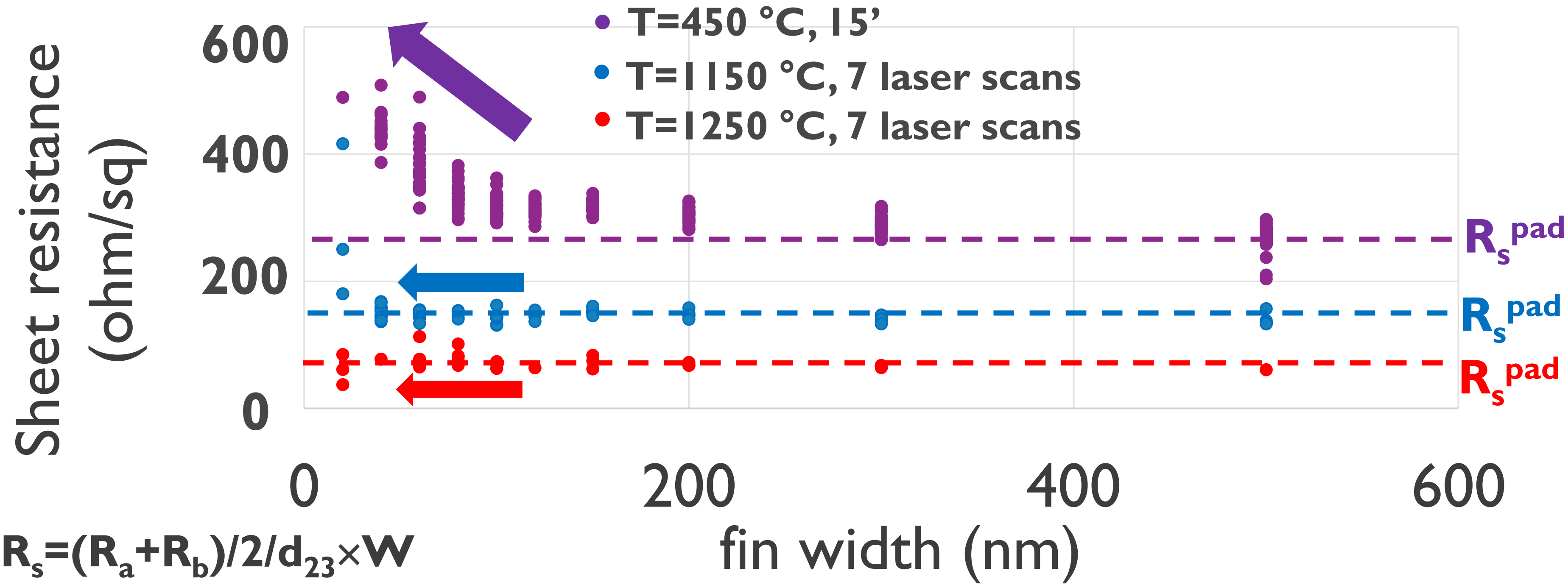
- **Resistor model fits the measured data → resistivity +- independent from dimension (mostly geometrical confinement)**

B-IMPLANTED FINS : EXPERIMENT VS THEORY



- Resistor model fits the measured data → resistivity +- independent from dimension (mostly geometrical confinement)
- Annealing lowers the measured fin resistance

SHEET RESISTANCE VS FIN WIDTH: B-IMPLANTED Si FINS



$R_s=(R_a+R_b)/2/d_{23}\times W$

- **Long low-T anneal : dimension-dependent R_s**

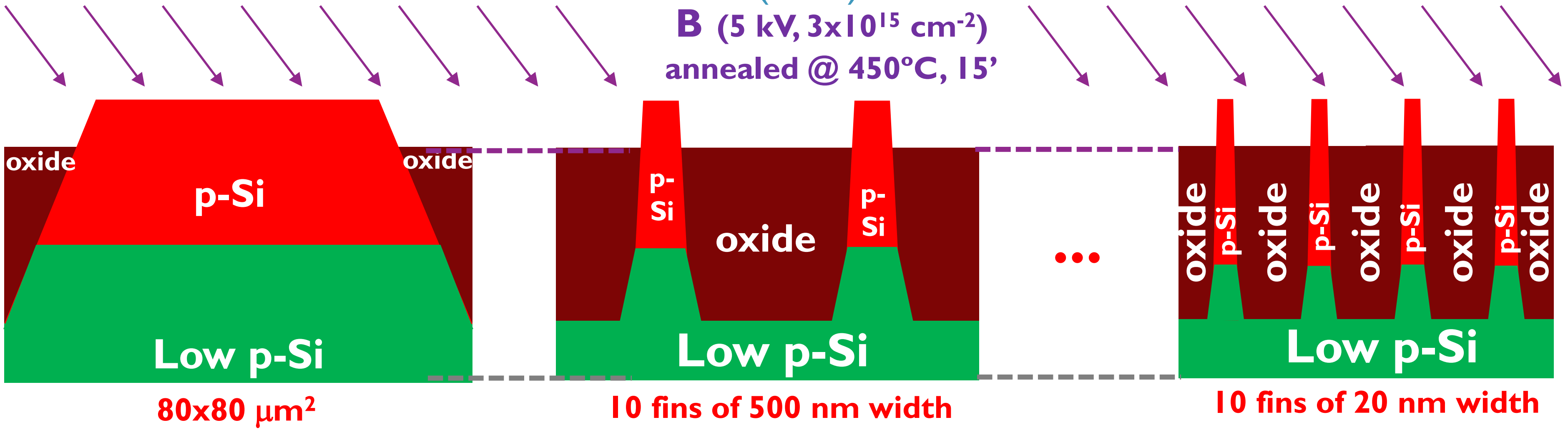
→ Depletion effect, degraded mobility, defects, dopant diffusion?

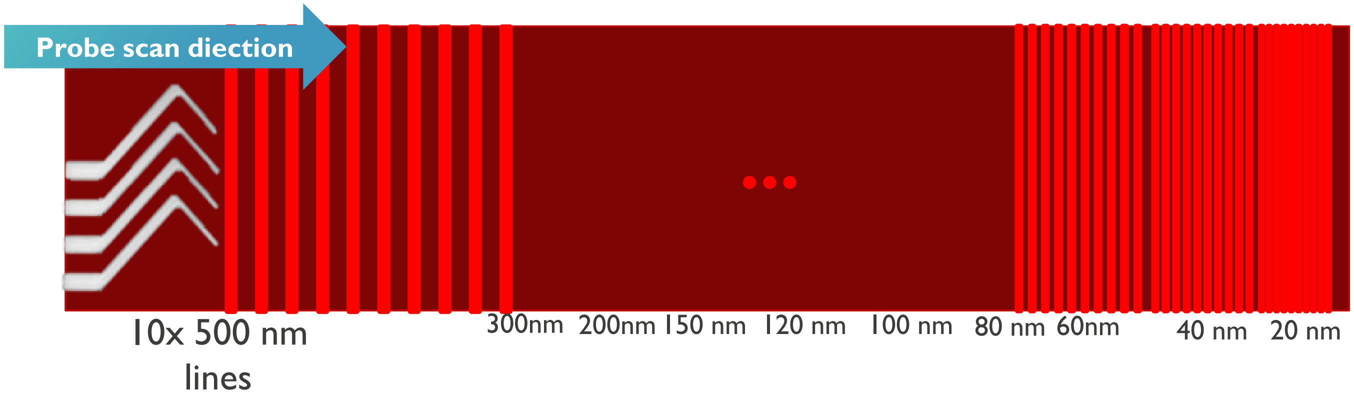
- **Laser anneal → R_s ~ independent from width**

OUTLINE

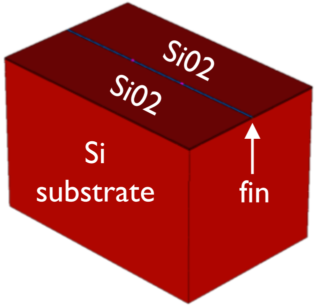
- Basics
- Proof of concept : P+N Si fins
- **leakage information : P+P Si fins**
- III-V fins

TEST SAMPLE: B-IMPLANTED FINS (P+P)

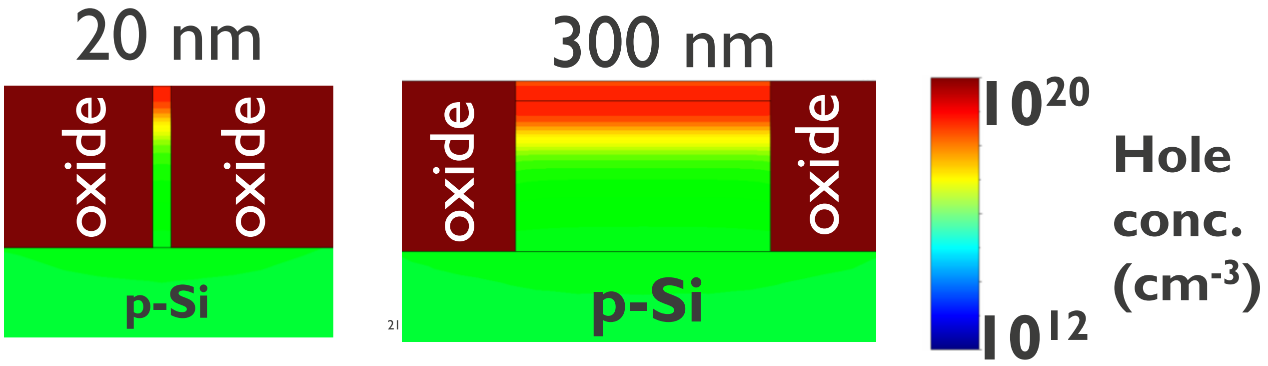




B-IMPLANTED Si FINS : SIMULATIONS (P+P)



- **P+P fins**
- **Different widths**
- **same R_s =314 ohm/sq**



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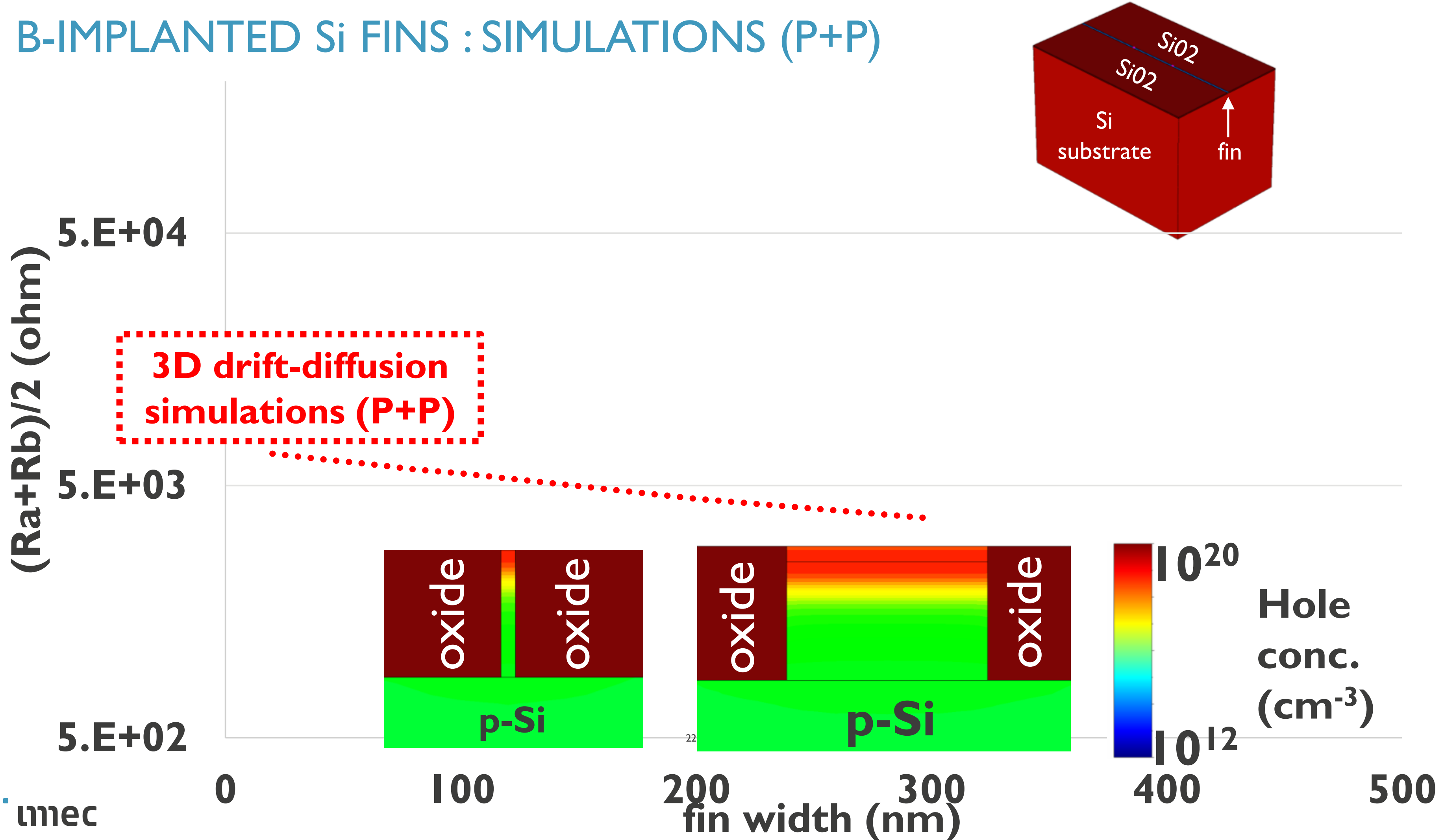
B-IMPLANTED Si FINS : SIMULATIONS (P+P)



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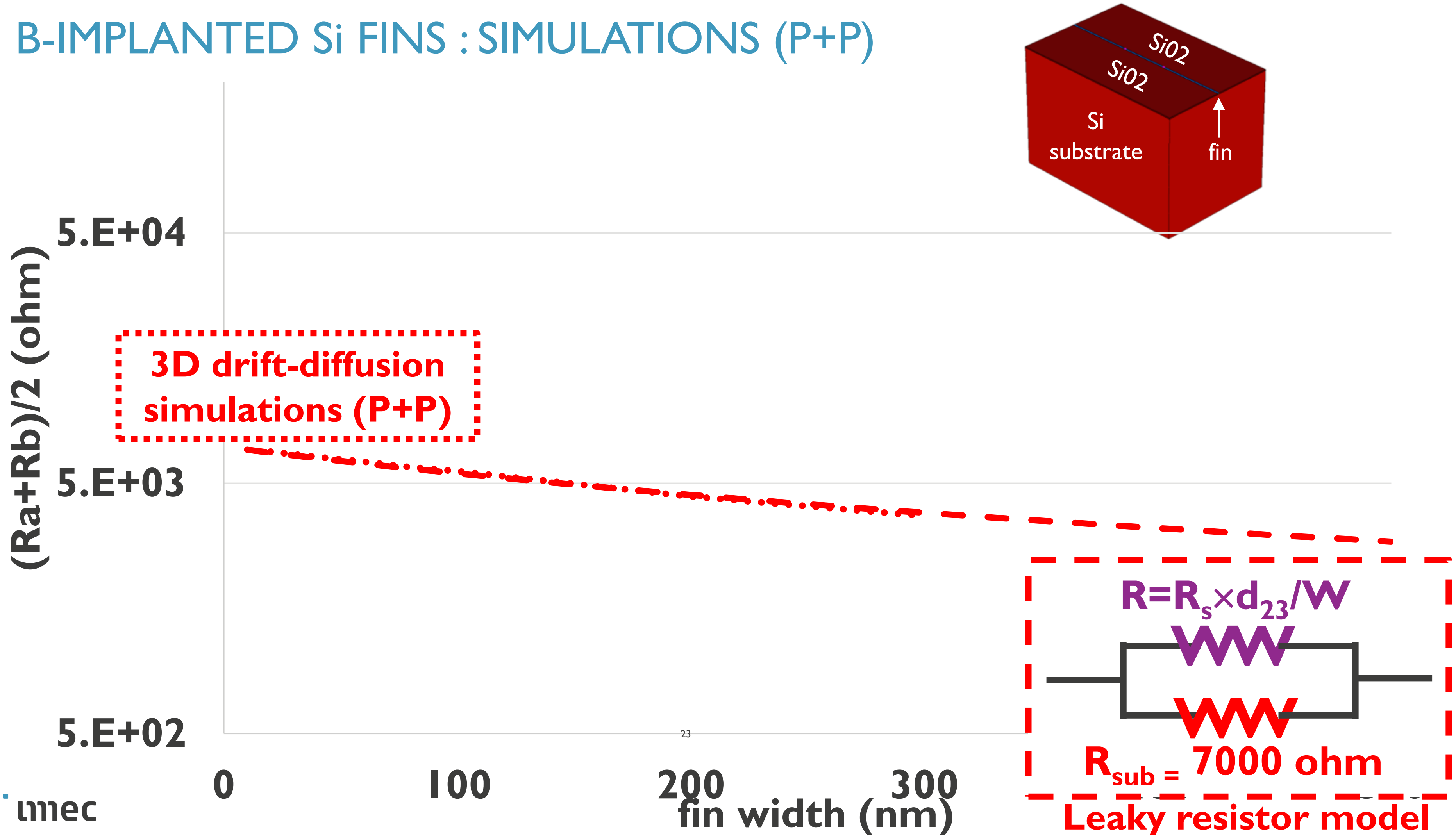
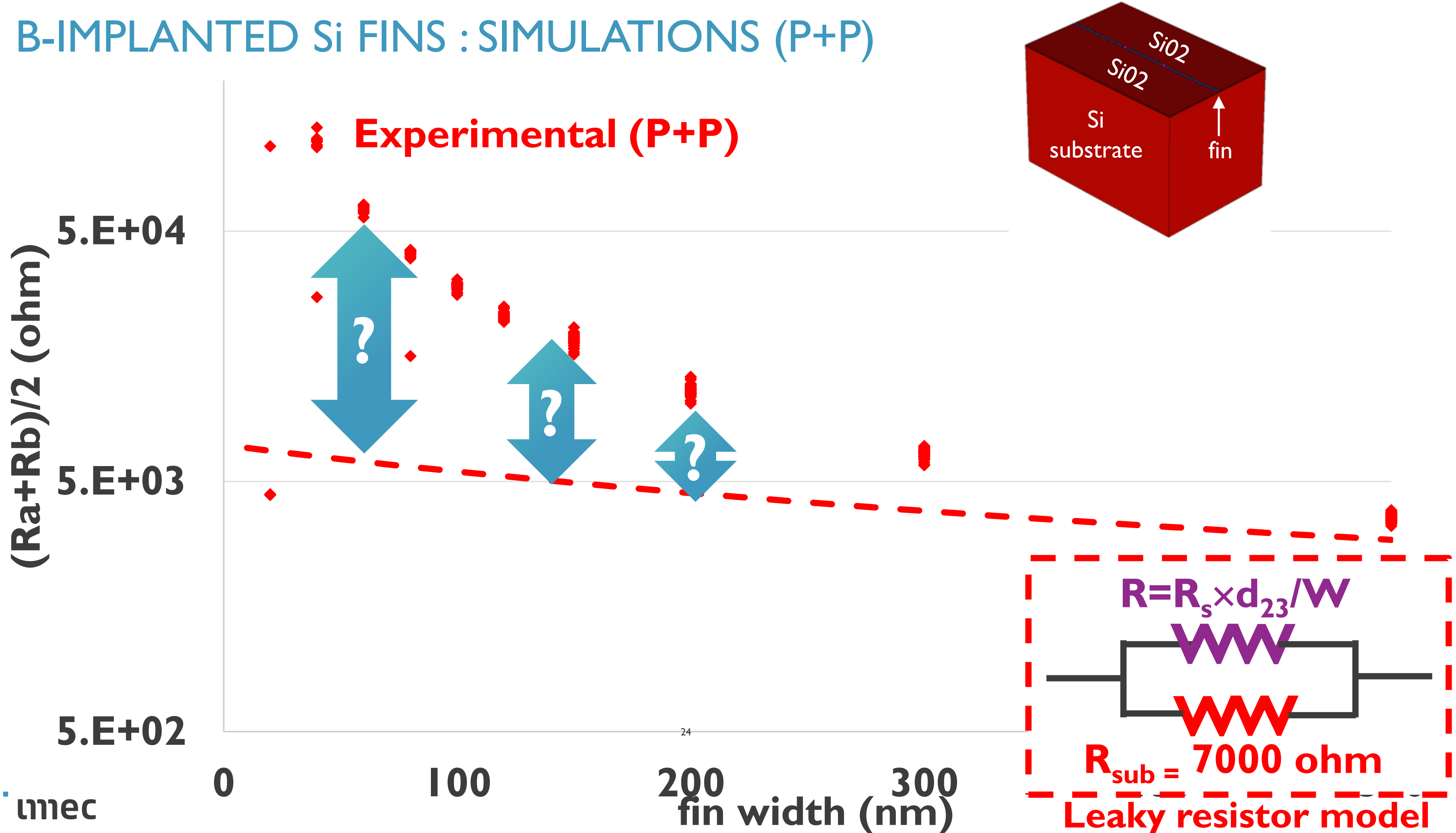


B-IMPLANTED Si FINS : SIMULATIONS (P+P)



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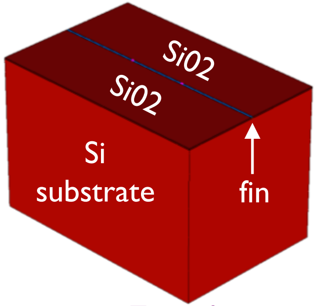

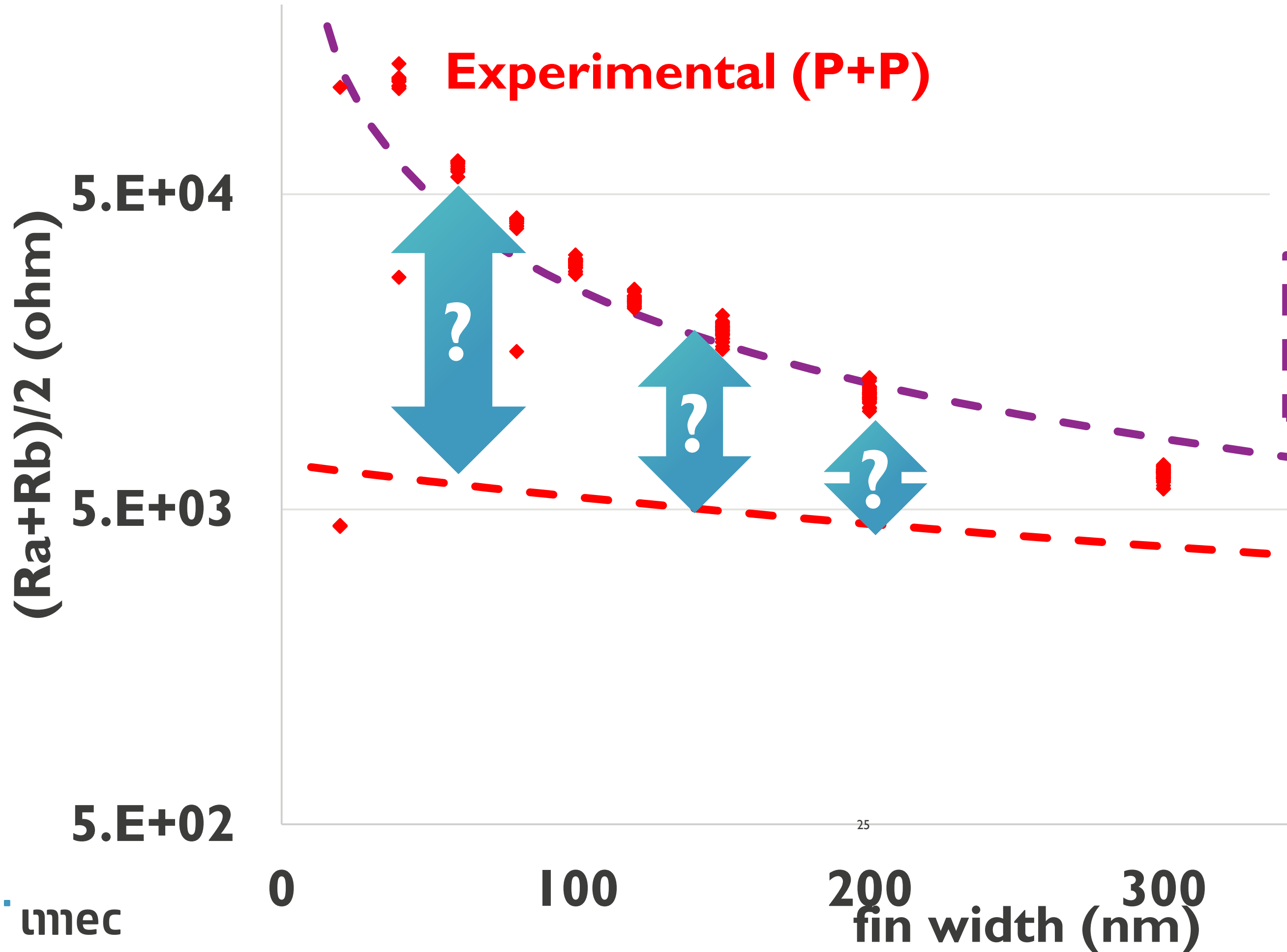

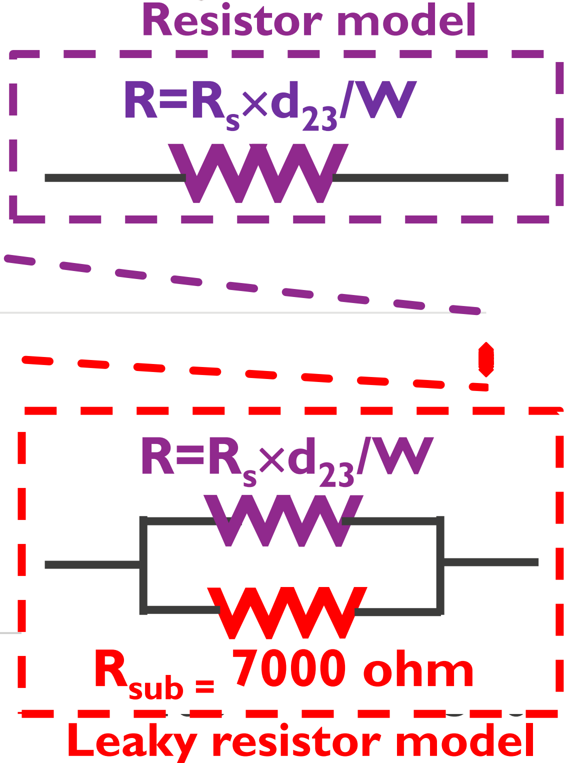

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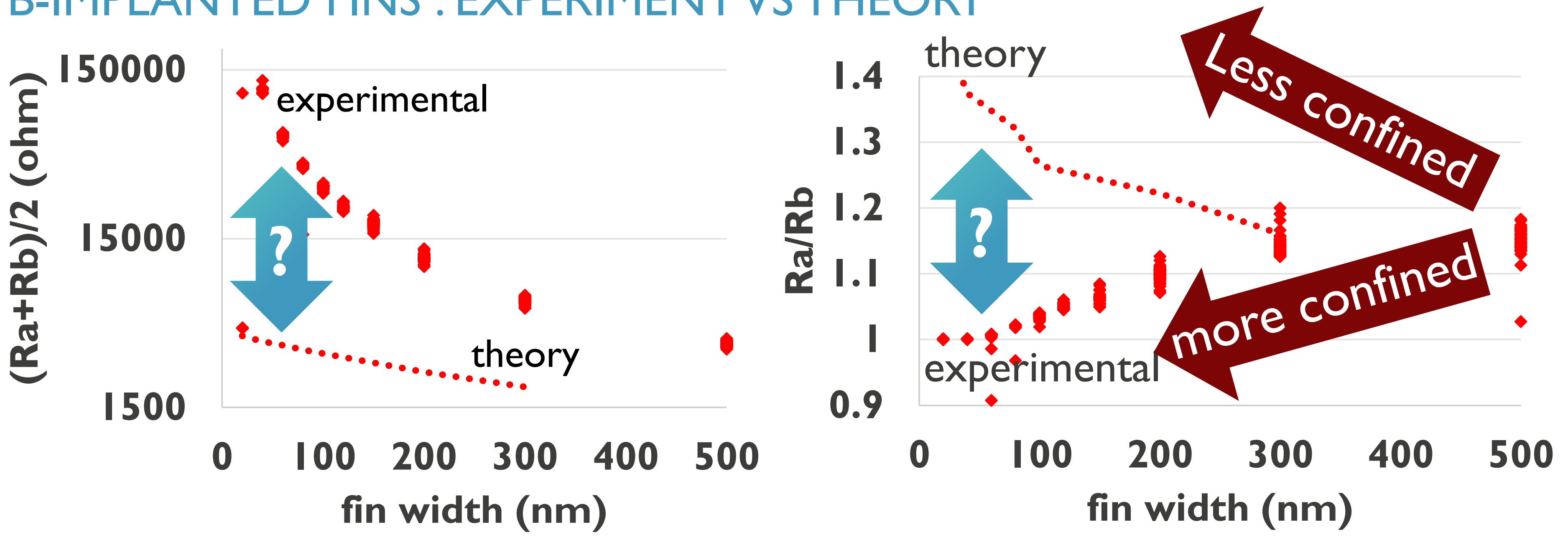
B-IMPLANTED FINS : EXPERIMENT VS THEORY

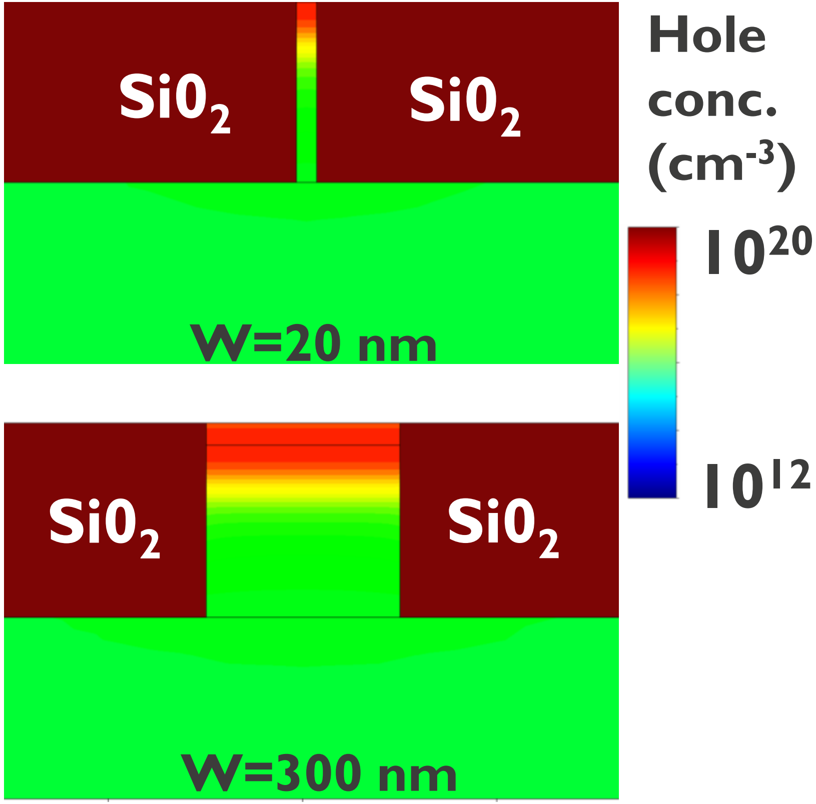


Discrepancies theory vs experiment:

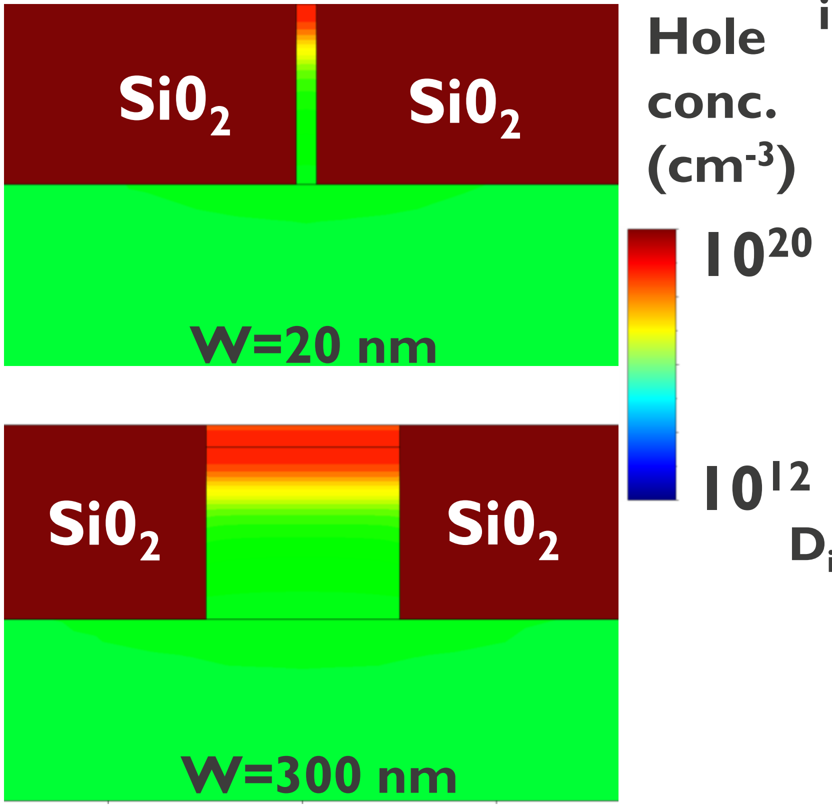
- Higher resistance is measured, especially in narrow fins
- More confined (1D) current is measured in narrow fins

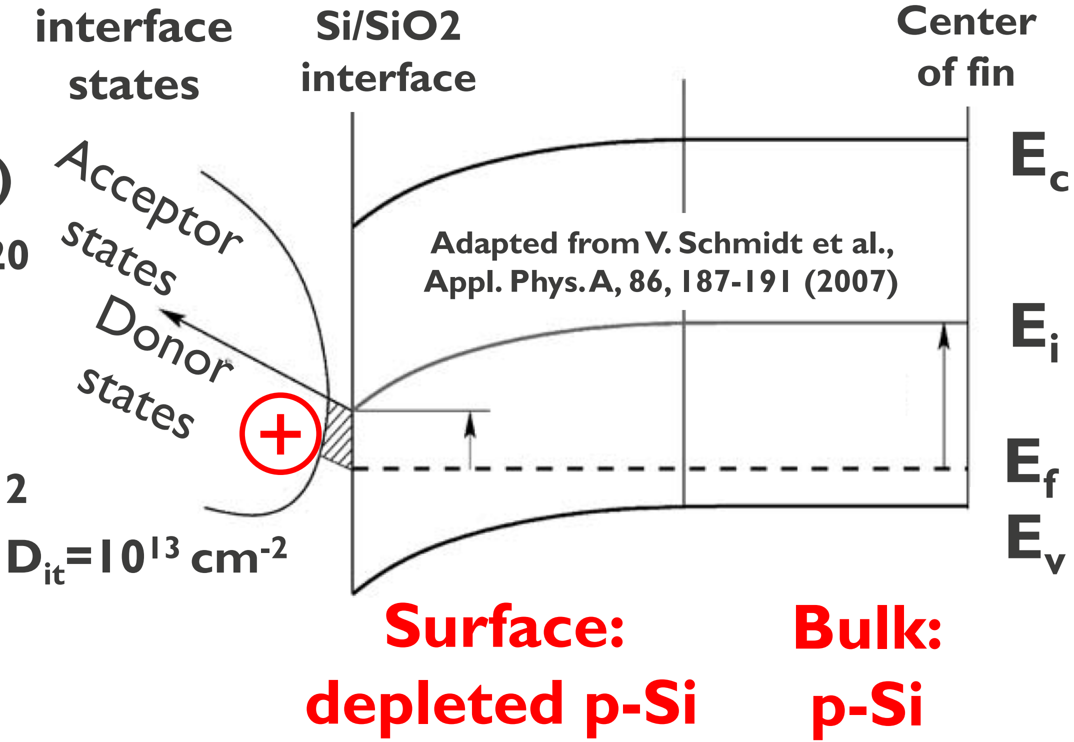
→ Fins get gradually isolated from substrate as width decreases

SURFACE DEPLETION DUE TO INTERFACE STATES (IS) AT THE Si-SiO_2 INTERFACES:

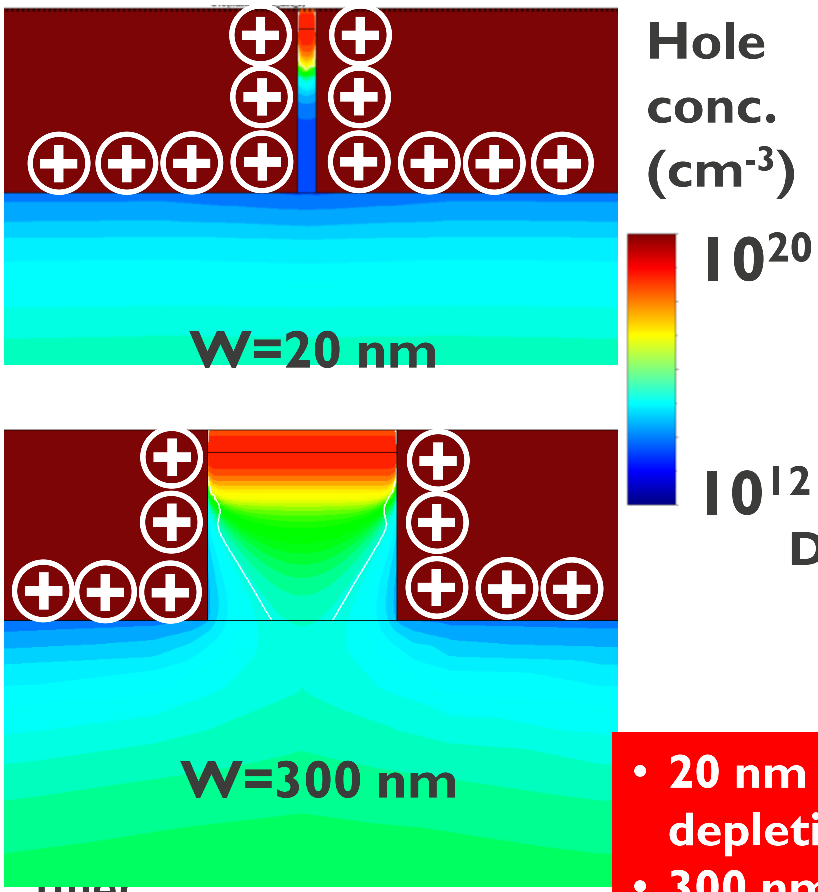


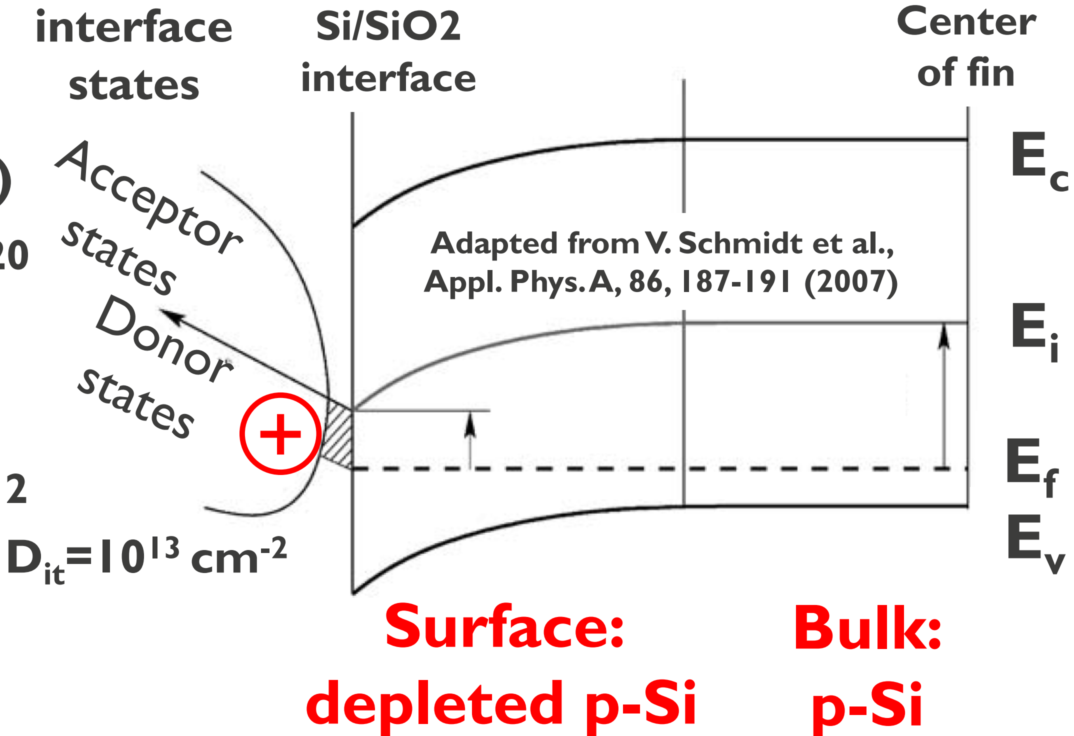
SURFACE DEPLETION DUE TO INTERFACE STATES (IS) AT THE Si-SiO$_2$ INTERFACES:





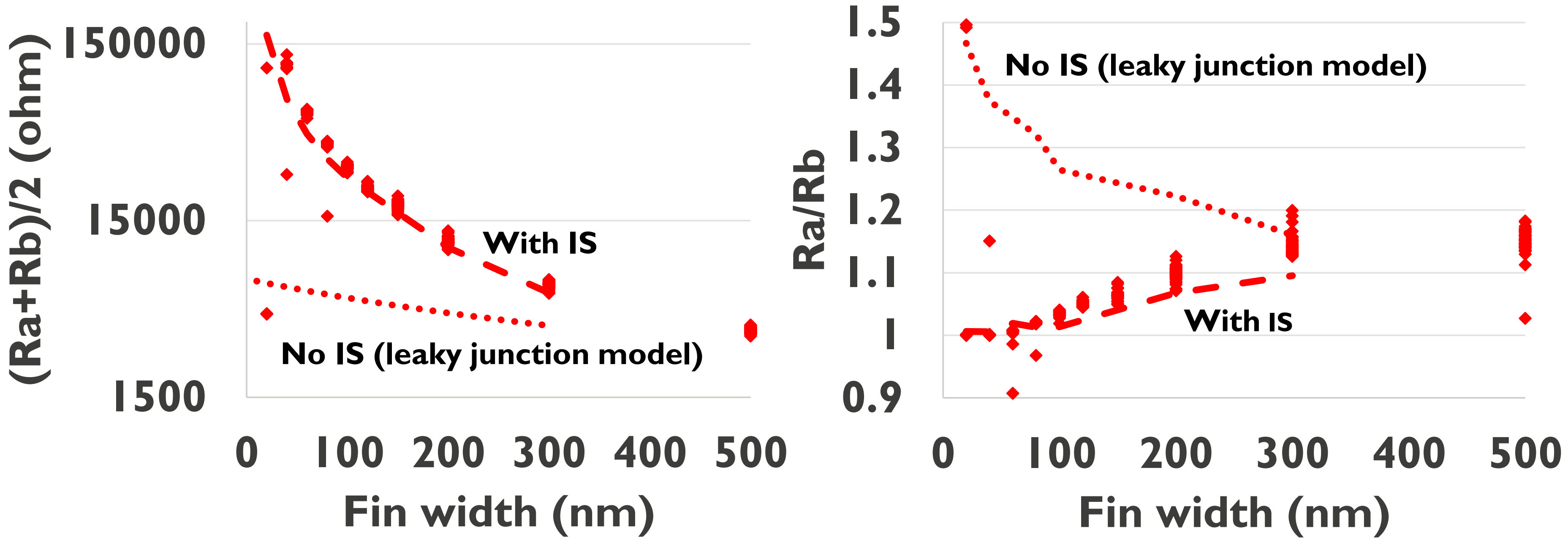
SURFACE DEPLETION DUE TO INTERFACE STATES (IS) AT THE Si-SiO_2 INTERFACES:





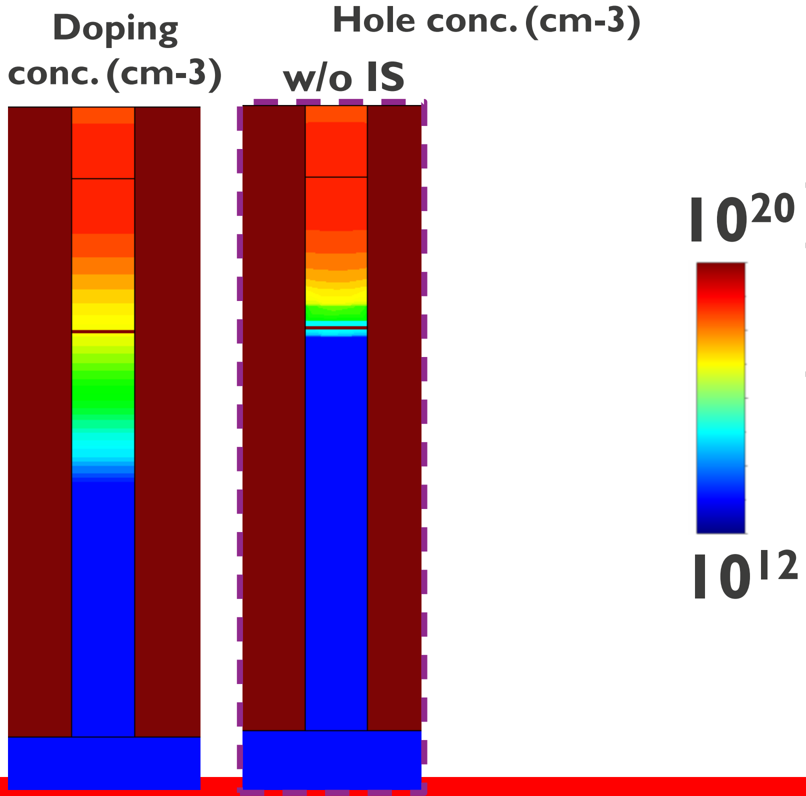
- 20 nm wide fin is electrically isolated by IS-induced depletion
- 300 nm wide fin is still leaky

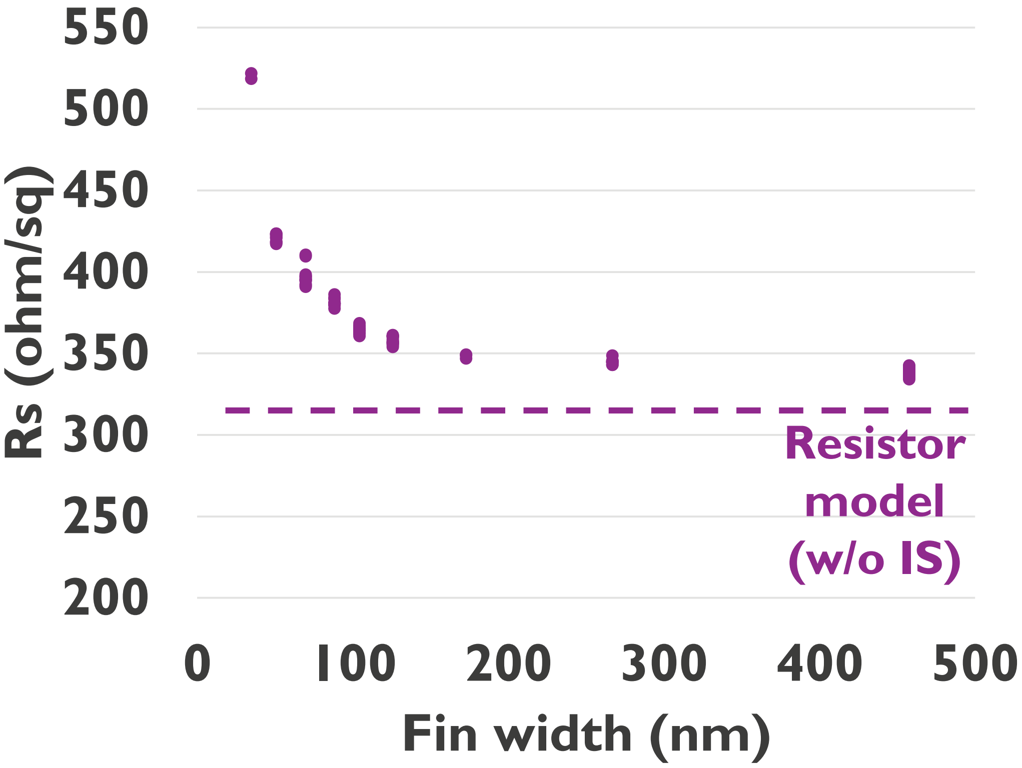
B-IMPLANTED FINS : EXPERIMENT VS THEORY



- Interface states → dimension-dependent current flow in P+P fins
- Leakage currents are strongly reduced in confined volumes (Si)

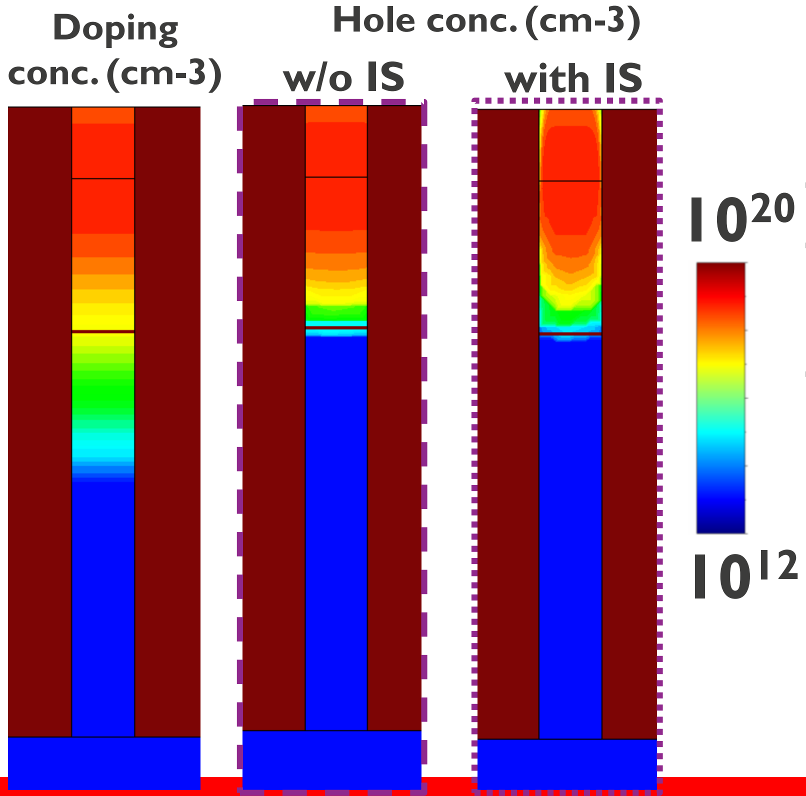
DEPLETION IN HIGHLY P-DOPED REGION

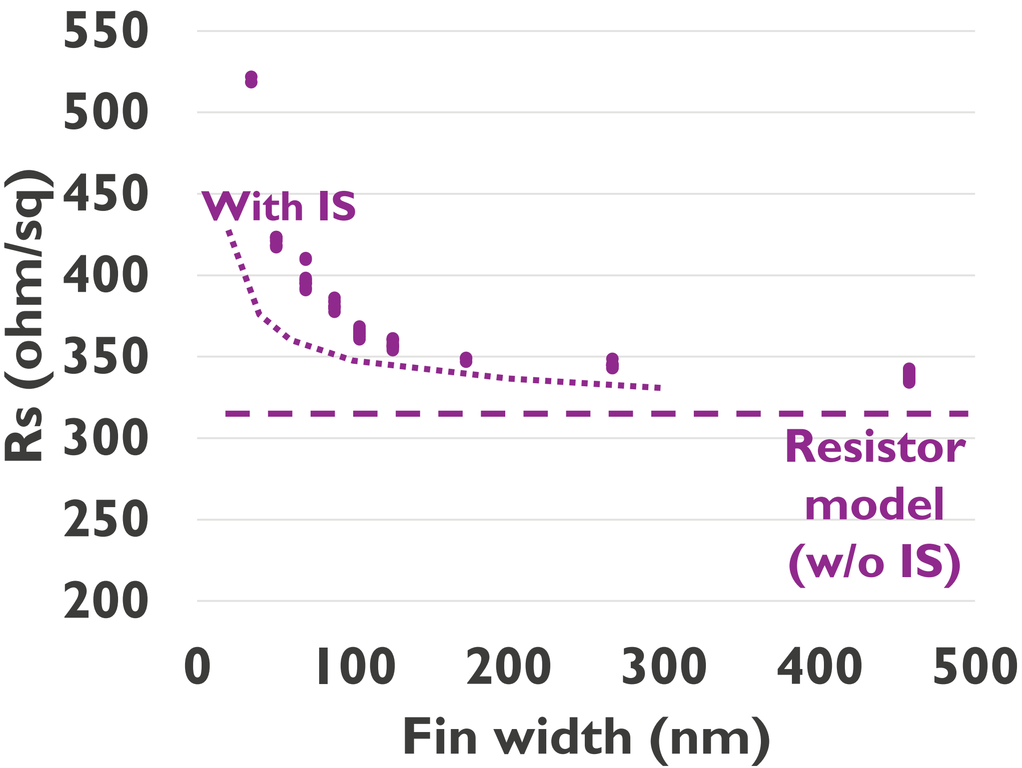




- **Resistor model fails to explain the increase in Rs with decreasing width**

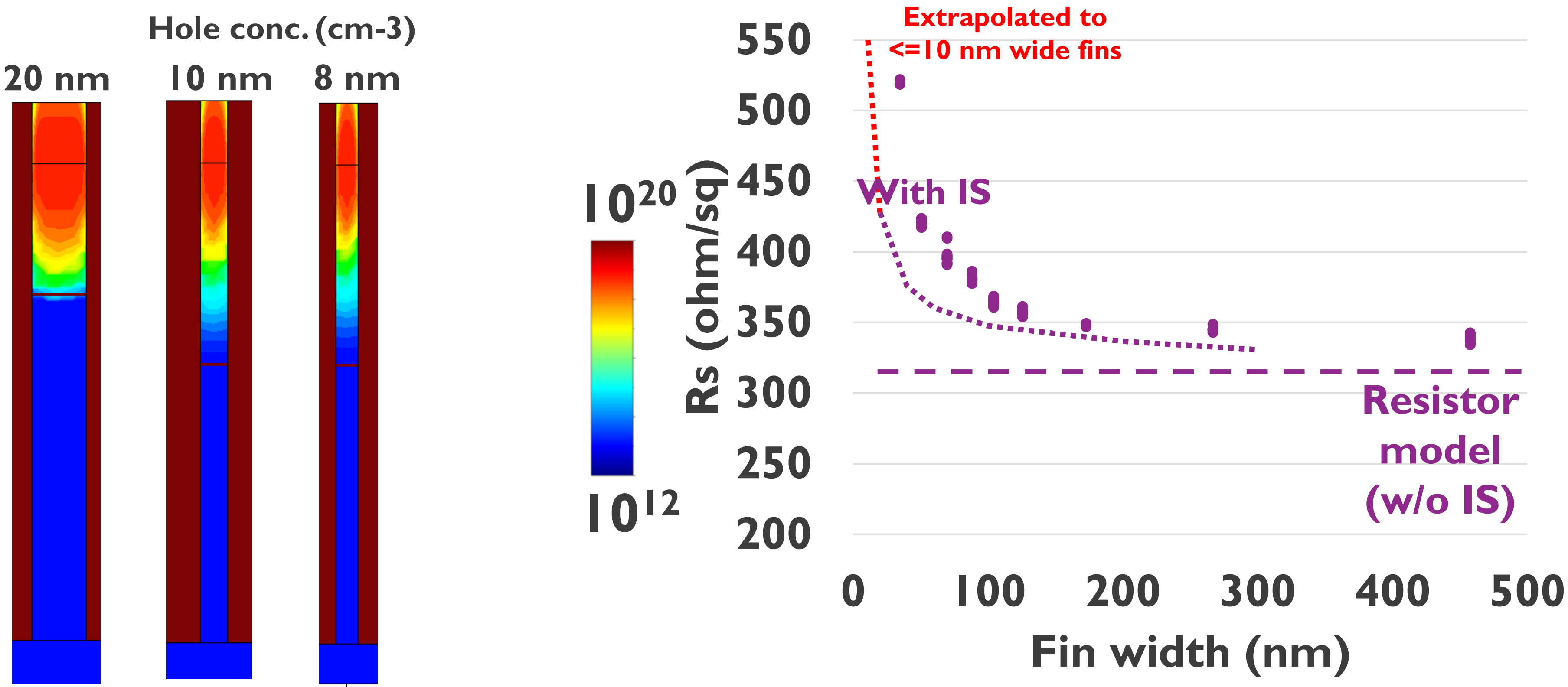
DEPLETION IN HIGHLY P-DOPED REGION





- Resistor model fails to explain the increase in Rs with decreasing width
- The increase in apparent sheet resistance is (partly) due to IS-induced depletion

DEPLETION IN HIGHLY P-DOPED REGION

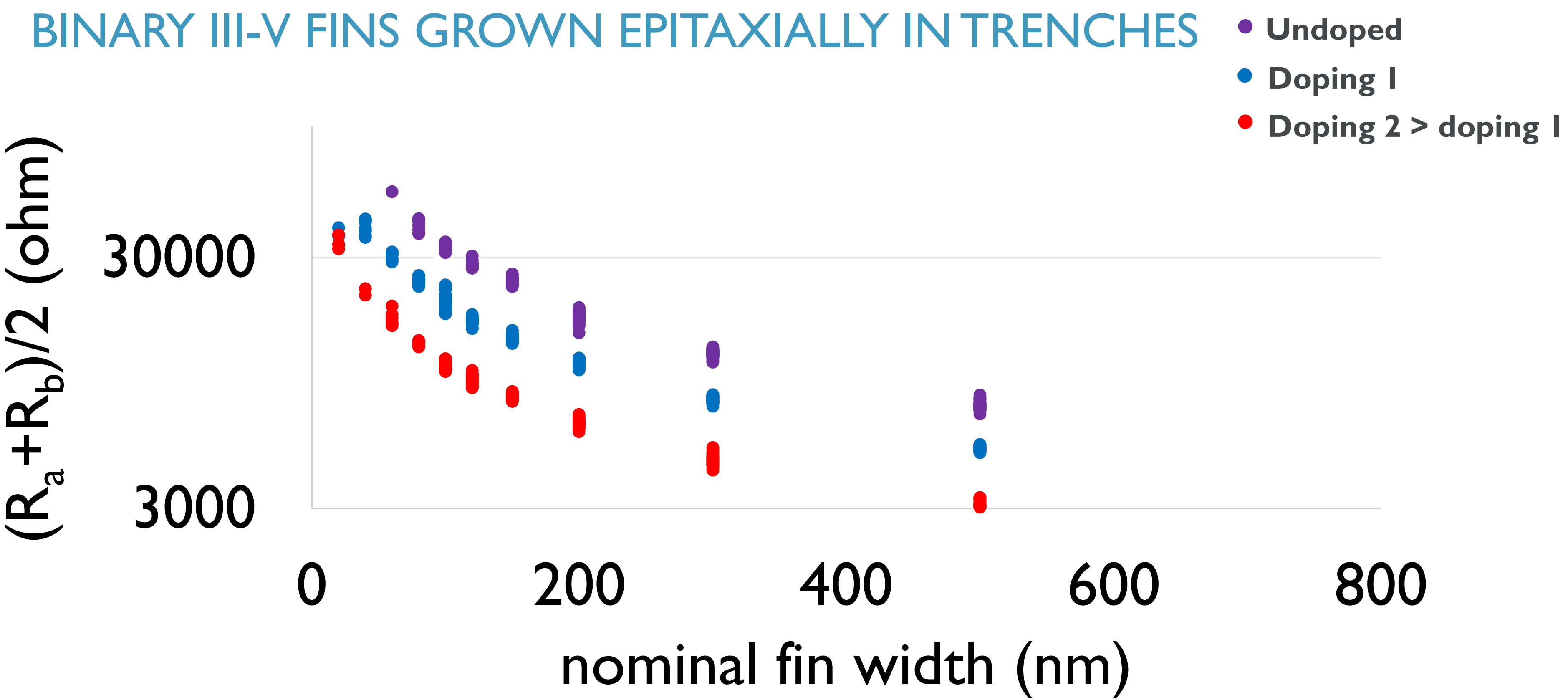


- Resistor model fails to explain the increase in Rs with decreasing width
- The increase in apparent sheet resistance is (partly) due to IS-induced depletion
- Dramatic impact of depletion expected on narrowest fins

OUTLINE

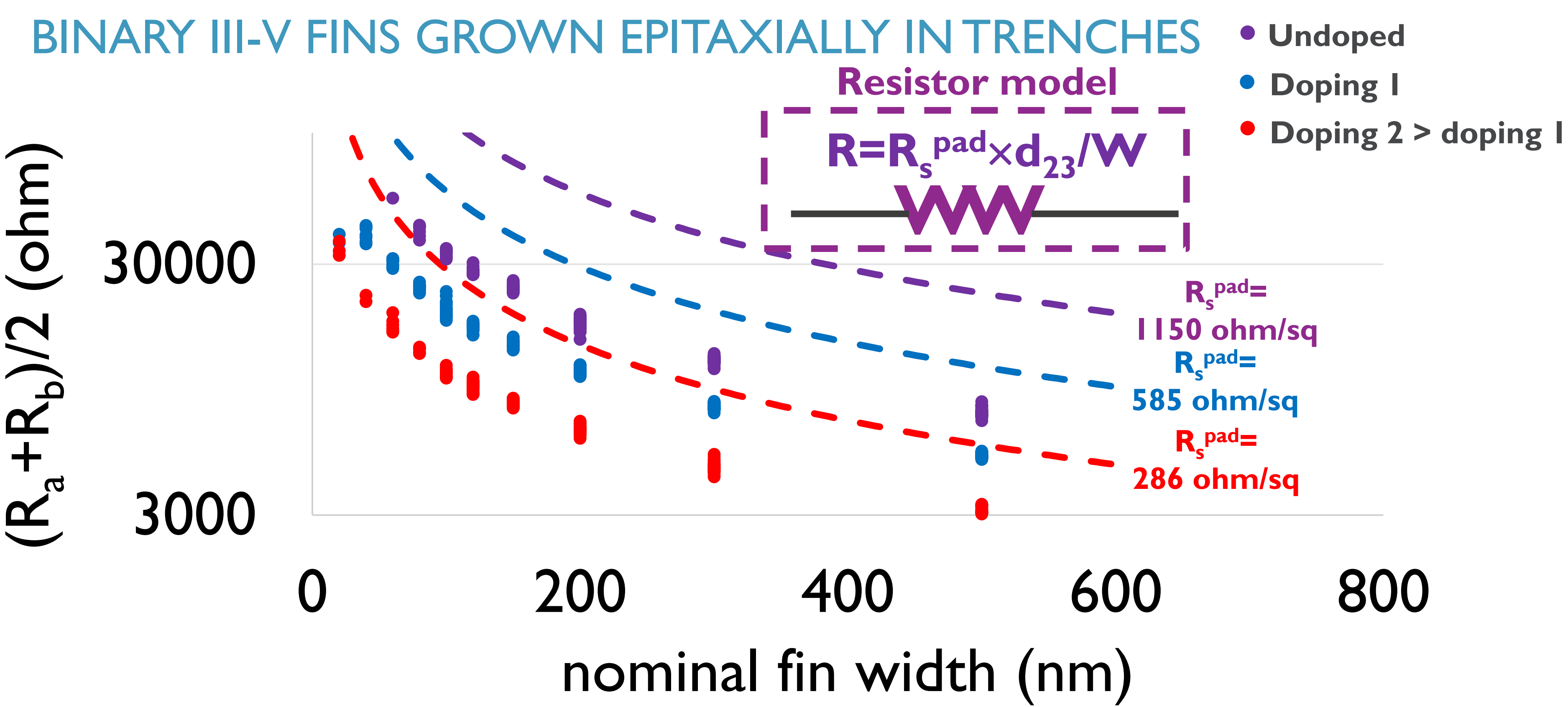
- Basics
- Proof of concept : P+N Si fins
- leakage information : P+P Si fins
- **III-V fins**

BINARY III-V FINS GROWN EPITAXIALLY IN TRENCHES



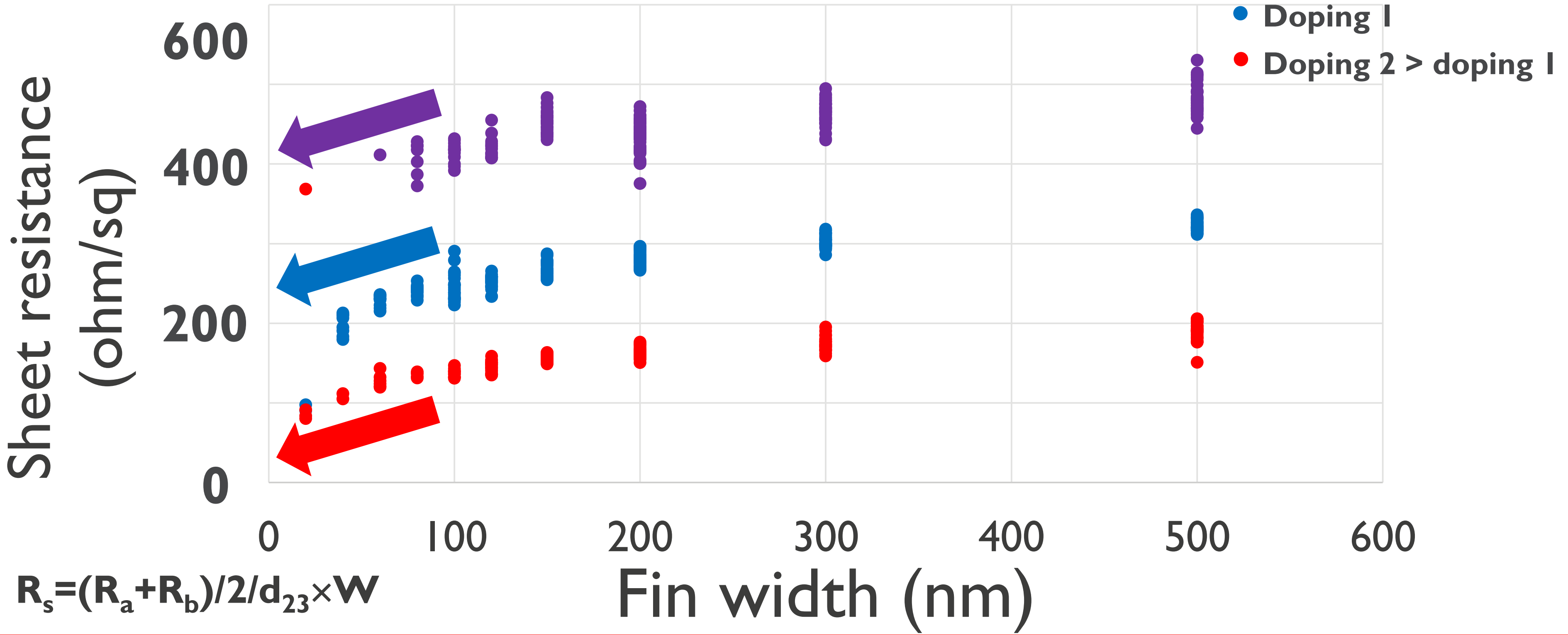
- **Doping reduces measured fin resistance**

BINARY III-V FINS GROWN EPITAXIALLY IN TRENCHES



- **Doping reduces measured fin resistance**
- **R_s is 2x to 4x lower than in the pad**

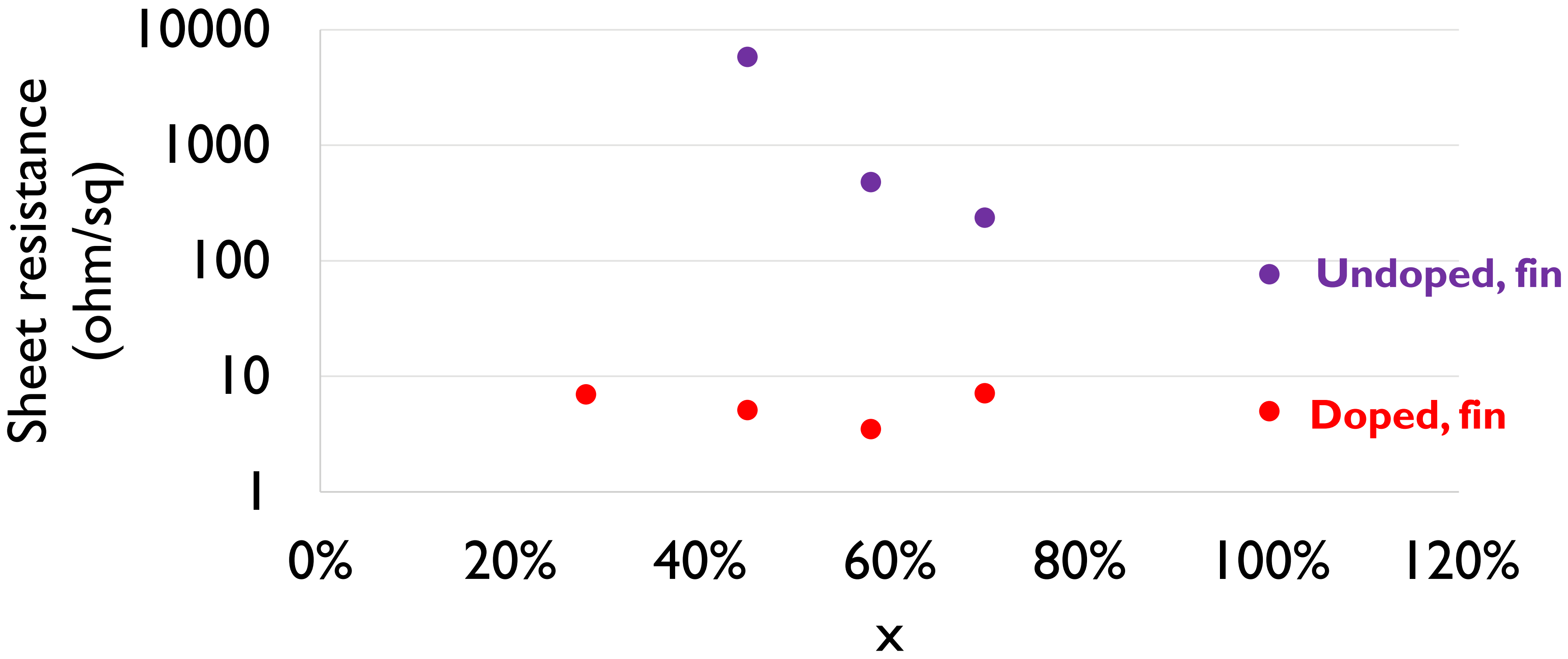
SHEET RESISTANCE VS FIN WIDTH



$R_s=(R_a+R_b)/2/d_{23}\times W$

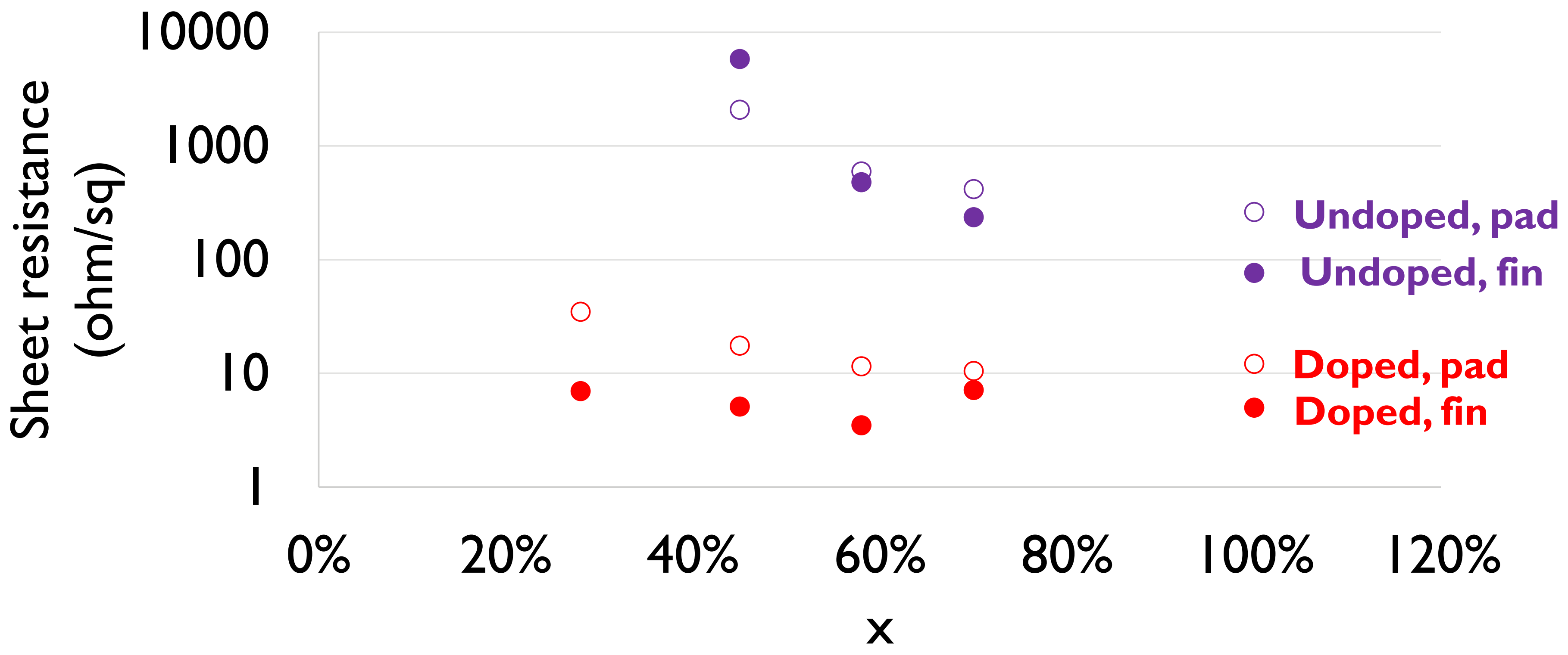
- Doping reduces measured fin resistance
- R_s is 2x to 4x lower than in the pad
- R_s drops when fin width decreases

300-NM WIDE $In_XGa_{1-X}As$ FINS GROWN EPITAXIALLY IN TRENCHES



- **Rs varies with doping and In content**

300-NM WIDE $In_XGa_{1-X}As$ FINS GROWN EPITAXIALLY IN TRENCHES



- **Rs varies with doping and In content**
- **Pads and fins qualitatively similar but quantitatively different (up to 5x difference)**

CONCLUSIONS

- In-line m4pp measurements of fins with widths down to 20 nm:
  - Sheet resistance
  - Junction leakage

- Measured resistance on B-implanted Si fins on n-Si (p+n)
  - geometrical confinement (wide fins)
  - Depletion effect in narrow fins → 2-3X more resistive than bulk

- Measured resistance on B-implanted Si fins on p-Si (p+p)
  - Interface states → depletion region → strongly reduced leakage in narrow fins

- Outlook: uncover the physics of resistivity in confined volumes (defects, depletion effects,...)

Metrology for future 3D-technologies

www.metro4-3D.eu

This project include open access to the assessed instruments. Refer to the project website for information

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 688225.

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