INDIVIDUAL DEVICE ANALYSIS USING HYBRID TEM-SCALPEL SSRM METROLOGY

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Materials & Components Analysis

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METROLOGY and 3D ARCHITECTURES

HYBRID METROLOGY

“ FLUID CROSS-TECHNIQUES COMPLEMENTARITY ”

OUTLINE

Motivation

Scalpel SSRM-TEM
Basic Principles

Applications
and Results

SSRM past and future

Scalpel SPM for 3D tomographic capability

Combining TEM and Scalpel SPM

Sample preparation / Analysis flow

SSRM past and future

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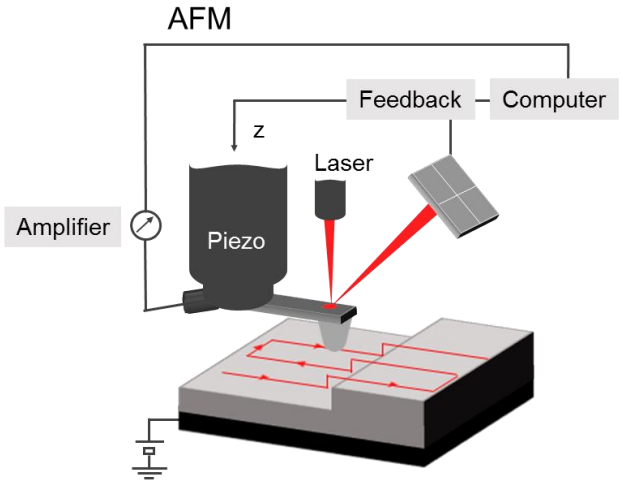
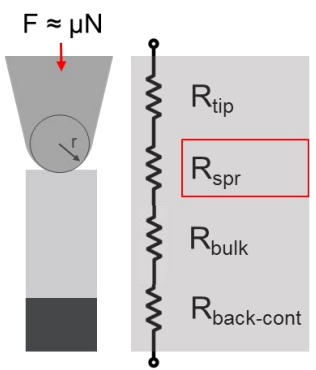
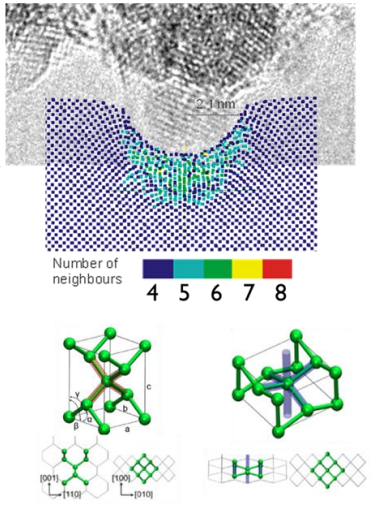
SSRM BASIC PRINCIPLES

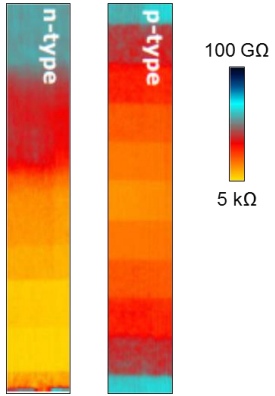






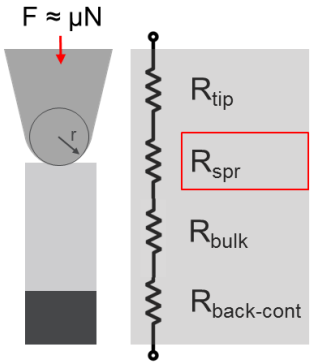
$$R_{spreading} = \frac{\rho}{4a}$$

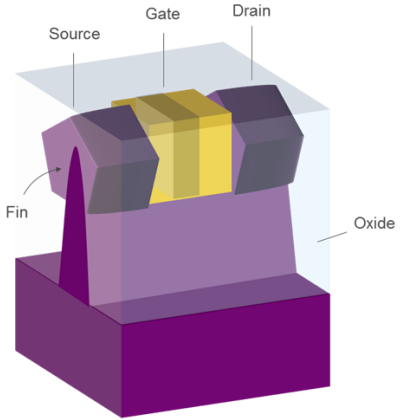
$$\rho = \frac{1}{e\mu_n n} \text{ or } \rho = \frac{1}{e\mu_p p}$$



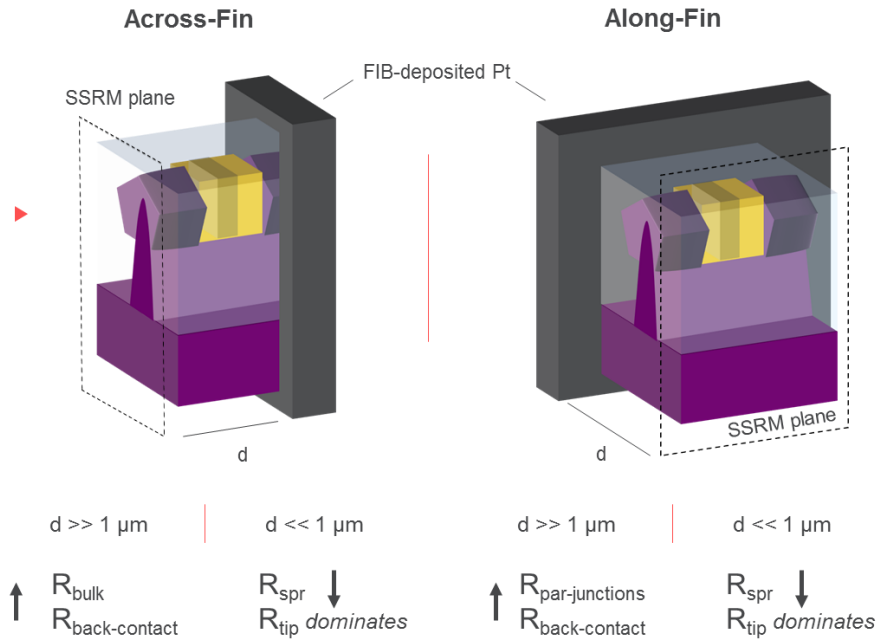
[P. Eyben, et al. *Mater. Sci. Eng. B*, **124–125**, 45–53, 2005]
[K. Mylvaganam, et al., *Nanotechnology*, **20**, 305705, 2009]
[A. Schulze, Ph.D Thesis, KU Leuven, 2013]

SSRM FOR CONFINED VOLUMES ANALYSIS



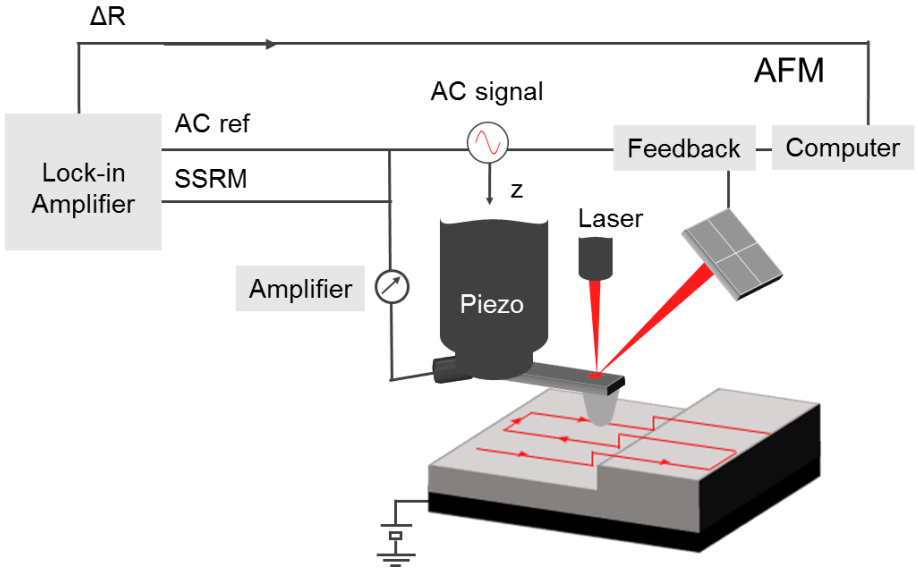


FinFET back-contact alternatives



[Vandervorst, W., Mater. Sci. in Semi. Proc., 2016]

FFT-SSRM BASIC PRINCIPLES



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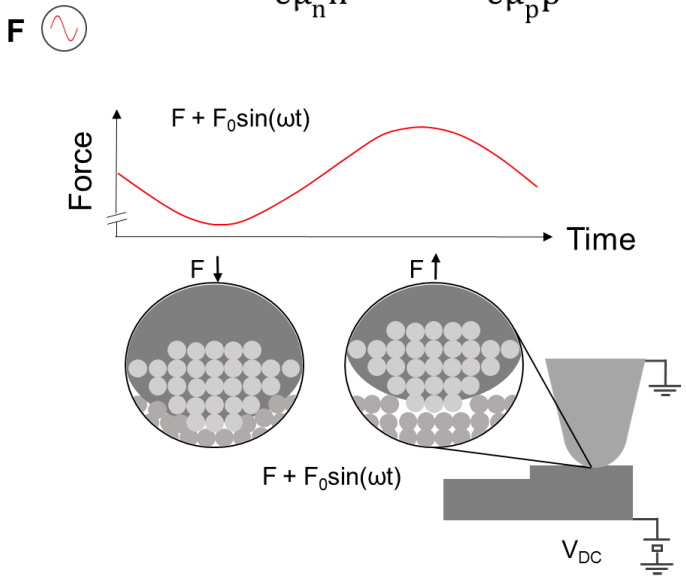
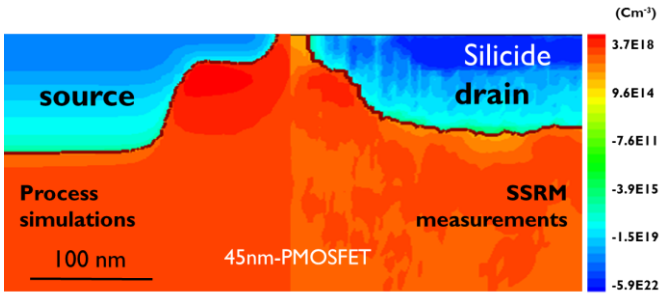
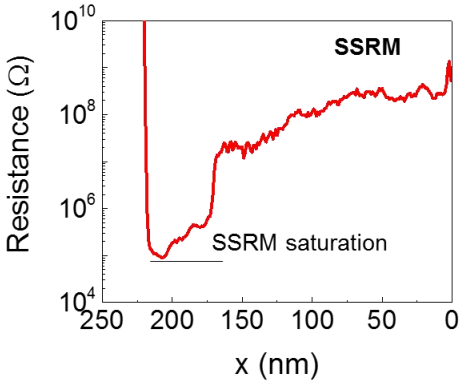


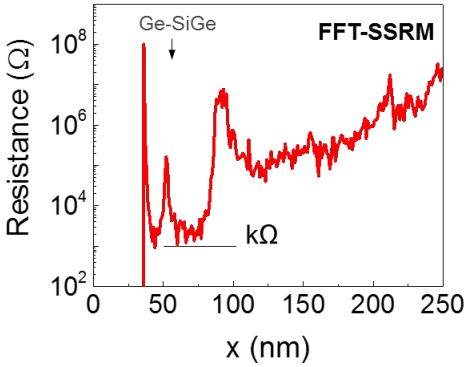
[A. Schulze, et al., *Ultramicroscopy*, **161**, 59–65, 2016]

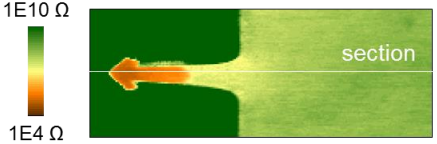
22 YEARS OF NANOELECTRONICS CHARACTERIZATION IN 2D

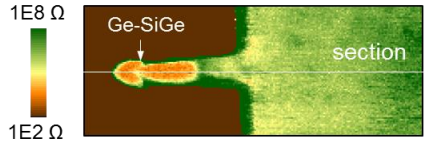
- Carriers profiling
- Quantification/Calibration











SSRM

[Nazir, A., et al, IEEE Trans. Electron. Dev., 61, **2014**]
[Schulze, A, et al., *Nanotechnology*, *22*(18), **2011**]

FFT-SSRM

[Vandervorst, W., Mater. Sci. in Semi. Proc., 2016]

CHARACTERIZATION IN 2D

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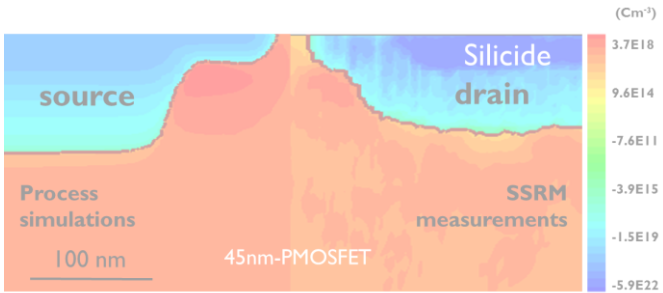
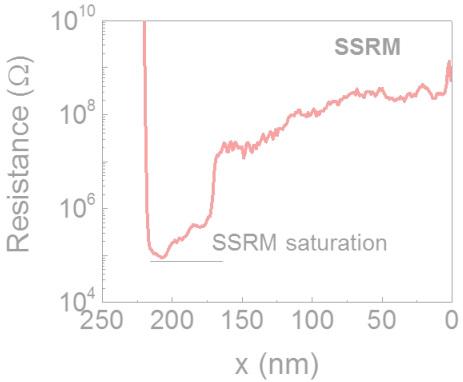
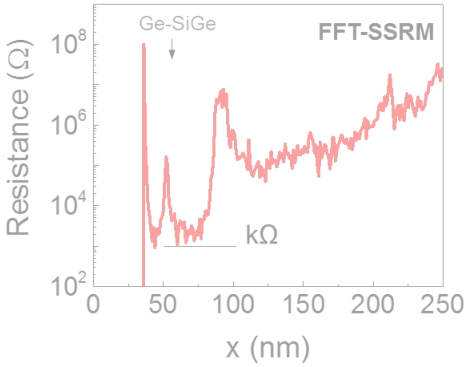
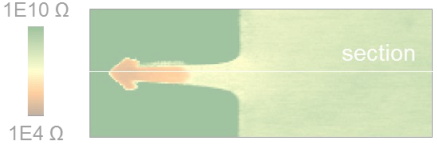
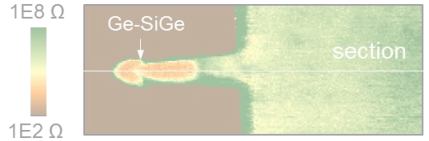










SSRM

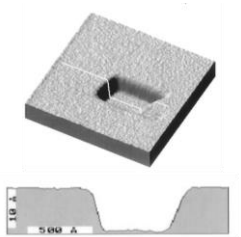
[Nazir, A., et al, IEEE Trans. Electron. Dev., 61, **2014**]
[Schulze, A, et al., *Nanotechnology*, *22*(18), **2011**]

FFT-SSRM

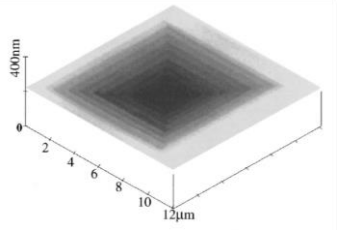
[Vandervorst, W., Mater. Sci. in Semi. Proc., 2016]

SCALPEL FOR 3D TOMOGRAPHY

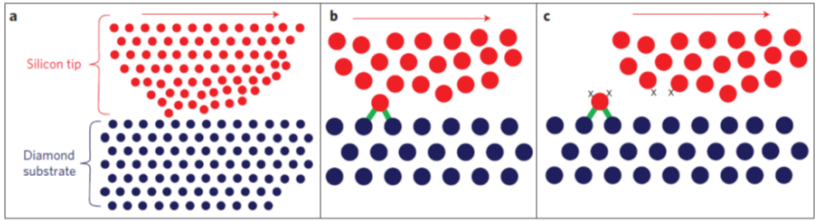
The transition from 2D to 3D



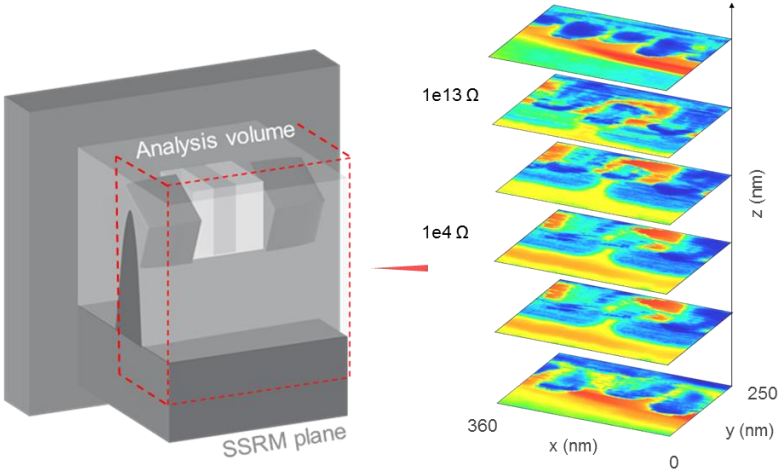
[Hu, J. et al., Surf. Sci., 237, (**1995**)]



[Xu., M.,W. et al., Appl. Phys. Lett., 81, (**2002**)]

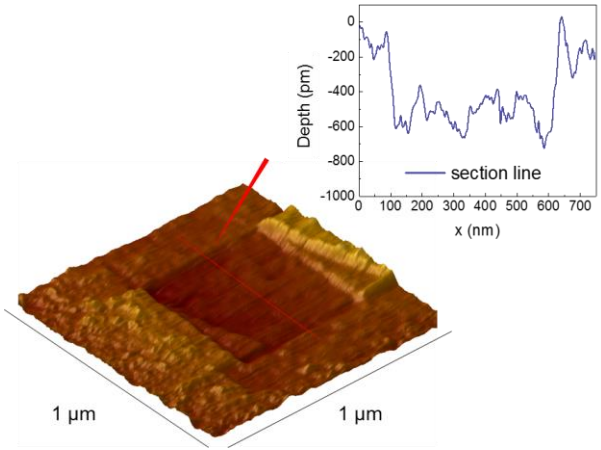


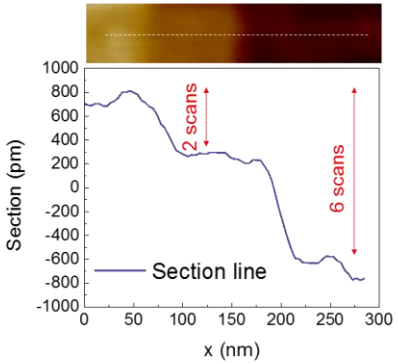
[Jacobs, T. D. B., & Carpick, R. W., *Nature Nanotechnology*, *8*(2), (2013)]

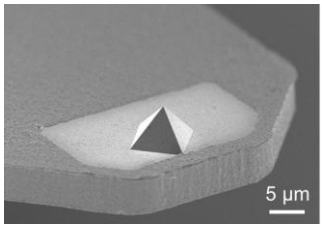


A stress-assisted chemical reaction → Atom-by-atom **removal**

A SLICE-AND-VIEW APPROACH BY TIP-INDUCED MATERIAL REMOVAL

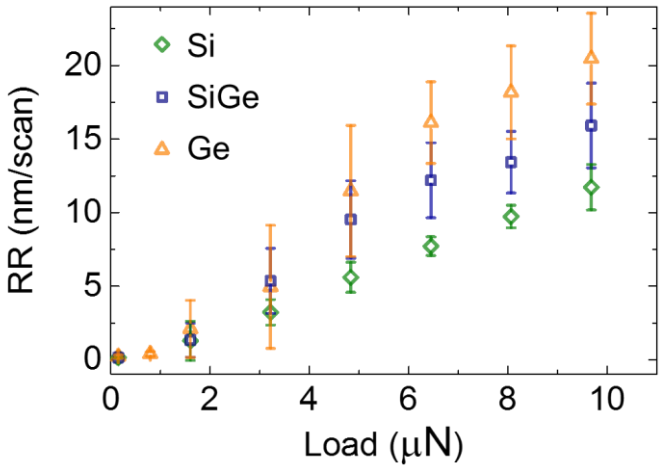






[Hantschel, T. et al., *Physica Status Solidi (a)*, *206*(9), **2006**]

Removal performed on: Si, SiGe, Ge, InGaAs, InP, TiN, Cu, Ti, TaN, Ru, HfO_2, SiO_2, Al_2O_3 and Au



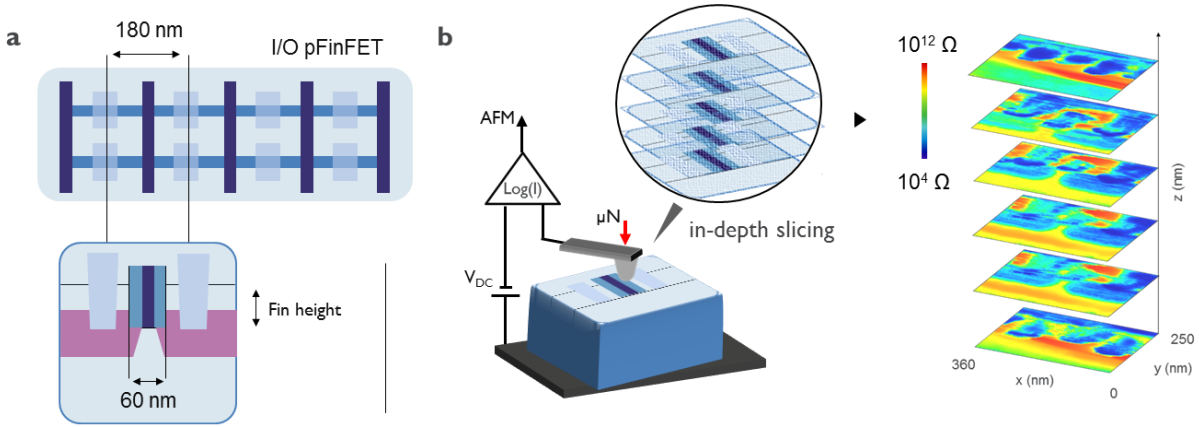
SSRM past and future

Scalpel SPM for 3D tomographic capability

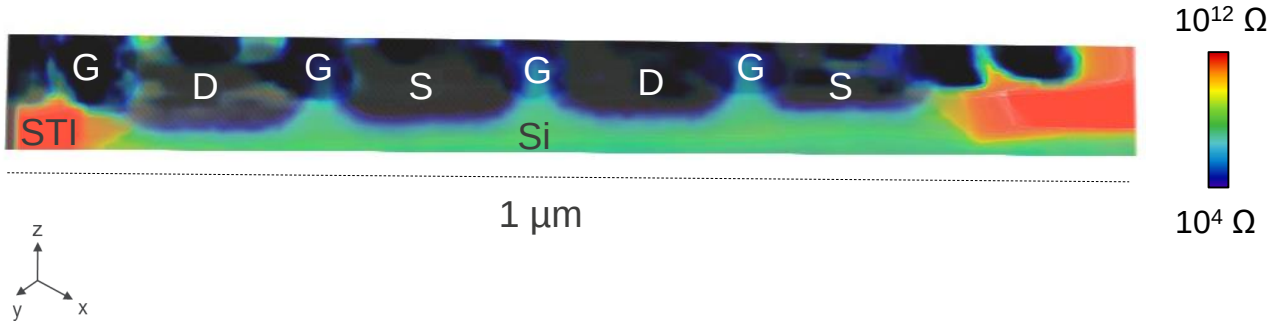
Combining TEM and Scalpel SPM

Sample preparation / Analysis flow

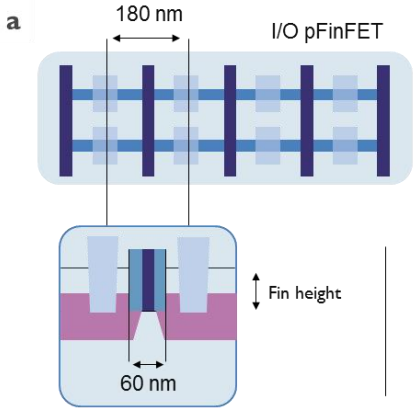
SCALPEL SSRM APPLICATIONS FOR LOGIC DEVICES

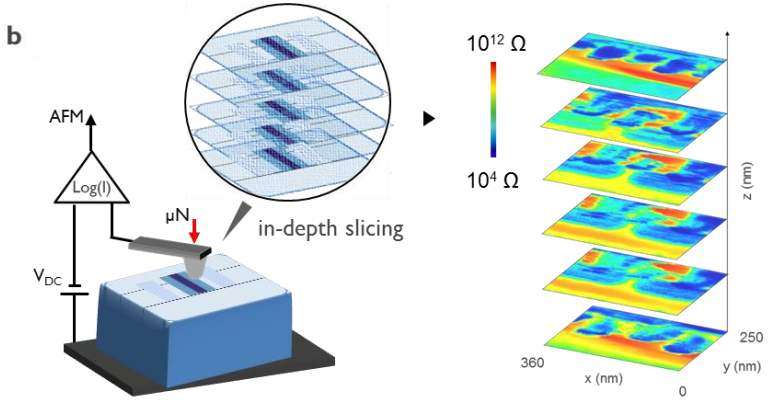


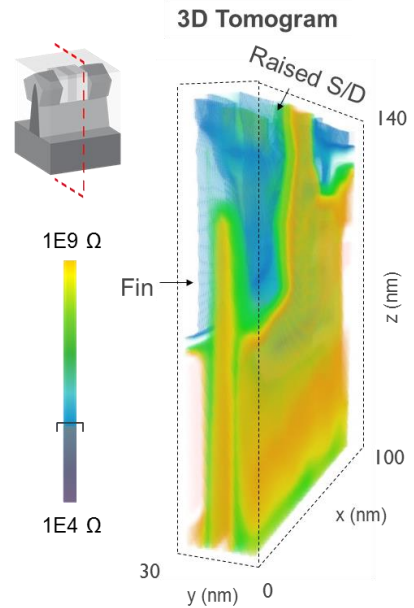
[Vandervorst, W., Mater. Sci. in Semi. Proc., 2016]
[Celano, U., VLSI-Technology, **2016**]
[Celano, U., IEDM Tech. Dig., **2013**]

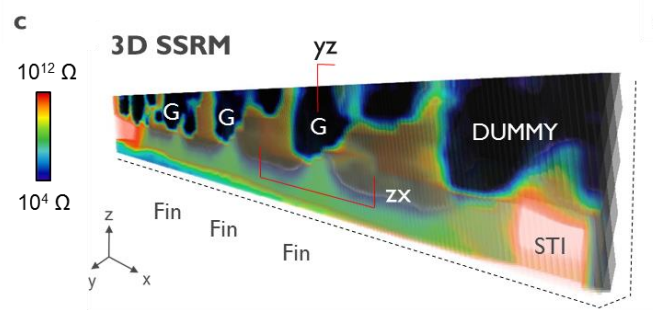


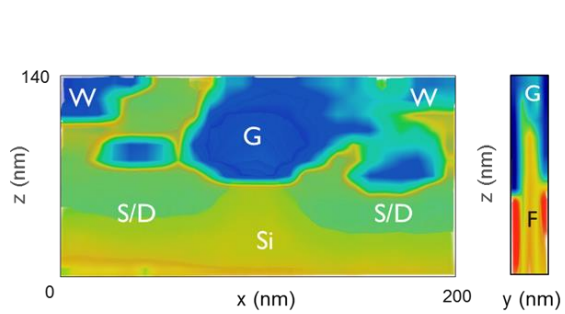
SCALPEL SSRM APPLICATIONS FOR LOGIC DEVICES







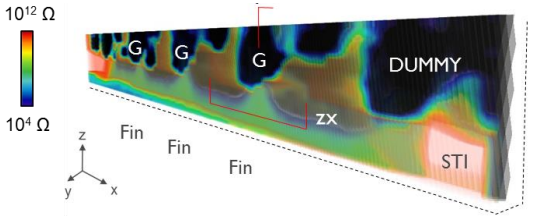


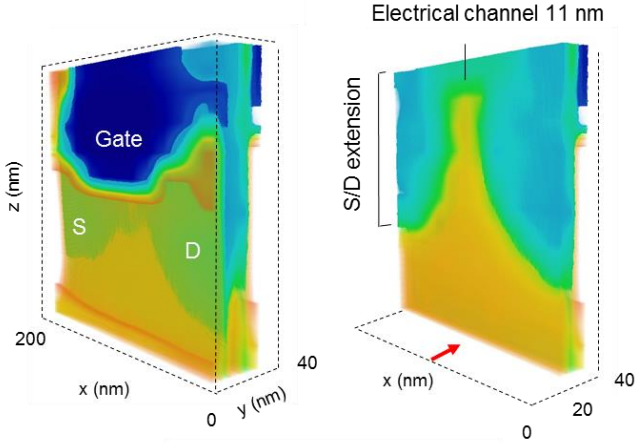


[Vandervorst, W., Mater. Sci. in Semi. Proc., 2016]
[Celano, U., VLSI-Technology, **2016**]
[Celano, U., IEDM Tech. Dig., **2013**]

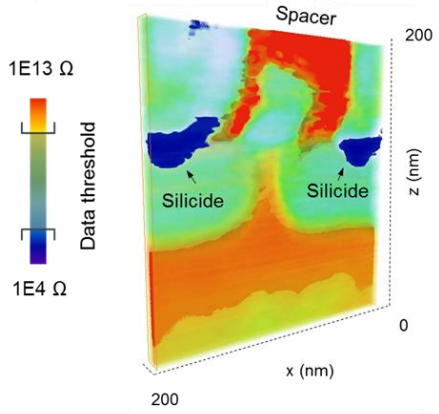
3D TOMOGRAM ANALYSIS CAPABILITY

Details on a FinFET 22 nm node

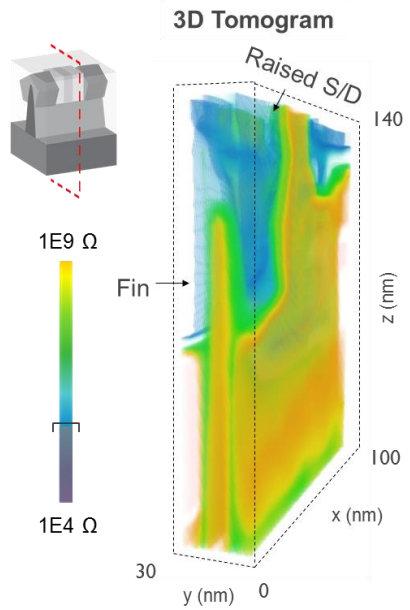




3D resistance map analysis



Structural composition



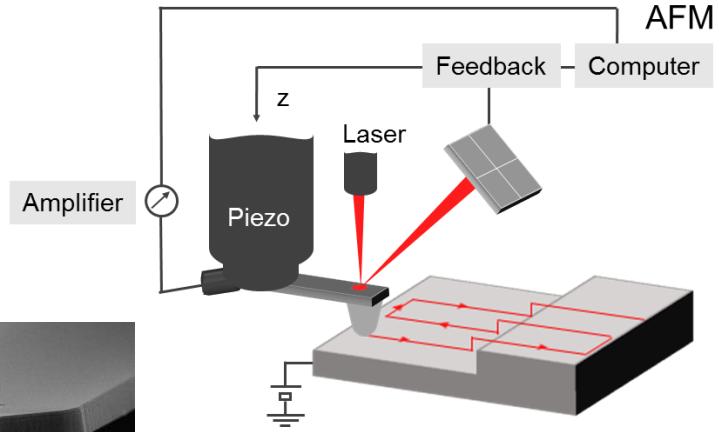
SSRM past and future

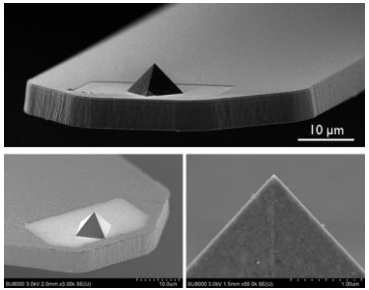
Scalpel SPM for 3D tomographic capability

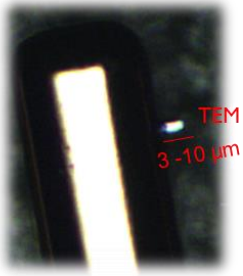
Combining TEM and Scalpel SPM

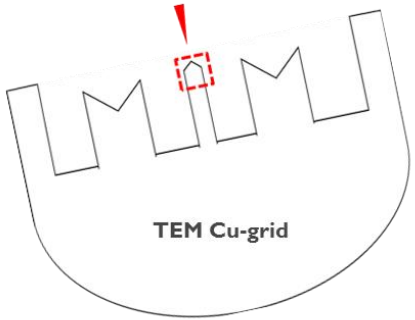
Sample preparation / Analysis flow

CO-EXISTENCE OF SCALPEL SSRM AND TEM



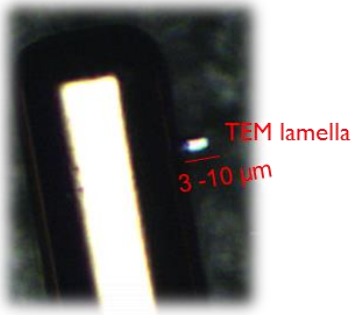


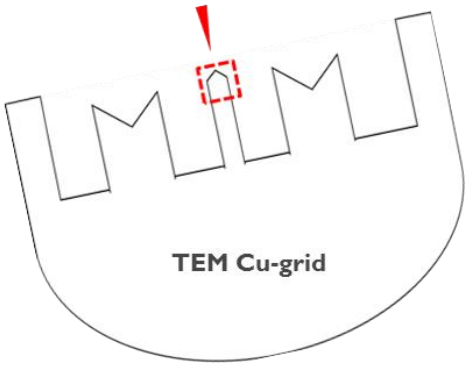


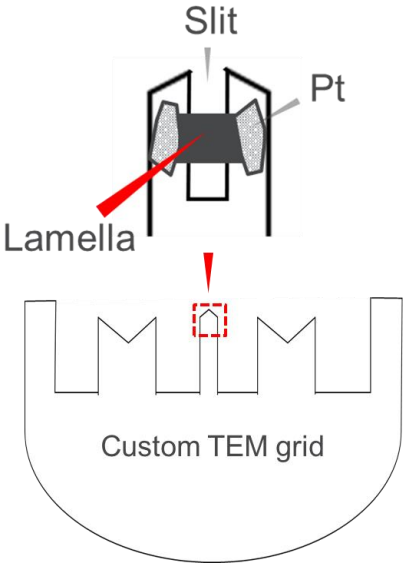


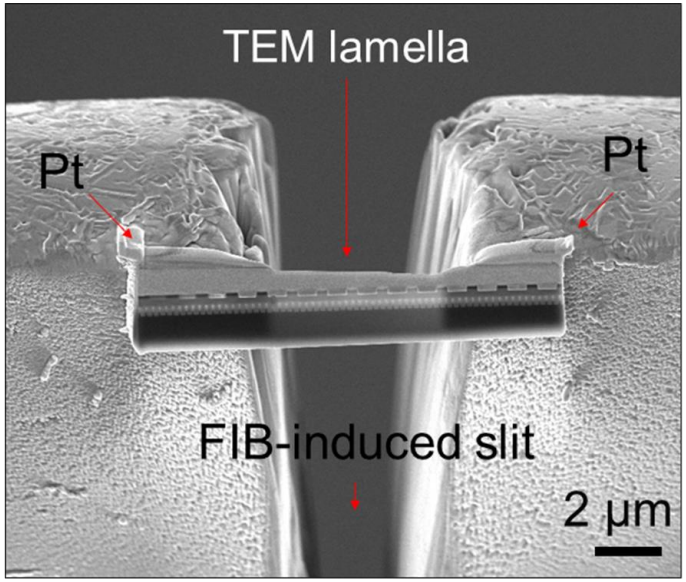
[T. Hantschel et al., Physica status solidi (a), 206, (2009)]
[M. Tsigkourakos et al., Carbon, 79, (2014)]

ELECTRON TRANSPARENCY COUPLED WITH MECHANICAL STABILITY









FIB-induced grid & Sample positioning | TEM analysis | Scalpel SSRM

Repeat

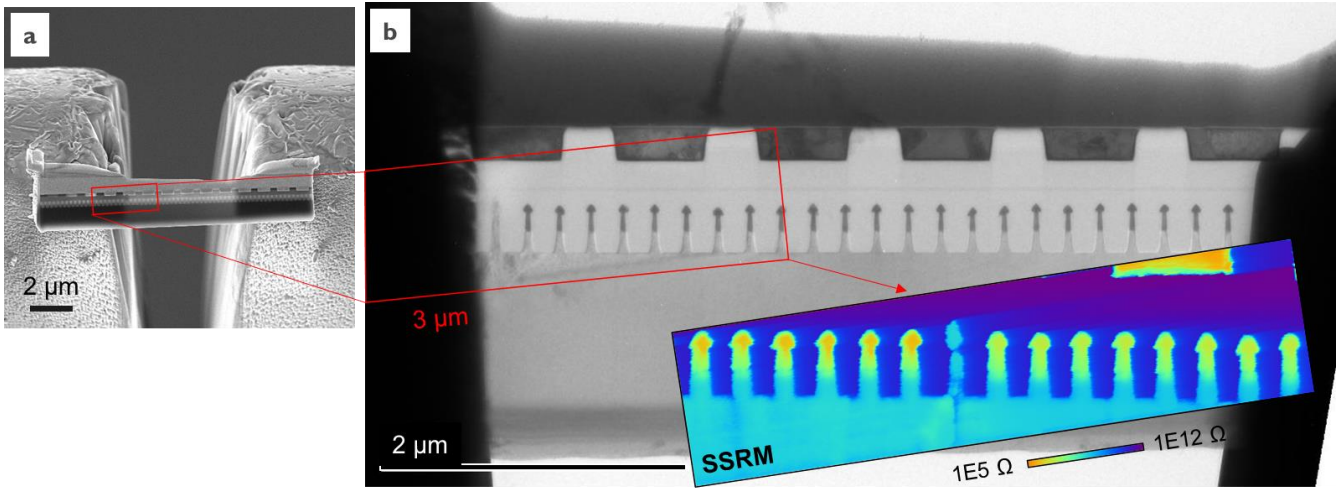
Real case study on p-FinFET

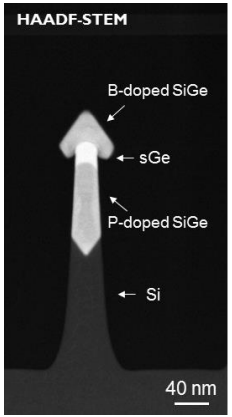
Interface between SiGe raised S/D and sGe

Site-specific analysis

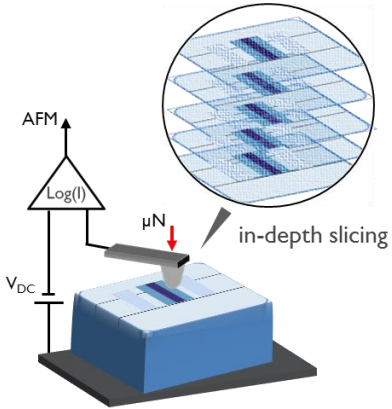
metaMetrology

HYBRID METROLOGY: REAL CASE STUDY

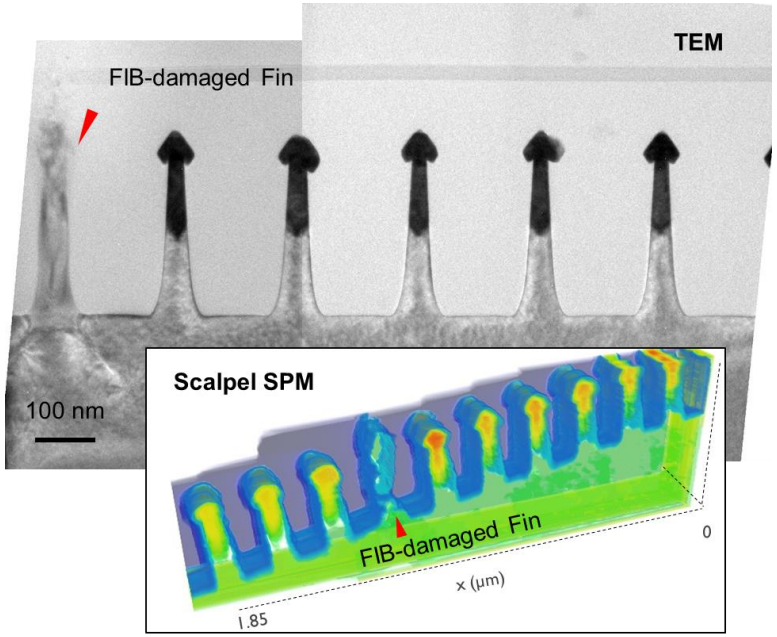


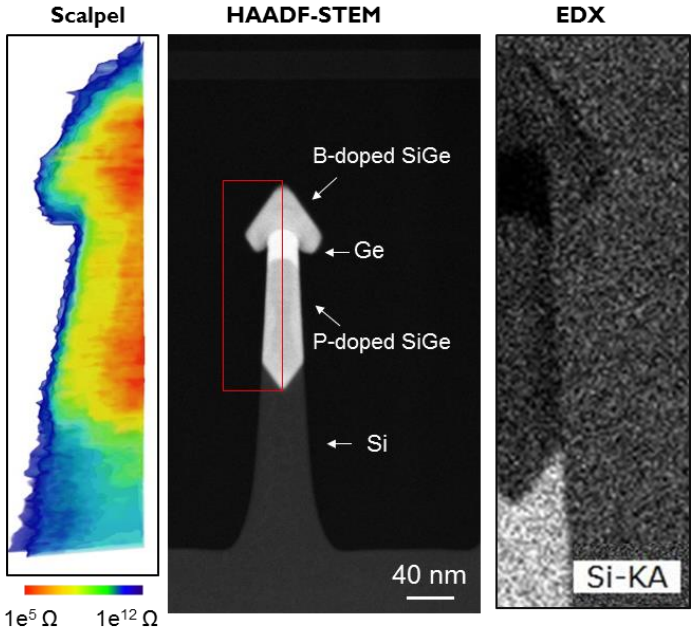


[Mitard, J., *VLSI-Technology*, **2016**]

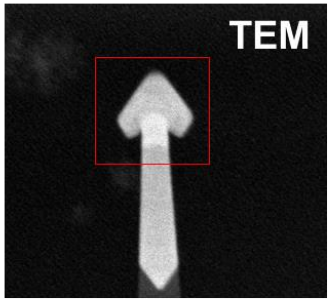


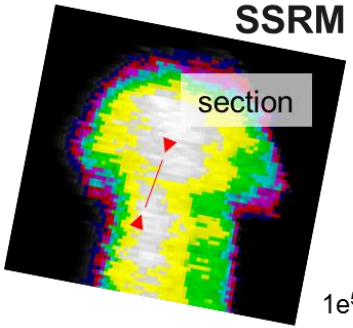
INDIVIDUAL DEVICE ANALYSIS SCALPEL-SSRM / TEM

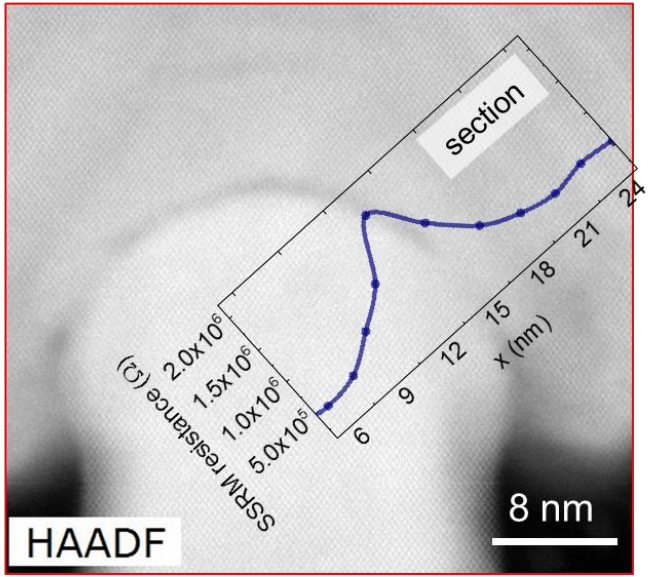




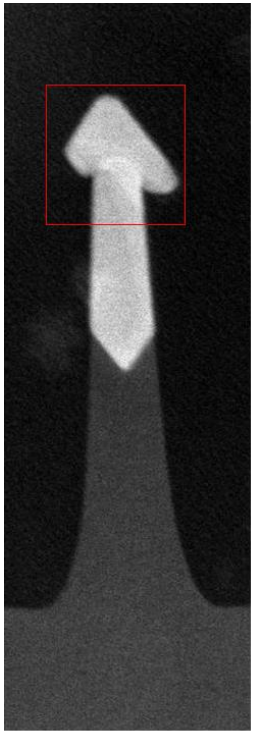
INTERFACIAL LAYER BETWEEN RAISED S/D SiGe AND Ge

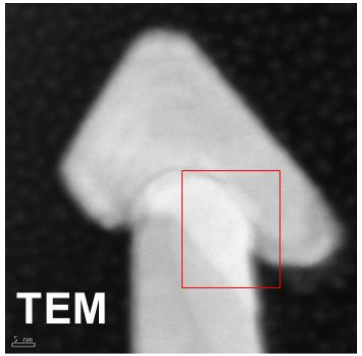


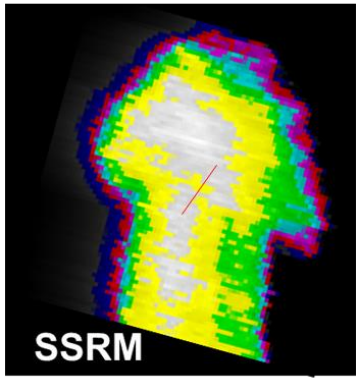




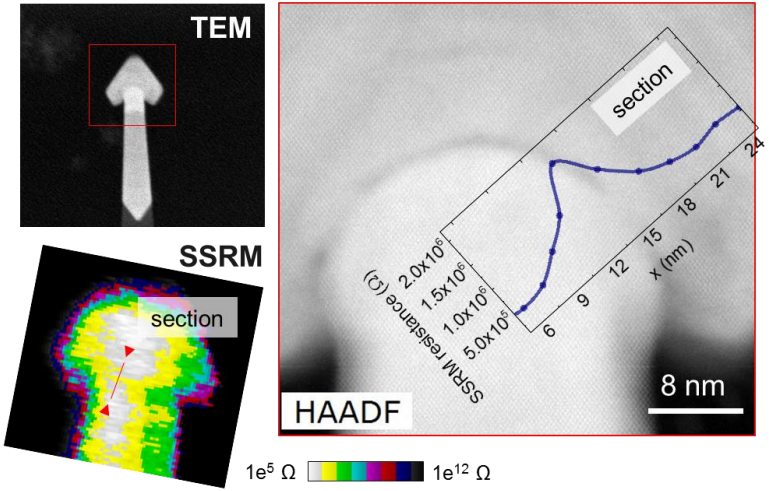
1e^5 Ω 1e^{12} Ω

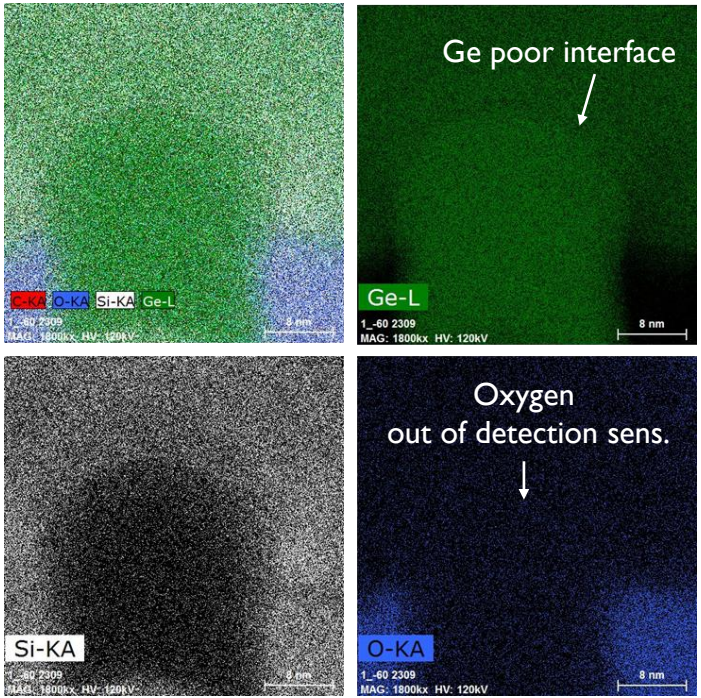






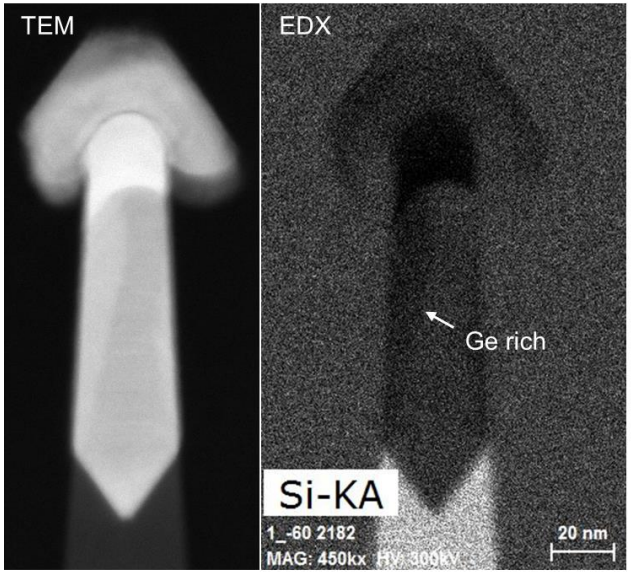
INTERFACIAL LAYER BETWEEN RAISED S/D SiGe AND Ge

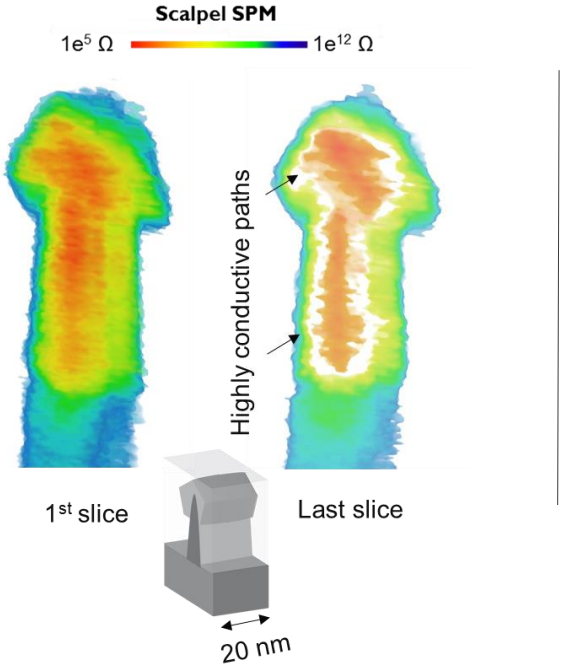


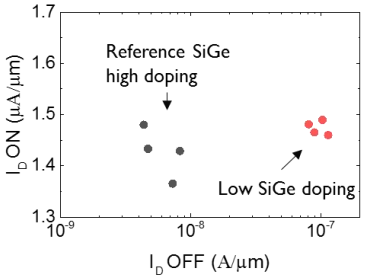


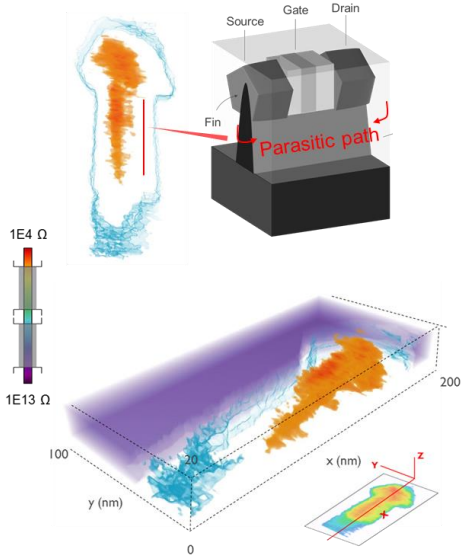
SITE-SPECIFIC ANALYSIS UNDER-FIN PARASITIC

[Mitard, J., *VLSI-Technology*, ***2015***, pp. 1–2]









Real case study on p-FinFET

Interface between SiGe raised S/D

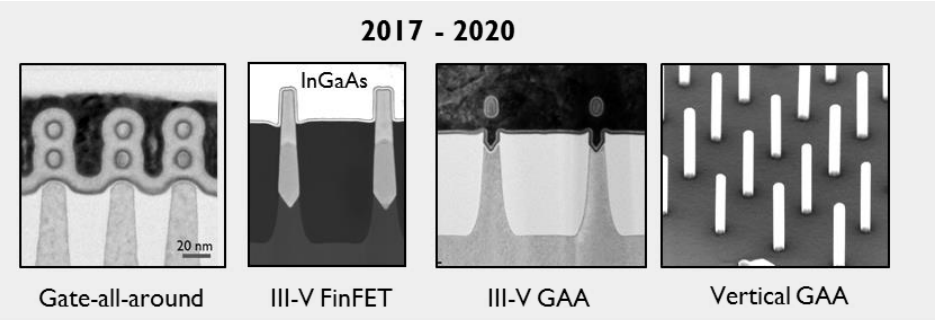
Site-specific analysis

Meta-Metrology

"An abstraction behind another concept, used to complete or add to the latter"

OUTLOOK AND CONCLUSIONS

CONCLUSIONS



Hybrid metrology

- Scalpel SPM is combined with TEM
- New sample-prep. and workflow is designed
- Local nm-precise, 3D characterization structural / electrical for confined volumes
- Material characterization / Process qualification / Device Failure analysis

Outlook

- Applications to emerging logic devices
- GAA / III-V
- Artifacts correction in SSRM in confined volumes and TEM inspections

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