INSIGHT-DRIVEN PROCESS DEVELOPMENT: FROM FUNDAMENTALS TO APPLICATION

T NUYTTEN

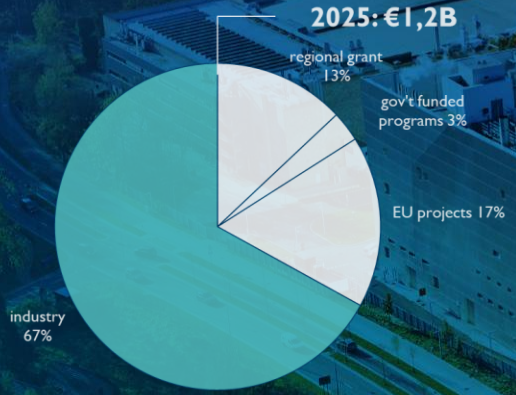
Levitronix CMP & Ultrapure Chemicals Conference 2026


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imec

talented employees

~6500 skilled people

~100 nationalities



world-class infrastructure

~12,000m2 cleanroom
+6,000m2 cleanroom expansion

€3,5B investment
+€2,5B additional investment

over 250 tools

24/7 operation

global ecosystem

- Equipment Suppliers
- Material Suppliers
- Design & System Companies
- IDMs & Foundries
- Academia and RTO
- Start-Ups & SMEs

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● R&D ● Representative office

our impact extends across key application domains



compute

health

automotive

industry

consumer electronics

aerospace & security

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Our impact extends across key application domains

compute

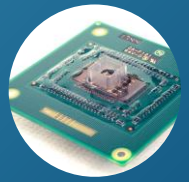
health

automotive

industry

consumer electronics

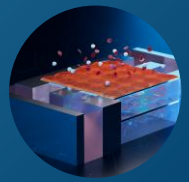
aerospace & security



DNA sequencing



process analytic technology



blood brain barrier



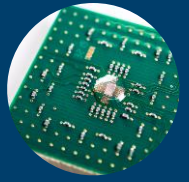
neuroprobe



140 GHz radar in deeply-scaled CMOS



integrated photonics for on-chip lidar



edge-AI chip



CMOS-based NIR and SWIR imagers

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Our impact extends across key application domains

compute

logic

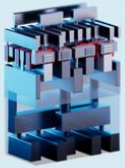
memory

interconnect

litho

other

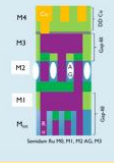
NS



CFET



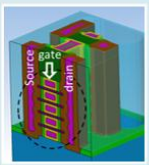
Nano-IC



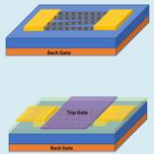
LNA EUV



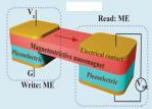
2D FET



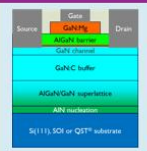
CNT FET



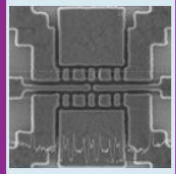
Spin logic



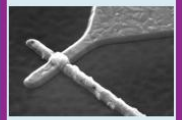
GaN Power



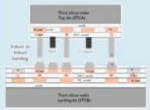
Spin QB



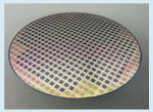
SC QB



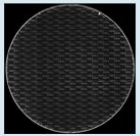
3Di



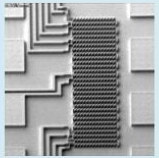
D2W



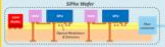
W2W



RDL



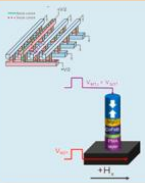
OIO



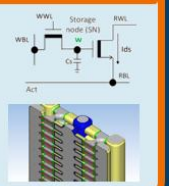
Adv RF



MRAM



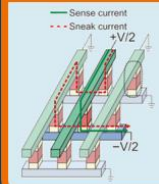
DRAM



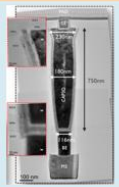
HNA EUV



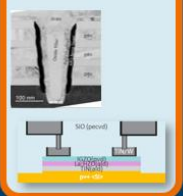
SCM



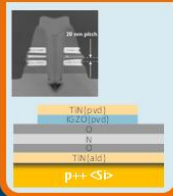
FeRAM



FeFET



NAND

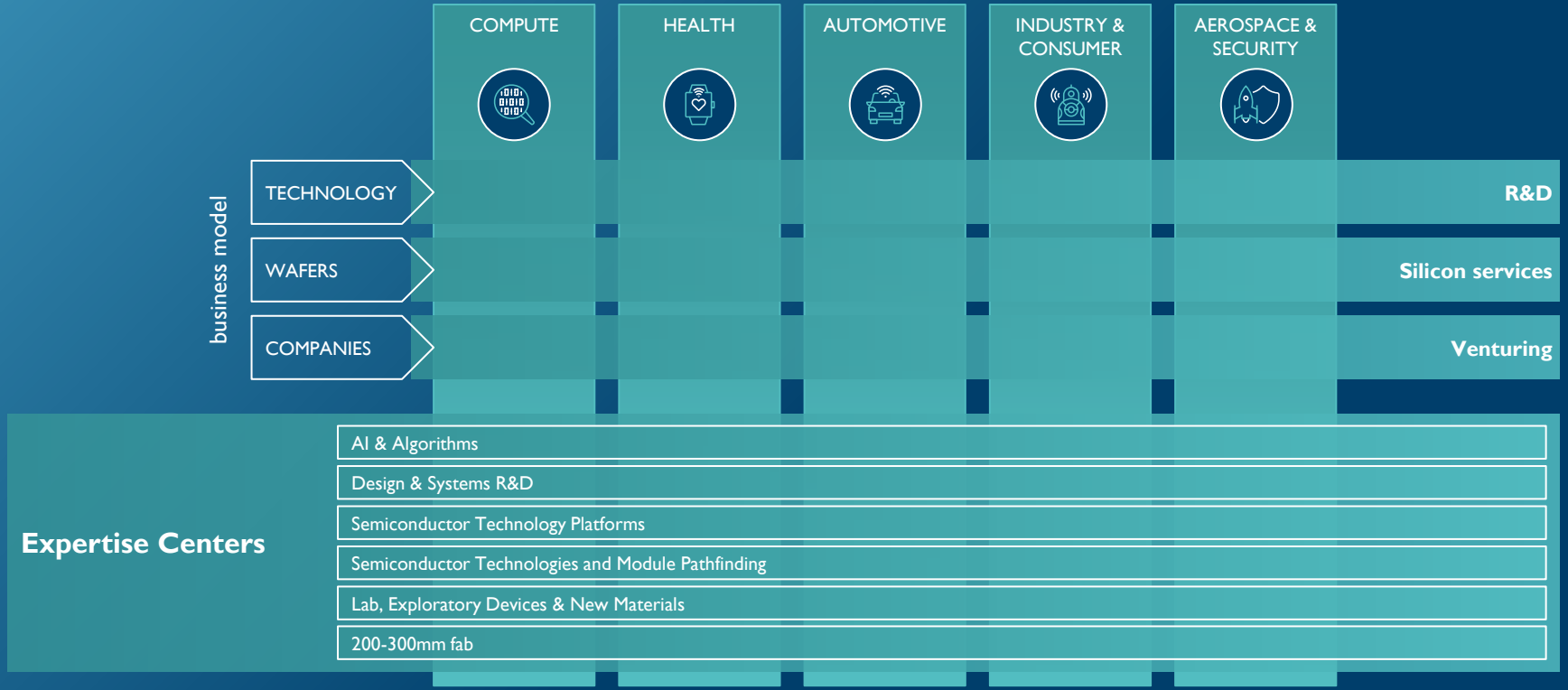


Liq Mem



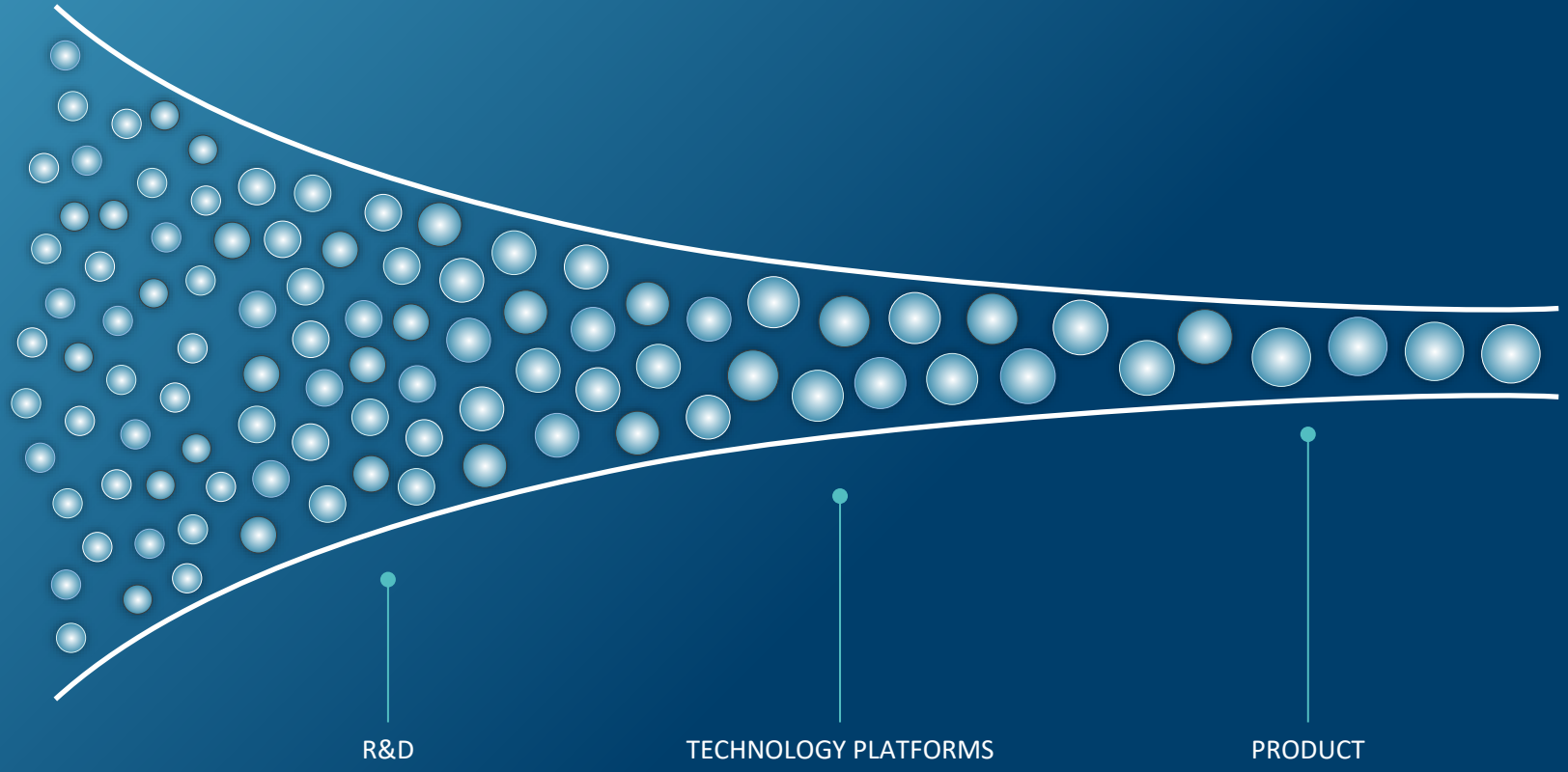
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How imec brings value to its partners



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From breakthrough to impact



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Fundamental process insight
on materials and interfaces
as innovation driver

Ge segregation causes roughness disparity / mitigation by passivation

Ge atoms segregating into the Si, during the initial stages of the Si layer growth, driven by more energetically favorable Ge-terminated surfaces

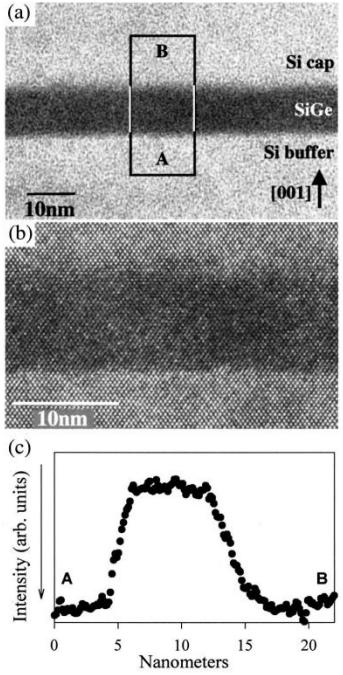


FIG. 1. (a), (b) 002 and high resolution [110] images of SiGe channel in Si matrix, and (c) inverted intensity profile across the region outlined in (a).

Norris J Appl Phys 86 7183 (1999)

- Ge atoms preferentially replacing Si atoms at the surface to minimize the surface free energy.
- DFT simulations further confirmed that Ge-terminated structures are energetically favored over Si-terminated structures by 0.38 eV per dimer.

- Mitigation: surface treatments with hydrogen (H) or chlorine (Cl)
- The higher bond dissociation energy of Si–H and Si–Cl than that of Ge–H and Ge–Cl results in more stable Si-terminated surfaces, limiting Ge segregation.

- SiGe-to-Si interface can be improved by passivation (Cl or H) – as also confirmed by XRR
- This passivation provides better starting surfaces and limits the Ge segregation
- Theoretical study on self-limiting process: Fukatsu Appl Phys Lett 59 3103 (1991)

Jung Appl Surf Sc 690 162553 (2025) and refs therein

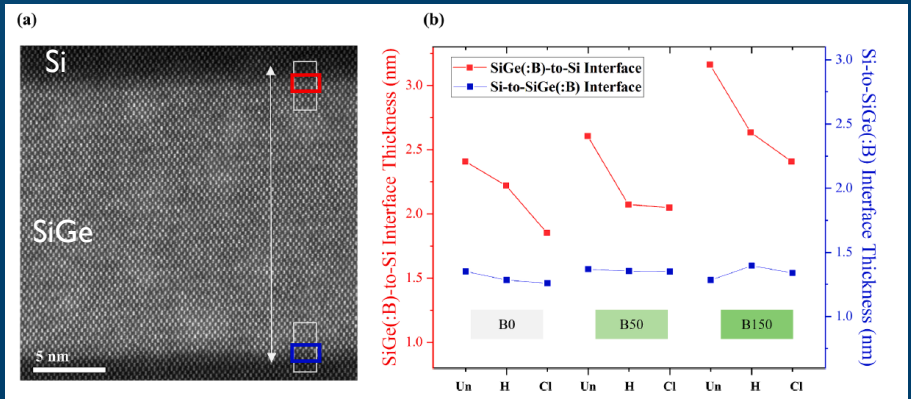
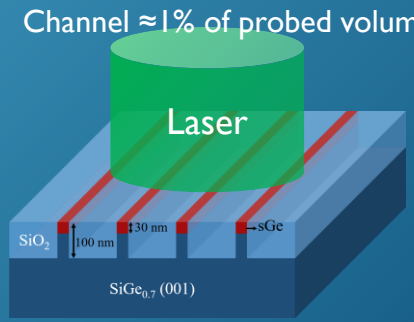
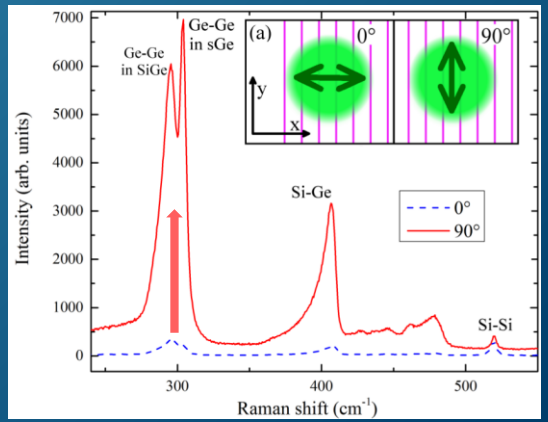


Fig. 7. (a) Cross-sectional STEM image highlighting the regions used for interface analysis. The blue box indicates the Si-to-SiGe(:B) interface, and the red box indicates the SiGe(:B)-to-Si interface. (b) Calculated Si-to-SiGe(:B) and SiGe(:B)-to-Si interface thicknesses, based on different surface treatments (untreated (Un), H-treated (H), and Cl-treated (Cl)) and B concentrations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Nanofocusing of light

Making deep sub-wavelength structures visible again



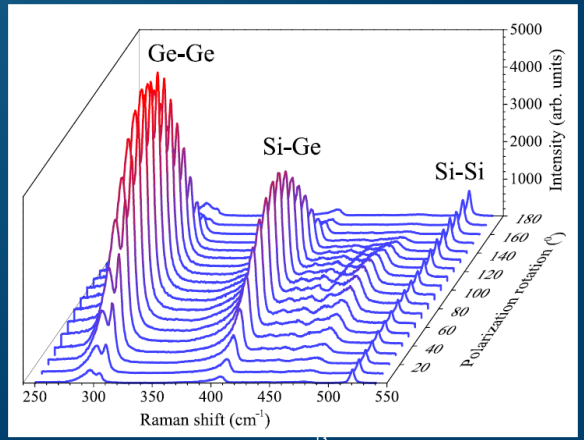


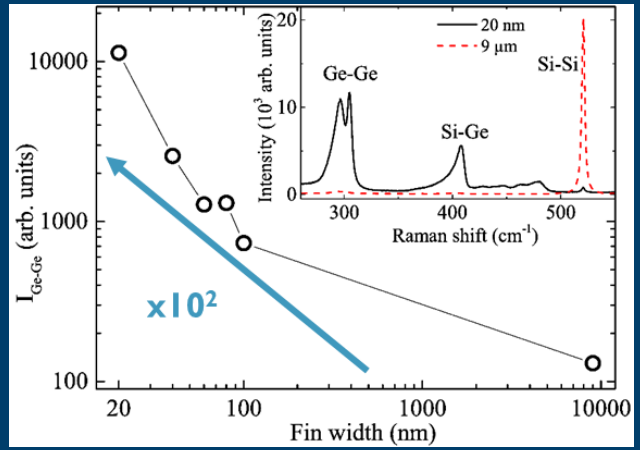


Configuration:

- Fully automatic 300mm stage with autofocus
- 325 405 473 532 633 nm laser excitation
- Motorized laser and Raman polarization kit
- Multipoints: coordinate-based wafer maps that can run without analyst supervision

- Raman response dictated by geometric properties: critical dimension, pitch
- Allows for isolation of the signal of the ROI
- All strengths of Raman are re-enabled at the nanometer scale
- Opens path for Raman dimensional metrology

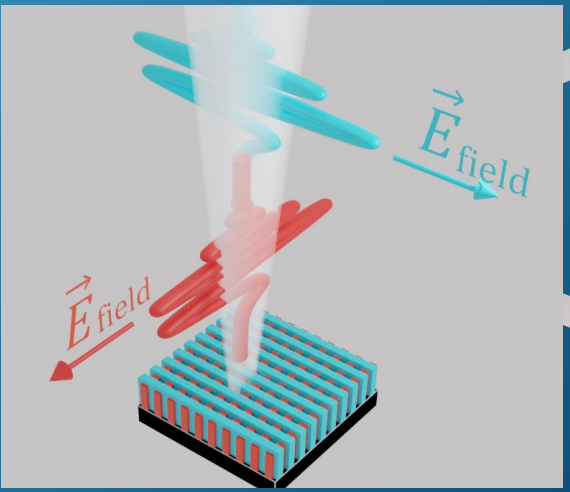


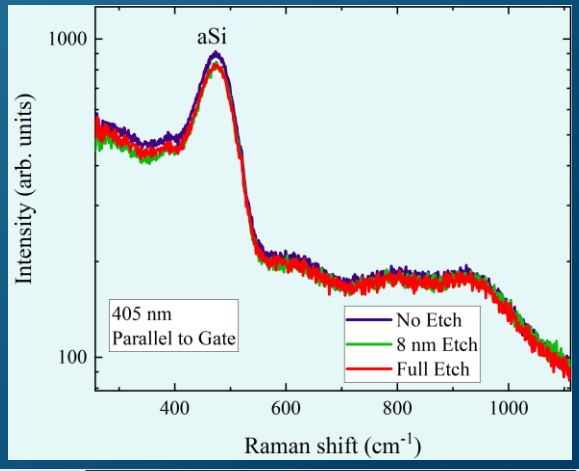


Kuhn FCMN 2013
Nuytten Appl. Phys. Lett. **106** 033107 (2015)
Bogdanowicz Appl. Phys. Lett. **108** 083106 (2016)
Gawlik Appl. Phys. Lett. **113** 063103 (2018)
Nuytten APL Mat. **6** 058501 (2018)
Nuytten Appl. Phys. Lett. 125 053506 (2024)
Nuytten US 12,216,057B2

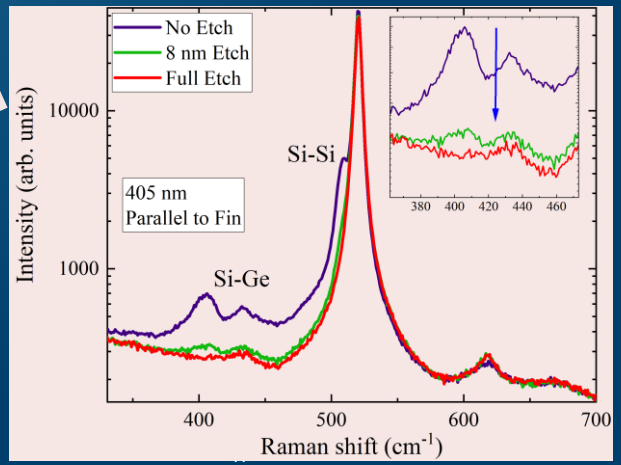
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Tunable selectivity for 3D volumes

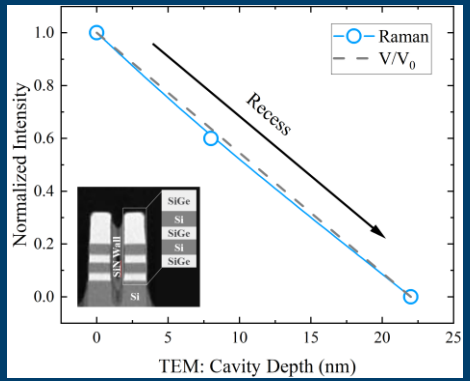




- All samples show identical aSi signature
- No SiGe visible at all



- Sensitivity to SiGe recess
- No aSi visible at all (!)

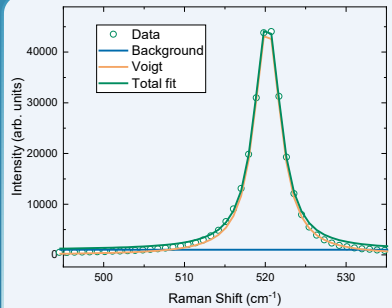


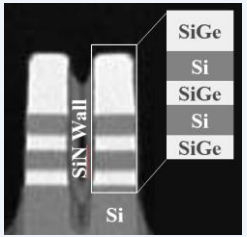
J. Bogdanowicz et al, Nanoletters 24, 1191 (2024)
Nuytten Appl. Phys. Lett. 125 053506 (2024)
Nuytten US 12,216,057B2

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Applications and opportunities
Universal across technology roadmaps

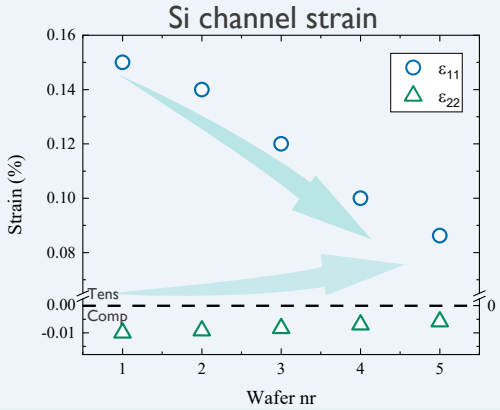
Channel Strain

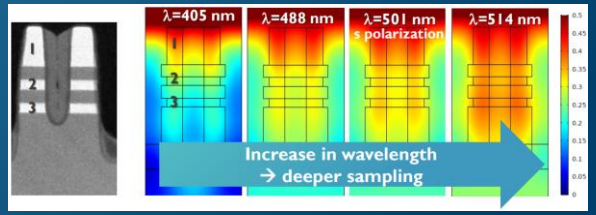




DOE on FS SiGe etch
- Fit cSi at 405 nm coming from channel
- Extract stress and strain

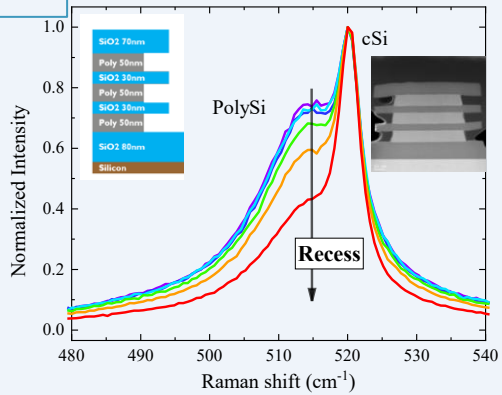
Relaxation:
- Tensile strain along
- Comp. strain across

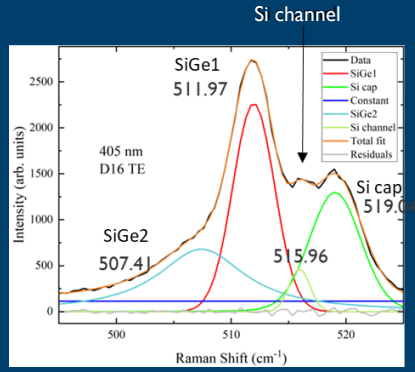




Memory stack CD

Universally applicable when signal can be isolated







Strain along channel (ε_{11})	+1.6%
Strain across channel (ε_{22})	-0.1%

Summary

- Continued semiconductor innovation will require deep process understanding
- Fundamental insight is critical for enabling breakthrough technology development
- Illustrations of this philosophy include the leverage of advanced metrology for insight into nanoscale interface phenomena

Acknowledgements





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