Summer school on Epitaxy
MATEPI 2025
Porquerolles June 22-27 2025

Round Table “from fundamental research to industry opportunities"

Nicolas Vaissiere (3-5 Lab) – Fabien Deprat (STMicro) – Clement Merckling (imec)

June 26th, 2025

Introduction

About myself

PhD (2011-2014)

- @CEA Saclay/ENS Cachan → Heteroepitaxy of diamond on iridium for X-ray detector

Post-doc (2014-2017)

- @Gemac Versailles/CNRS → p-type doping during diamond growth by MOCVD for transistors
- @LPCIM Palaiseau/Ecole Polytechnique → Silicon on III-V at low temperature by PECVD for solar cells

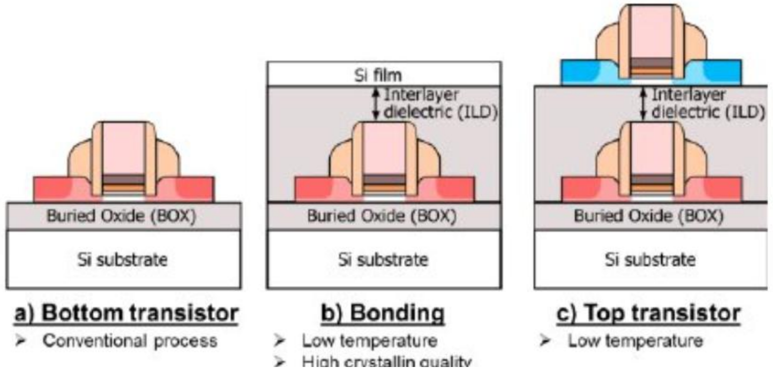
Since 2017

- @Nokia/III-V Lab → MOCVD epitaxy researcher
- Development of advanced III-V structures for telecoms (lasers, modulators, amplifiers…)

Personnal presentation

An unexpected journey

- Engineering school on Electronics, Programming and Physics
- PhD : CEA Leti on 3D sequential integration (monolithic 3D)
- Since 2017 : Epitaxy Process Development at STMicroelectronics, Crolles 300 mm Fab



Group IV epitaxy (Si, SiGe and As, P and B)

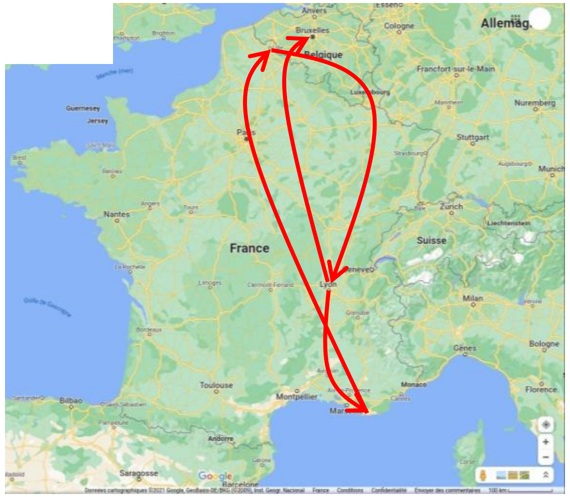
RP-CVD of ATMO-CVD
Temperature range : 550 °C to 1130 °C
RP-CVD : 5 Torr to 600 Torr

Team : 7 permanents, 3 PhD students and 2 Master2 students

Clement MERCKLING

Curriculum Vitae

- MSc's in Microelectronic – ISEN Toulon & Lille (1999 – 2004)
- MSc's in Materials Science – University of Lille (2003 – 2004)
- PhD in Materials Science – Ecole Centrale de Lyon (2004 – 2007)
- Postdoc (2007 – 2008)
  - *CNRS entrance exam (2008)*
- Researcher (2008 – 2011)
- Senior Researcher (2011 – 2013)
- Principal Member of Technical Staff (2013 – 2024)
  - *ERC Consolidator Grant (2019)*
- Scientific Director (from 2024)
- Part-time (10%) Associate Professor in Material Engineering (from 2021)



A PhD… why ?

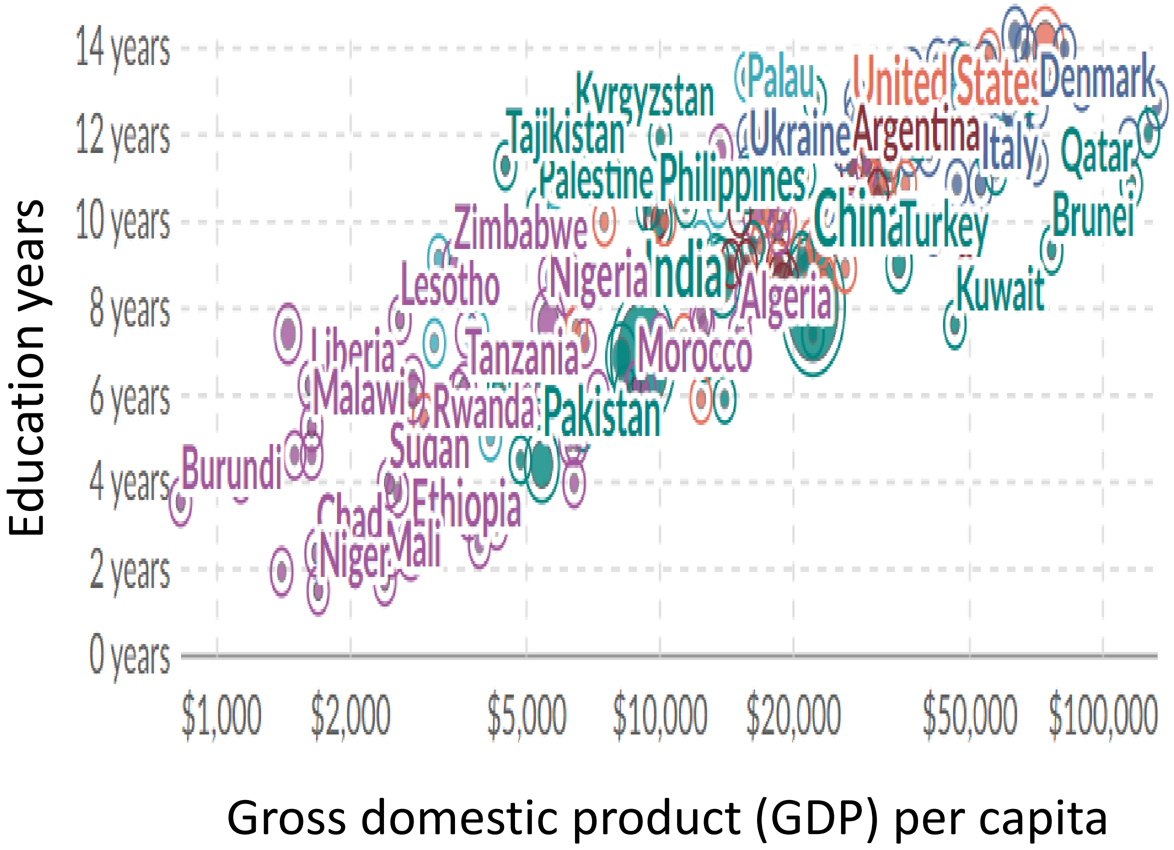
Doctor of Philosophy (PhD)

- A Doctor of Philosophy (PhD) is the highest academic degree awarded by universities in most countries

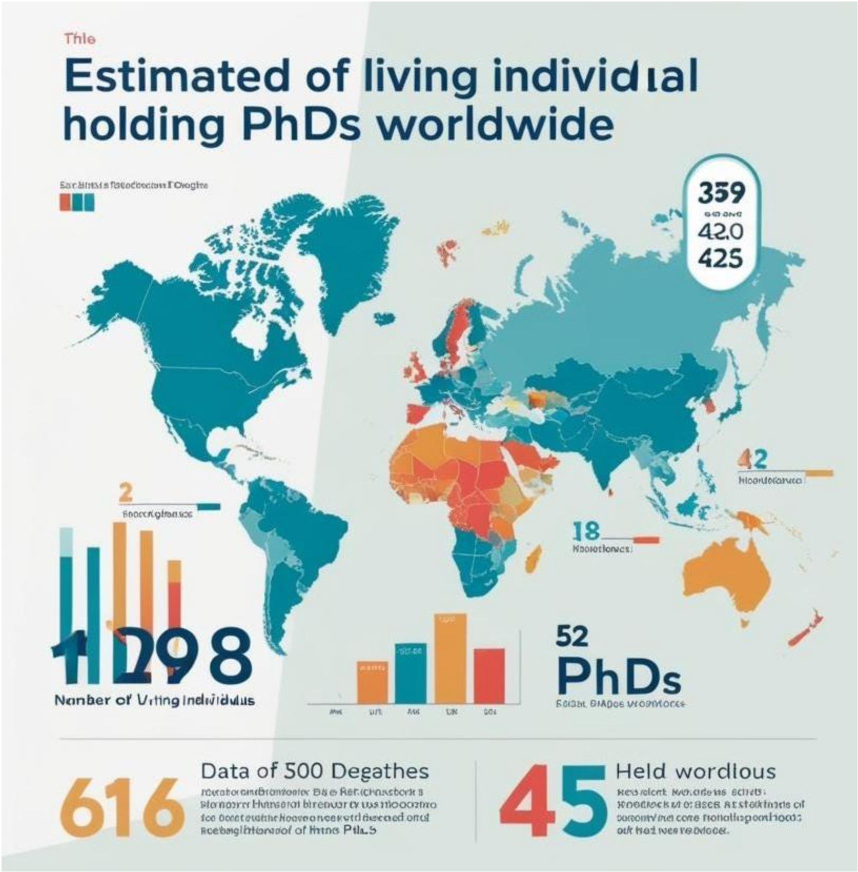
"The doctoral degree originated in the 9th century schools of the Muslim world in the professions of law, medicine and theology"

Education & innovation

- Education is key to economic



- Less than 2% of the population holds a PhD



Education & innovation

- Some of the greatest inventions and most novel ideas come from students, professors and researchers

Facebook's founder and CEO Mark Zuckerberg launched the site as a 19 year old sophomore at Harvard in 2004.

Google was founded in 1998 by Larry Page and Sergey Brin while Ph.D students at Stanford University, CA

“Innovation distinguishes between a leader and a follower.”

Steve Jobs


LIFE AFTER PH.D.
NEXT EXIT

The reality …

Plenty of opportunities…

R&D Center

Imec, LETI, Fraunhofer, …

Industry

IDM, Foundries, supplier,

Academia

Universities, CNRS, …

Plenty of opportunities…

R&D Center

Imec, LETI, Fraunhofer, …

Industry

IDM, Foundries, supplier,

Academia

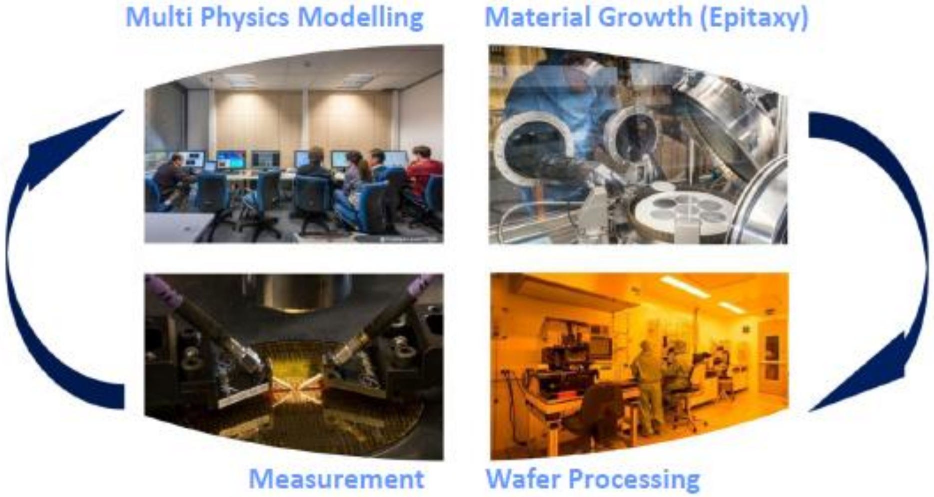
Universities, CNRS, …

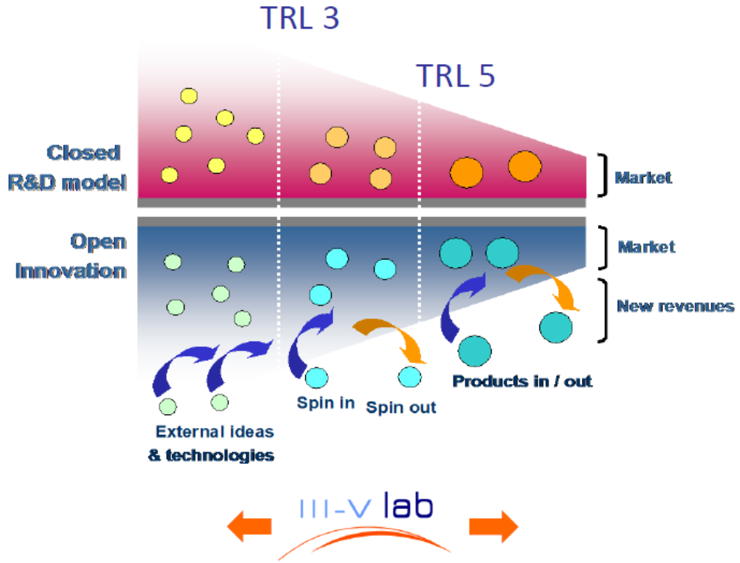
More concretely …

III-V Lab – Economic Interest Grouping

III-V lab
20 years in 2024

- **A private research lab between Thales, Nokia & CEA/Leti**
  - 120 research staff – 20 PhD students
  - 2000 m² of clean rooms (Epitaxy/Processing/Testing)





Hybrid RF GaN Circuit

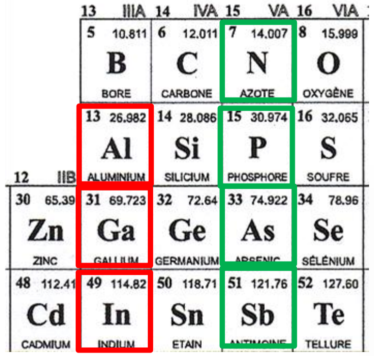
Laser diode for atomic clock

- **Sales & services**
  - R&D services
  - Technology transfer
  - Sale of devices and wafers
- **Spin-offs**

- **Applications:**
  - Nokia: Optical and wireless networks and communications technologies
  - Thales: Defence, security, space, aerospace and transportation
  - CEA/Leti: Exploitation for high volume applications

NOKIA cea leti THALES Building a future we can all trust

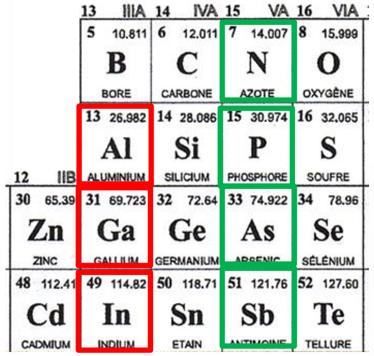
Our epitaxial platform



- **9 reactors – 2 technologies**
  - MBE – GSMBE from RIBER
  - MOCVD (horizontal & vertical) from AIXTRON

- **Capacities**
  - For R&D towards small scale production of III-N; III-As/P; III-Sb
  - Wafer capacity examples: 6x2’’, 7x3’’, 5x100mm; 150mm; 200mm

Our epitaxial platform



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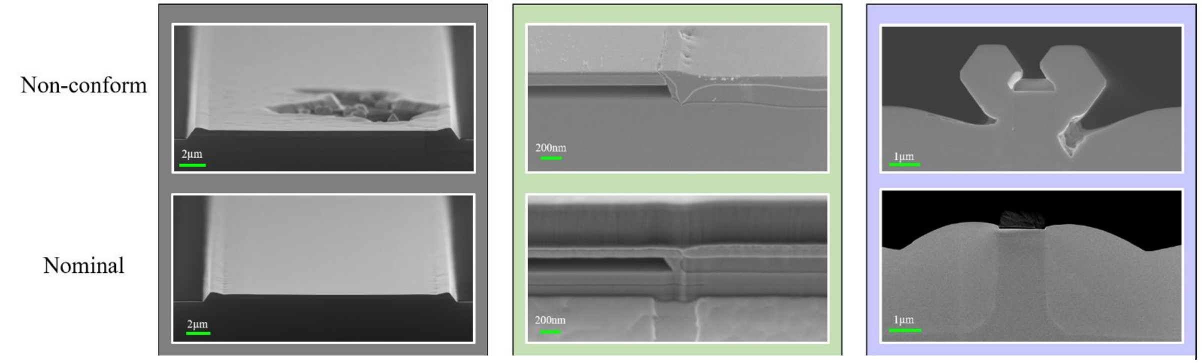


Selective area / Butt-Joint / Lateral

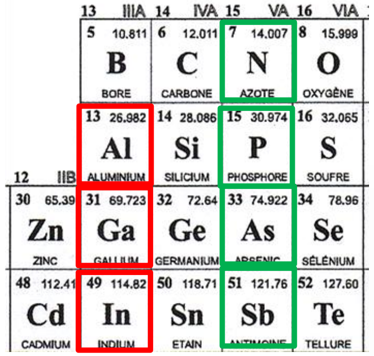
&

Regrowth on InPoSi

Need of in-situ characterization

Our epitaxial platform

III-V lab
20 years in 2024



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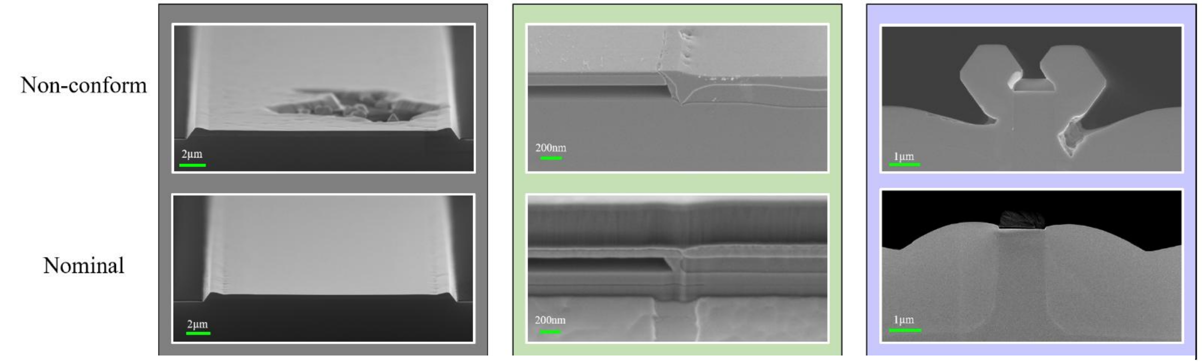

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Regrowth on InPoSi

Need of in-situ characterization

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III-V lab
20 years in 2024

Opportunities in epitaxy

Our national industrial ecosystem

III-P
Almae Technologies

III-As
LYNRED BY SOFRADIR & ULIS

3SP Technologies Source of Smart Solutions
III-As/P

MACOM
OMMIC innovating with III-V'S
III-N/As

ST
III-N

Optoelectronics/Photonics in Europe

IQE
III-V Epi
United Kingdom

Fraunhofer HHI
Germany
INNOLUME

SPARC
Spain

SMART PHOTONICS
Netherland

Suppliers (press release/social media)

RIBER
France

AIXTRON
Germany

Order for a Compact 21 research platform in France
Posted on Thursday, June 27, 2024 - 08:00 am

06/27/2024	PDF Order for a Compact 21 research platform in France

New order for a MBE 49 GaN production machine in Asia
Posted on Tuesday, June 25, 2024 - 08:00 am

06/25/2024	PDF New order for a MBE 49 GaN production machine in Asia

Major order in Asia for a RIBER MBE 49 production system
Posted on Monday, June 24, 2024 - 08:00 am

06/24/2024	PDF Major order in Asia for a RIBER MBE 49 production system

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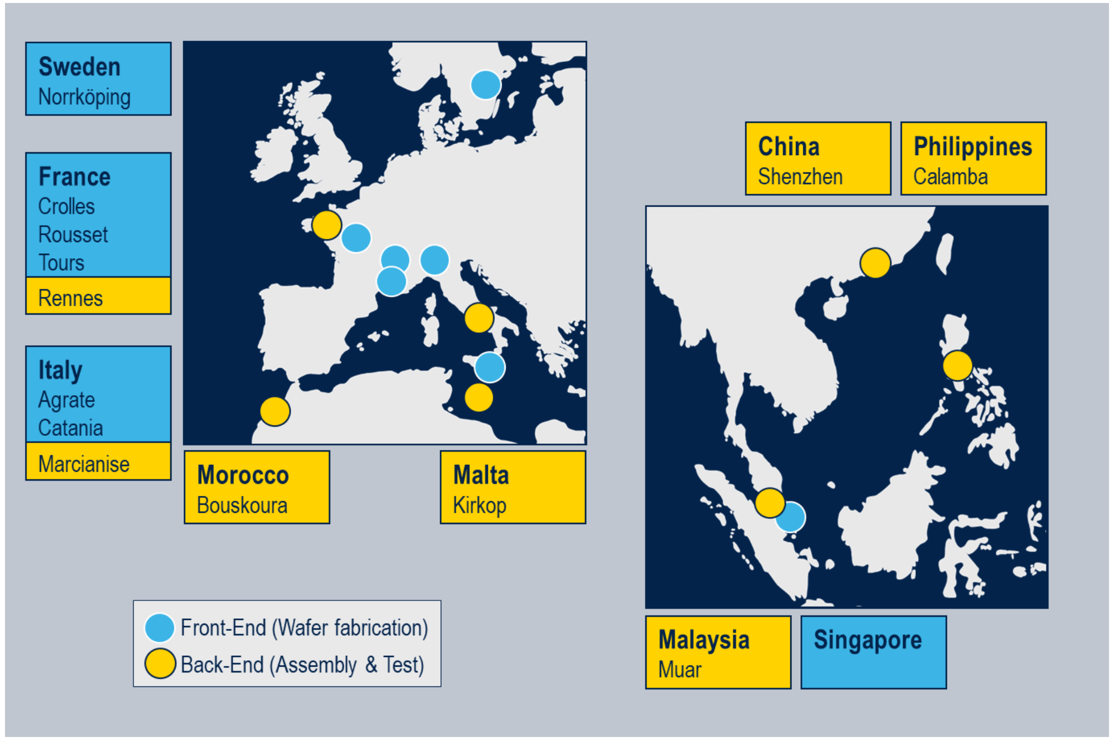
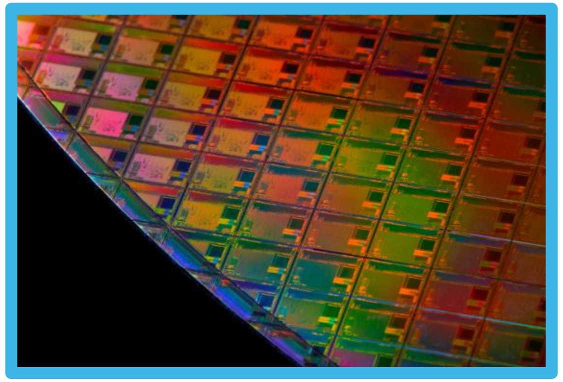
cea leti
THALES Building a future we can all trust

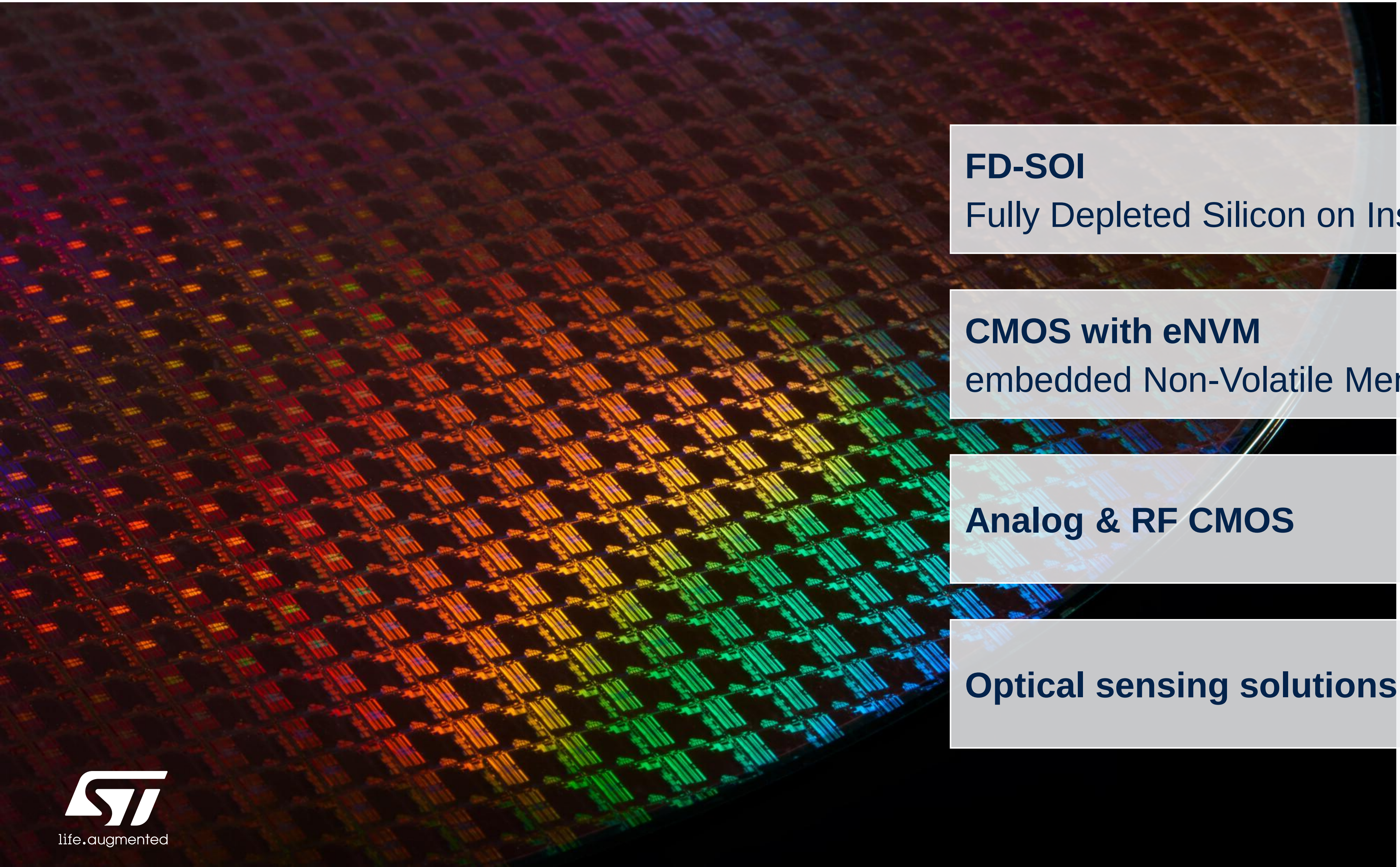
STMicroelectronics - Short presentation

- STMicroelectronics is an Integrated Device Manufacturer
  - Design, manufacture and sell integrated circuits





The key technologies developed at ST’s Crolles site



FD-SOI
Fully Depleted Silicon on Insulator

CMOS with eNVM
embedded Non-Volatile Memory CMOS

Analog & RF CMOS

Optical sensing solutions

life.augmented

Where we find chips made in Crolles

In industry

- Robots
- Automation
- Asset tracking
- Metering
- Professional tools
- Agriculture

In homes

- Smart lights
- Heat pumps
- Automation
- Solar panels
- Home appliances
- Metering

In cities

- Environmental sensors
- Smart building & security
- Transportation infrastructure and electric vehicles
- Smart lights
- Smart grid
- Structural health monitoring

In cars

- Battery management
- Suspension, traction and transmission
- ADAS
- Telematics, audio and navigation
- Drowsiness detection
- Control units for airbags, windows, mirrors and seats

Where we find chips made in Crolles

In smartphones

- Cameras
- Displays
- Face recognition and security
- Wireless connectivity
- User interface and sensors
- Energy management & chargers
- Headphones

In computers

- Cameras and user interfaces
- Secure processing
- Sensors
- Signal conditioning and USB
- Power management
- Chargers

In healthcare

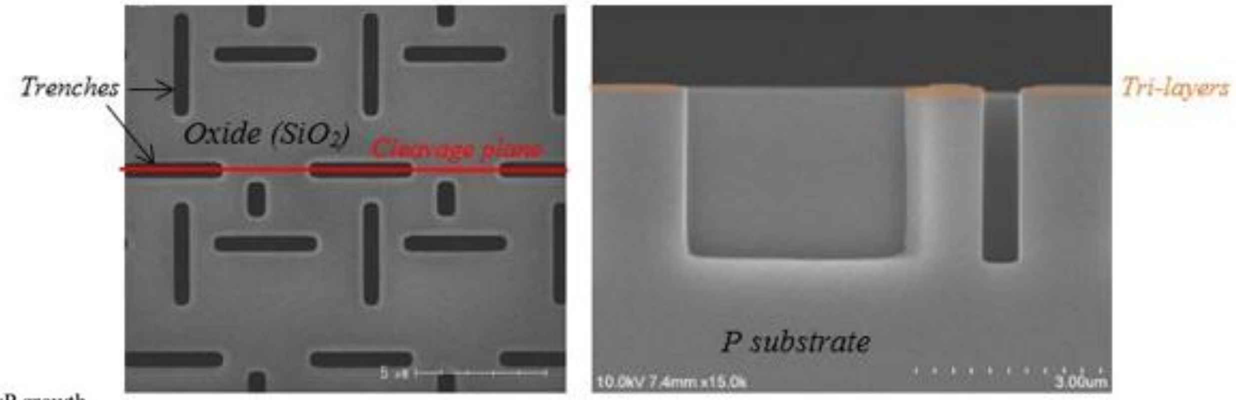
- Medical imaging
- ECG
- Ultrasound
- Biometric analysis
- Teleassistance
- Prosthesis
- Insulin pumps & glucometers

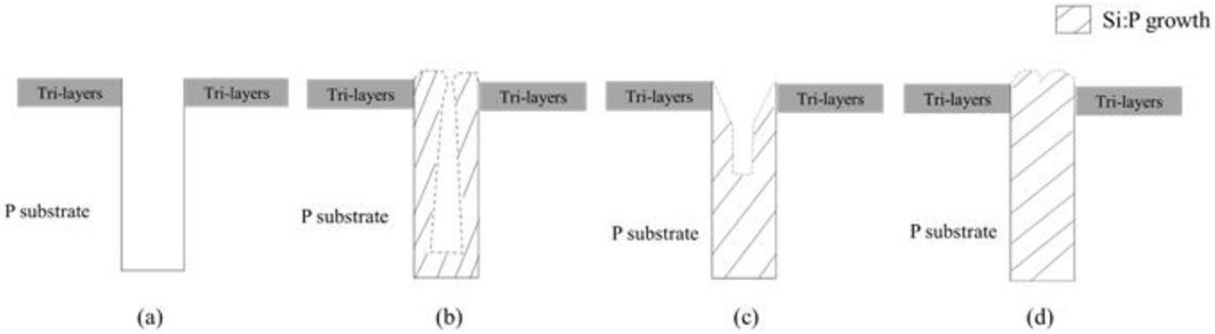
In space

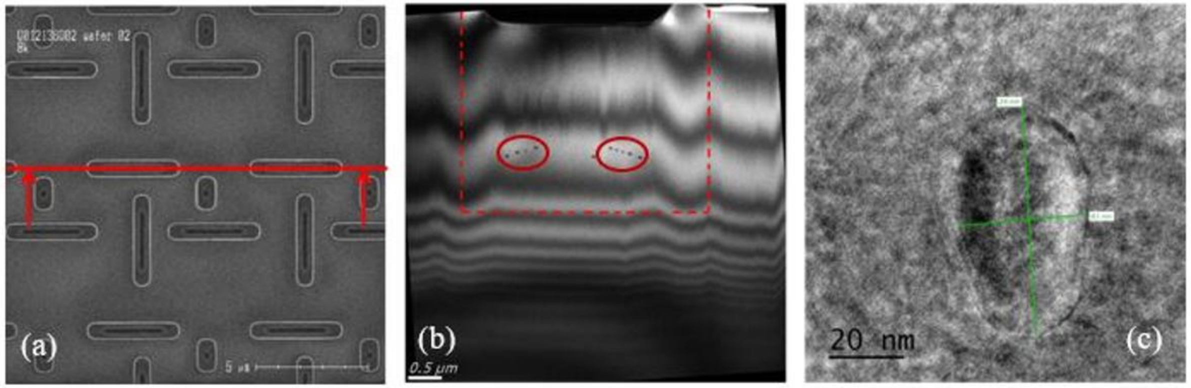
- Satellites
- Probes
- Instruments

Previous PhD

- Fill deep trench with Si:P epitaxy

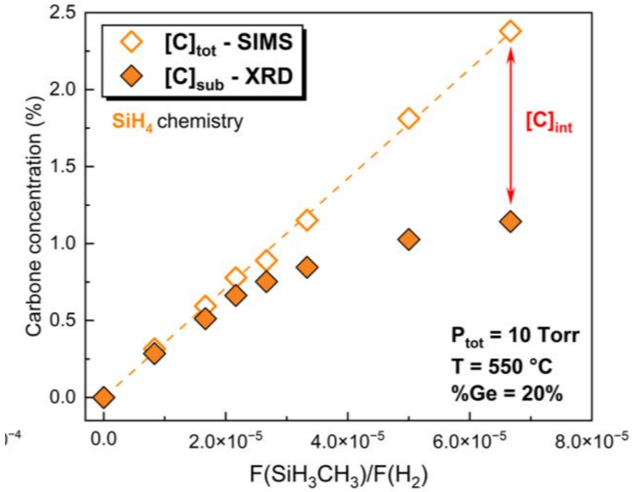


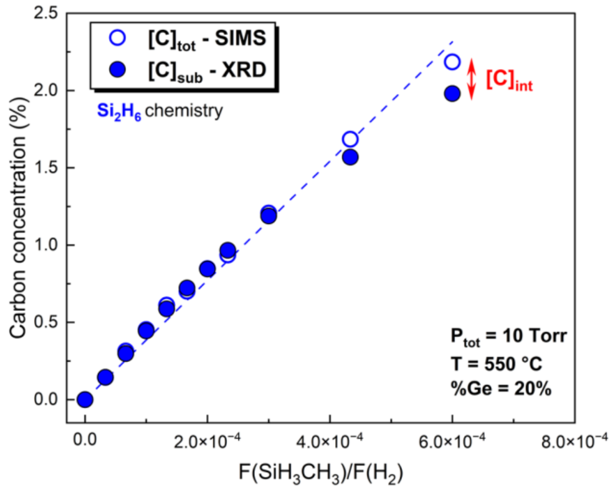


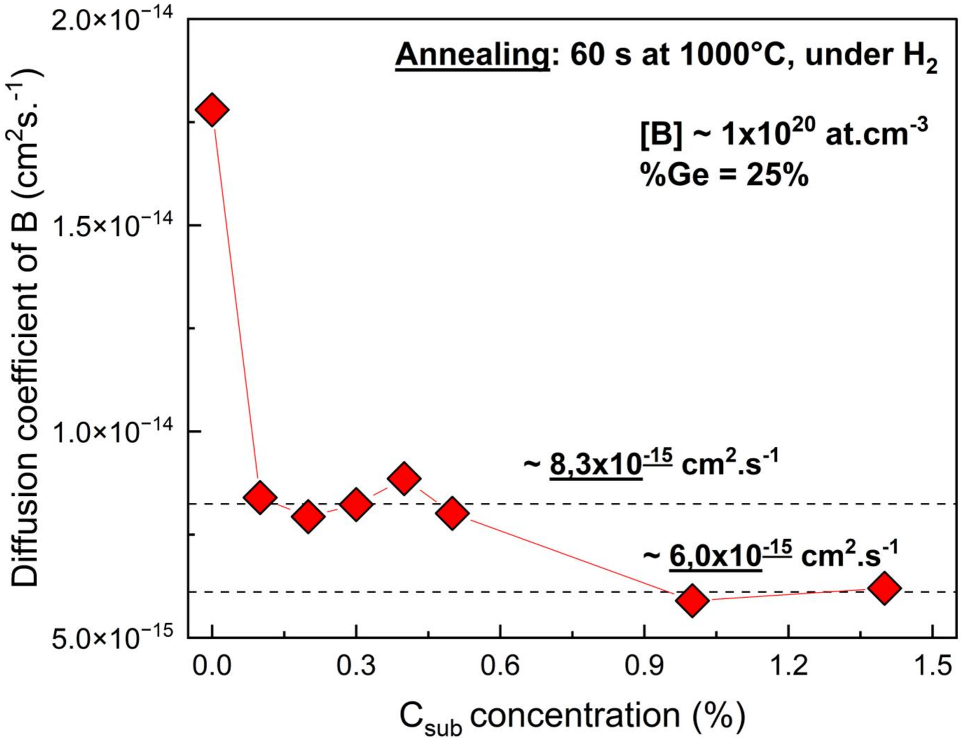


Previous PhD

- HBT : Reduce boron diffusion by addition of C into SiGe





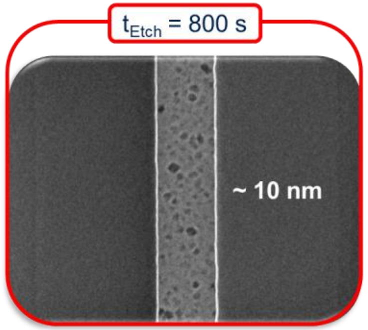


The addition of carbon reduces the diffusion coefficient by ~3

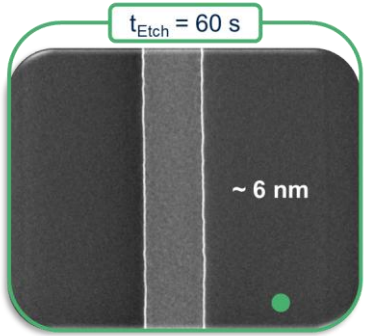
PhD in progress

- Heterojunction Bipolar Transistors :
  - Integration of high carbon concentration SiGeC thin film on patterned wafers - SIMAP

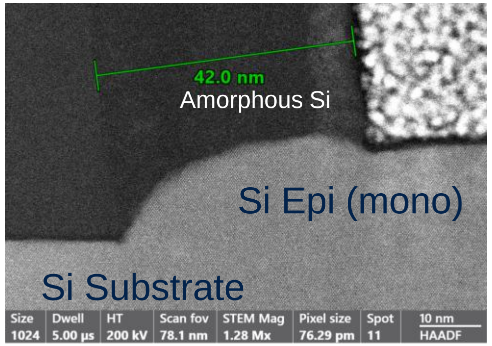
Cyclic deposition etch



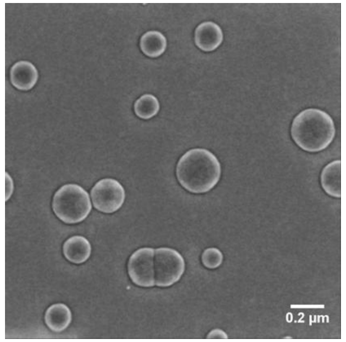
Deposition etch



  - Development of non selective SiC:B epitaxy – IM2NP
- Low temperature epitaxy (< 600 °C)
  - Interface between amorphous and monocrystalline Si – IM2NP



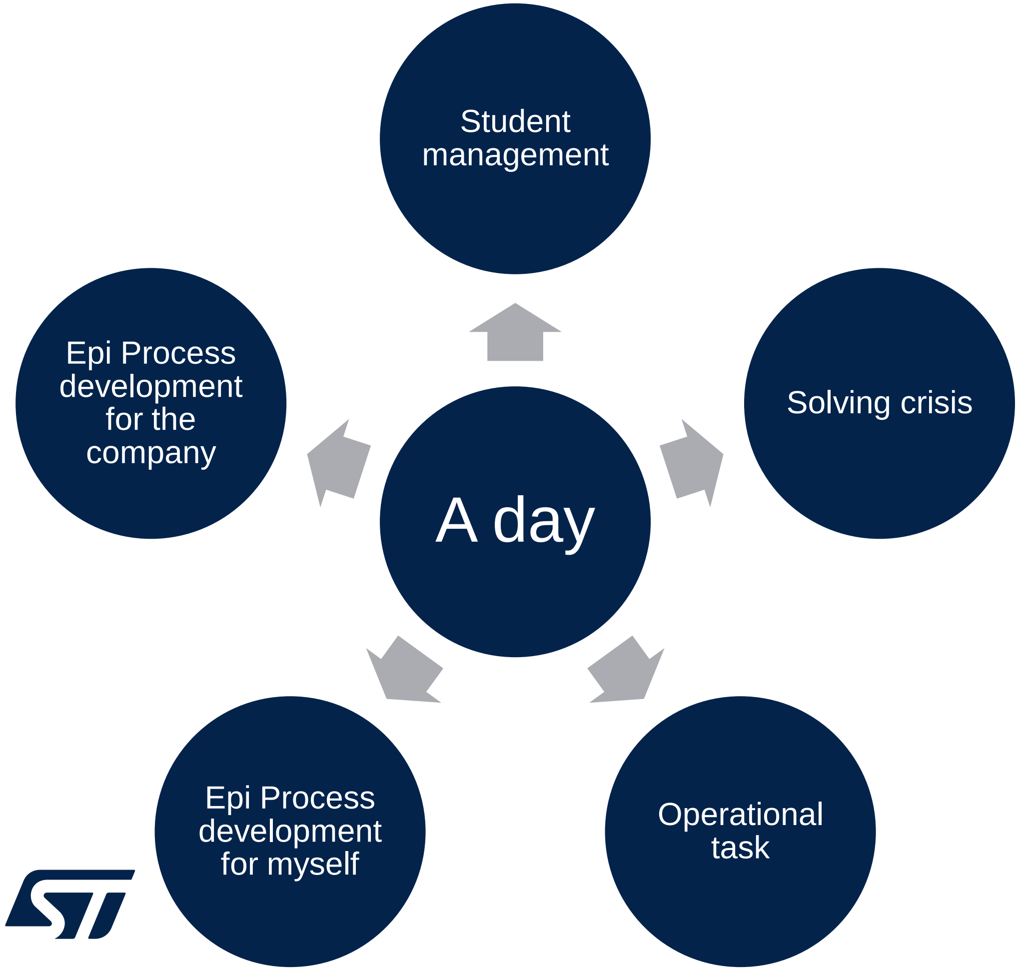
Top view SEM



Si epi at 550 °C with Si2H6

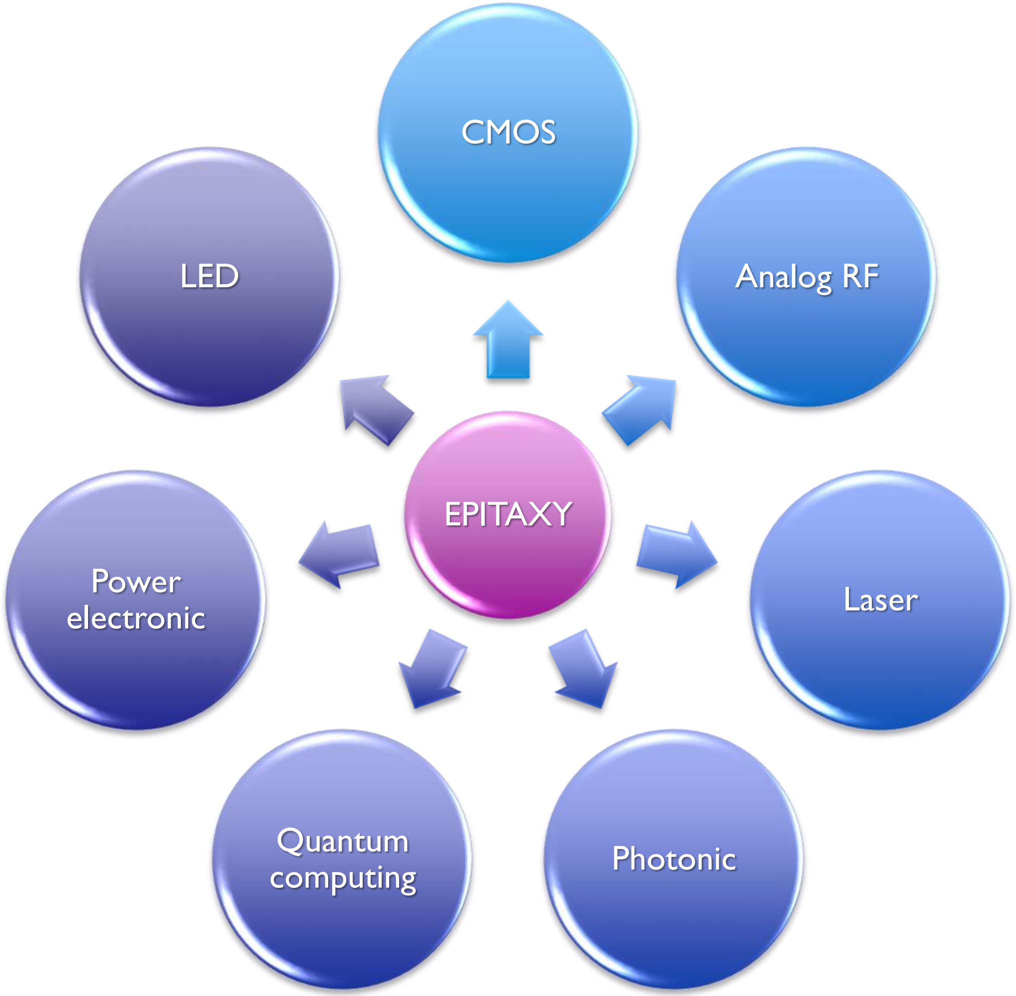
A day in the office, as it usually goes

Full of unexpected events: be prepared for anything



- Operational task → process the Si substrate for other people or teams
- Solving Crisis → meet the project deadline
- Student management
- Epitaxy process for the company : ensure project progress
- Epitaxy for myself : Advance development without associated project

Epitaxy @ center of novel technologies

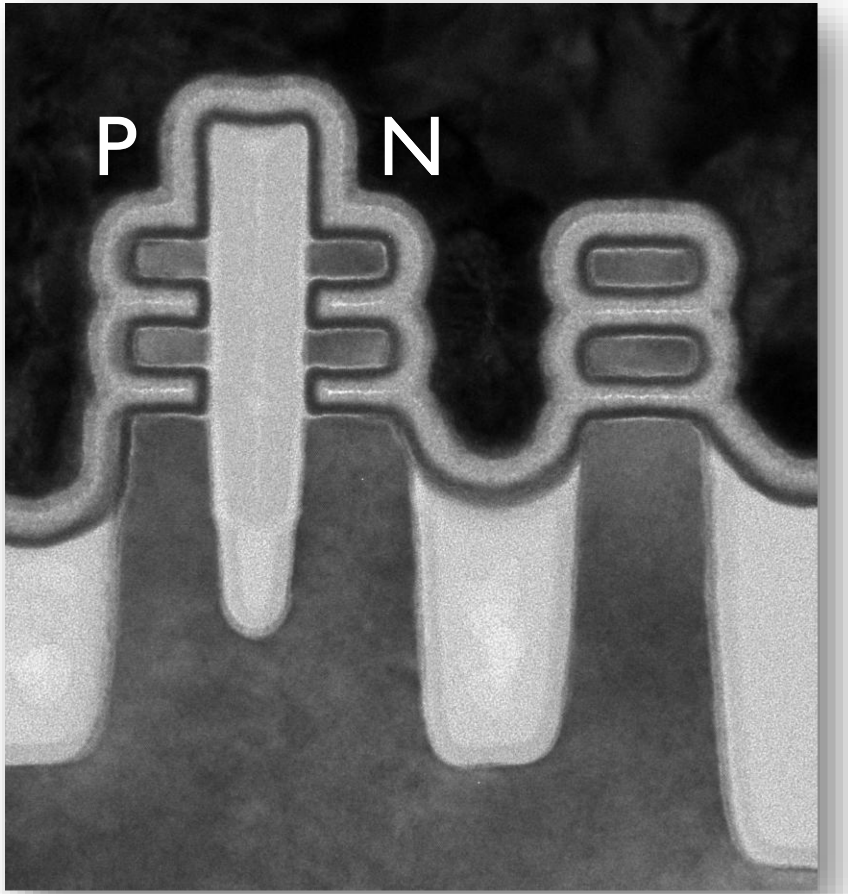


Advanced CMOS

SiGe

- The forksheet device has recently been proposed as the most promising device architecture to **extend the GAA nanosheet** device generation with additional scaling and performance beyond 2nm technology node.
- Unlike nanosheet devices, the sheets are now controlled by a **tri-gate forked structure** – realized by introducing a *dielectric wall* in between the p- and nMOS devices before gate patterning. This wall physically isolates the p-gate trench from the n-gate trench, allowing a much **tighter n-to-p spacing** than what is possible with either FinFET or nanosheet devices.

Forksheet GAA nanosheet

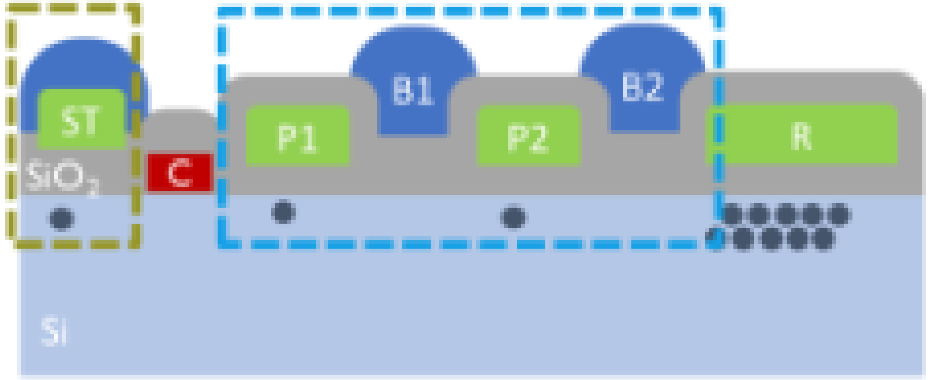


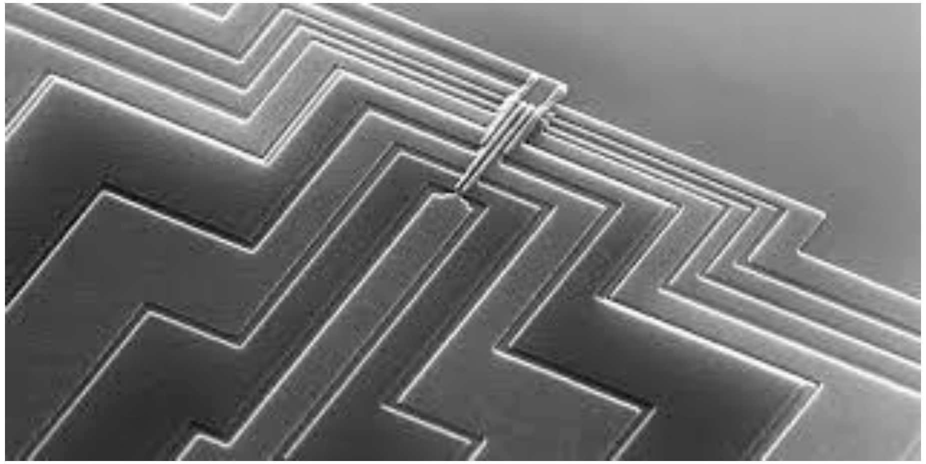
https://www.imec-int.com/en/press/imec-reports-first-electrical-demonstration-integrated-forksheet-devices-extend-nanosheets

Quantum technologies

Si, SiGe, Ge QD spin qubits

- The long-term vision for quantum computing is the ability to leverage millions of noise-free qubits to address selected problems that are hard to solve with classical computers.
- Application fields that may benefit from this technology include materials synthesis, pharmaceutical drug development, and cybersecurity, to name a few. Various quantum computing platforms with diverse types of qubits are under investigation, and worldwide efforts are ongoing to scale up from hundreds to millions of qubits.
- Having different levels of maturity, each platform has its own needs for scaling up. Common challenges include well-controlled qubit integration in large-size wafer facilities and the need for electronics to interface with the growing number of qubits.



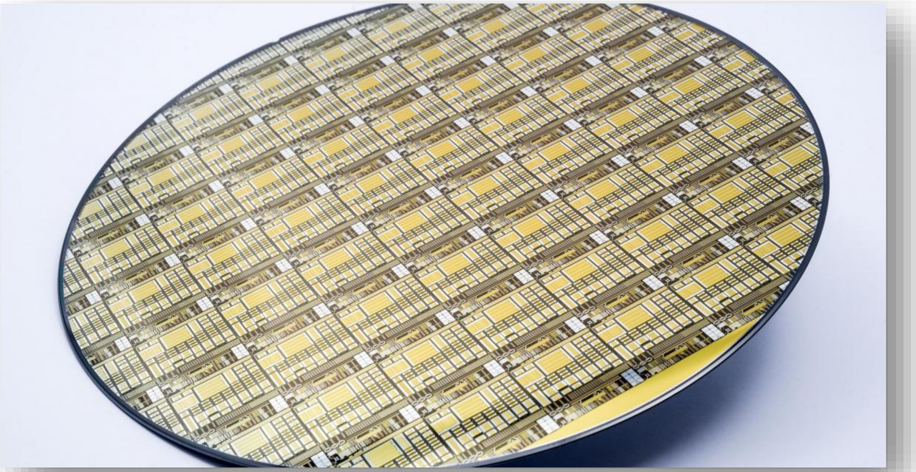


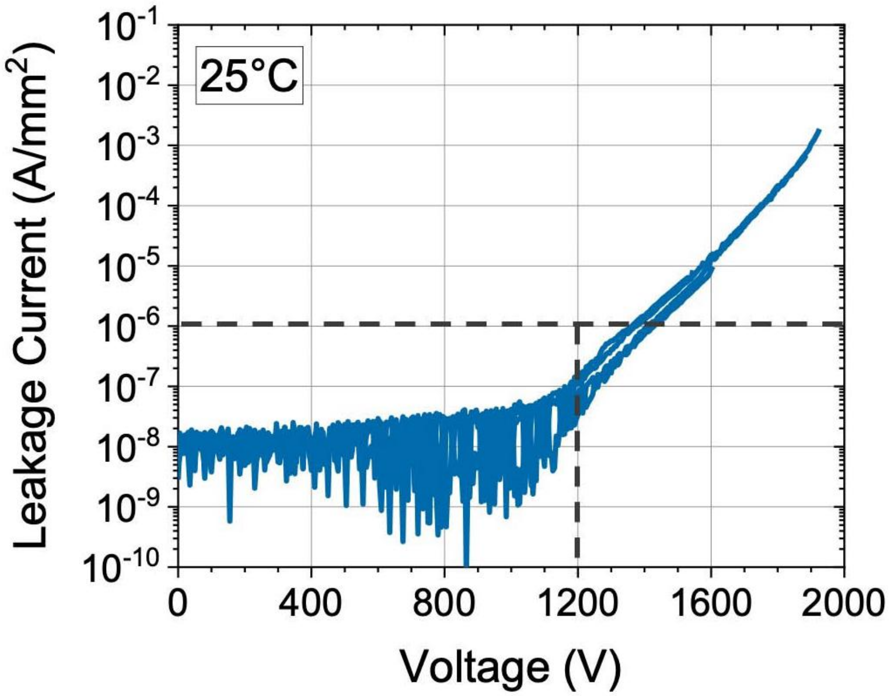
https://www.imec-int.com/en/articles/progress-upscaling-si-spin-and-superconducting-based-quantum-technologies

Power electronic

GaN

- Wide-bandgap materials gallium-nitride (GaN) and silicon-carbide (SiC) have proved their value as next-generation semiconductors for **power-demanding applications**.
- SiC-based technology is the most mature, but it is also more **expensive**. Over the years tremendous progress has been made with GaN-based technology grown on for example 200mm Si wafers.
- However, achieving operating voltages higher than 650V has been challenged by the difficulty of **growing thick-enough GaN buffer** layers on 200mm wafers.
- The manufacturability of 1200V-qualified buffer layers opens doors to highest voltage GaN-based power applications such as electric cars, previously only feasible with silicon-carbide (SiC)-based technology.



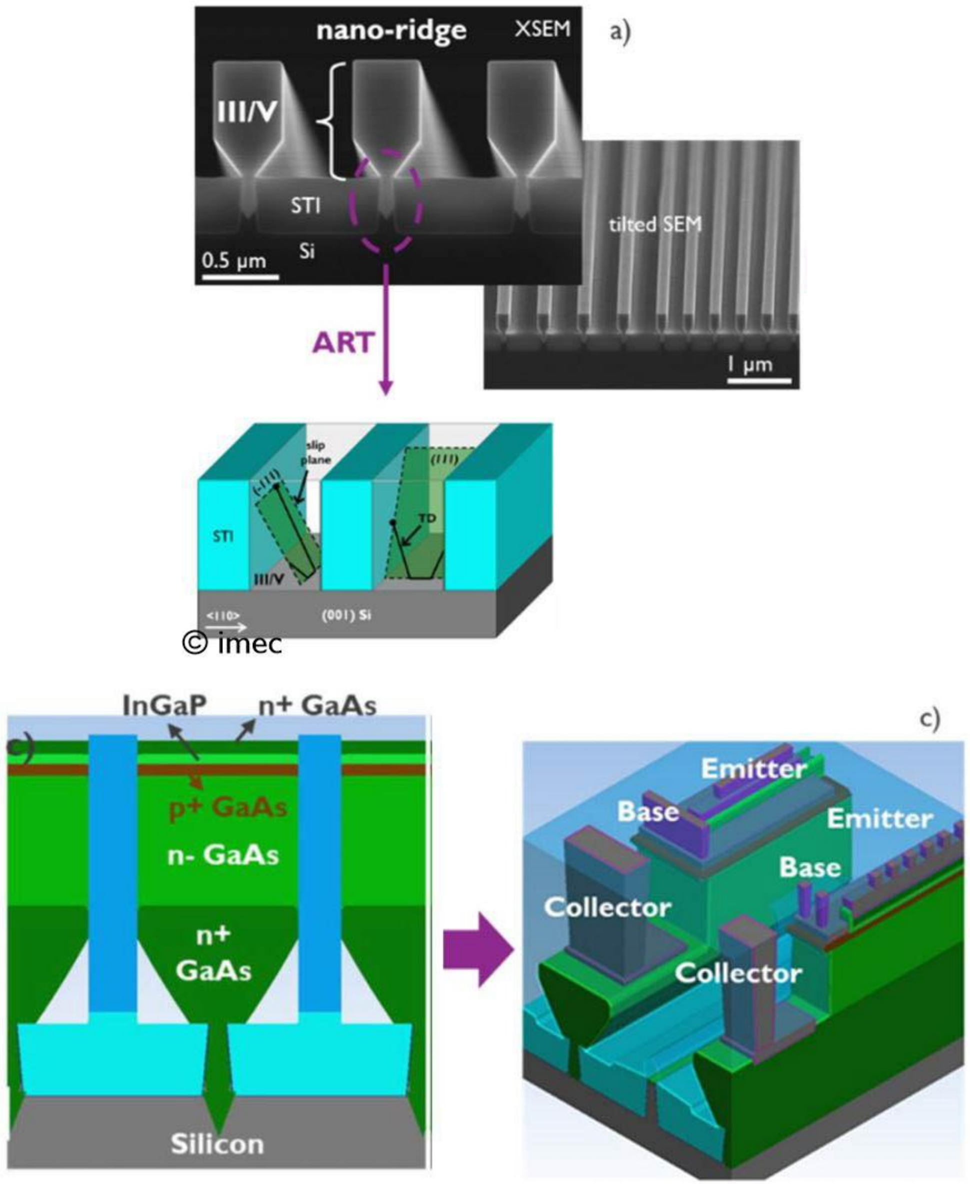


https://www.imec-int.com/en/press/imec-and-aixtron-demonstrate-200-mm-gan-epitaxy-aix-g5-c-1200v-applications-breakdown-excess

Beyond 5G RF Front-End Modules

III-V's

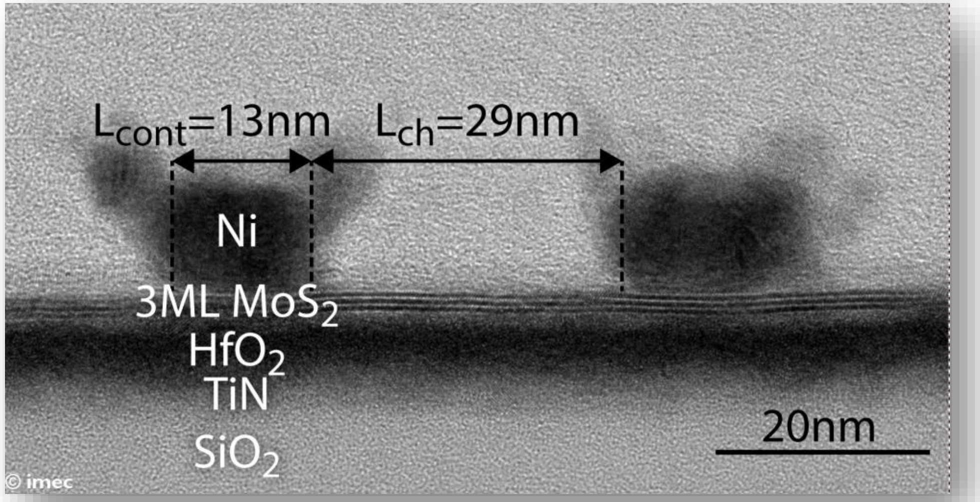
- To enable the next-generation **RF front-end modules** beyond 5G, imec explores CMOS-compatible III-V-on-Si technology
- Functional GaAs/InGaP HBT devices grown on 300mm Si have been demonstrated as a first step towards the enablement of InP-based devices.
- A low defect density device stack with below $3x10^6$ cm^{-2} threading dislocation density was obtained by using **III-V nano-ridge engineering** (NRE) process.
- The devices perform considerably better than reference devices, with GaAs fabricated on Si substrates with strain relaxed buffer (SRB) layers.



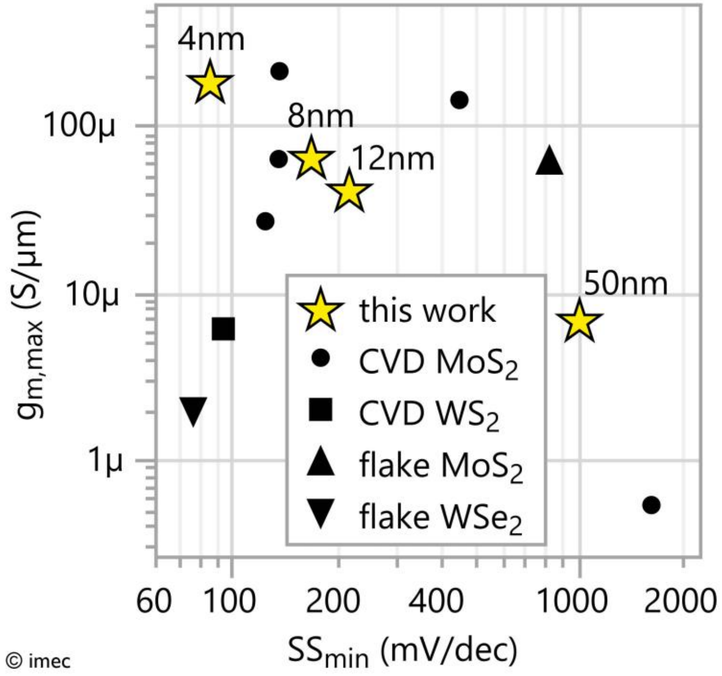
https://www.imec-int.com/en/articles/imec-demonstrates-scalable-iii-v-and-iii-n-devices-on-si-targeting-beyond-5g-rf-front-end-modules

Beyond CMOS

2D materials



- MoS_2 is a 2D material, meaning that it can be grown in stable form with nearly **atomic thickness** and atomic precision.
- Imec synthesized the material down to monolayer (0.6nm thickness) and fabricated devices with **scaled contact** and **channel length**, as small as 13nm and 30nm respectively.
- These very scaled dimensions, combined with **scaled high-k oxide gate thickness**, have enabled the demonstration of some of the best device performances so far.

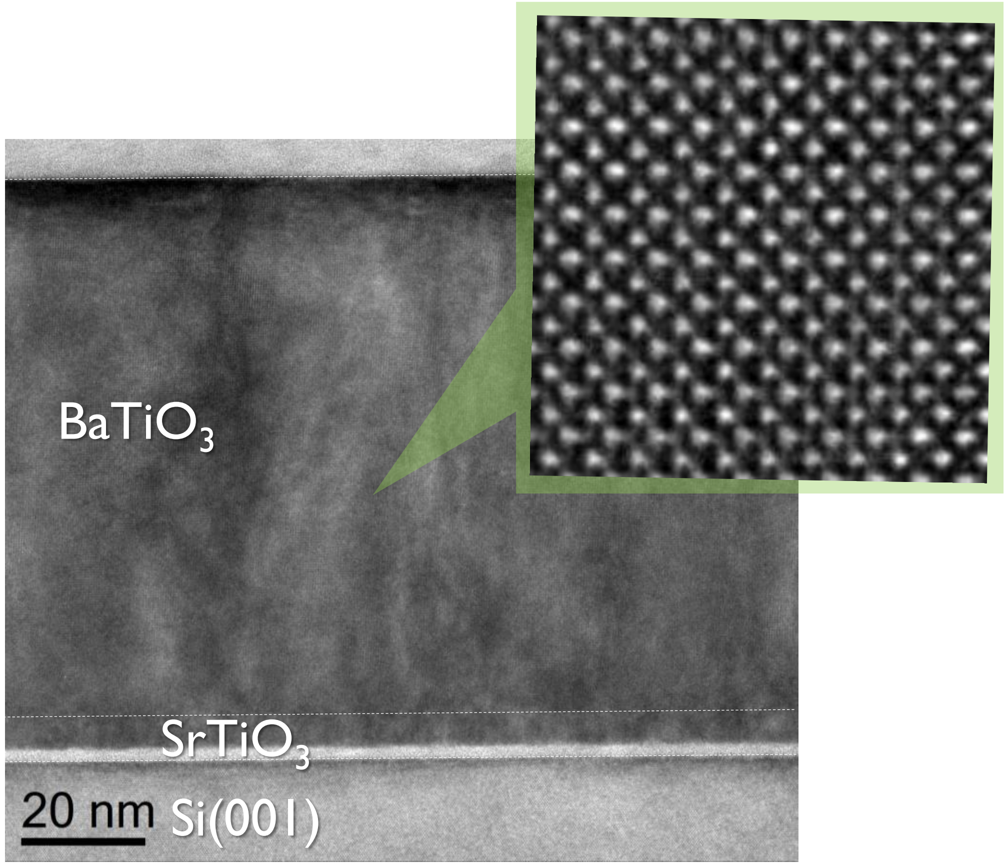


https://www.imec-int.com/en/articles/imec-shows-excellent-performance-in-ultra-scaled-fets-with-2d-material-channel

imec KU LEUVEN erc

Photonic & quantum

- Metal-oxides open new and unique functionalities
- Complex (perovskite) heterostructure with coherent interfaces for exploratory devices (logic, memory, quantum, photonic …)



Thank you, more questions ???