FUTURE CMOS & BEYOND-CMOS METROLOGY NEEDS

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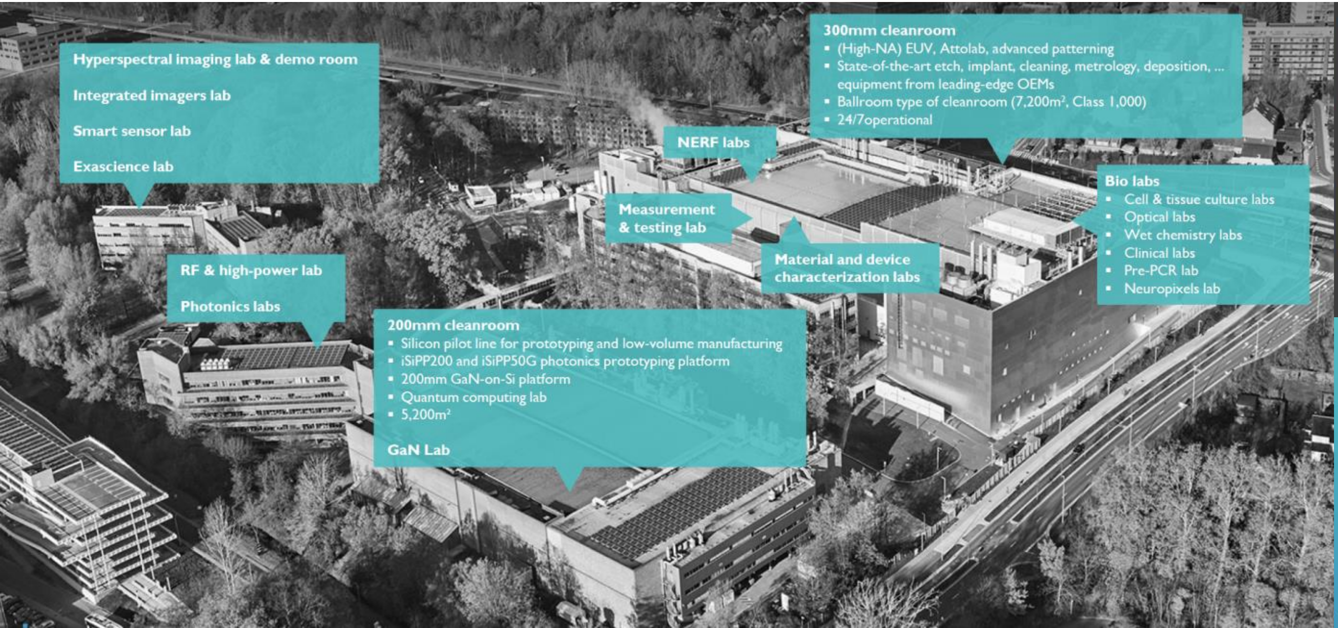
IMEC (INTER-UNIVERSITY MICRO-ELECTRONICS CONSORTIUM)

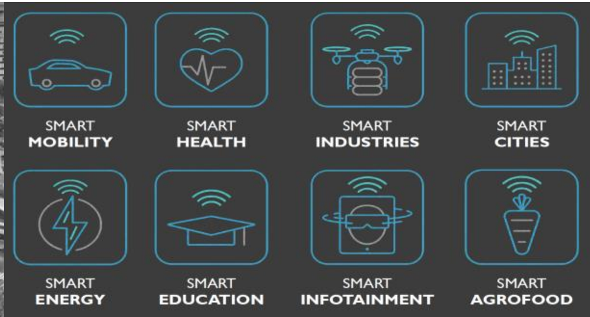
- Imec is a nanotechnology R&D organization (an RTO)
- Imec is centred in Leuven, Belgium.

WORLD-CLASS INFRASTRUCTURE
> 12,000 M² CLEANROOM
CAPACITY

MORE THAN
4,500 SKILLED PEOPLE
FROM OVER 95 NATIONALITIES

A
TRUSTED PARTNER
FOR COMPANIES, STARTUPS & ACADEMIA





IMEC FORECASTS

- CMOS scaling for memory, logic & interconnect
  - New architectures
  - New materials

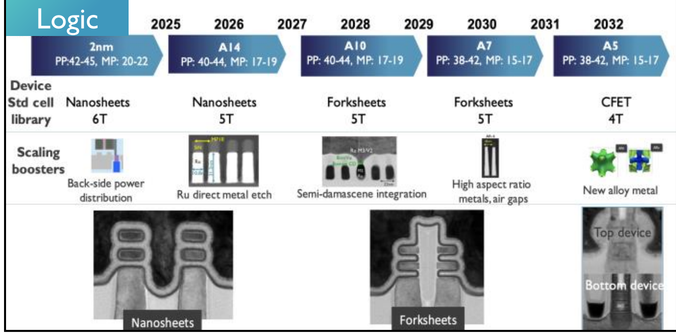
More complex analysis needed faster

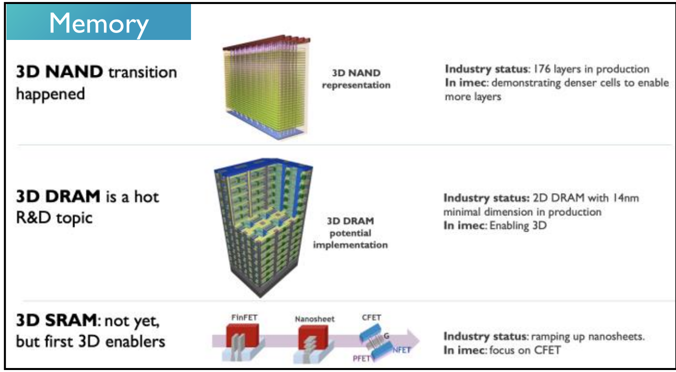
- Beyond CMOS for memory, logic & interconnect
  - 2D materials
    - Graphene
    - TMDs
    - TIs

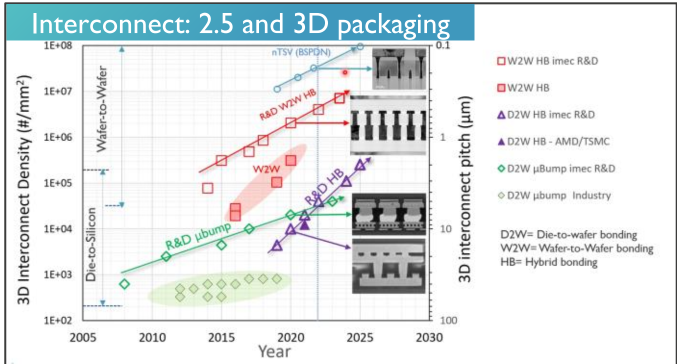
New measurement requirements (mobility, spin, spin dynamics, …)

- Beyond von Neuman (quantum compute)
  - Josephson junction?
  - TI based, … ?

Required metrologies to be defined







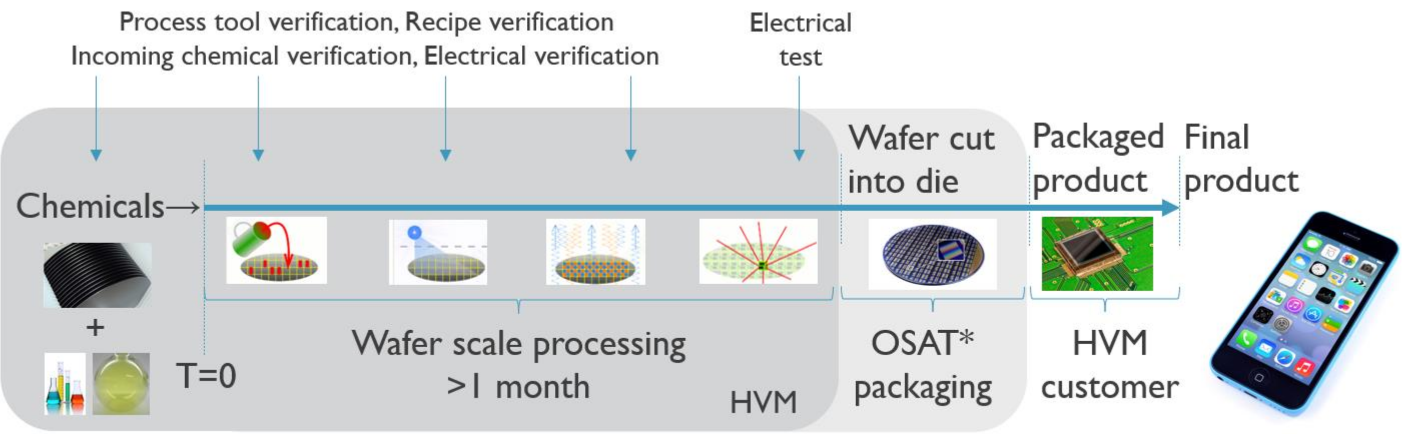
imec

IC DEVICE MANUFACTURING 101

*Metrology/materials characterization provides an eye on the process and allows for R&D

If you can't see it, you can't control it (process control)

If you can't see it, you can't improve it (R&D)



- Requirement 1: Extreme control of input materials and process recipes/process tools

  Precision is paramount → Best insight into process variations

- Requirement 2: Identify process steps/recipes/tools that have greatest impact on yields

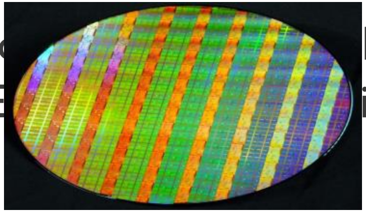
  Analysis is costly → Only do analysis where needed, i.e., after critical steps

*And there are others for supporting R&D+HVM

PROPERTIES/ANALYTICAL TOOLBOX

Incoming chemicals

VPI ... UV-
v ... s,
l ... .



Pr ... M,
TE ... ith

Failure Analysis

Wafer processing

- Dimensions
- Composition
- Dopants
- Strain
- Electrical

Techniques:

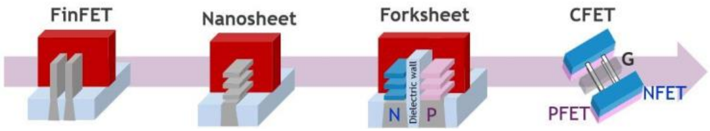
- Optical
- TEM/SEM
- SPM
- XPS/EDS
- XRD/Raman
- SIMS
- APT
- C-V etc.

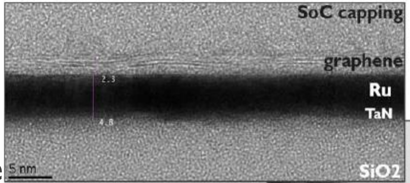
SPM includes: AFM, SSRM, STM, nanoprobe, etc
C-V includes: Hg-Probe, Faast, Thermowave, 4pt probe, etc

METROLOGY SUPPORT OF TOMORROW'S IC INDUSTRY

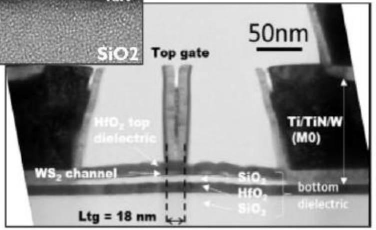
INLINE (IN THE FAB) AND OFFLINE (LABS)

- Metrology gaps
  - CMOS: Faster time to data on more complex structures
  - Beyond CMOS: Added properties will need to be measured





Graphene



WS_2

- What additional support is needed
  - More academic collaboration?
  - More industry collaboration?
  - More fundamental R&D?
  - More synchrotron?

Yes to all,
but these need to be balanced,
well scoped, more aligned, and faster

- And: There needs to be a renewed alignment on definitions
  - The drive stems from the increased use of correlative metrologies (use of multiple techniques)

BEYOND-CMOS METROLOGY NEEDS

INLINE (IN THE FAB) AND OFFLINE (LABS)

- Beyond-CMOS devices will be recognized through the integration of 2D materials into process flows
- 2D materials display much higher mobilities than materials used in CMOS devices (Si/SiGe) and in some cases the charge carriers are also spin locked
- To follow these properties, <u>new metrologies</u> will need to be added, both in the lab and in the fab, and exiting metrologies will need further development

FIGURE 1. CD-SAXS metrology has evolved from synchrotron-based measurements [3] (left) to the pioneering NIST prototype system [4] (middle) to KLA's x-ray metrology system (right), which is a highly sensitive, production-capable metrology system for semiconductor manufacturers.

Driving In-Fab High Aspect Ratio Memory Solutions with CD-SAXS

Jon Madsen, Andrei Shchegrov, Thaddeus G. Dziura, Tianhan Wang, Antonio Gellineau, Sergey Zalubovsky, and Joseph A. Di Regolo

Structure (CDs)

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Spin + B

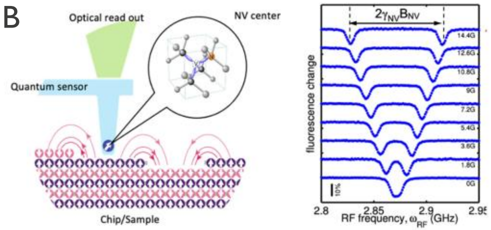

FIGURE 1. Principle of Scanning NV Magnetometry. The quantum sensor is an all-diamond SPM probe containing a single NV center (left). A combination of optical and microwave pulse generates the optically detected magnetic resonance (ODMR) spectra shown on the right. The amplitude of the B field at the NV center position directly translates into a splitting of the two main resonances (Zeeman effect). A full map of the magnetic stray field is obtained by recording such ODMR spectra as the probe is scanned over the sample.

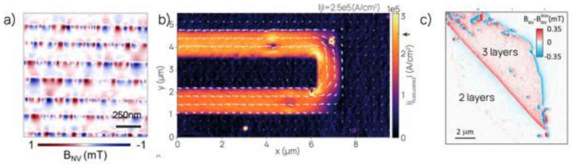

FIGURE 2. Examples of application using SNVM. (a) Non-invasive imaging of the magnetic stray field produced by ultra-scaled nanowires (sample IMEC). The data shows 7 nanowires which present magnetic field variations on the nanoscale attributed to local structural or compositional inhomogeneities in the nanowire. b) Current density map reconstructed from the measurement of magnetic field induced by a 250um current in a microwire. c) Quantitative imaging of the magnetic field produced by an odd or even number of atomically thin layers of CrI_3. The measurements, performed in cryogenic environment, reveal the antiferromagnetic nature of the material in the limits of few atomic layers.

DEVELOPMENT OF NV MAGNETOMETRY FOR SPIN MAPPING AT THE ATOMIC SCALE

Mathieu Munsch

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