

# Differential Reflective Metrology

## An innovative variability measurement for advanced FD-SOI material

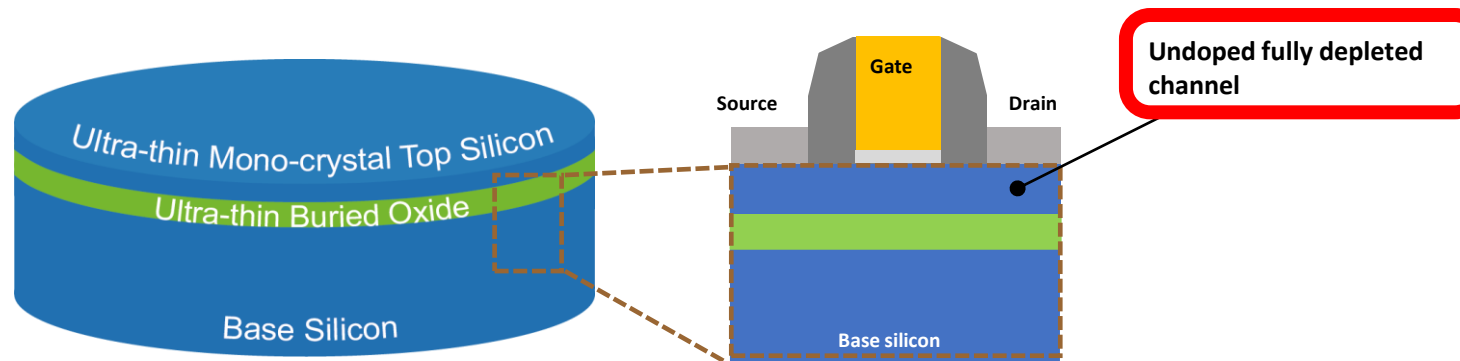
Jean-Michel Billiez (Soitec, France)

- 1 FD-SOI, technology to meet market requirements
- 2 One innovative metrology for Å control in HVM
- 3 Layer thickness variation modeling
- 4 Innovative FD-SOI thickness control at all scales

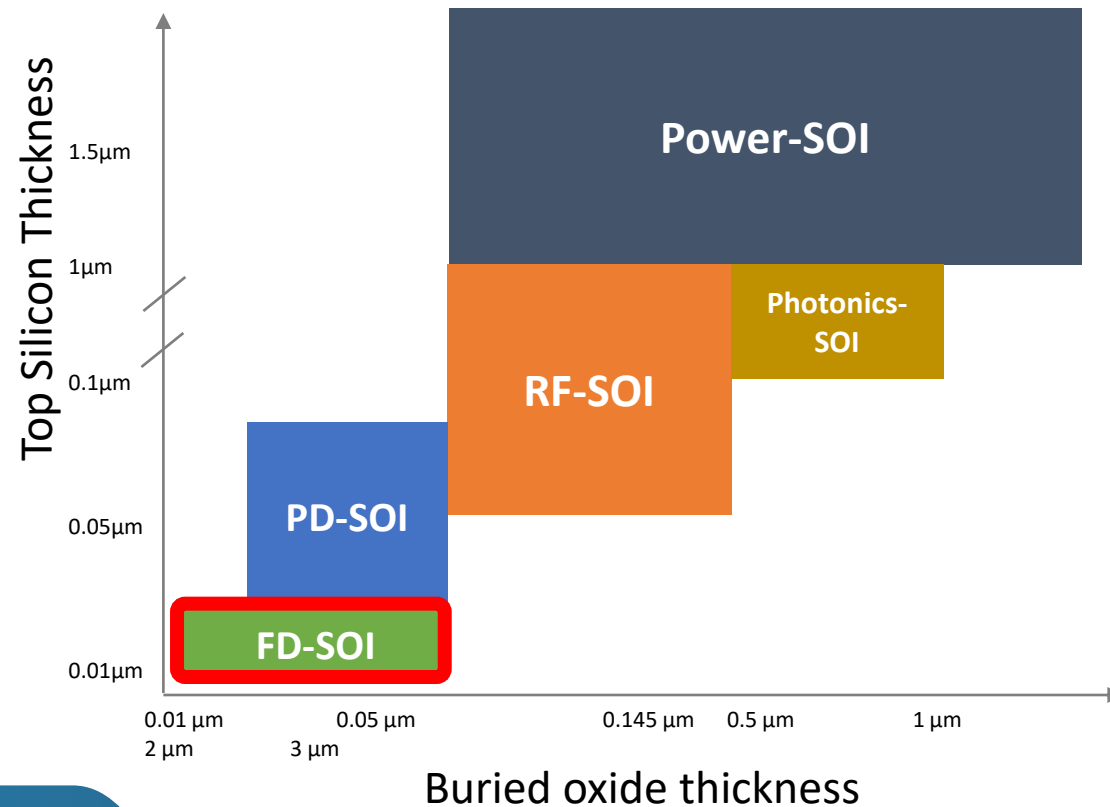
- 1 FD-SOI, technology to meet market requirements
- 2 An innovative metrology for Å control in HVM
- 3 Layer thickness variation modeling
- 4 Innovative FD-SOI thickness control at all scales

- IDM & IC design early adopters
  - ✓ Microcontrollers and processors / nodes 65nm, 28nm, 22nm, 12nm
- Customer requirements
  - ✓ Power-efficient (Mobile),
  - ✓ Highly reliable and high voltage integration (Automotive)
  - ✓ Easy analog/RF integration (5G)
  - ✓ Cost & battery efficiency (IoT)
  - ✓ Performance computing (Edge AI)

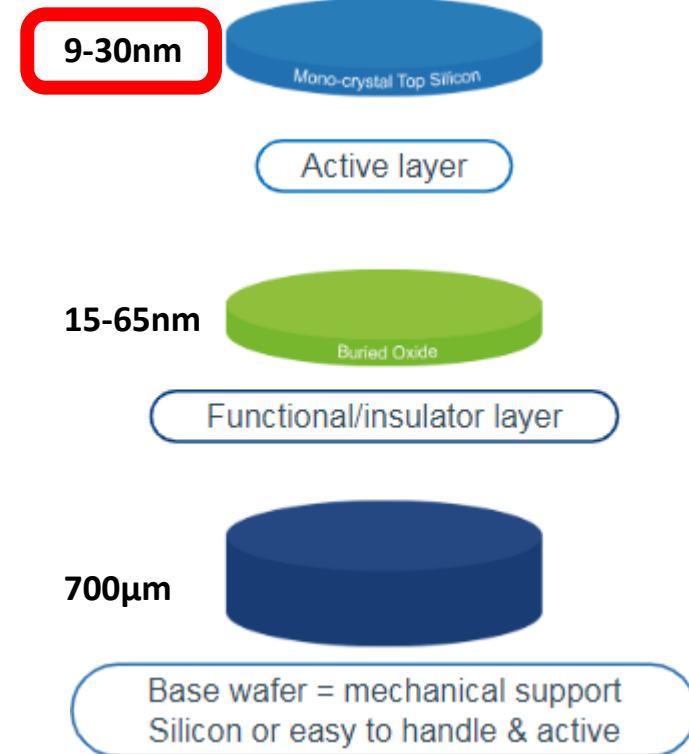
## Planar FD-SOI transistor



- Thinnest Silicon On Insulator (SOI) portfolio product

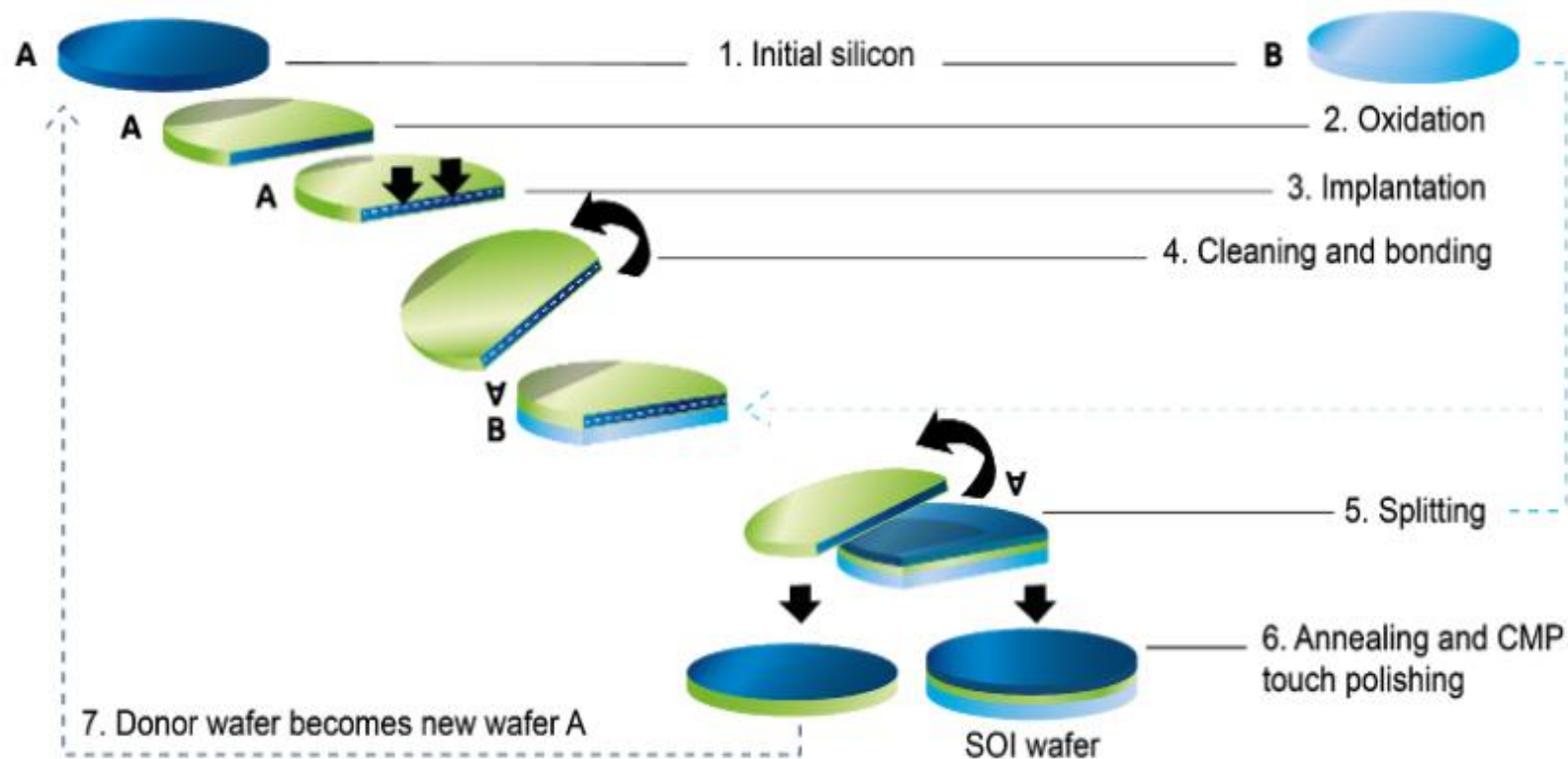


Indicative layer thickness



- A mature technology for FD-SOI

- ✓ Industrial manufacturability
- ✓ Flexibility of material integration

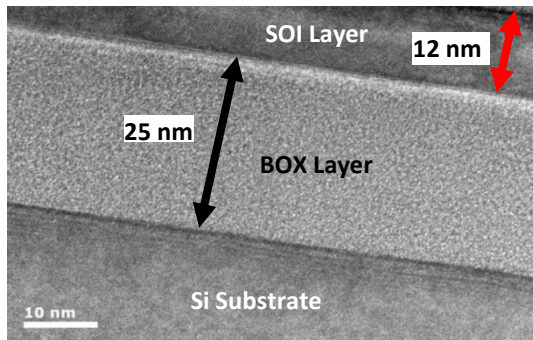


- 1 FD-SOI, technology to meet market requirements
- 2 An innovative metrology for Å control in HVM
- 3 Layer thickness variation modeling
- 4 Innovative FD-SOI thickness control at all scales

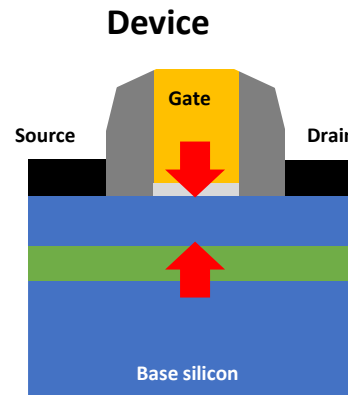
- Control of SOI thickness is a key parameter

- ✓ Contributes to device performance
- ✓ Extremely uniform SOI and BOX layers are required

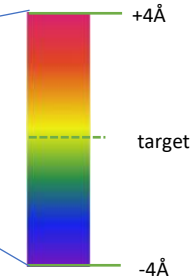
FD-SOI substrate



Critical  
dimension



SOI layer uniformity  
required  $\pm 4\text{\AA}$  today,  $\pm 3\text{\AA}$   
tomorrow



8\AA over full wafer

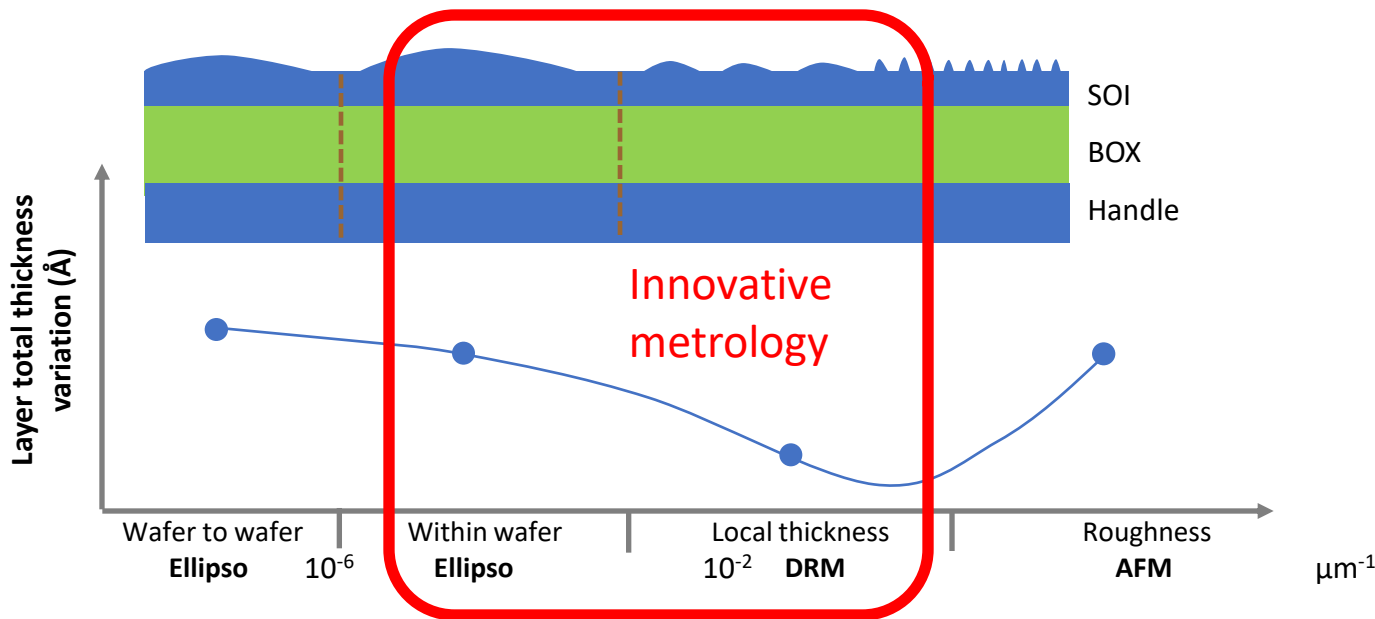
= 5mm over Europe  
boundary Portugal-Poland





- An innovative metrology for all included SOI thickness control

- ✓ All frequencies which contribute to SOI thickness variation



specification

Global thickness uniformity  
 $\pm 4\text{\AA}$

Local thickness uniformity  
 $< 4\text{\AA}$  Peak-to-Valley

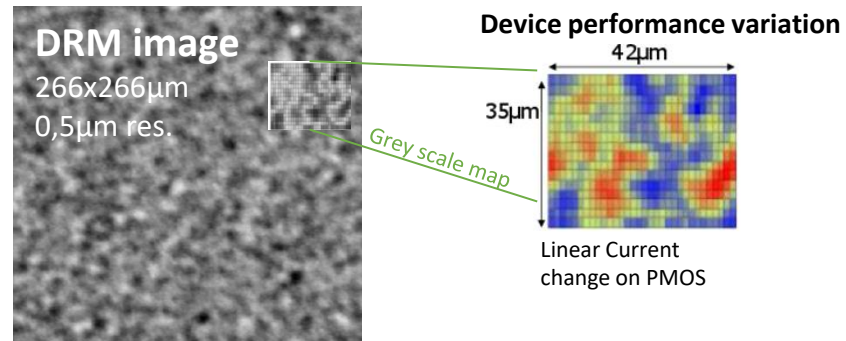
Roughness  
DRM  $6\text{\AA}$  max

- Differential Reflective Microscopy (DRM)

✓ IP 2013 > 1st Gen tool 2016 (Roughness) > 2nd Gen tool optimized for local scale & wafer scale (2019)

## Device scale

50x  
magnification

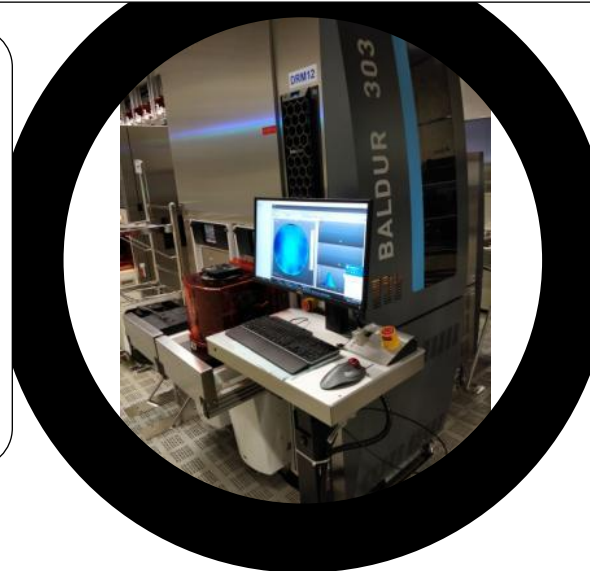
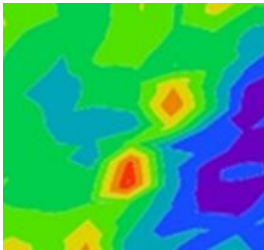


## Local control (1,25x magnification)

DRM image  
10x10mm

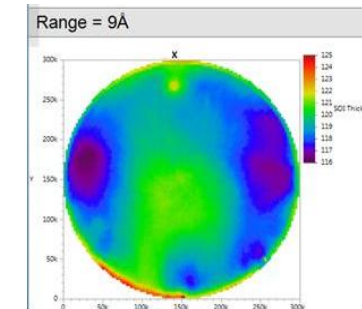


Detail of DRM map with  
scaling 1x1mm



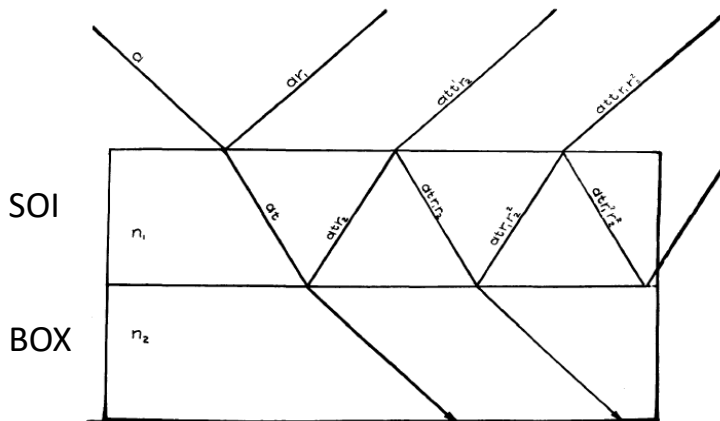
## Wafer scale control (1,25x magnification)

DRM Si thickness  
40000 sites map



- Based on the dependence of the optical reflectivity of a layer on its thickness

- ✓ Reflectivity calculations using matrix formalism
- ✓ Matlab realization to model reflectivity in 2 layer material substrate (thanks to E. Navarro)



Fresnel complex reflection and transmission coefficients

**Reflectivity for SOI stack = function (thickness<sub>SOI</sub>, thickness<sub>BOX</sub>, polarization, angle, wavelength)**

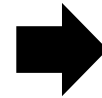
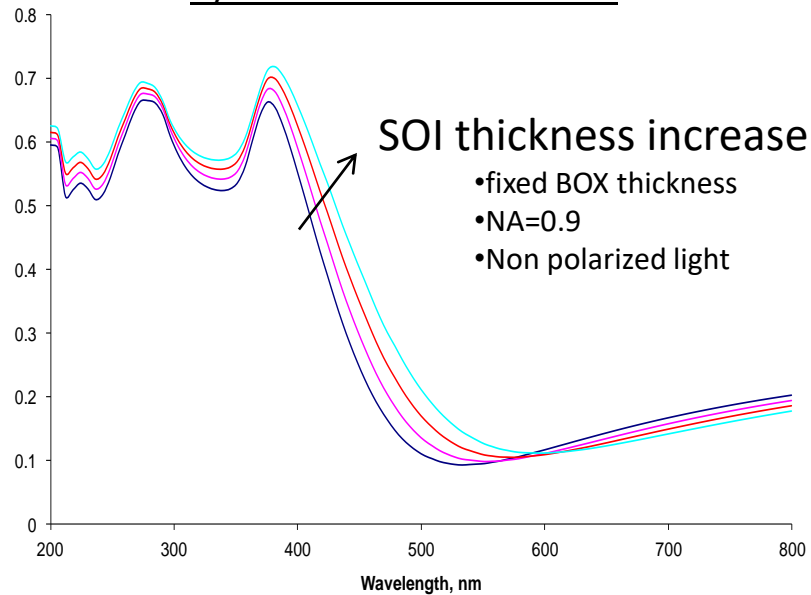
In optical microscope: random polarization, angle integrated over Numerical Aperture, wavelength selected by interferential filter ( $\pm 5\text{nm}$ )

Source: P.-E. Acosta-Alba et al., ECS Journal of Solid State Science and Technology, 2013

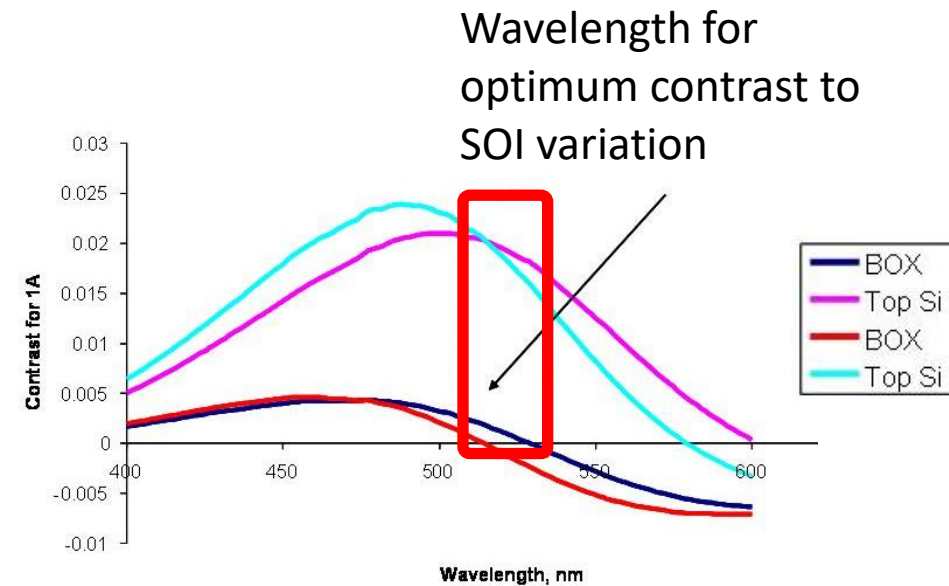
- 1 FD-SOI, technology to meet market requirements
- 2 One innovative metrology for Å control in HVM
- 3 Layer thickness variation modeling
- 4 Innovative FD-SOI thickness control at all scales

- Total reflectivity depends on thickness change of 2 layers
  - ✓ Reflectivity becomes only sensitive to SOI layer thickness variation at specific wavelength

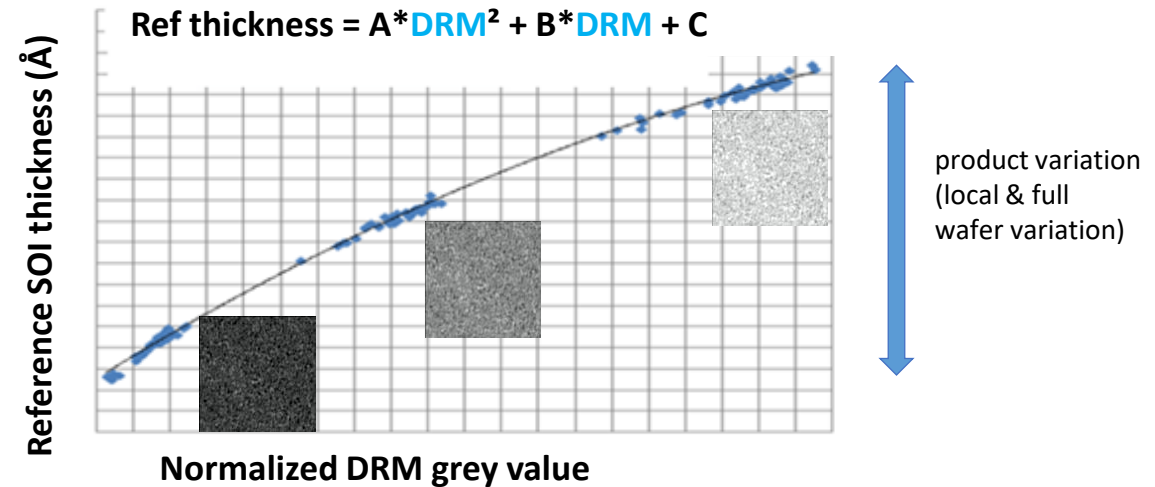
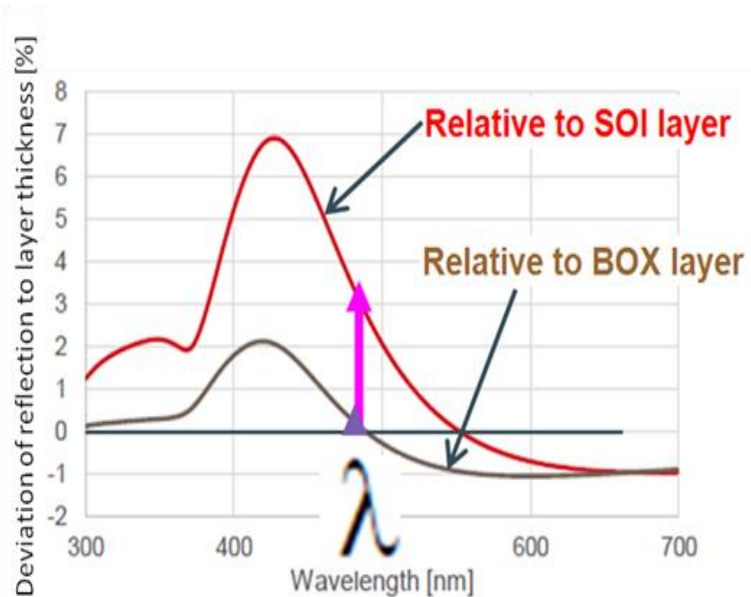
Total reflectivity vs. Wavelength  
by SOI thickness 11 to 14nm



Relative change of reflectivity to a thickness of 1Å



- 1st Gen DRM: 1 wavelength system (2016)
  - ✓ Calibration of total reflectivity against thickness
  - ✓ >100 sites covering the full range of product variation
  - ✓ Ellipsometry is reference metrology for very thin wafers (spot size 50μm)
- DRM value is transformed into thickness by 2nd order polynome (statistical approach)



Source: HSEB 2018



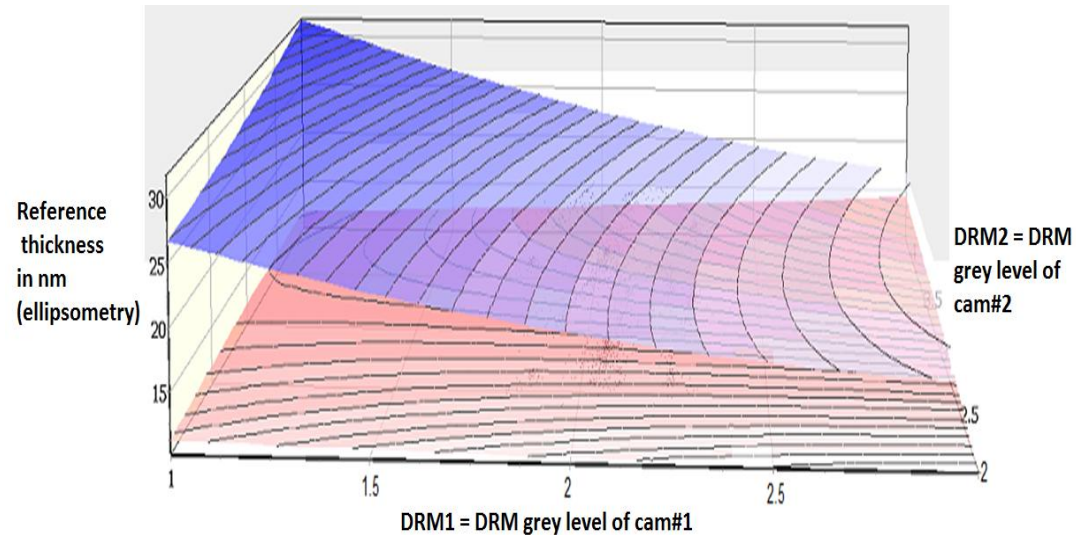
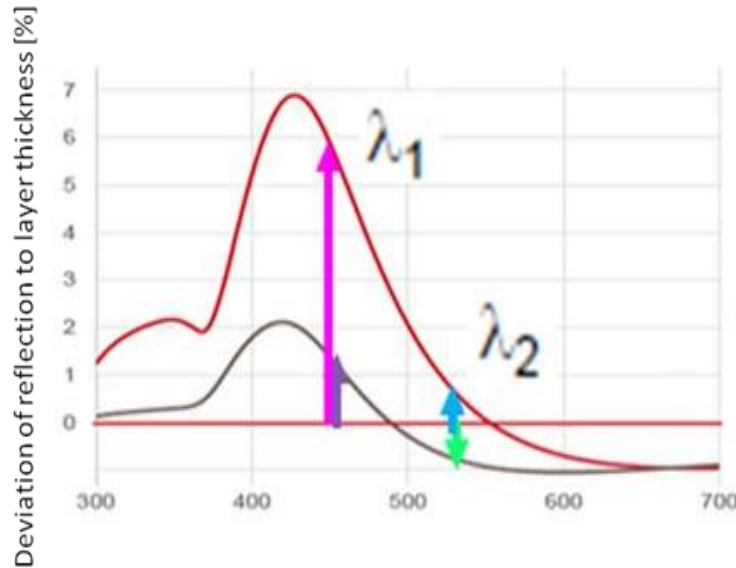
- 2nd Gen DRM: 2 wavelenth system (2019)

- ✓ 2 detectors and perfect alignment of images
- ✓ >100 sites covering the full range of product variation of both layers
- ✓ DRM transformed into thickness by approximation in 2nd order polynome

Thickness layer#1 =  $f(A_i, \text{DRM1}, \text{DRM2})$

Thickness layer#2 =  $f(B_i, \text{DRM1}, \text{DRM2})$

where  $A_i$  and  $B_i$  are parameter sets with 6 parameters each

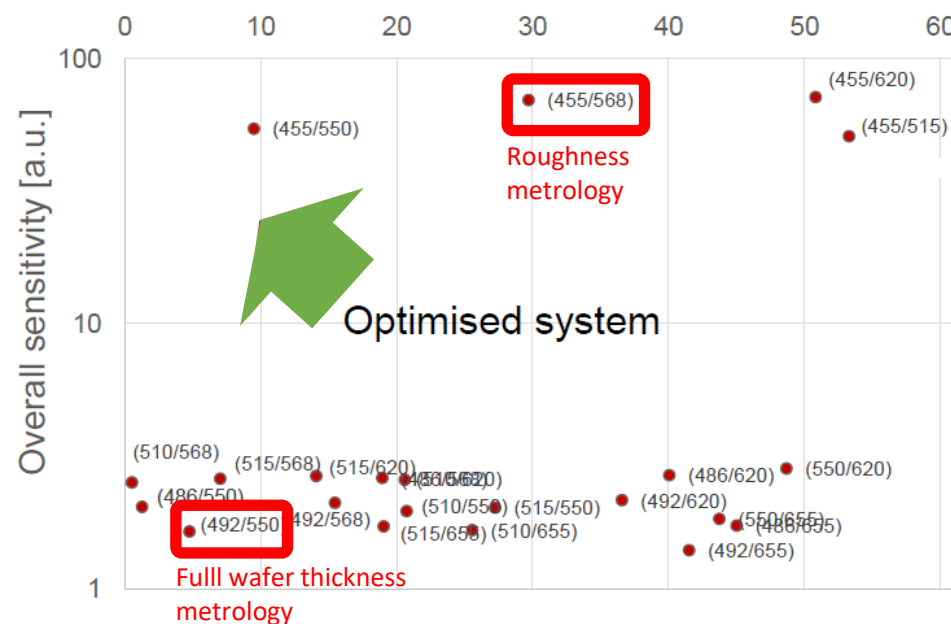


Source: HSEB 2018

- Selection of appropriate pair of filters

- ✓ maximize sensitivity to SOI thickness variation and minimize residual contribution of BOX
- ✓ 6 pre-determined filters for optimum products flexibility

Sensitivity vs. degree of cross-correlation between SOI and BOX layers



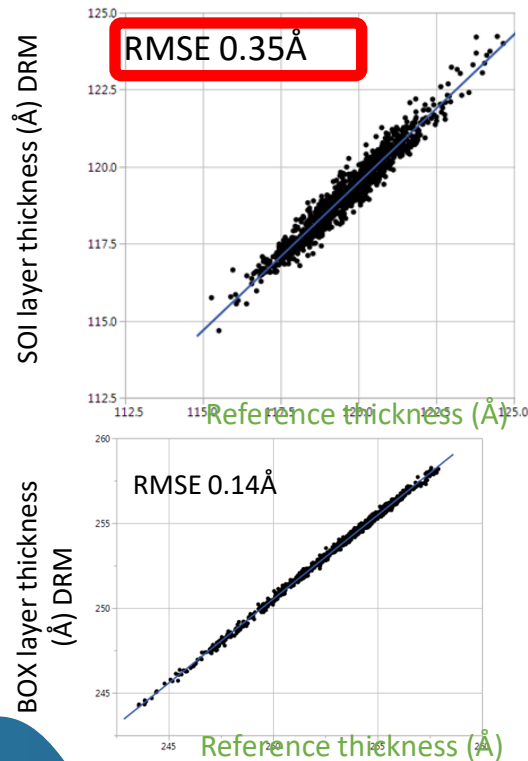
Source: HSEB 2018



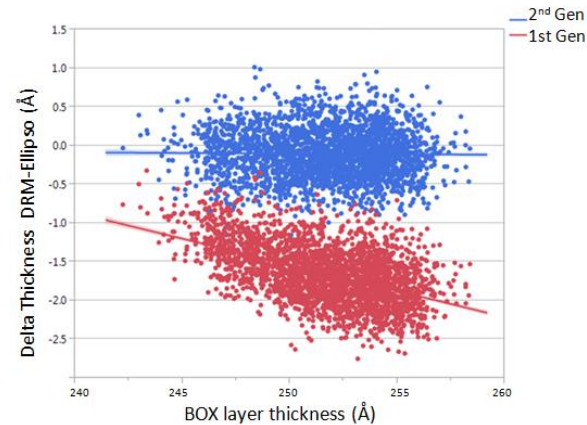
- Accuracy equivalent to ellipsometer

✓ Site to site correlation: DRM 266\*266 $\mu$ m (smallest size) vs. Ellipsometer 50 $\mu$ m beam size

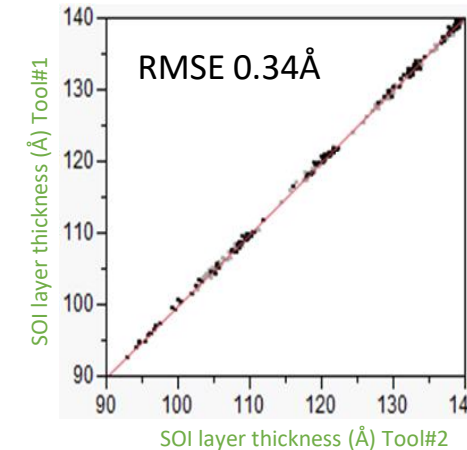
DRM



SOI thickness is measured independently to BOX thickness



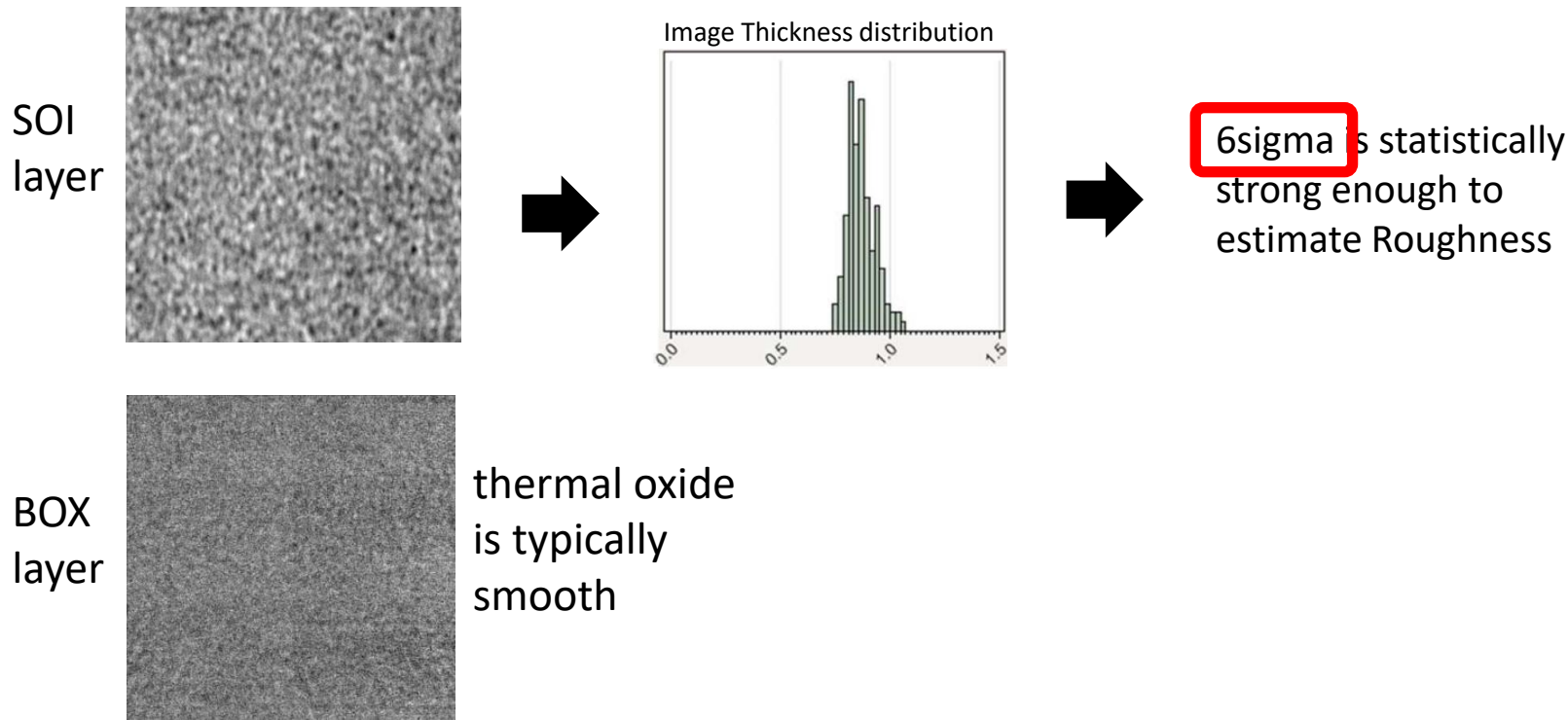
Reference metrology  
Tool to tool correlation



- 1 FD-SOI, technology to meet market requirements
- 2 One innovative metrology for Å control in HVM
- 3 Layer thickness variation modeling
- 4 Innovative FD-SOI thickness control at all scales

- Roughness modelization

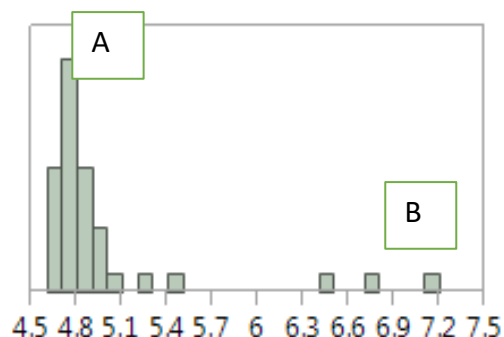
- ✓ thickness image 266 $\mu$ m x 266 $\mu$ m
- ✓ 1 Million pixels
- ✓ 0.5 $\mu$ m optical resolution



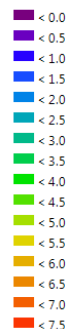
- High performance metrology

- ✓ Accuracy of metrology enables to exhibits small differences

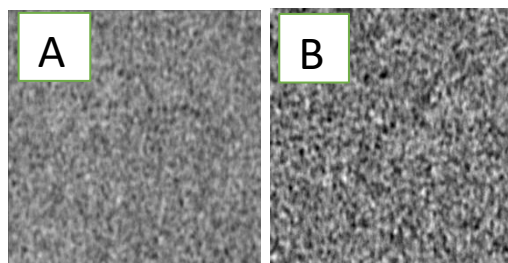
SOI roughness data (Å)



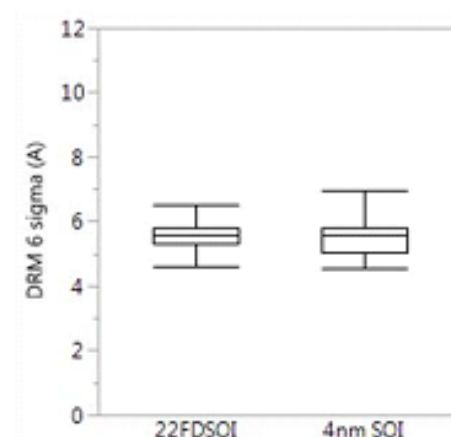
Roughness 6sigma in Angstrom



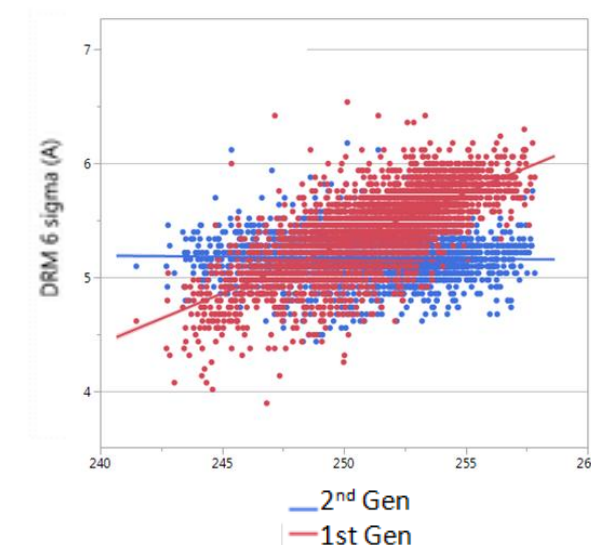
DRM Thickness images



6sigma performance vs technology



6sigma dependency to BOX thickness

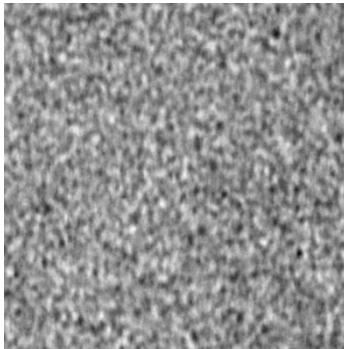


BOX layer thickness (Å)

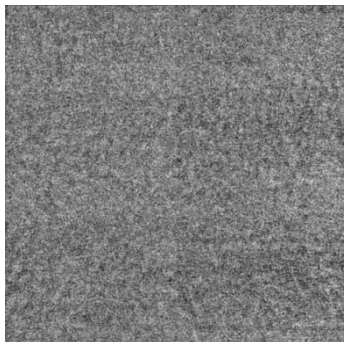
- Thickness modelization

- ✓ thickness image 10mmx10mm
- ✓ 12 $\mu$ m optical resolution

Thickness image  
of SOI layer

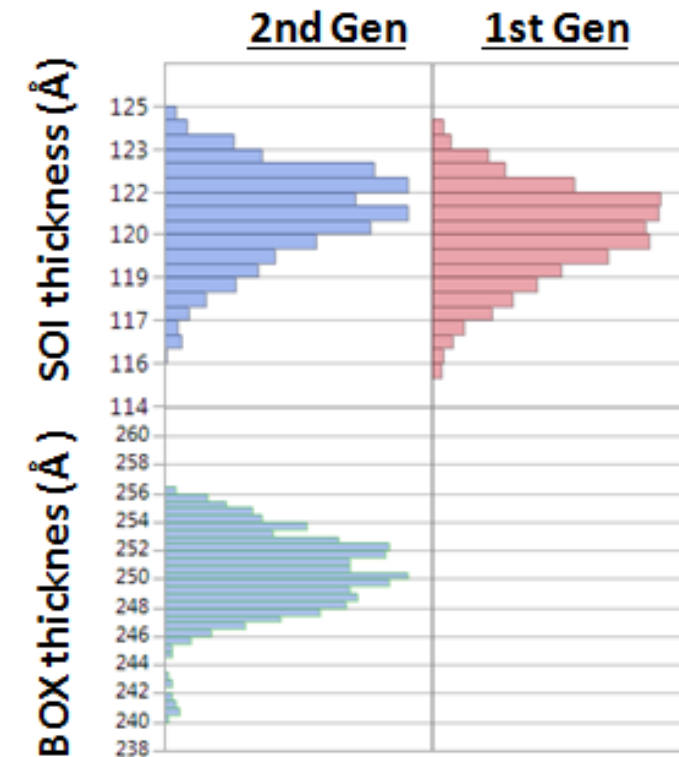


Thickness image  
of BOX layer

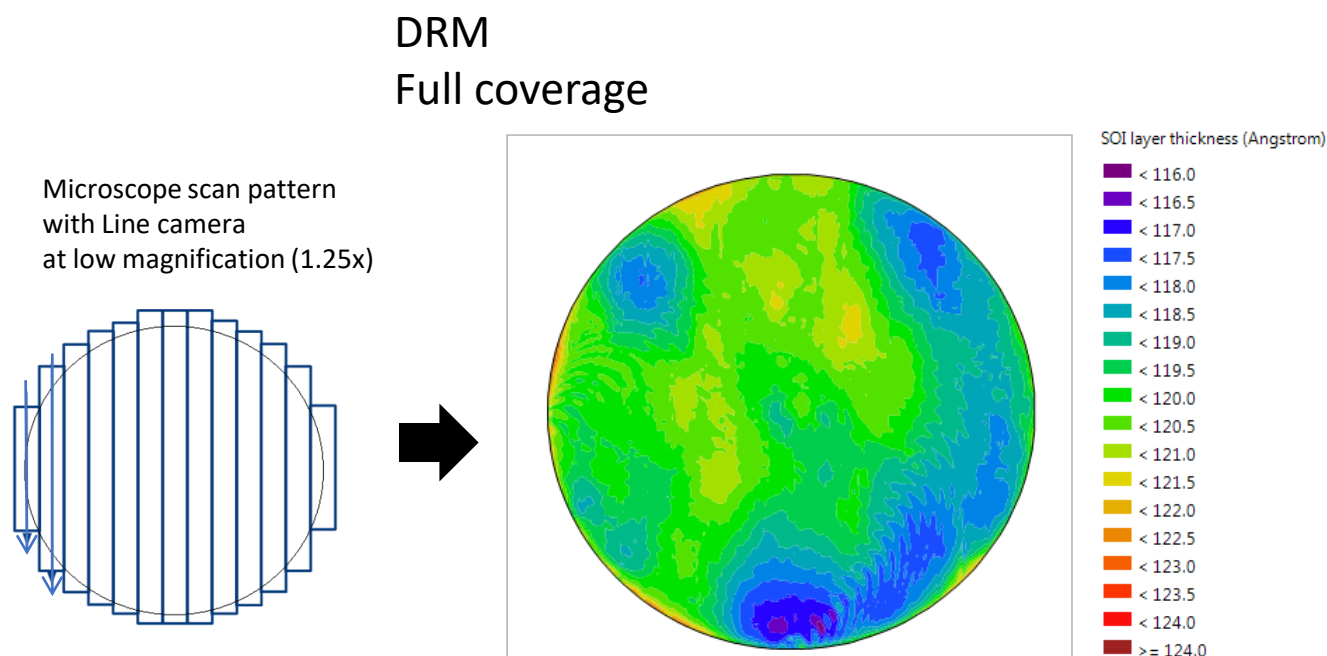


Result=  
**Average** of  
thickness image

SOI and BOX layers thickness variation  
with DRM



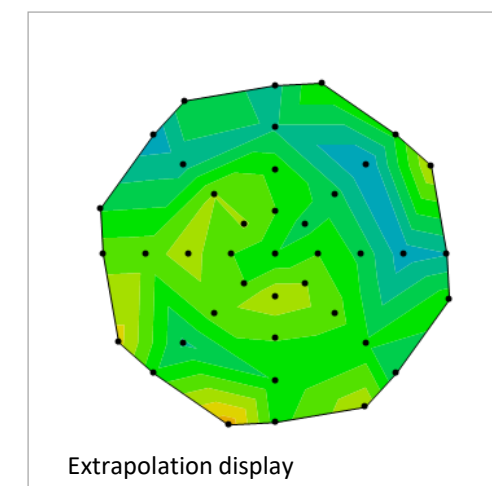
- Full wafer scan for extremely high sampling
  - ✓ DRM 100% wafer coverage at high throughput
  - ✓ Whereas Ellipsometer spot size is  $40\mu\text{m}$  and 41 standard site map



sampling

100% wafer area is covered

Ellipsometry  
standard 41 sites sampling



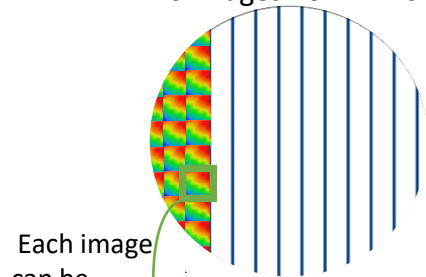
0.0004% area I sampled



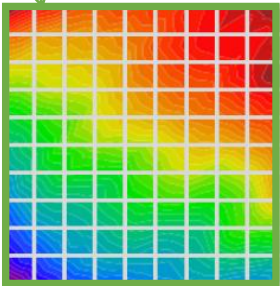
- Metrology can adapt to device dimension

- ✓ 1 thickness value by image or subdivision
- ✓ 1 additional thickness value by subdivision of image

Line scan generates  
416 images 10mmx10mm



Each image  
can be  
subdivided



416 sites

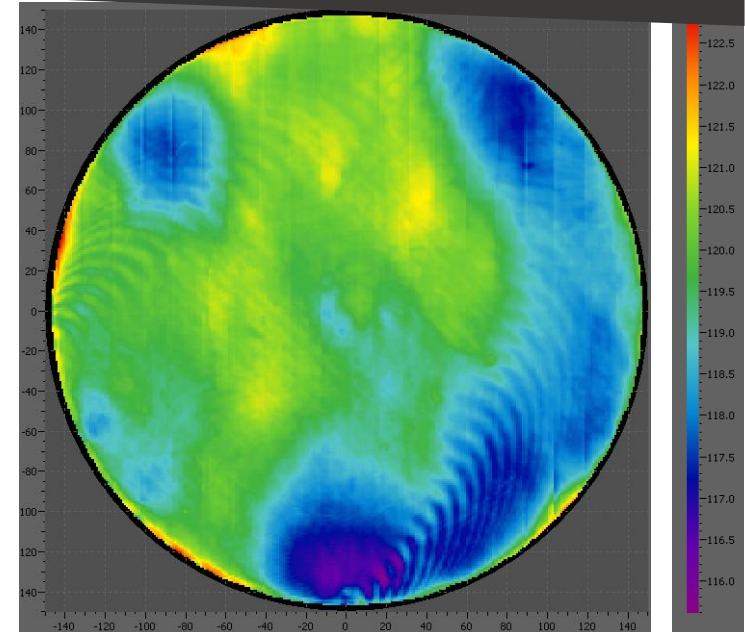
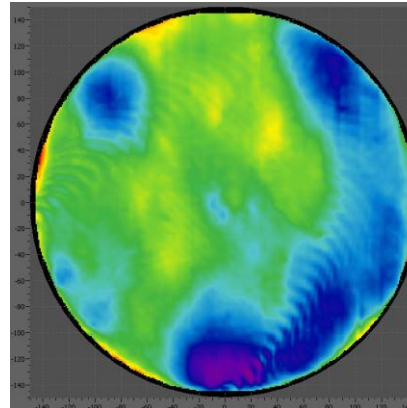
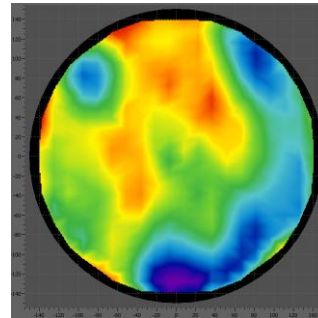
10mmx10mm each  
no subdivision

10.421 sites

1mmx1mm each  
5 subdivisions

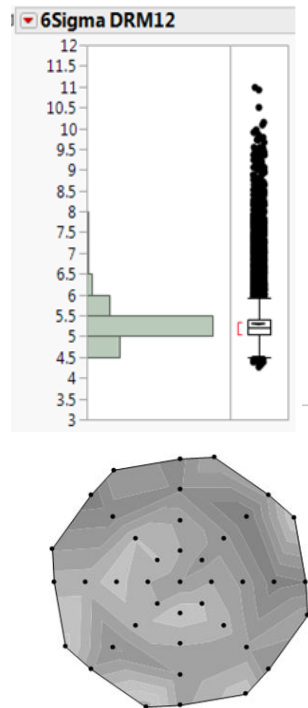
40.000 sites

2mmx2mm each  
10 subdivisions

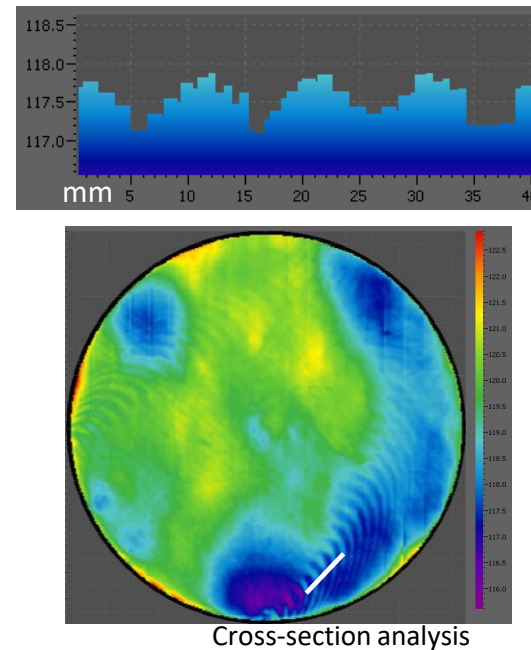


- DRM is innovative metrology for extensive control of FD-SOI thickness uniformity
  - ✓ Thickness variability within device scale
  - ✓ Local thickness control at device scale
  - ✓ 100% wafer control

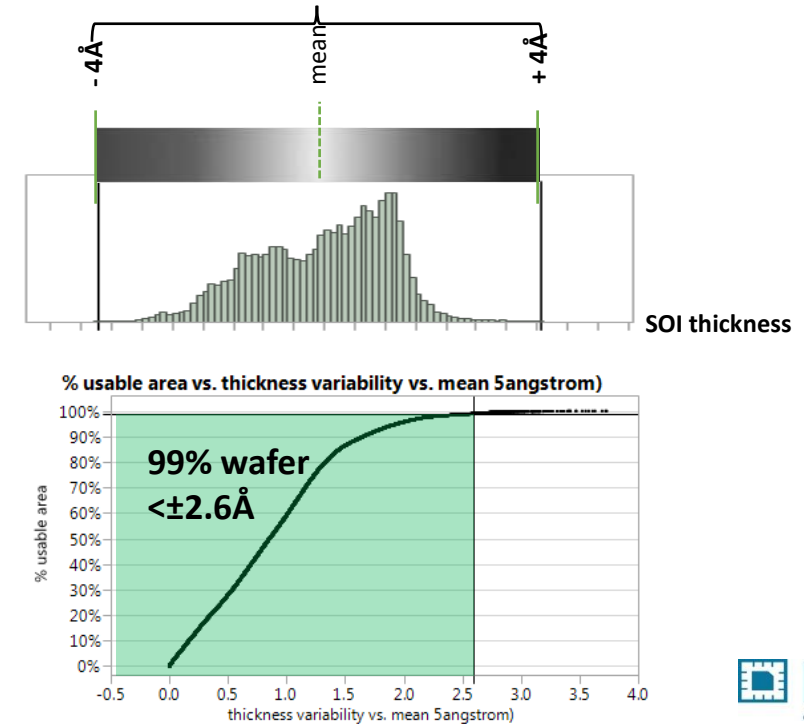
Average roughness <5Å



FD-SOI Local thickness profile <1Å variation



99,97% wafer within  $\pm 4\text{\AA}$





R&D work and **F**irst **I**ndustrialization **D**eployment (FID) related to the content presented in this document\* are supported by the French Government in the frame of the Important Project of Common European Interest (IPCEI) for microelectronics and as part of Nano 2022.



# Differential Reflective Metrology: An innovative variability measurement for advanced FD-SOI material (support of TF1 Energy Efficient Chips in IPCEI)

J.-M. Billiez<sup>1</sup>, W. Schwarzenbach<sup>2</sup>

<sup>1,2</sup>SOITEC, France

<sup>1</sup>Email : [jean-michel.billiez@soitec.com](mailto:jean-michel.billiez@soitec.com)

<sup>2</sup>Email : [walter.schwarzenbach@soitec.com](mailto:walter.schwarzenbach@soitec.com)

*Follow us on:*

 Soitec

 @Soitec\_FR / @Soitec\_EN

 Soitec



*For more information, visit us at:*

 [www.soitec.com](http://www.soitec.com)