micro and nanoelectronics
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Hybrid Metrology & 3D-AFM Enhancement For CD Metrology Dedicated To 28 nm Node And Below Requirements

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nanotools scanning probes

leti

cea

OUTLINE

1- Introduction

2- New AFM3D probes breakthrough

3- Hybrid Metrology for High Volume Manufacturing

4- Conclusion

1- INTRODUCTION

➲ **Overarching Goals and Motivations**

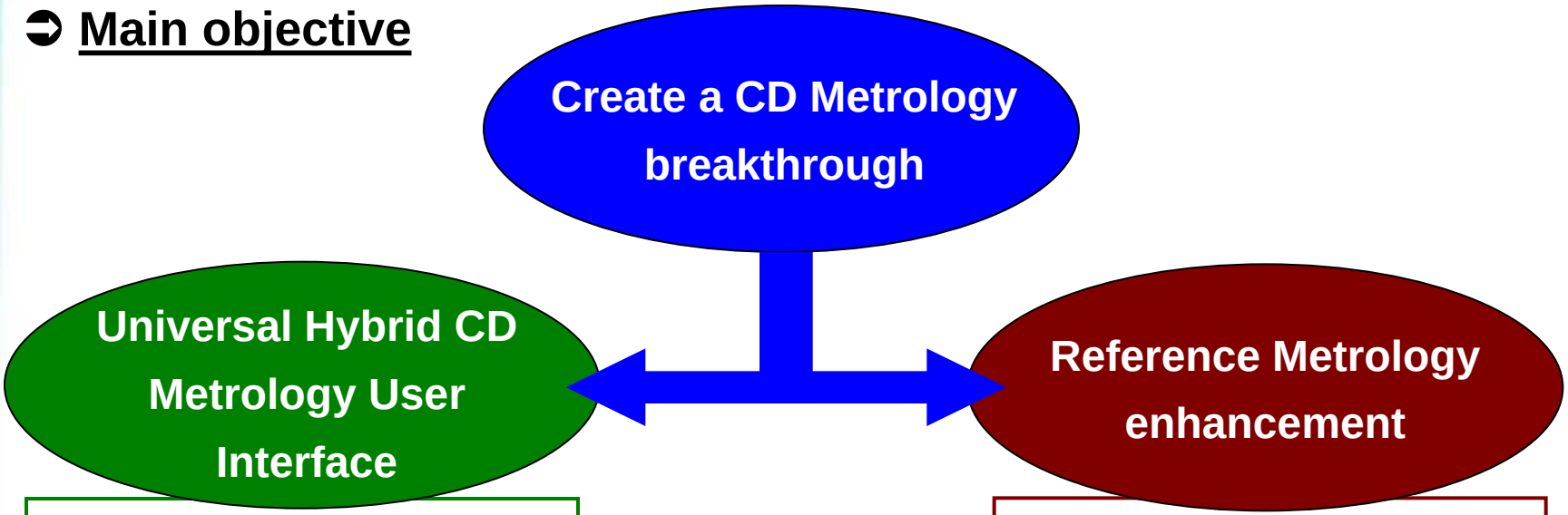
❶ **Reduce process variability,**

❷ **Improve R&D work and manufacturing control process quality,**

❸ **Reduce excessive costs of advanced tech. nodes**

➔ **Improving accuracy of Physical CD measurement**

➲ **Main objective**



OUTLINE

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2- New AFM3D probes breakthrough

3- Hybrid Metrology for High Volume Manufacturing

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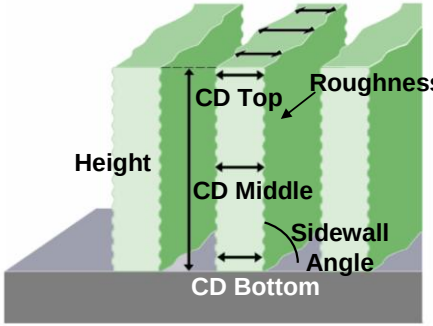
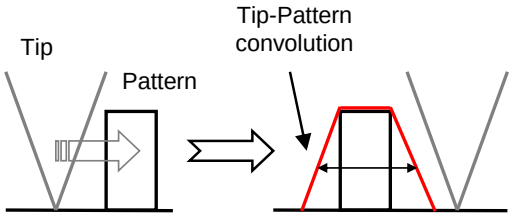
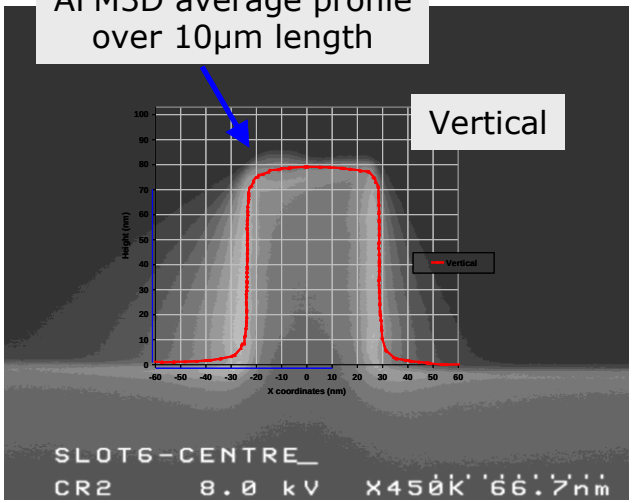
2- New AFM3D probe breakthrough

3D-AFM reference metrology quick reminder

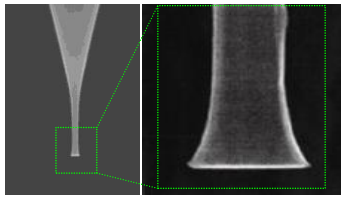


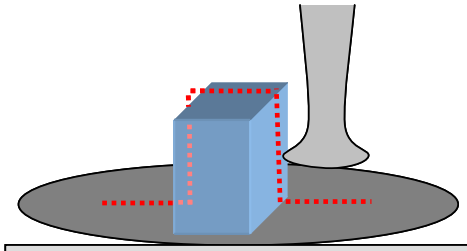


AFM3D average profile over 10µm length

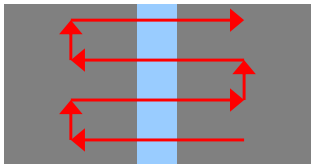


Boot shape AFM tips

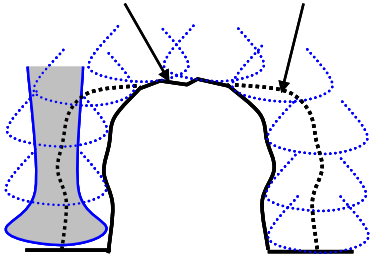


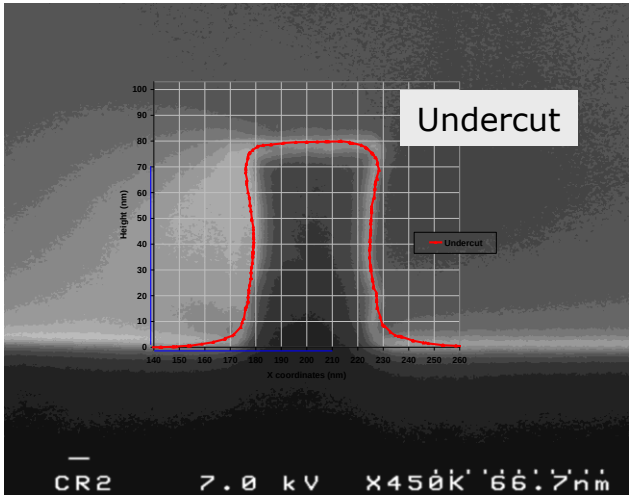


3D-AFM technology from Veeco Instruments



Pattern Convoluted pattern

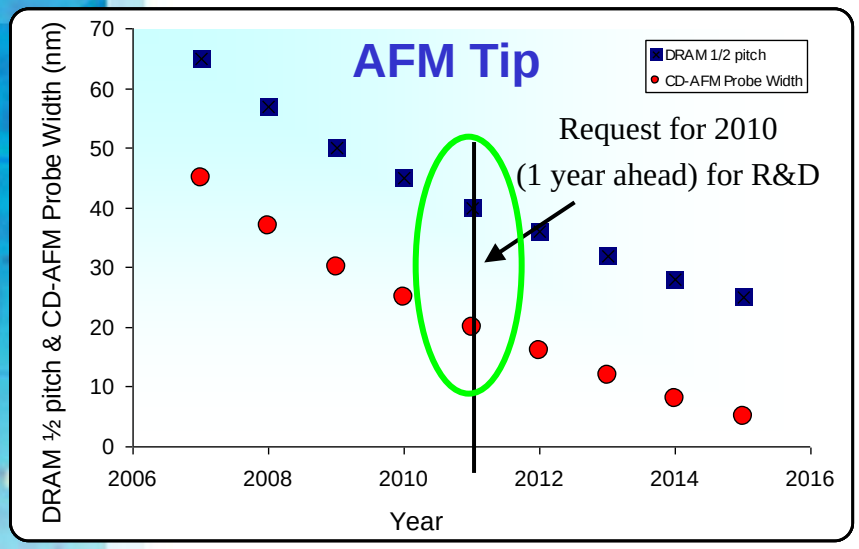




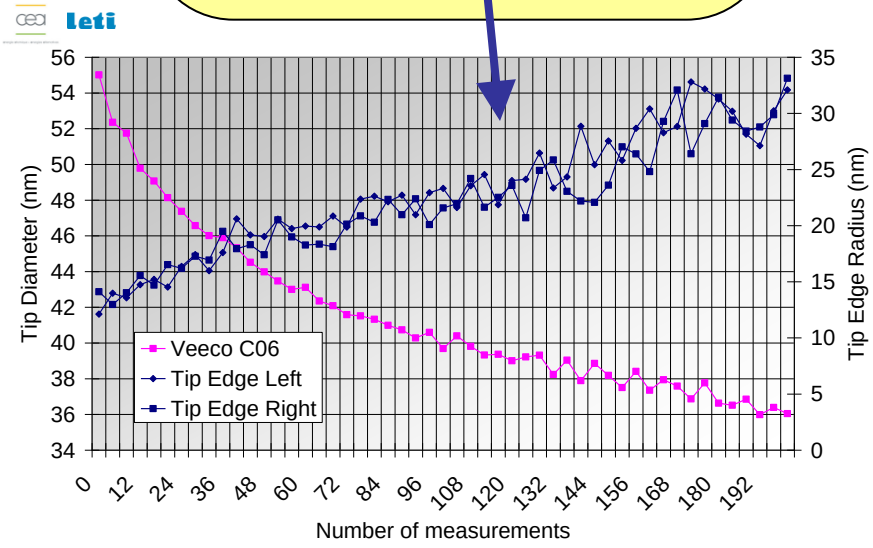
2- New AFM3D probe breakthrough

➲ State of the art

Conventional silicon based AFM tip can not answer to ITRS recommendations



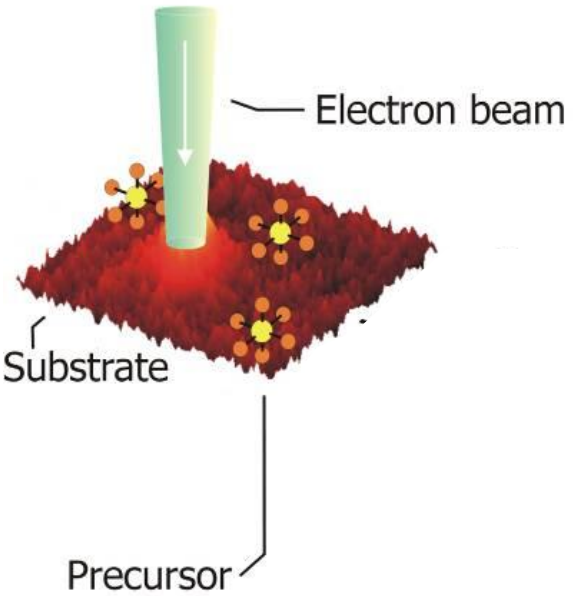
- Tip diameter limited
- Isotropic plasma etching
- Design limited
- Not easily customizable
- Not tilt corrected for 3D structures
- Resolution degrades over tip lifetime



Need for a technology breakthrough

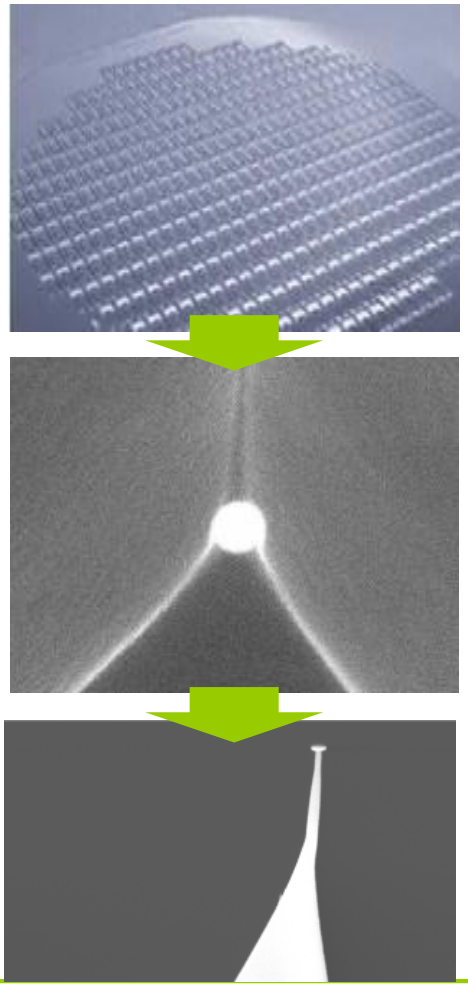
2- New AFM3D probe breakthrough

Automated, e-beam process …



- >50 parameters
- control of shape + material

… wafer production tool



- In-line quality check

… results in:

DURABILITY
Hardness 8x of silicon. Low tip wear, excellent lifetime.

PRECISION
Orientation better ½ . nanometer accuracy in shape and dimensions. 100% tip quality check (CD-SEM).

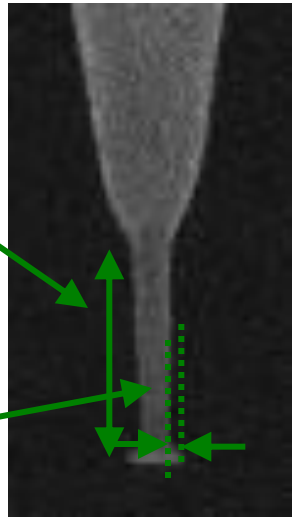
2- New AFM3D probe breakthrough

Tip Width
Design & Materials

Tip Wear
&
Tip Edge Radius

Tip effective
Length

Lateral Reach
(or Max Overhang)



1- Tip Diameter, Design & Materials

2- Tip Wear & Tip Edge Height

3- Overall shape

4- Tip Reliability

2- New AFM3D probe breakthrough

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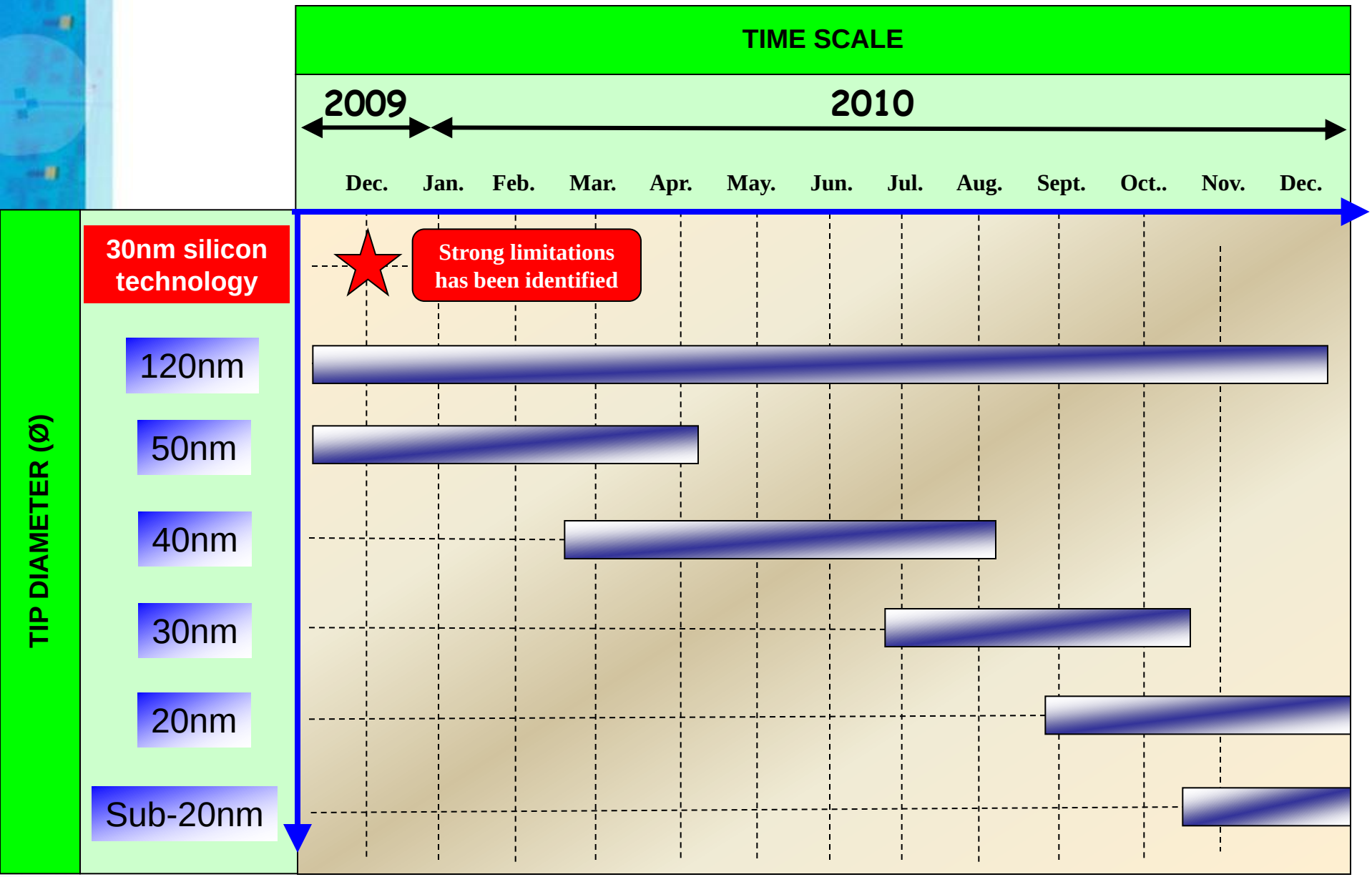
2- New AFM3D probe breakthrough

Tip Width
Design & Materials



2- New AFM3D probe breakthrough

1- Tip Diameter, Design & Materials

2- Tip Wear & Tip Edge Height

3- Overall shape

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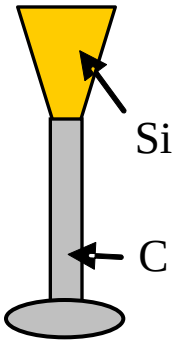
2- New AFM3D probe breakthrough

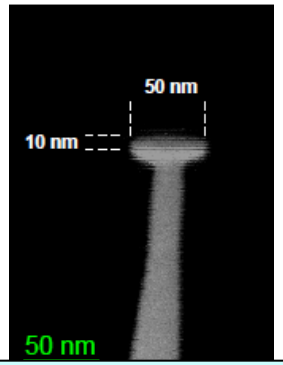
Tip Wear & Tip Edge Radius

➲ **Tip Enhancement (Tip Wear & Edge Height)**

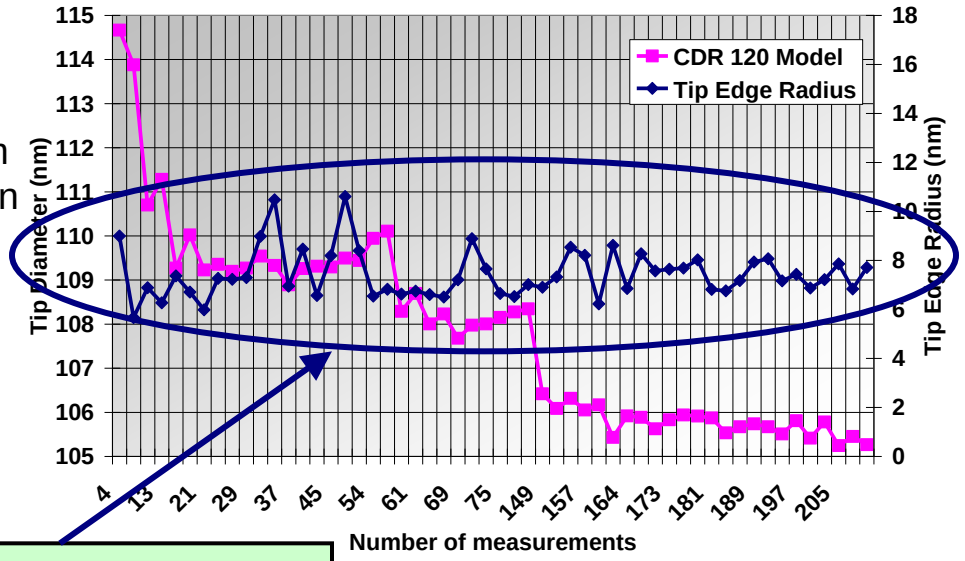
- Improvement of bottom resolution and decrease of cost

Maintain resolution over tip lifetime





Electron Beam Induced Carbon Processing



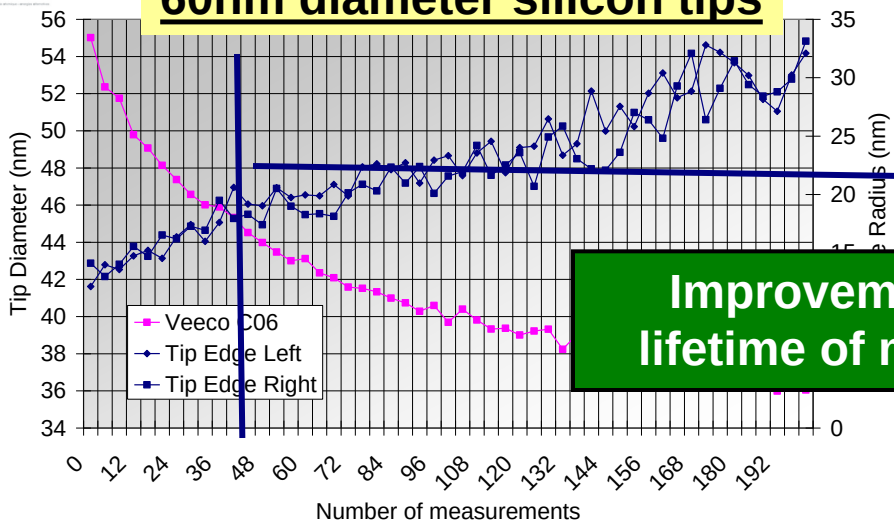
- Resolution do not depend on tip wear
- All tips are tilt corrected
- Orientation is at 90 0.5

Tip Edge Height is remaining constant over tip wear

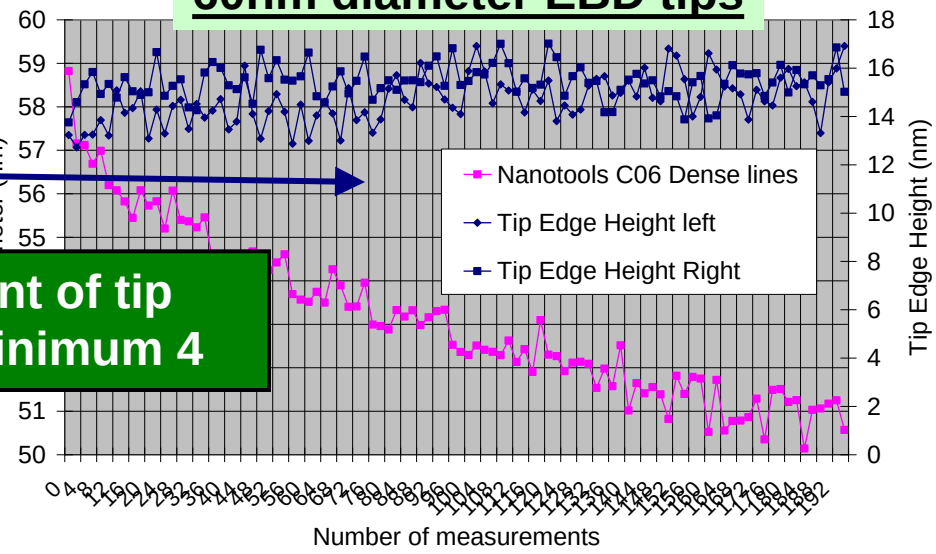
2- New AFM3D probe breakthrough

Tip Wear & Tip Edge Radius

60nm diameter silicon tips

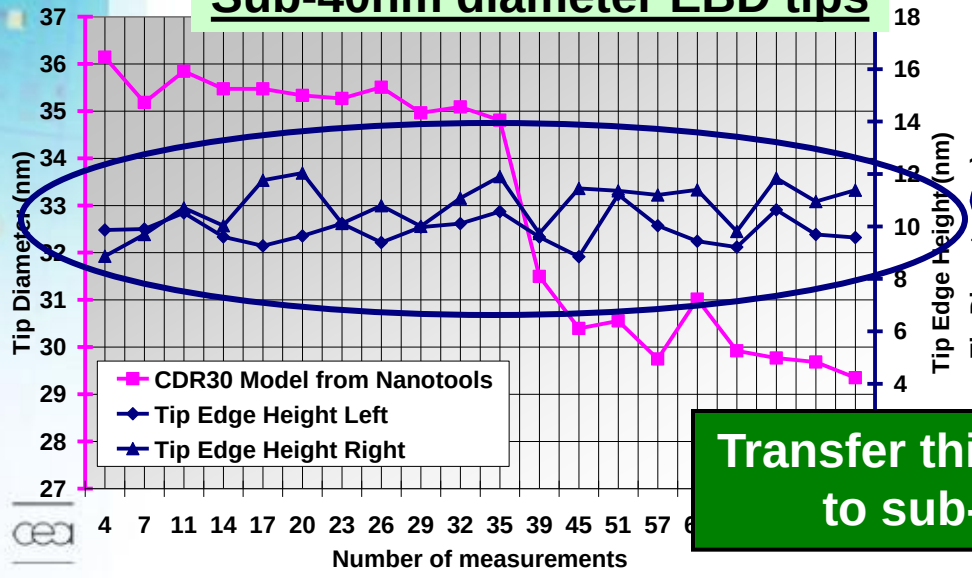


60nm diameter EBD tips

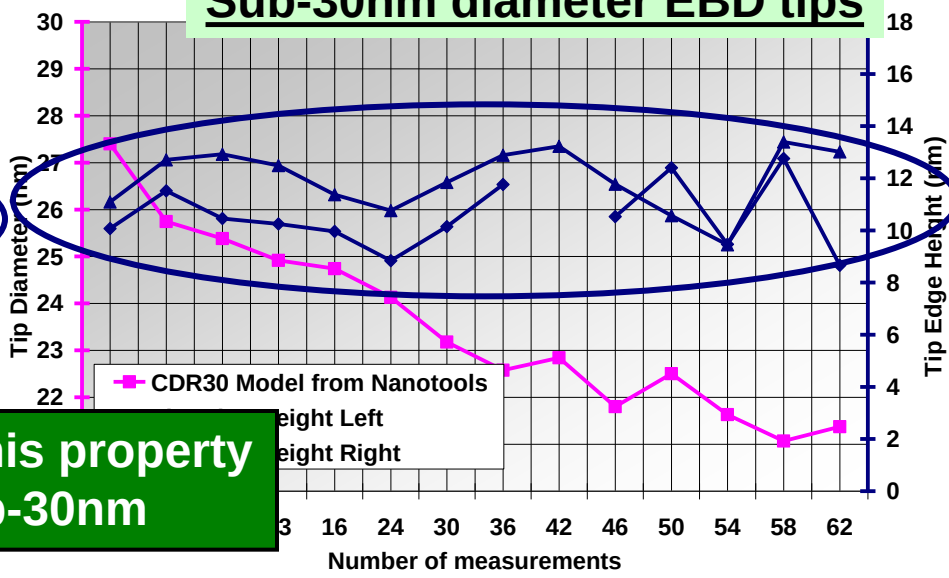


Improvement of tip lifetime of minimum 4

Sub-40nm diameter EBD tips



Sub-30nm diameter EBD tips



Transfer this property to sub-30nm

2- New AFM3D probe breakthrough

1- Tip Diameter, Design & Materials

2- Tip Wear & Tip Edge Height

3- Overall shape

4- Tip Reliability

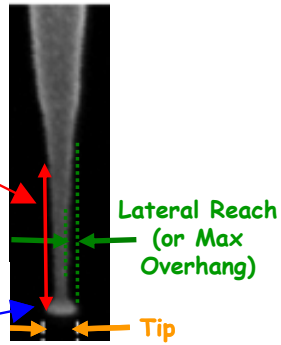
2- New AFM3D probe breakthrough

Overall Shape

➲ Tip Enhancement (Overall Shape)

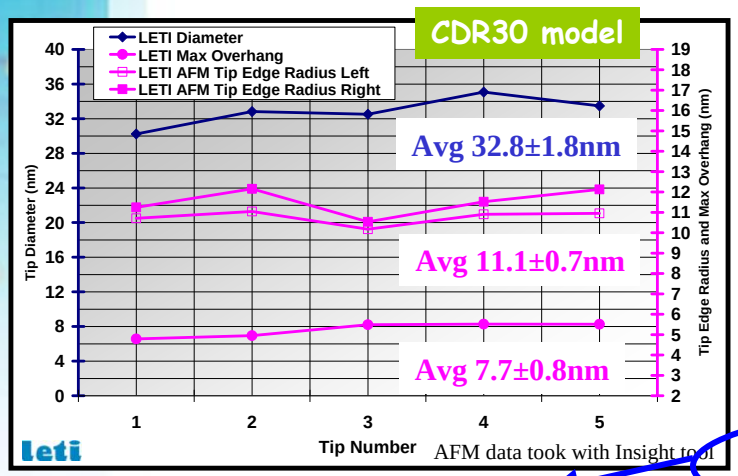
- Validation for production use

EBD Tip technology



Unique and Relevant results for the introduction of such tip into production environment

Key parameters for advanced Roadmap Requirements



1-A constant tip edge radius will maintain the resolution of AFM3D over tip lifetime

2- For small tip model (namely sub-32nm tip)

a- **Diameter very close to 30nm** (Successful SEM and AFM matching exercise to control the process)

b- **Diameter dispersion = 5%** of the average diameter;

c- **Small edges radius = 10-11nm**;

d- **Important lateral reach capability (47%** of the tip radius)

e- **Tip symmetry**

f- **Customizable tip (apex angle)**

Will be addressed in the next slides

2- New AFM3D probe breakthrough

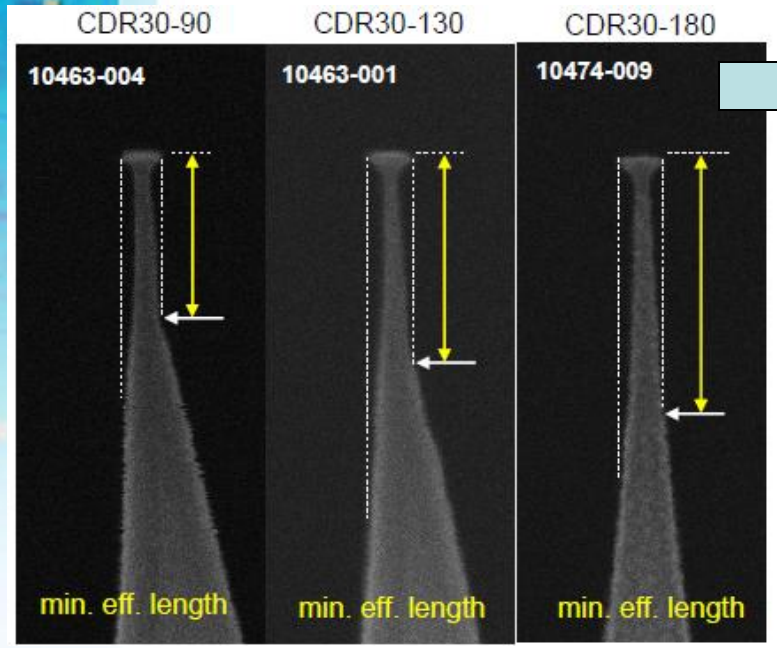
Overall Shape

➲ **Tip Enhancement (Overall Shape)**

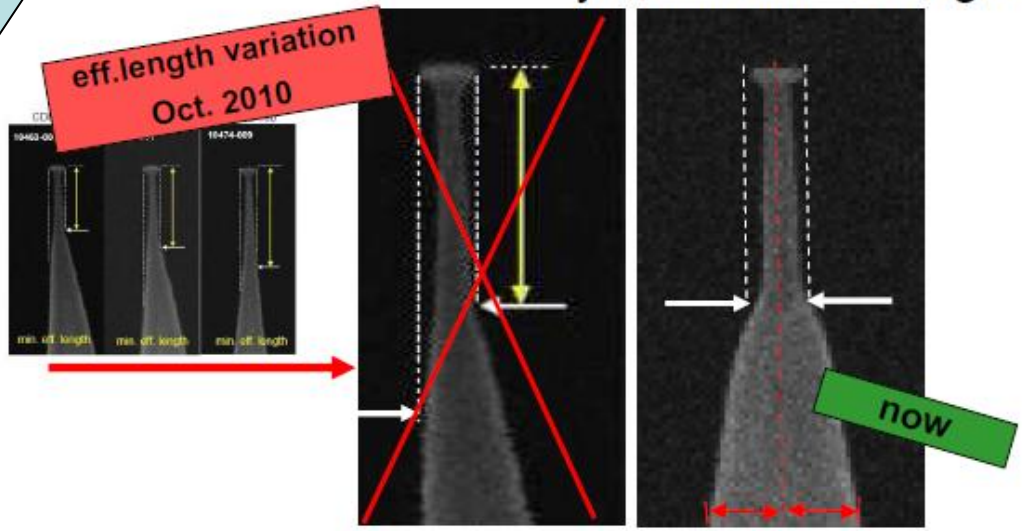
- For FinFet Structures and small spaces measurements

Need for perfect symmetrical tips

October 2010



January 2011



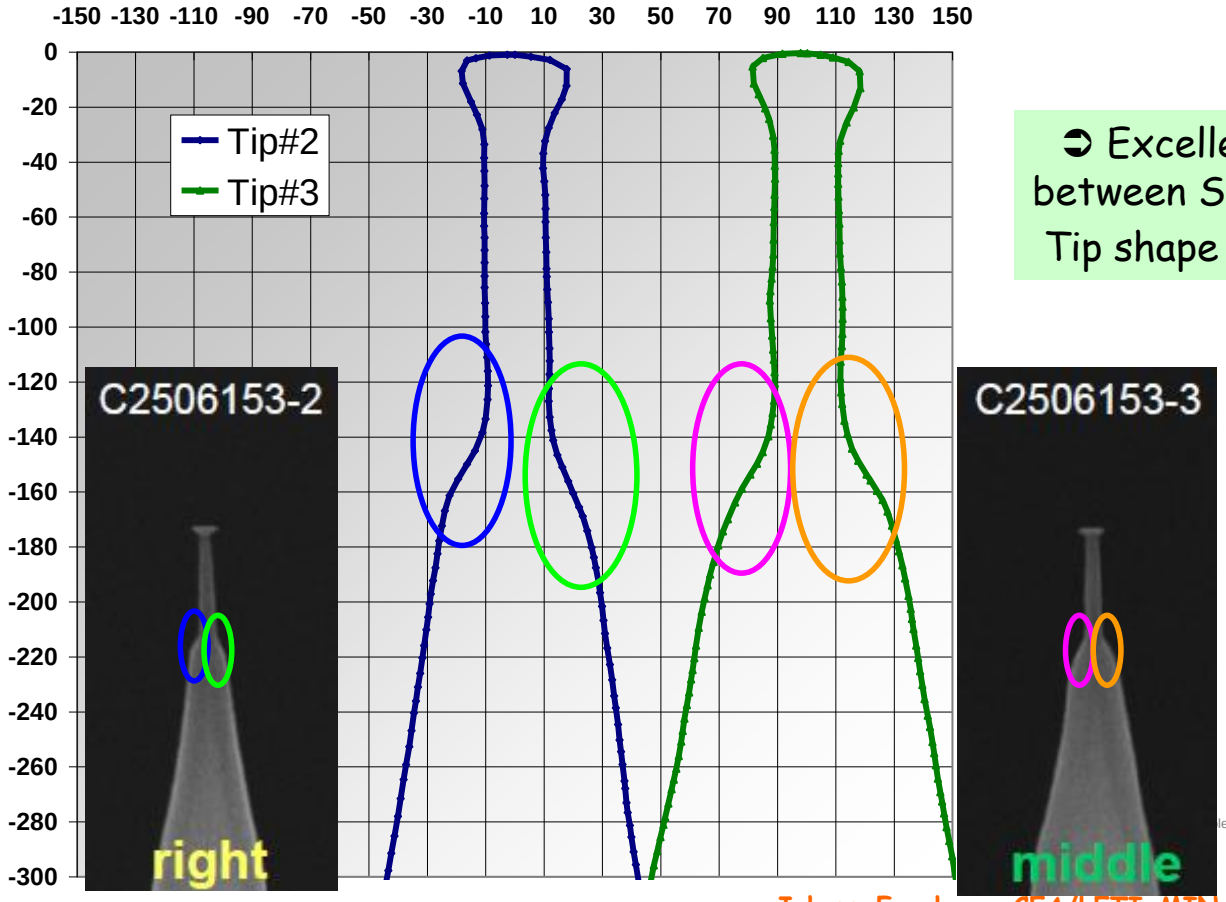
2- New AFM3D probe breakthrough

Overall Shape

➲ Tip Enhancement (Overall Shape)

- For FinFet Structures and small spaces measurements

Need for perfect symmetric tips



➲ Excellent agreement between SEM and AFM3D Tip shape reconstruction

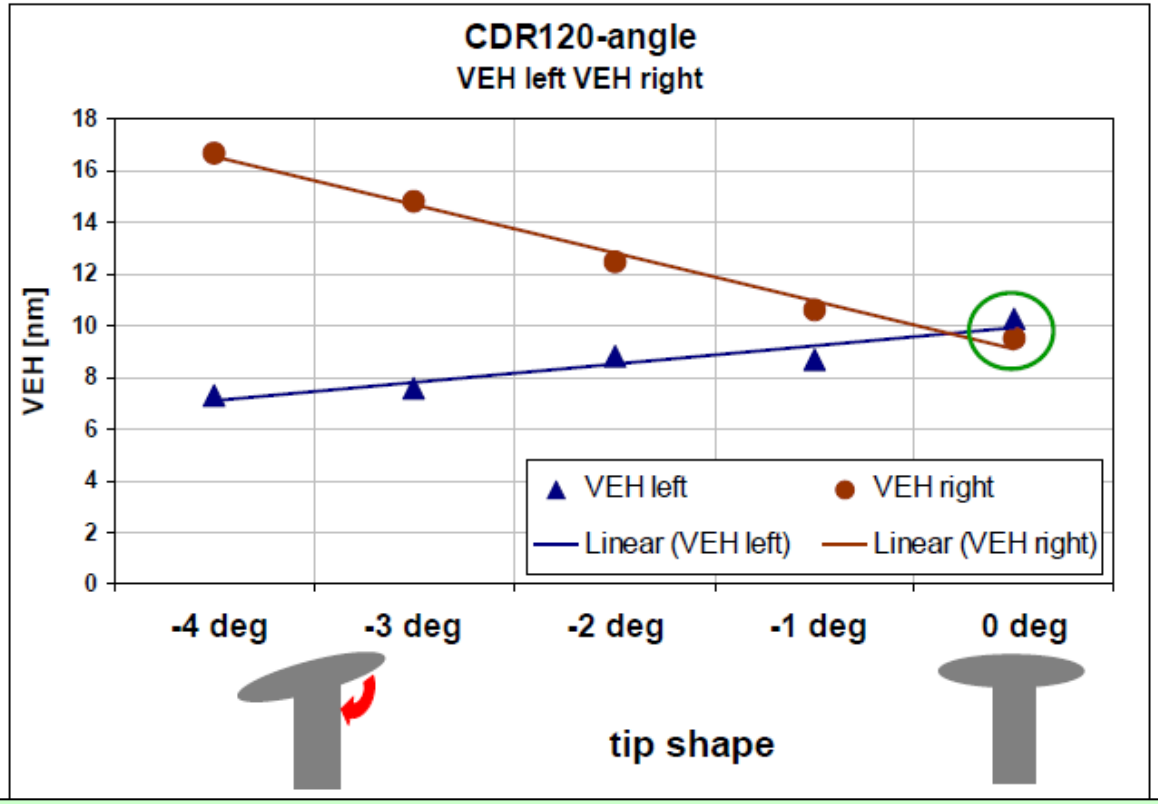
2- New AFM3D probe breakthrough

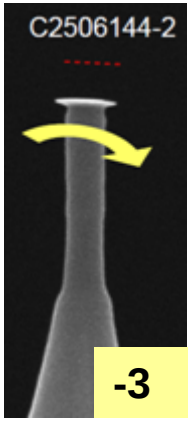
Overall Shape

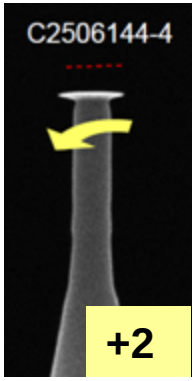
➲ **Tip Enhancement (Overall Shape)**

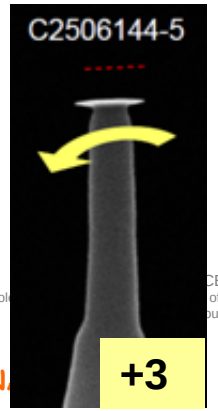
- For FinFet Structures and small spaces measurements

Need for apex angle precision









Excellent correlation and relative accuracy between AFM tip characterization and tip shape process control

2- New AFM3D probe breakthrough

1- Tip Diameter, Design & Materials

2- Tip Wear & Tip Edge Height

3- Overall shape

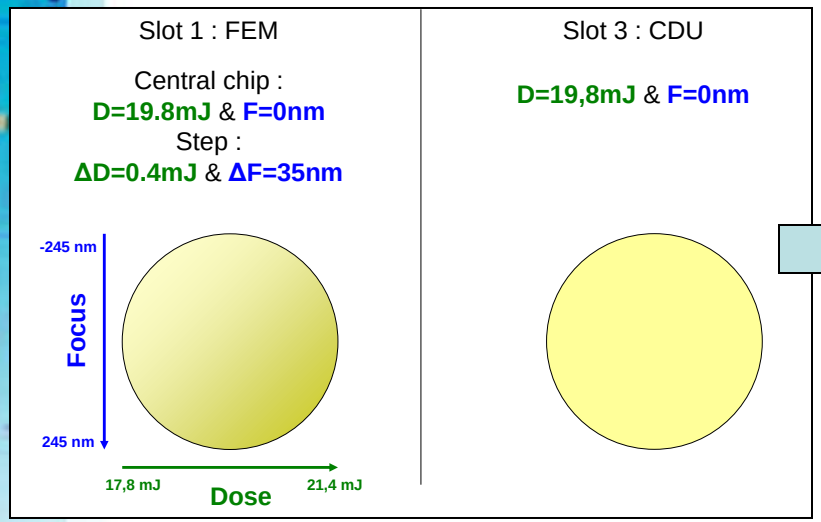
4- Tip Reliability

2- New AFM3D probe breakthrough

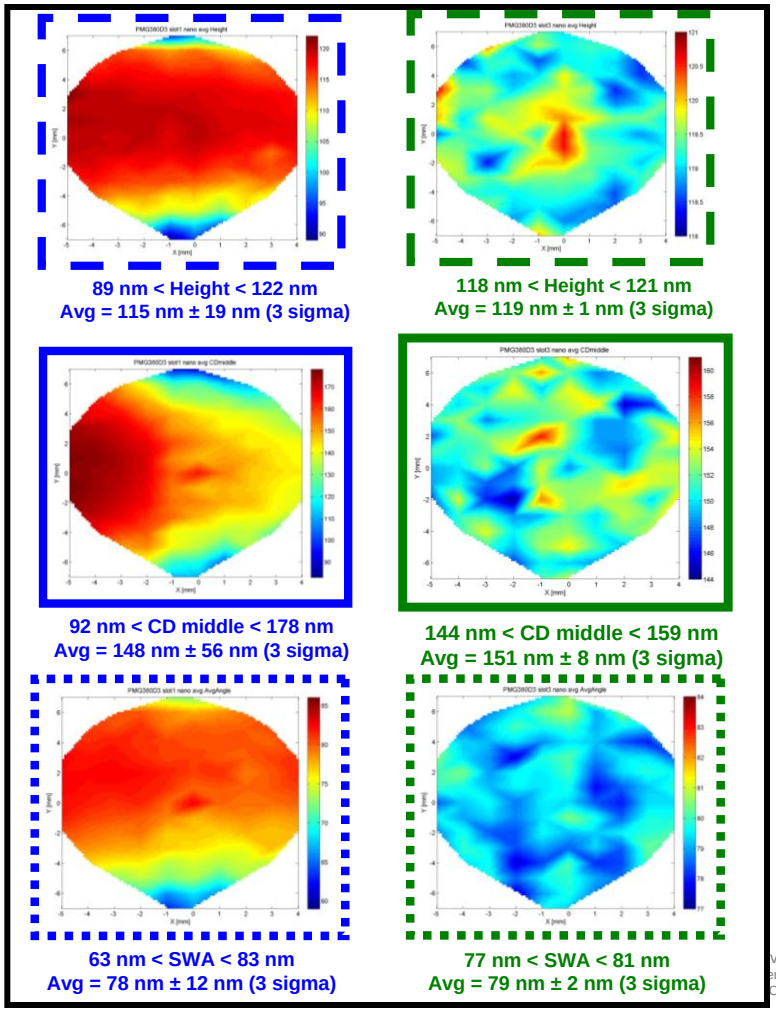
Tip Reliability

➲ Tip Enhancement (Tip Reliability)

- Validation for production use

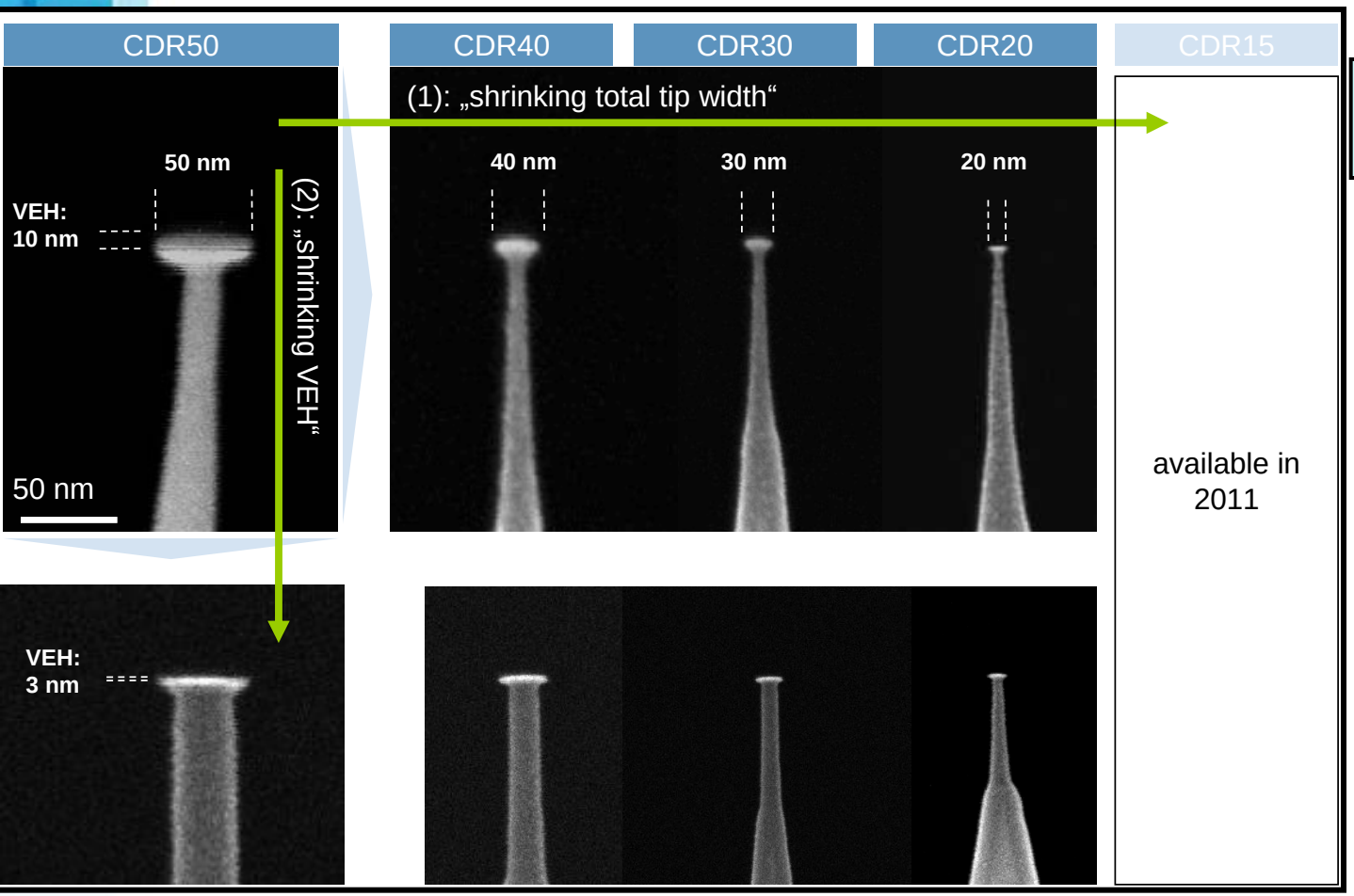


220 measurements per wafer

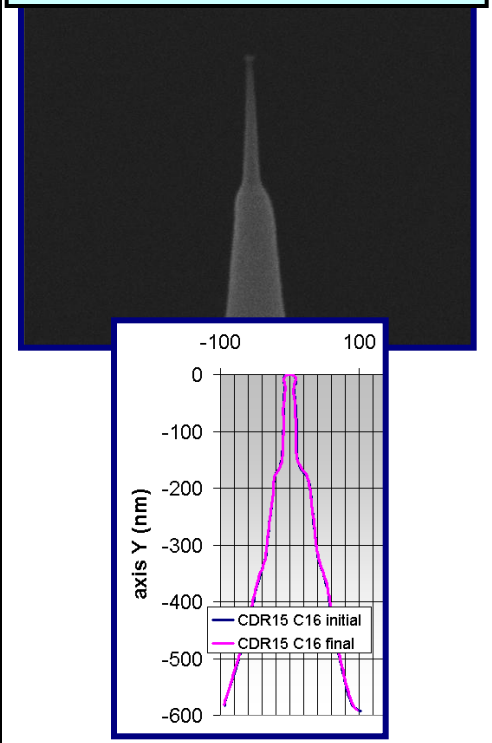


2- New AFM3D probe breakthrough

Introduction of EBD technology for Critical Dimension purpose to answer to sub-28nm nodes

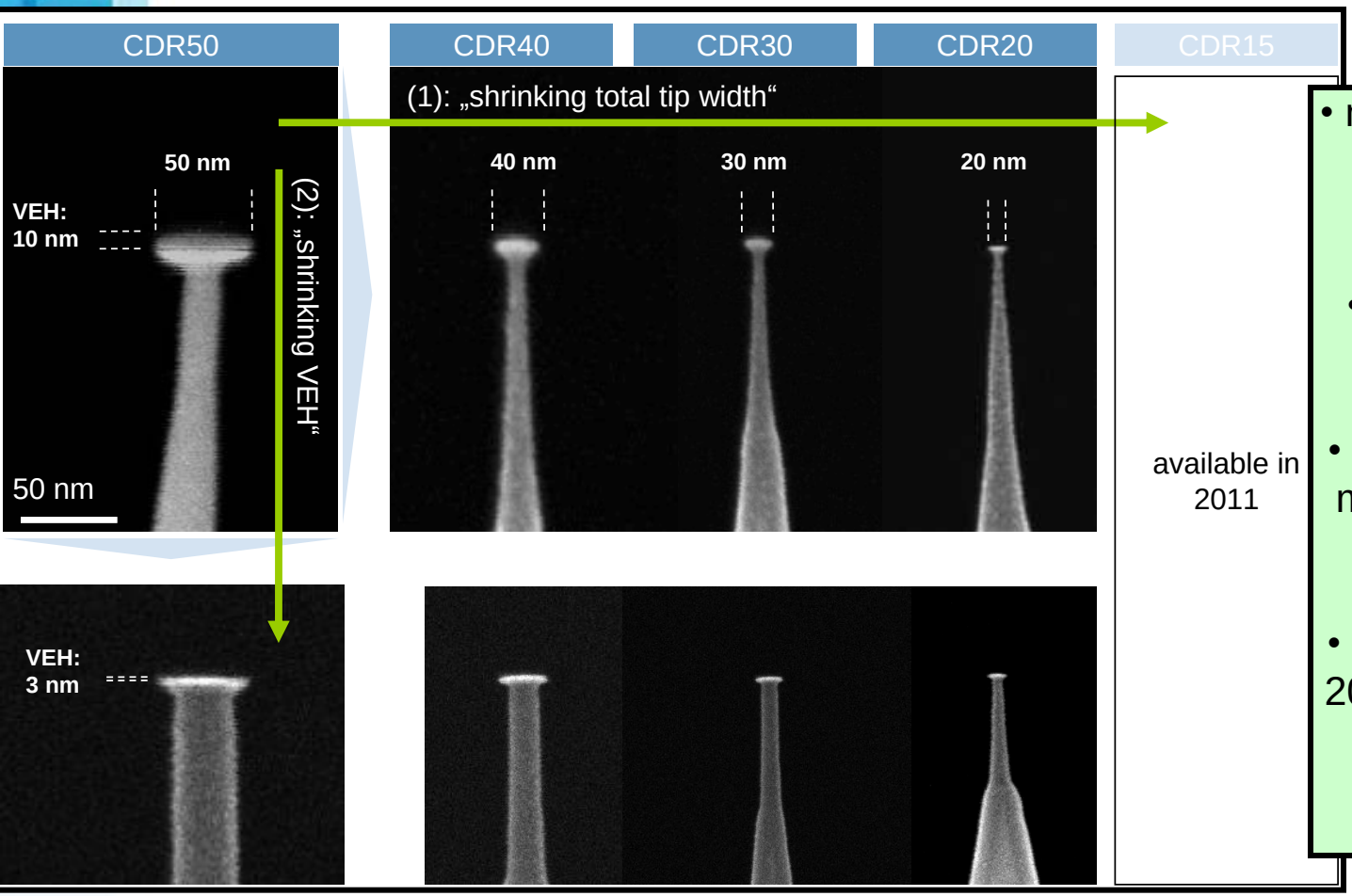


Preliminary Results CDR15 tips



2- New AFM3D probe breakthrough

Introduction of EBD technology for Critical Dimension purpose to answer to sub-28nm nodes



- made of bulk amorphous, diamond-like carbon (HDC/DLC)
- large overhang /lateral reach capability
- constant tip edge radius, maintains resolution over tip lifetime
- readily available down to 20nm. 15nm total tip width qualified during 2011.

OUTLINE

1- Introduction

2- New AFM3D probes breakthrough

3- Hybrid Metrology for High Volume Manufacturing

4- Conclusion

3- Hybrid Metrology for High Volume Manufacturing

➲ State of the art

1- Need for smart data analysis coming from different CD Metrology Techniques (i.e CD-SEM and AFM3D). ⇨ Reduce OPC cycle, reduce process variability through more accurate process window definition, reduce manufacturing process control variability

2- CD-SEM & Scatterometry algorithms need improvement to cope with new materials stack, profile variation, shrinkage phenomena, electron proximity effect, parameters correlation (…)

3- Carrying out AFM3D or TEM measurements and trying to match individually data to CD-SEM or OCD data is not very efficient (time consuming, only a basic target to target comparison)

➲ The exercise is useful but it is not a full accomplished work

➲ The advantages of reference metrology are not fully exploit

NEED THROUGHPUT & SMARTER ANALYSIS

3- Hybrid Metrology for High Volume Manufacturing

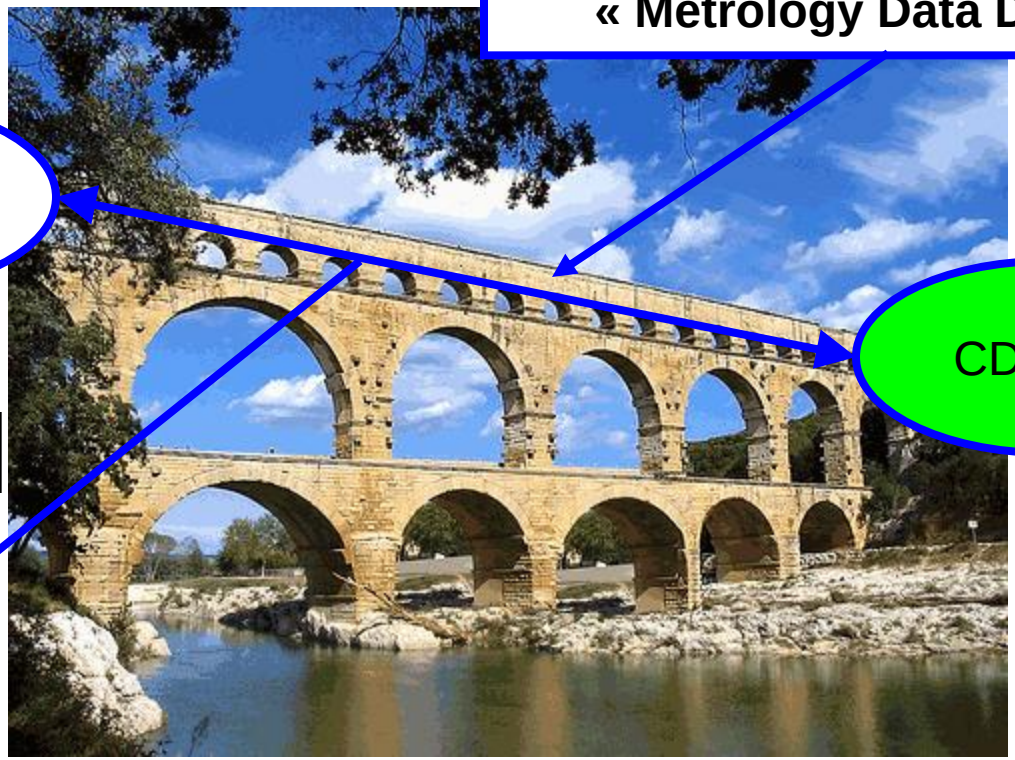
Hybrid Metrology Solution

Hybrid Metrology Software as a
« **MetroDataduct** »
« **Metrology Data Driver** »

Reference Metrology

CD-SEM

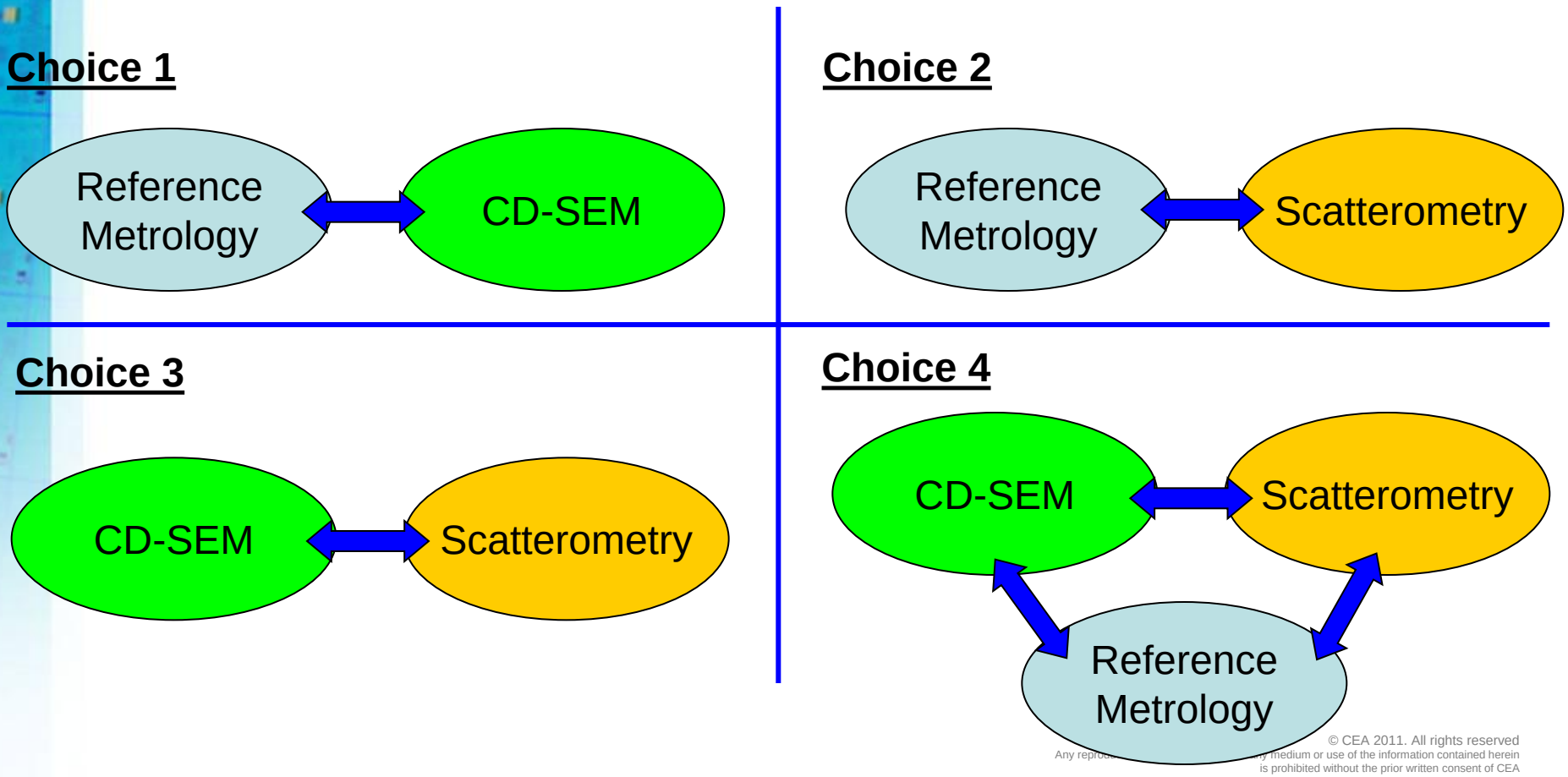
Aqueduct Section



The « Pont du Gard » (Gard Bridge)
Former Roman Aqueduct Bridge (“Aqua” water + “Ductus” = Drive)

3- Hybrid Metrology for High Volume Manufacturing

Hybrid Metrology can be part of any CD Metrology industrial strategy



3- Hybrid Metrology for High Volume Manufacturing

Choice 1: AFM3D & CD-SEM

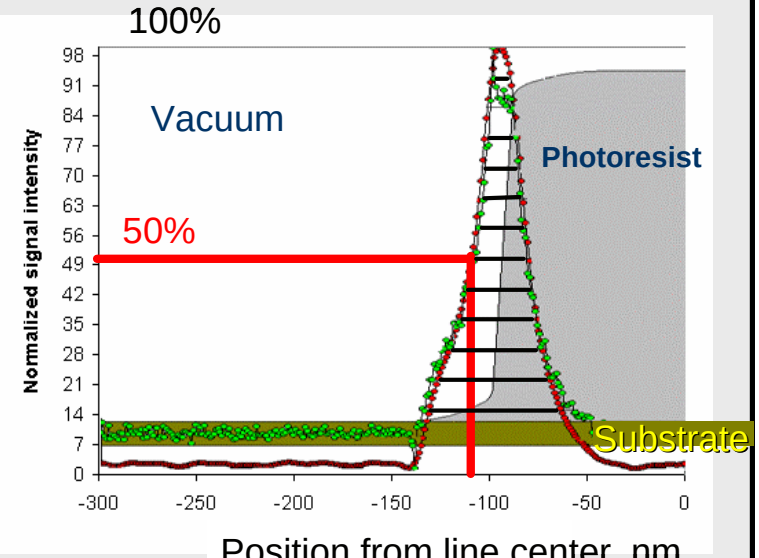
No Physical relationship between Secondary electron signal threshold analysis and physical measurement on the pattern

CRITICAL SHAPE METROLOGY (CSM)

Monte-Carlo SEM Simulation

Input: ✓ Line geometries ✓Material properties

✓ Landing energy ✓ Beam size



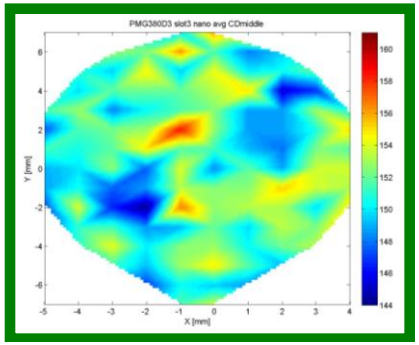
E-Beam size :

- zero beam - finite size

3- Hybrid Metrology for High Volume Manufacturing

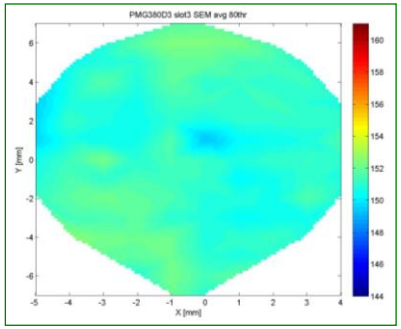
Choice 1: AFM3D & CD-SEM

AFM3D data for CD Middle



144 nm < CD middle < 159 nm
Avg = 151 nm ± 8 nm (3 sigma)

CD-SEM data

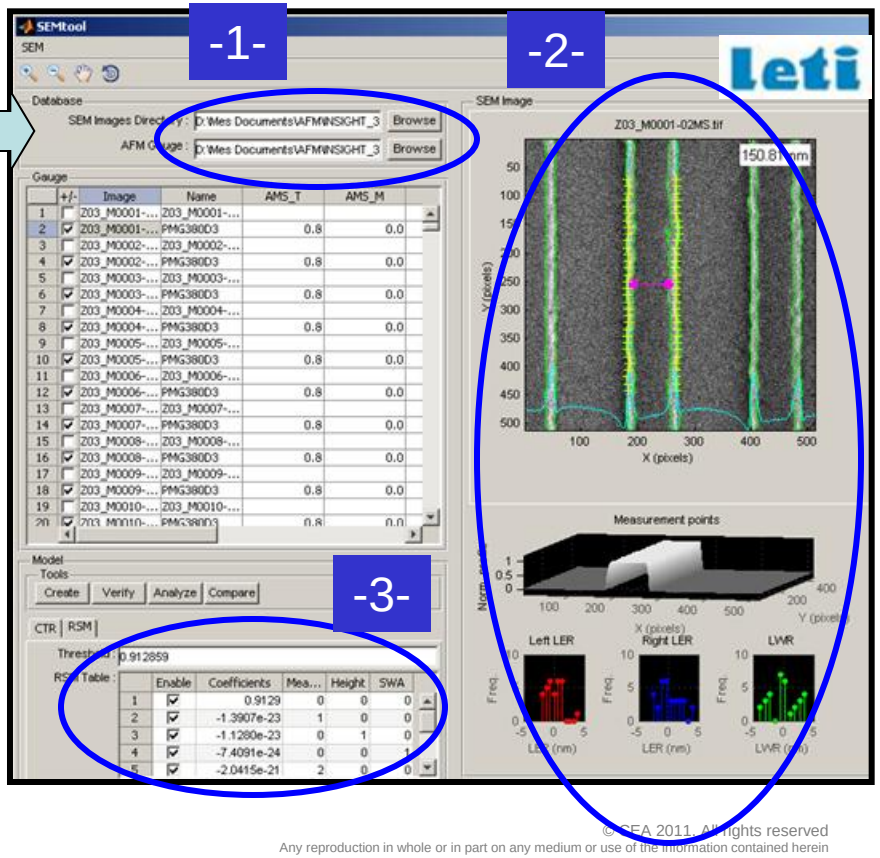


149 nm < CD < 153 nm
Avg = 151 nm ± 2 nm (3 sigma)

Because of multiple geometry variation across the wafer for CDU or FEM, the final error on process windows or process control can be huge

New Threshold computation in order to make CD-SEM more accurate (without changing any hardware, no impact on throughput, take into account electron proximity effect, shrinkage phenomenon…)

Hybrid Metrology Software Solution

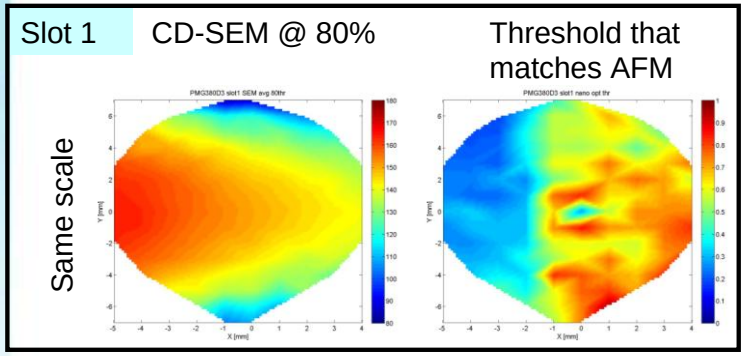


3- Hybrid Metrology for High Volume Manufacturing

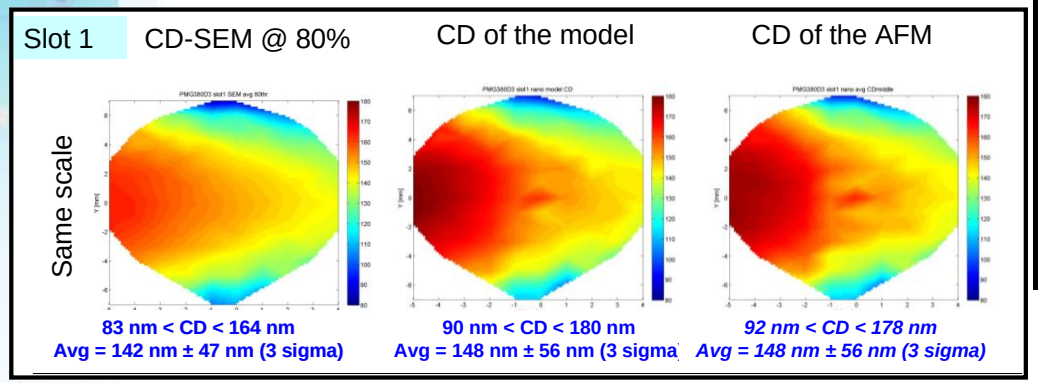
Choice 1: AFM3D & CD-SEM

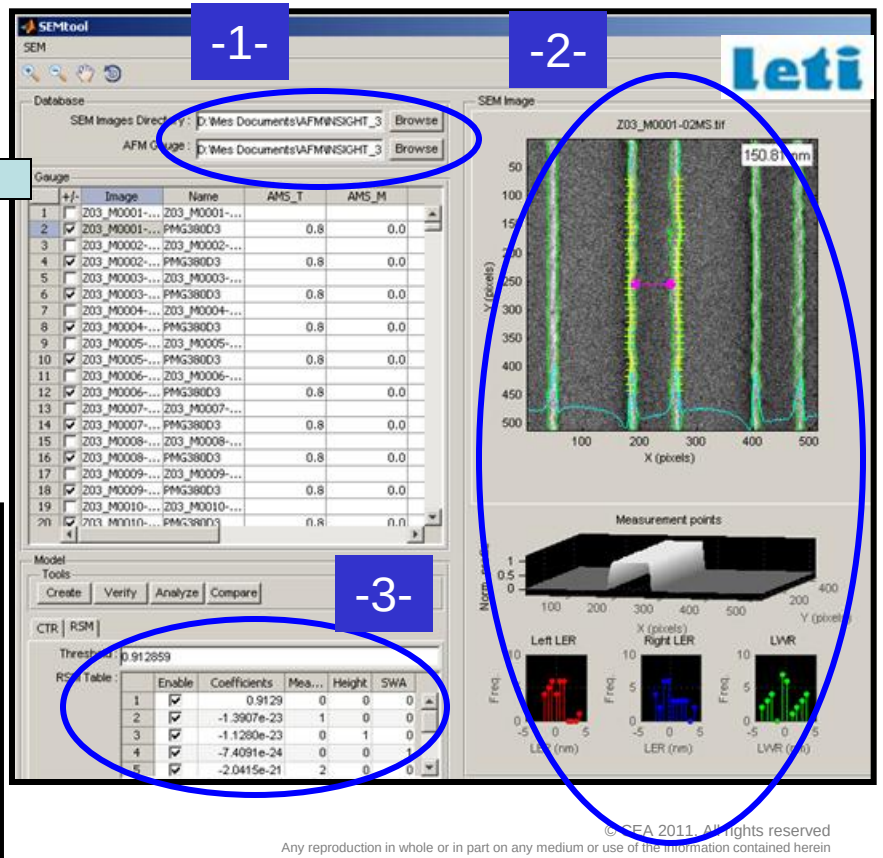
Hybrid Metrology Software Solution

Step 1: Define the right Threshold



Step2: Define CD of the model that match reference metrology





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4- CONCLUSION

1- Hybrid Metrology is an interesting alternative for the future of CD Metrology for HVM. **First demonstrator has been a success** and has demonstrated that something can be done to enhance CD Metrology **without major investments and must help in reducing costs and driving innovations**

➲ **LETI is working on a Universal hybrid metrology software that should be compatible with any kind of industrial strategy solution**

➲ **It should contribute to more manufacturing added value of CD Metrology**

2- New AFM3D tip breakthrough is necessary to overcome silicon based tips strong limitations. EBD Carbon tips is one solution.

➲ **We succeeded within a year to validate tip design and production usage down 20nm diameter (readily available). Full Carbon tips have been introduced with a better behavior than carbon nanotubes tips for CD Metrology.**

➲ **Continuation to provide state of the art tips to fulfill roadmap recommendations (for example for FinFet Metrology…)**

ACKNOWLEDGEMENTS

- Thanks to Nanotools Team in Munich with whom nothing would have been possible.

- Thanks to my team (Ludivine Dourthe and Pascal Faurie) for their excellent work that has contributed to obtain so many results.

- Thanks to Mazen Saied for his excellent work on hybrid metrology software

- Thanks to Narender Rana (IBM/Fishkill) who helps us to validate β tips on IBM wafers through ST/LETI/IBM Joint Development Program