3DSEM measurements of Stacked-NWs Transistors height using new eTilt Metrology Algorithm

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Agenda

- CMOS roadmap and 3D metrology needs
- 3DAM EU project
- Post fin patterning characterization
- Simulation study (Chariot)
- Summary

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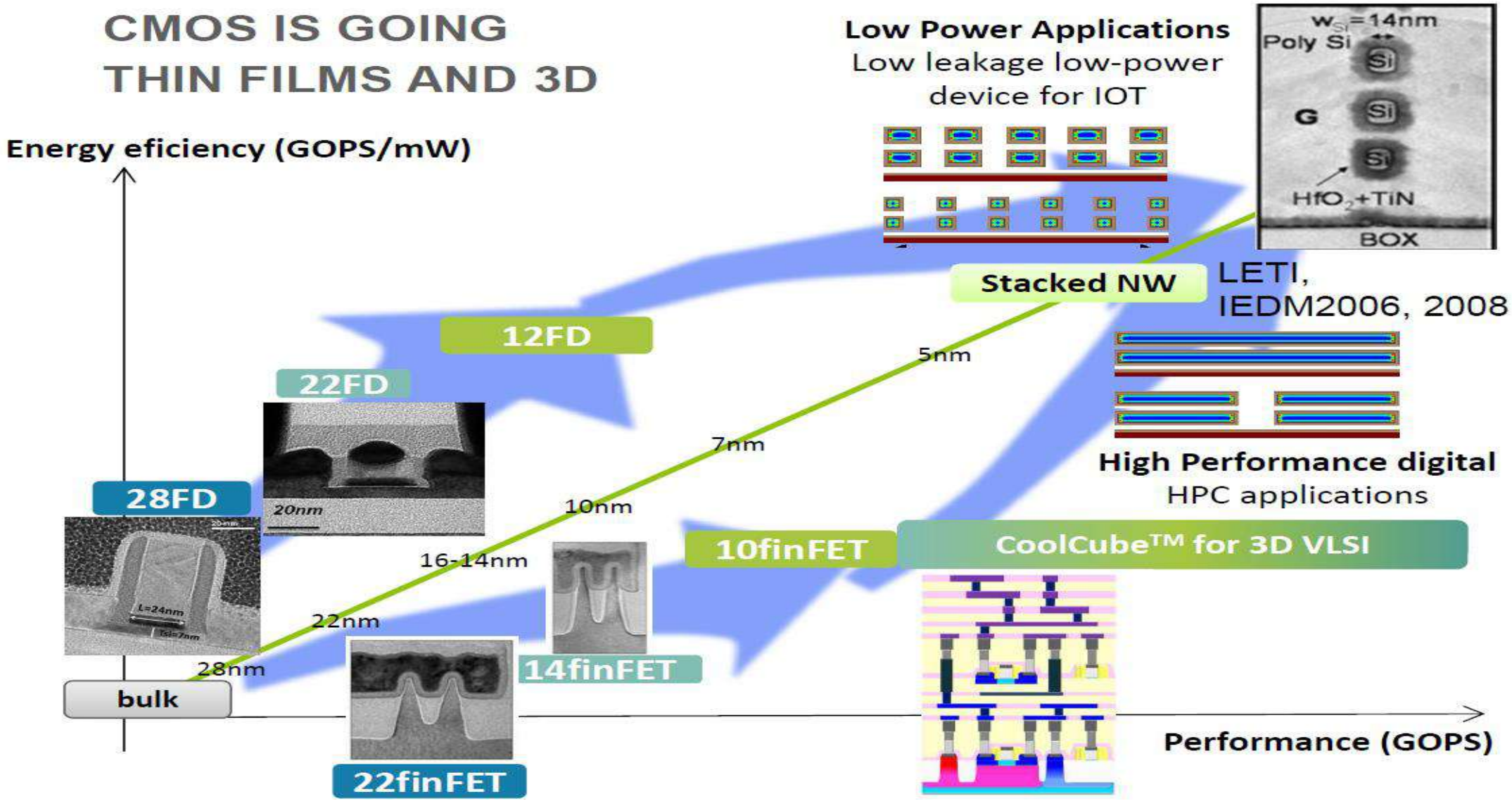
CMOS roadmap



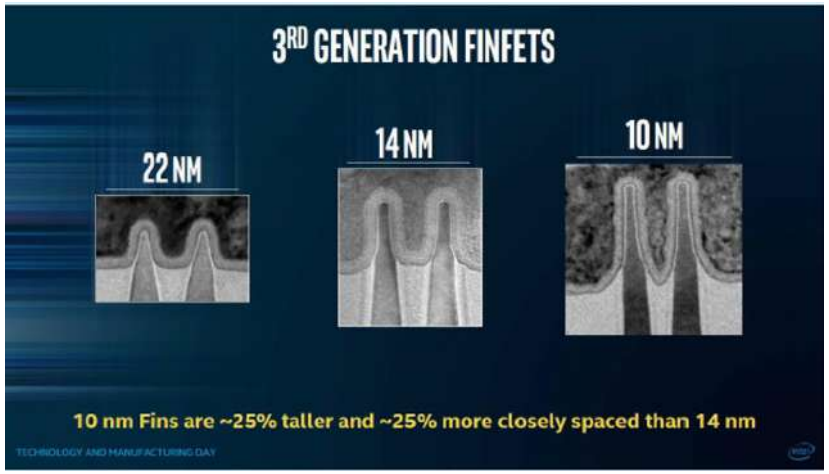
Thomas Ernst, LETI – Emerging technologies for the future of computing
Israel Innovation Week, April 2017

3D metrology – Technology overview

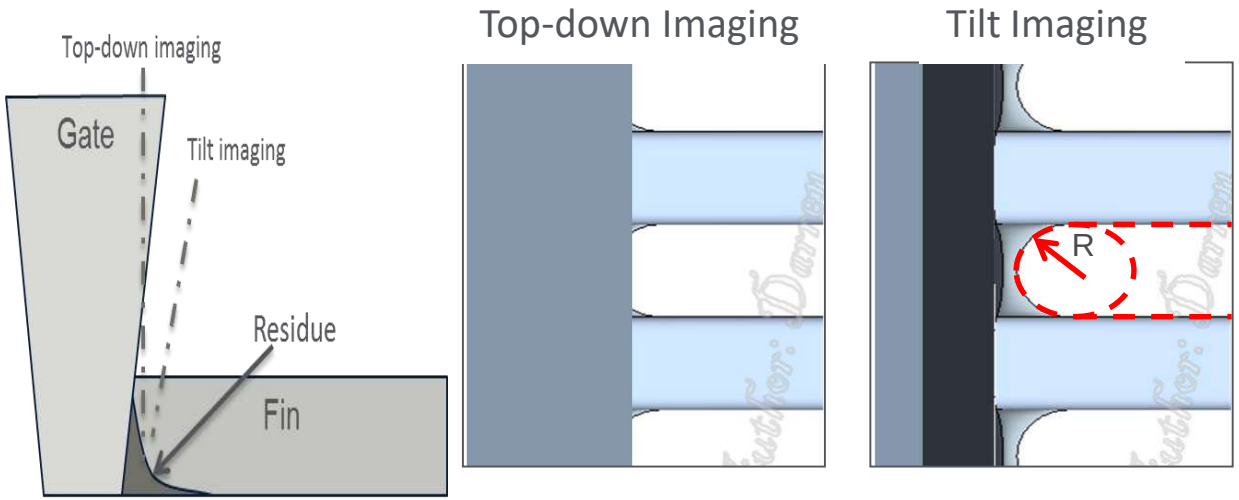
Technique:	CDSEM	OCD	AFM	TEM/XSEM
What to measure:	CD, roughness, material contrast	CD, Profile	CD, Height, Electrical contrast	CD, Profile
Where to measure:	Anywhere	Periodic grating	Anywhere	Anywhere
Time 2 measure:	Seconds	Seconds	Minutes to hours	Days
Time 2 recipe:	Minutes	Days to weeks	Minutes	Hours to day
Destructive:	Minor (resist)	Negligible	Negligible	Yes
Additional trengths:	✓ High 2D precision and sensitivity ✓ Results with Image	✓ Statistical pattern profile metrology	✓ Hight metrology with High accuracy ✓ Resutls with Image	✓ Full profile information ✓ High accuracy ✓ Resutls with Image
Limitation:	▪ Limited 3D metrology ▪ Affected by profile	▪ Requires specific target	▪ Tip wear ▪ Limited by pattern density	▪ Expensive for large statistical sample

Benjamin Bunday, A. F. Bello, Eric Solecky, Alok Vaid, "7/5nm logic manufacturing capabilities and requirements of metrology," Proc. SPIE 10585, Metrology, Inspection, and Process Control for Microlithography XXXII, 105850I (22 March 2018); doi: 10.1117/12.2296679

Challenges on advanced FinFET



Source: intel.com



Poly footing application

- Challenges
  - With nodes scalling, Fins are getting taller and narrower
  - Edge slope is not straight anymore

- Current limitation
  - CD SEM metrology is developed for planar measurements of straight lines/contacts (widths/diameters)

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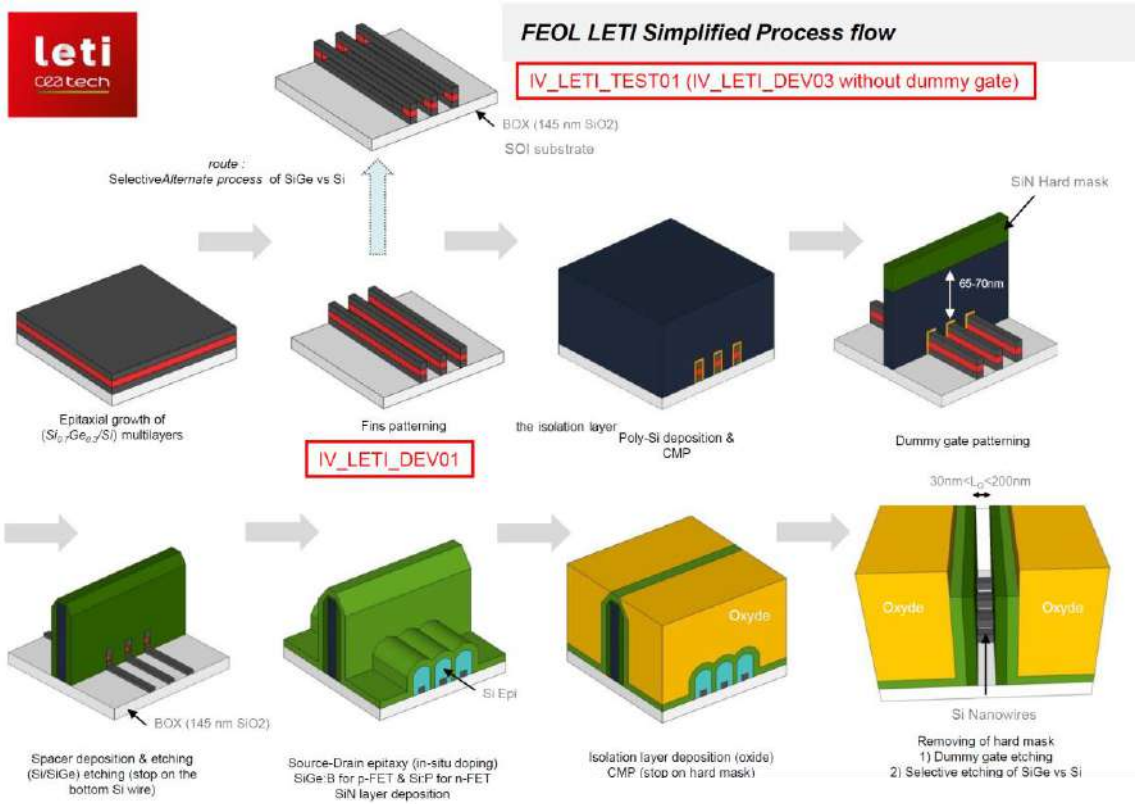
3DAM EU project frame

- Objective:
  - Develop the 3D metrology for the 3D technology

- Test vehicule:
  - Gate All Around FET from LETI post fins patterning composed of:
    - 12nm Si sheet
    - 12nm Si/Ge sheet
    - 12nm Si sheet



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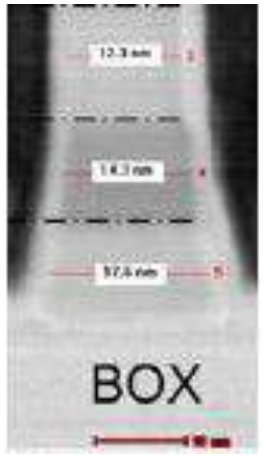
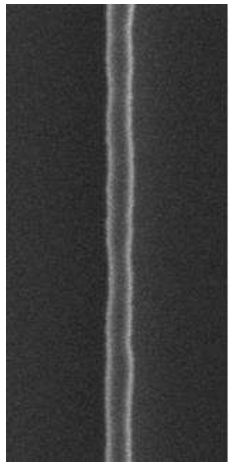
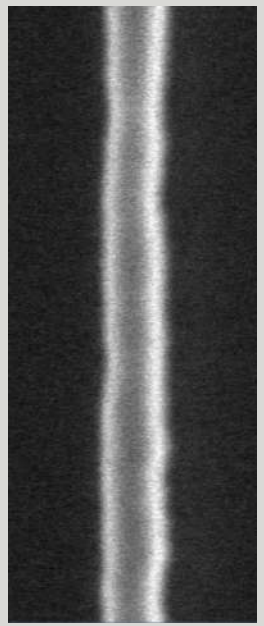
Tilt imaging post fin patterning



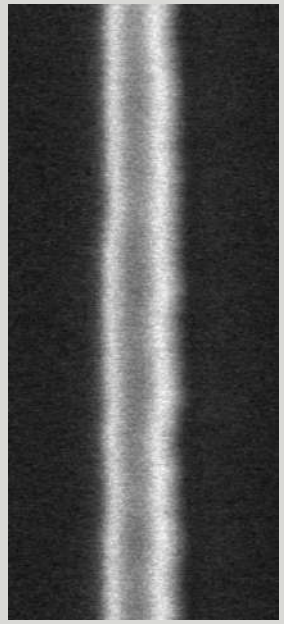
Generic image



SEM top view



5deg tilt view

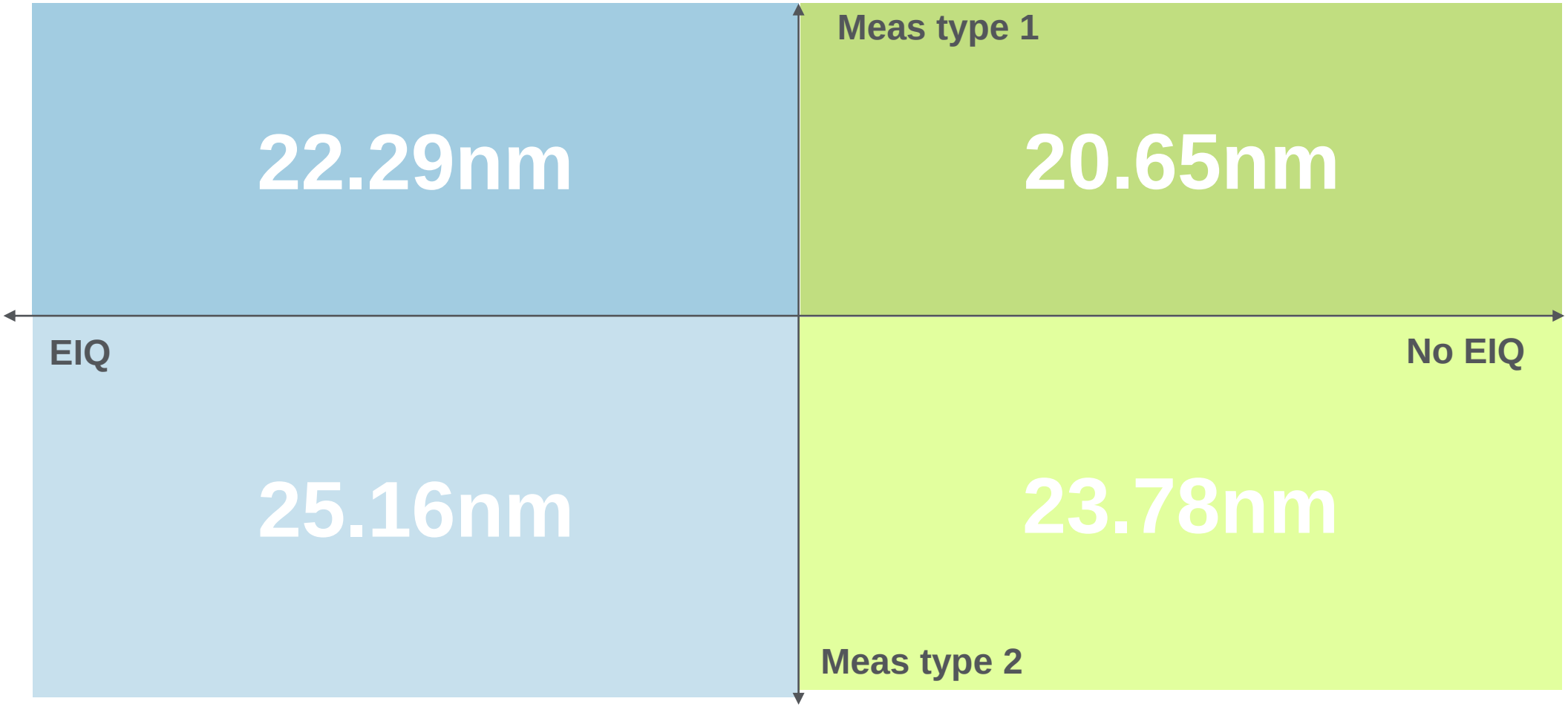


12deg tilt view

Using eTilt technology

- In order to characterize the features in 3D (height, slope) we need to have a better appreciation of the 3D aspect of this feature by using eTilt technology

Height measurement results with LEA



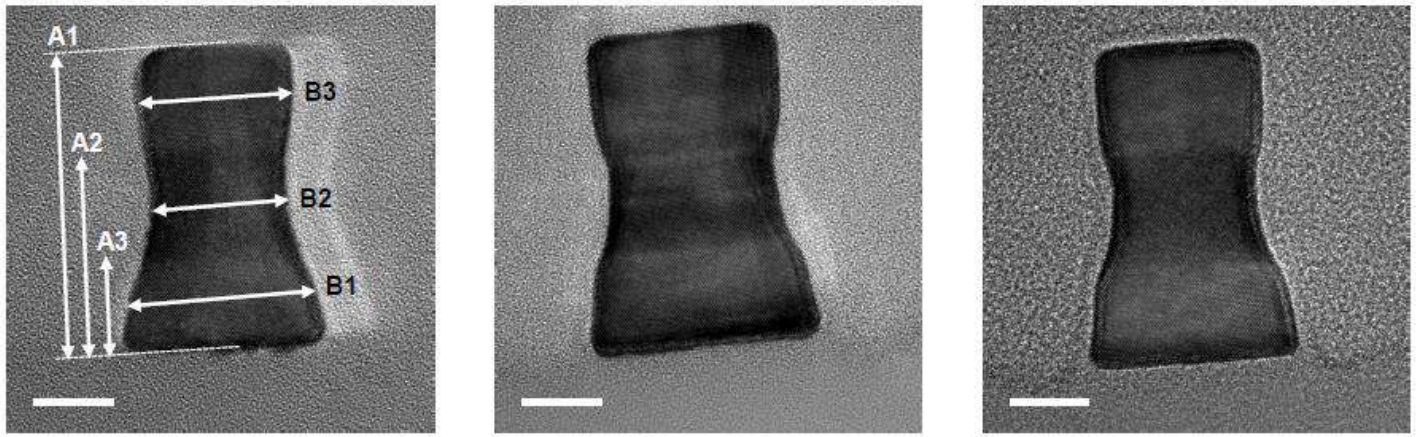
Up to 5nm difference on the topo points placement

Correlation with TEM X-Section

leti ceatech

P6 DEV7

Die 1 | Die 3 | Die 5



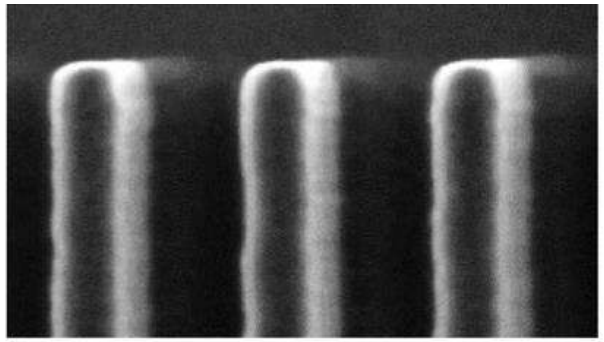
+/- 0,5 nm	A1	A2	A3	B1	B2	B3
Die 1	38,7	25,0	12,3	23,5	17,0	19,2
Die 3	39,8	23,4	12,5	27,0	21,4	23,9
Die 5	40,6	26,7	13,2	24,7	18,3	20,8

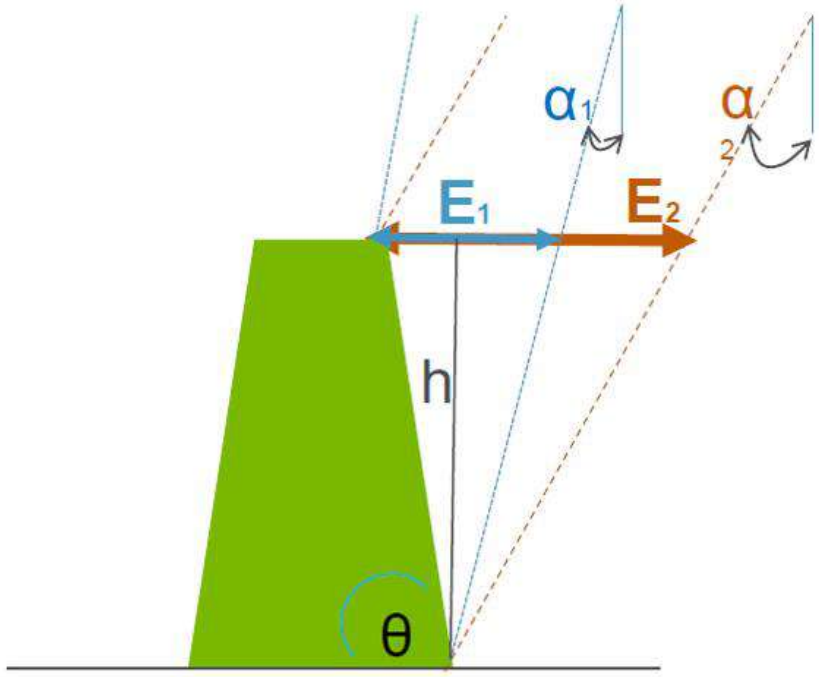
CDSEM3D measurement are off by 15nm

3D Measurement basic

$$\begin{cases} E_1 = SideWall(CD) + \tan\alpha_1 \cdot h \\ E_2 = SideWall(CD) + \tan\alpha_2 \cdot h \end{cases}$$

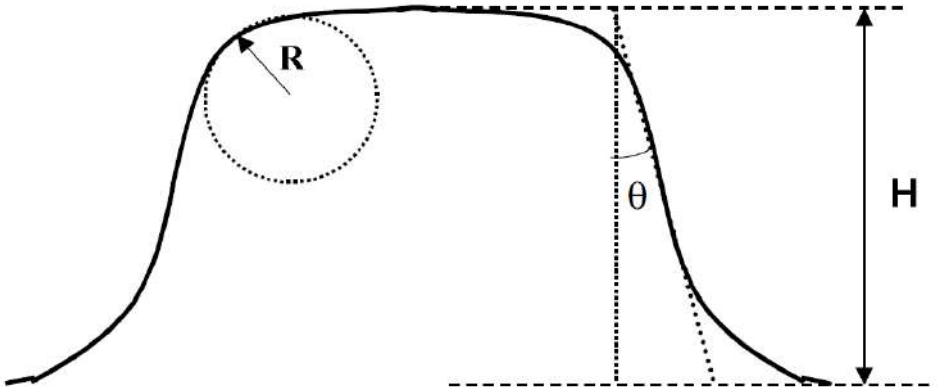
$$\begin{cases} h = \dfrac{E_2 - E_1}{\tan(\alpha_2) - \tan(\alpha_1)} \\ \theta = \arctan\left(\dfrac{E_2 - E_1}{E_1 \tan\alpha_2 - E_2 \tan\alpha_1}\right) \end{cases}$$

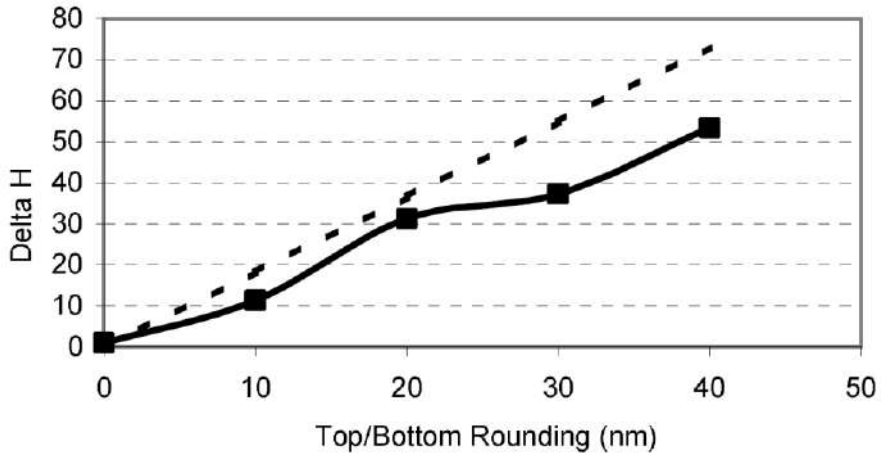




- Tilt angle is limited by pattern aspect ratio

What is the challenge on Edge width for Height reconstruction?



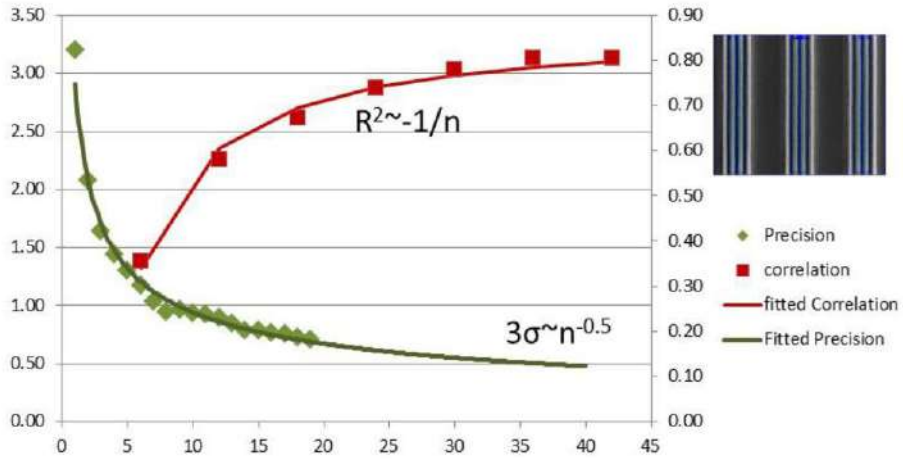


Roman Kris, Ofer Adan, Aviram Tam, Albert Yu. Karabekov, Ovadya Menadeva, Ram Peltinov, Ayelet Pnueli, Oren Zoran, Arcadiy Vilenkin, "Height and sidewall angle SEM metrology accuracy", Proc. SPIE 5375, Metrology, Inspection, and Process Control for Microlithography XVIII, (24 May 2004); doi: 10.1117/12.537938

Bottom accuracy is key for height measurement

Precision measurement

$$3\sigma_h = \frac{\sqrt{(3\sigma_{E_1})^2 + (3\sigma_{E_2})^2}}{\alpha_2 - \alpha_1}.$$



Comparison CDSEM to OCD via R^2

Ideal sampling for reaching a precision <1nm is more than 12 lines

Xiaoxiao Zhang, Patrick W. Snow, Alok Vaid, Eric Solecky, Hua Zhou, Zhenhua Ge, Shay Yasharzade, Ori Shoval, Ofer Adan, Ishai Schwarzband, Maayan Bar-Zvi, "Solving next generation (1x node) metrology challenges using advanced CDSEM capabilities: tilt, high energy and backscatter imaging", Proc. SPIE 9424, Metrology, Inspection, and Process Control for Microlithography XXIX, 94240G (19 March 2015); doi: 10.1117/12.2087267

2.7nm precision at 3*sigma were achieved on height measurement (1 line)

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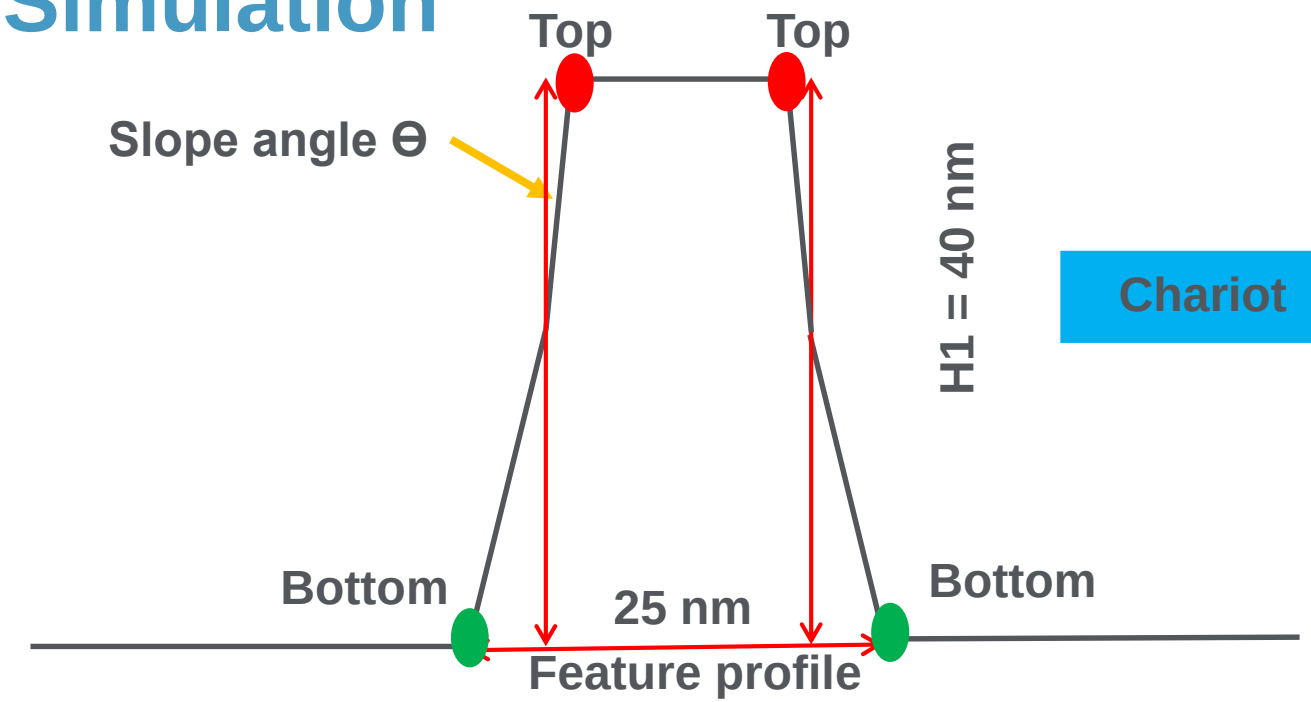
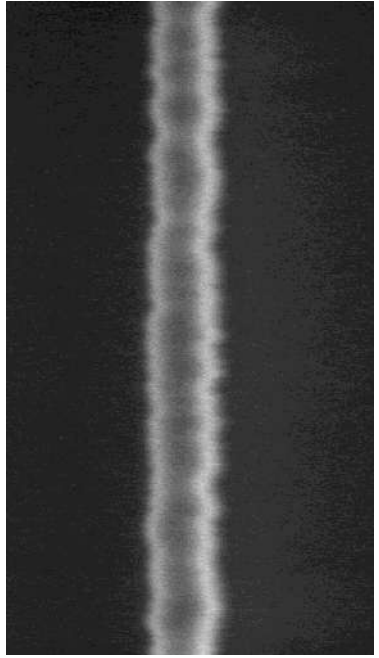
Simulation



Chariot

Simulated feature



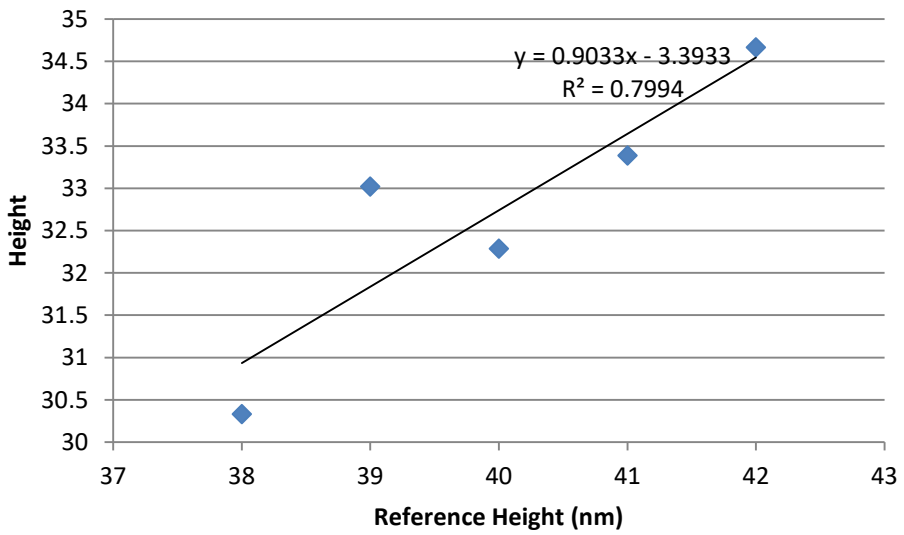
Real feature

Model profile with variable parameters(Height (H1), Theta)

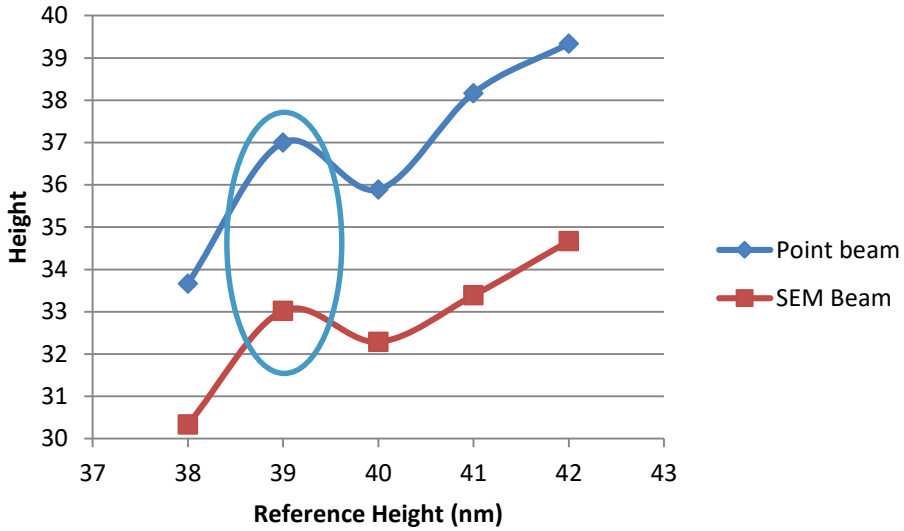
The problem: Accurate Definition of the Profile Top location through Image Analysis:

SEM Simulation to Real Profile (Ground Truth) comparison

Comparison with simulation



The Measured Height vs Reference Height



Beam Convolution influence on the Height Measurement

Simulation results are correlated to the reference height

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Summary

- 3DSEM remain the best method for inline measurement
  - Fast measurement (~sec)
  - Indie measurement (everywhere)

- New algorithms enable a more accurate height measurement with
  - Accurate detection of the bottom
  - Precision that is correlated to the sample size

- Simulation demonstrate that the new algorithms are not sensitive to
  - Height
  - Monotonic with slope

- VeritySEM 3D metrology improvement will address the 3D challenges for the Xnm nodes

Acknowledgements

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