MBIR Technology and Applications Introduction

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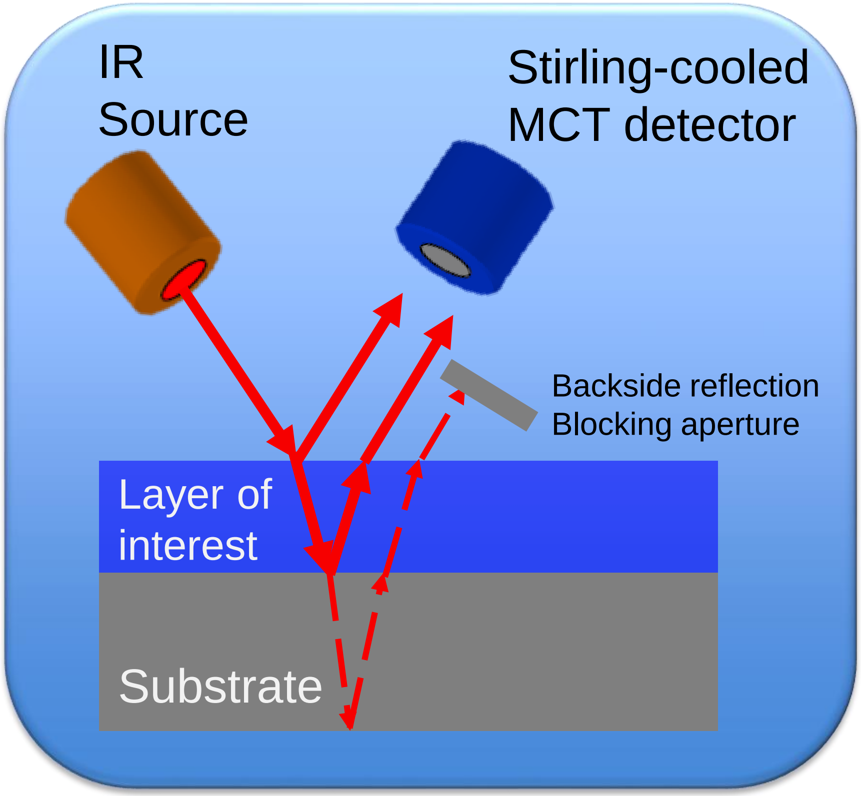
MBIR Technology and Product Introduction

Model Based Infrared Reflectometry (MBIR)

Instrument Setup



IR Source

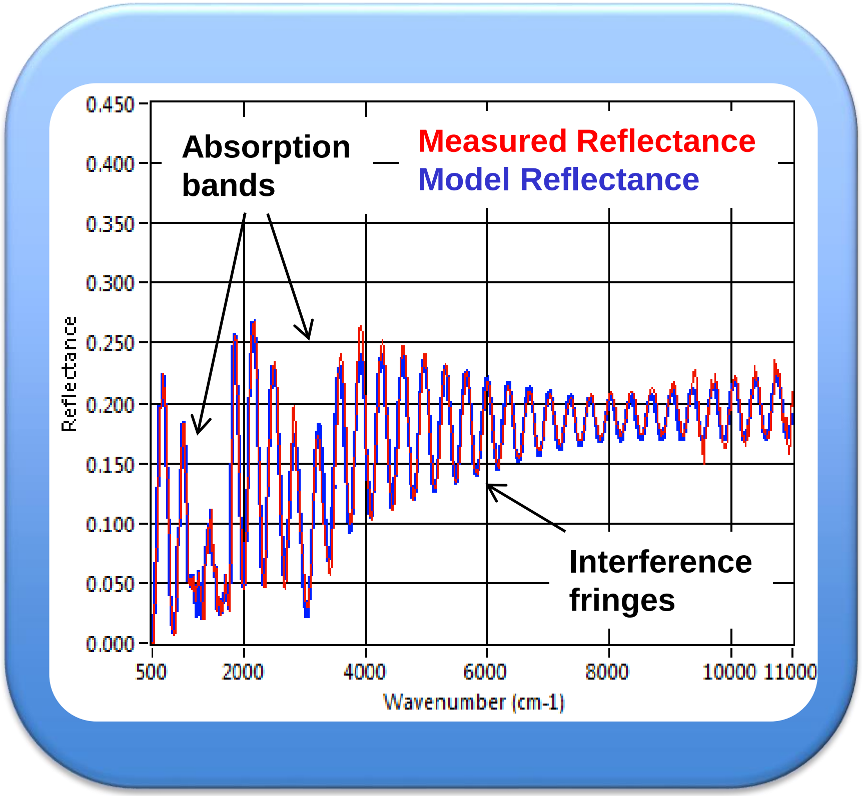
Stirling-cooled MCT detector

Backside reflection Blocking aperture

Layer of interest

Substrate

Example Measurement



Infrared light is reflected off the sample and the reflectance versus wavelength spectrum is analyzed with a model of the sample structure.

IR3200 Series: Configuration

- Technology: Model Based Infrared Reflectometry (MBIR)
- Fully Automated Platform
  - 2 Load Ports, E84 support, SECS/GEM
  - Wafer size configurable up to 300mm
- Cognex Patmax® pattern recognition software.
- Fast Camera based Autofocus
- Mini-Environment Temperature Control.
- Optical Configuration Options:

Product	Spot Size	Wavelength Range	Angle Of Incidence
IR3200N	200x800 µm	0.9-20 µm	45 deg
IR3200S	50 µm	0.9-20 µm	25 deg

Major MBIR Applications

Category	Application Examples
Doped EPI and Implant Applications	• Dopant Dose in thin SiGe, SiP and SiCP EPI layers • Ultra Shallow Junction Implant Dose and Depth
HAR Trench and Via Applications	• Shallow and Deep Isolation Trenches • Poly Recess Applications
3D Integration Applications	• Through Silicon Vias • Wafer Thinning
Memory Applications	• 3D NAND: Multilayer filmstacks; Geometry of Trenches and Vias • Amorphous Carbon: Film thickness; Geometry of Trenches and Vias • Stacked DRAM Storage Cell Geometry • Embedded Trench DRAM Geometry
BEOL Film Applications	• FBEOL TEOS Thickness • Polymer/resist thickness (PSPI, PIQ)
EPI Applications	EPI thickness and substrate doping level: • Silicon EPI • SiC EPI • GaN EPI

Doped EPI and Implant Applications

Spectral Range for MBIR Doping Metrology

MBIR wavelength range:

20 um	5 um	2.5 um	1.67 um	1.25 um	0.9 um
500 cm^{-1}	2000 cm^{-1}	4000 cm^{-1}	6000 cm^{-1}	8000 cm^{-1}	11000 cm^{-1}

Drude dispersion formula:

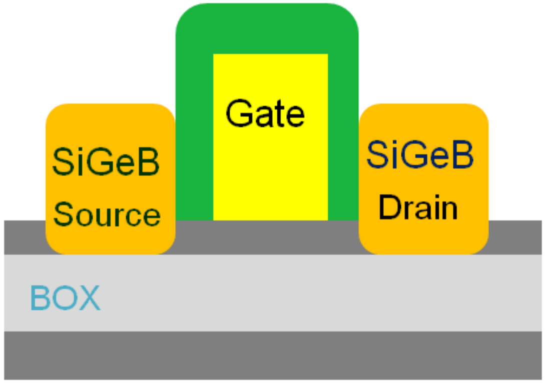
$$\varepsilon(\nu) = \varepsilon_{Si}(\nu) - \frac{4\pi N q^2}{\nu^2 + i\nu\gamma} / (2\pi c m^*)$$

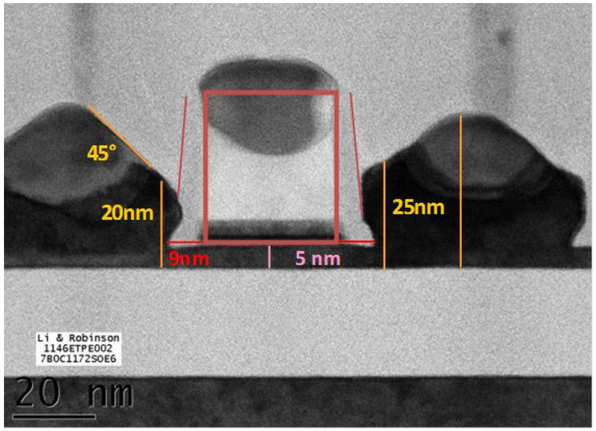
N = Free Carrier Concentration
ν = Wavenumber [cm-1]

Longer wavelengths
Sensitivity to free carriers

Doped EPI (SiGeB, SiCP, SiP)

14nm P-MOS, Raised Source Drain FDSOI





MBIR provides a means for non-destructive production monitoring of the doping in highly doped epitaxial layers, such as SiP, SiCP or SiGeB.

Doped EPI (SiGeB / SiP / SiCP), DOE Example

SiGe:B DOE Condition

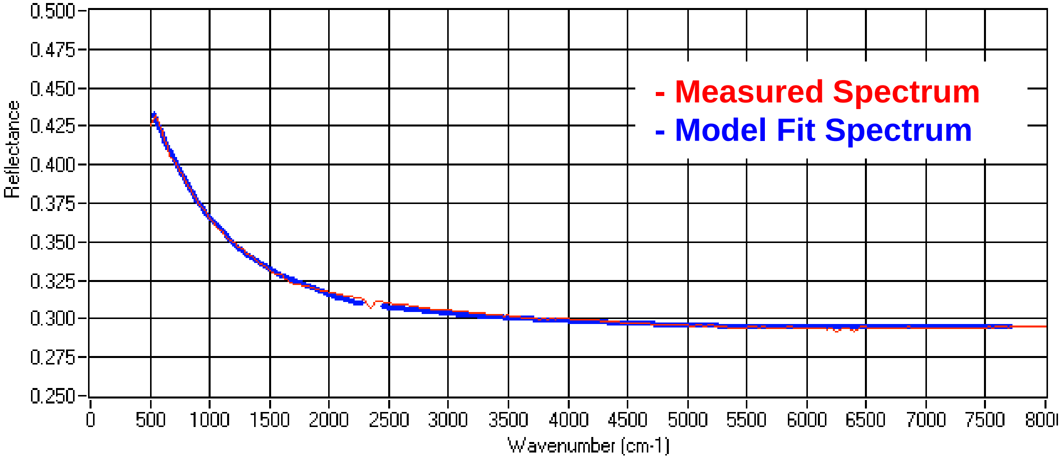
Wafer numb.	Deposi-tion time (A.U.)	GeH4 flow (A.U.)	B2H6 flow (A.U.)	XRR thick. at center (A.U.)	SIMS %Ge at center (A.U.)	SIMS [B] at center (A.U.)
#1	82	100	83	74	102	69
#2	100	81	83	61	90	146
#3	118	100	83	106	102	67
#4	100	119	83	129	111	44
#5	82	81	100	59	89	212
#6	82	119	100	114	109	58
#7	100	100	100	100	100	100
#8	100	100	100	100	99	98
#9	118	81	100	84	88	212
#10	118	119	100	166	109	62
#11	100	81	117	81	87	288
#12	82	100	117	92	98	133
#13	100	119	117	149	108	79
#14	118	100	117	131	99	131
#15	100	100	100	100	100	98
#16	82	119	100	120	110	58
#17	82	119	100	117	110	58

Filmstack

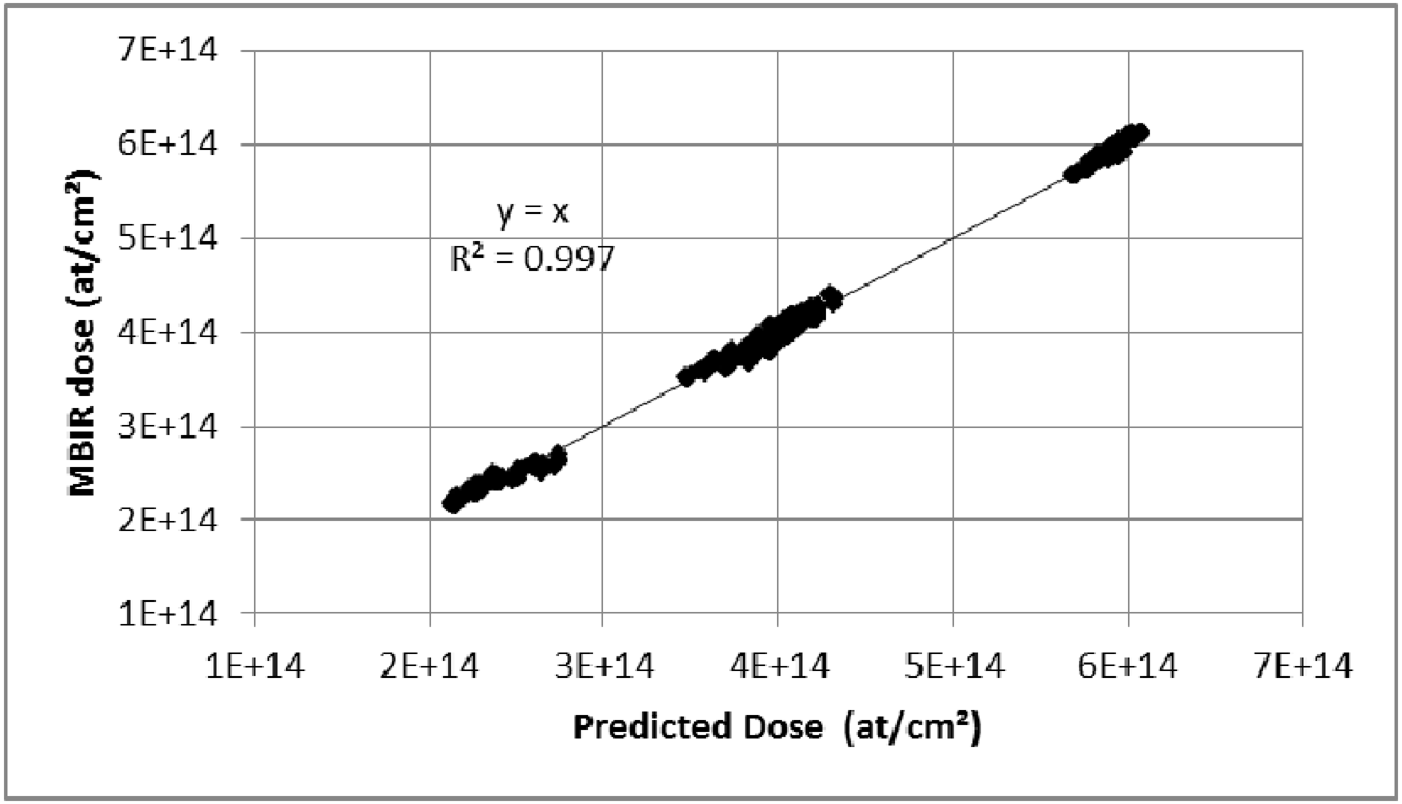

B-Doped SiGe

Silicon Substrate

MBIR Spectrum



MBIR Dose vs. Predicted Dose, DOE Example



- Good agreement between MBIR measurement and predicted dose

Source: MBIR for In-line Doping Metrology of Epitaxial SiGe:B and SiC:P Layers, R. Duru et al., ASMC 2013

Doped EPI MBIR Stability Data

B-Doped SiGe

Silicon Substrate

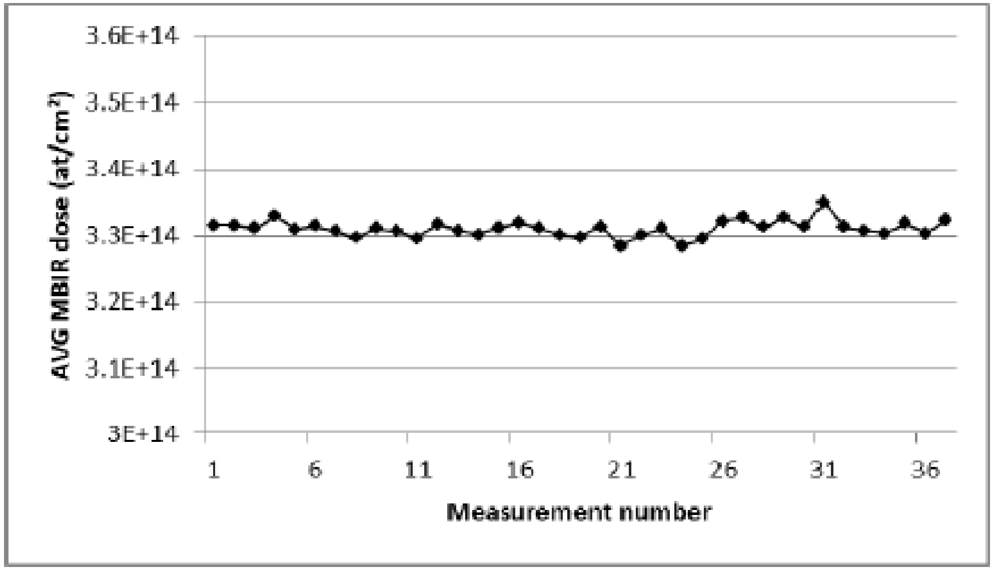


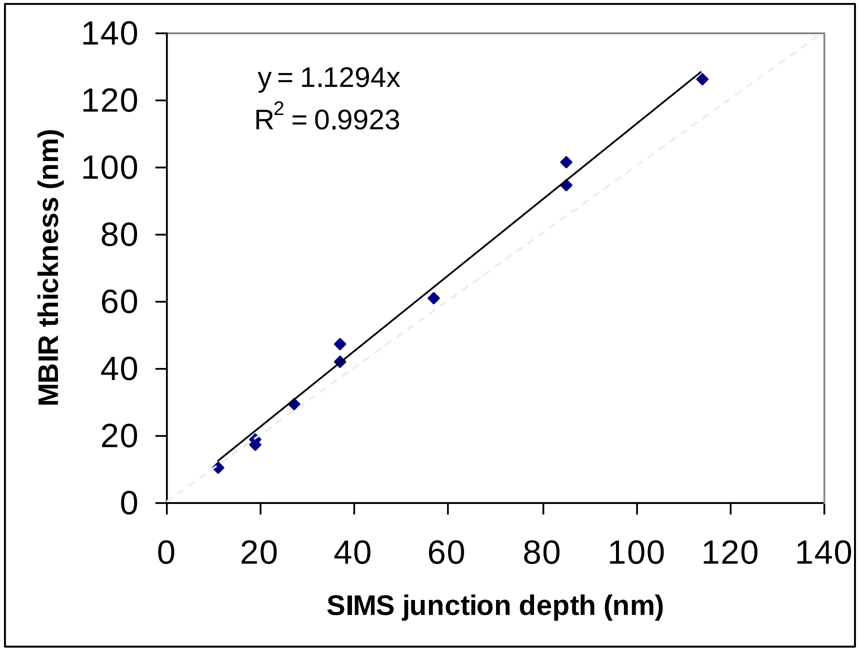
Fig. 10. Measurement stability over 3 months (average of 17pts). RSD=0.38%

Measurement stability monitored over a 3 month time period:
Boron Dose at 3.3E14 at/cm2
RSD (1σ) of 1.25E12 at/cm2
RSD (1σ) of 0.38%

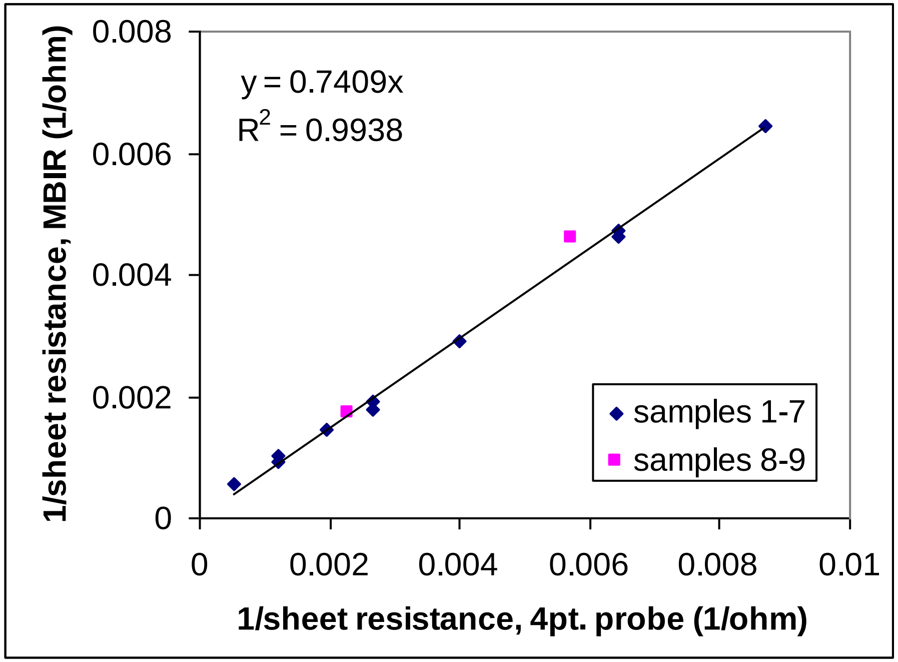
Source: MBIR for In-line Doping Metrology of Epitaxial SiGe:B and SiC:P Layers, R. Duru et al., ASMC 2013

Ultra Shallow Junction (Implant, Post Anneal)

Doped Layer Thickness



Sheet Resistance



The MBIR provides good sensitivity to measure:

- Doped Layer thickness
- Sheet Resistance

HAR Trench and Via Applications

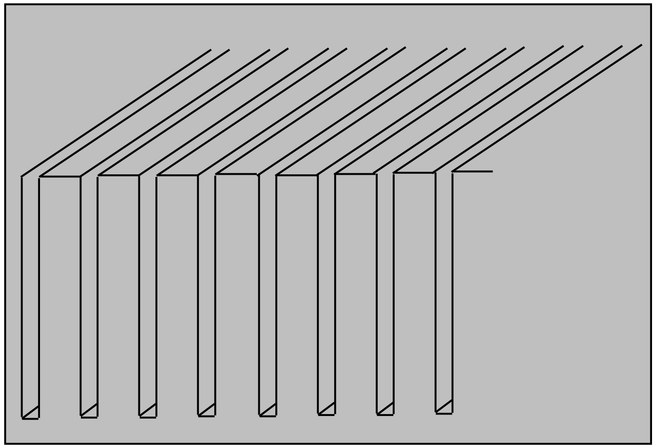
Spectral Range for MBIR HAR Trench Metrology

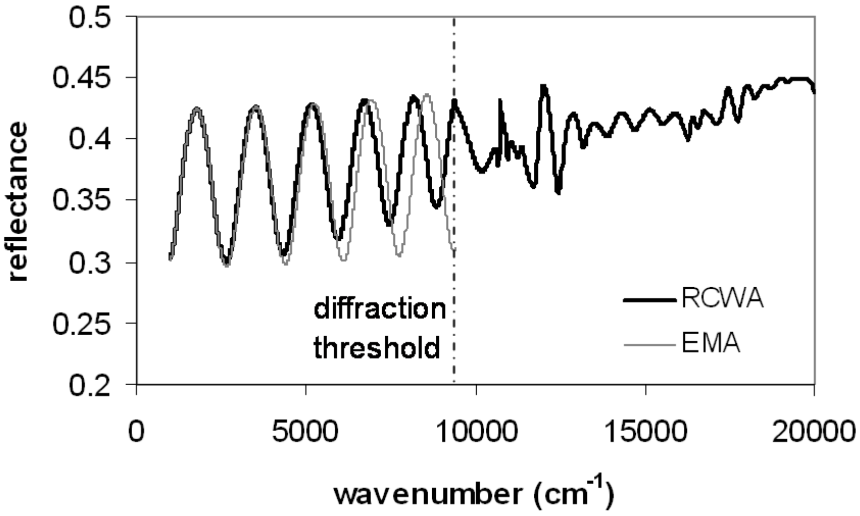
20 um	5 um	2.5 um	1.67 um	1.25 um	0.9 um
500 cm^{-1}	2000 cm^{-1}	4000 cm^{-1}	6000 cm^{-1}	8000 cm^{-1}	11000 cm^{-1}

Longer wavelengths
Effective Medium Approximation (EMA)

Short Wavelengths
Diffraction

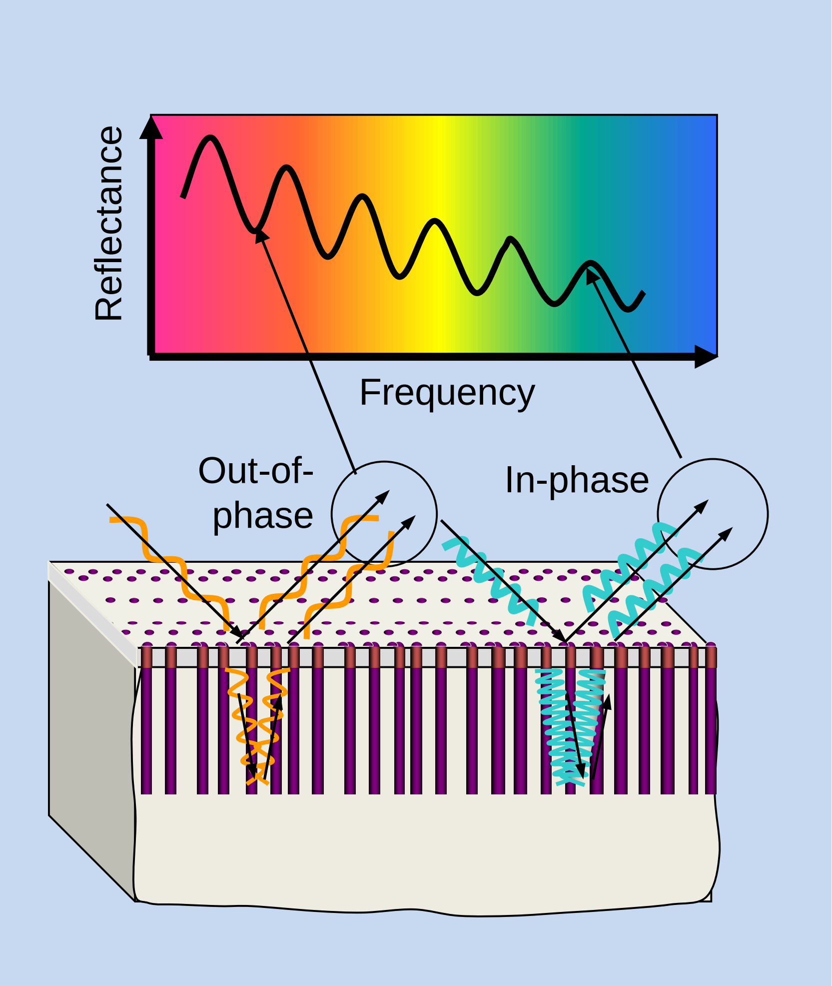
1 micron deep, 75 nm CD, 250 nm pitch



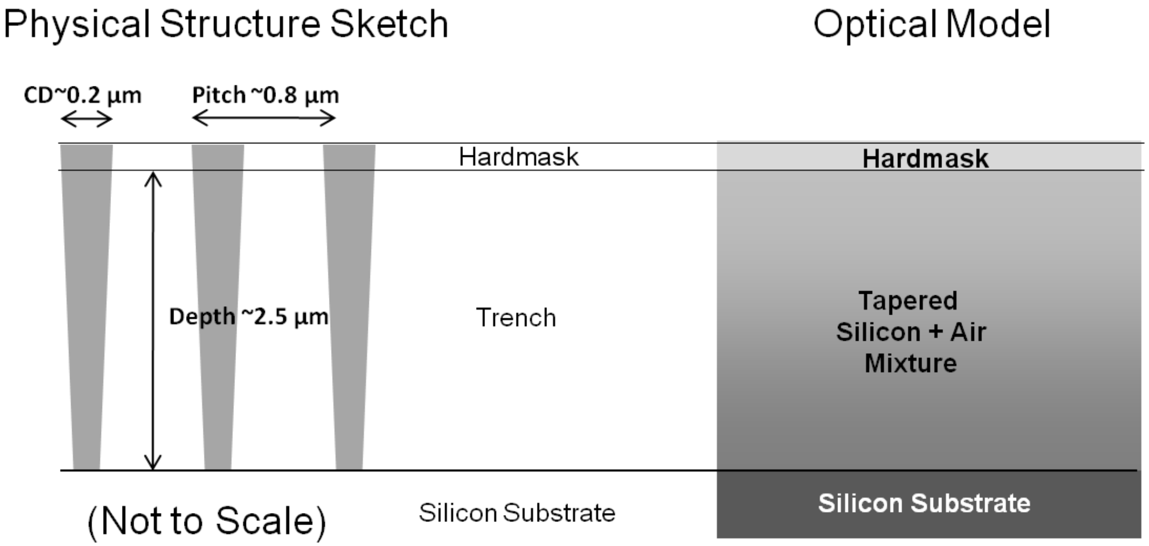


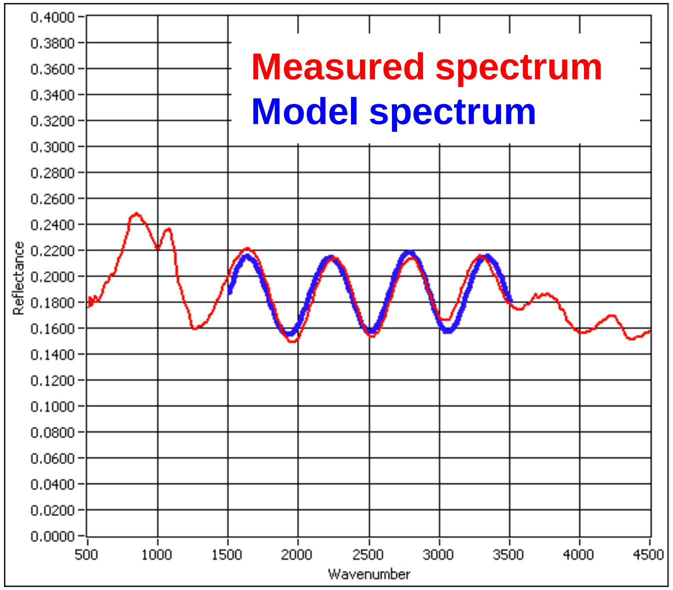
MBIR HAR Trench Measurement Principle

- Reflections & absorptions from trenches and films determine shape of reflectance spectrum
- Analysis of reflectance spectrum yields thickness, depth, CD, and composition
- Effective Medium Model makes the calculation simple and fast



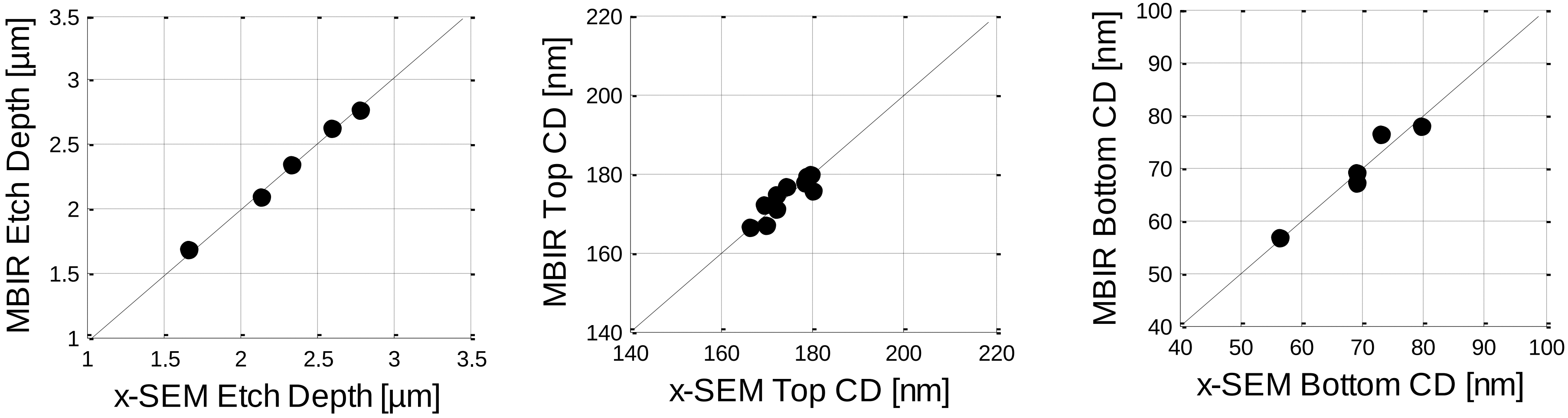
Deep Trench Isolation – MBIR Model





- By fitting a model to the measured spectra the following parameters can be measured:
  - Hardmask thickness
  - Top CD
  - Bottom CD
  - Trench Depth

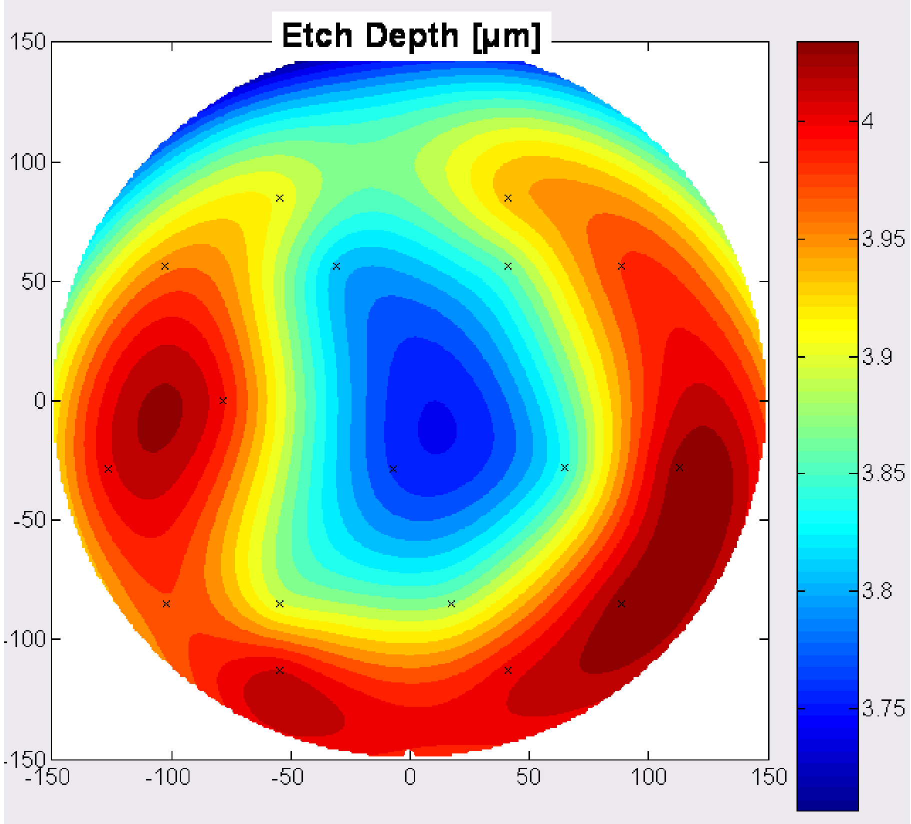
Deep Trench Isolation – Correlation



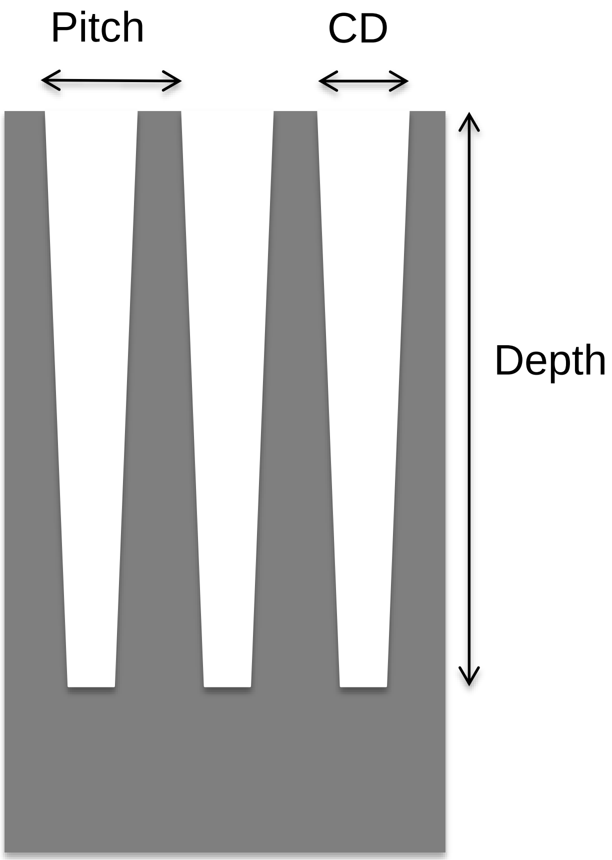
Excellent correlation results with x-SEM have been achieved

Deep Trench Isolation – Wafer Map

- One benefit of the MBIR in-line technique is to allow evaluation of within wafer variation in order to fine tune etch process recipes.
- 2D mapping of the depth is quick and easy to obtain.
- This is a key asset for etch process monitoring and etch tool requalification in a production environment.



Deeper Isolation Trench Example



Sample	Trench Depth [µm]	Trench CD [µm]	Pitch [µm]
1	10	0.4	0.8
2	15	0.4	0.8
3	30	0.4	0.8

The following slide contains two examples of power device measurement results from the structures listed in the table above.

One recipe used to analyze the three samples, with depth ranging from 10-30 µm.

Deeper Isolation Trench Example

- The plot to the right is showing an EMA model fit to the measured spectrum.

- A simplified description of how the spectral features correspond with structure variations is the following:
  - Etch depth – Fringe period
  - Bottom CD – Fringe amplitude
  - Top CD – Vertical spectrum offset

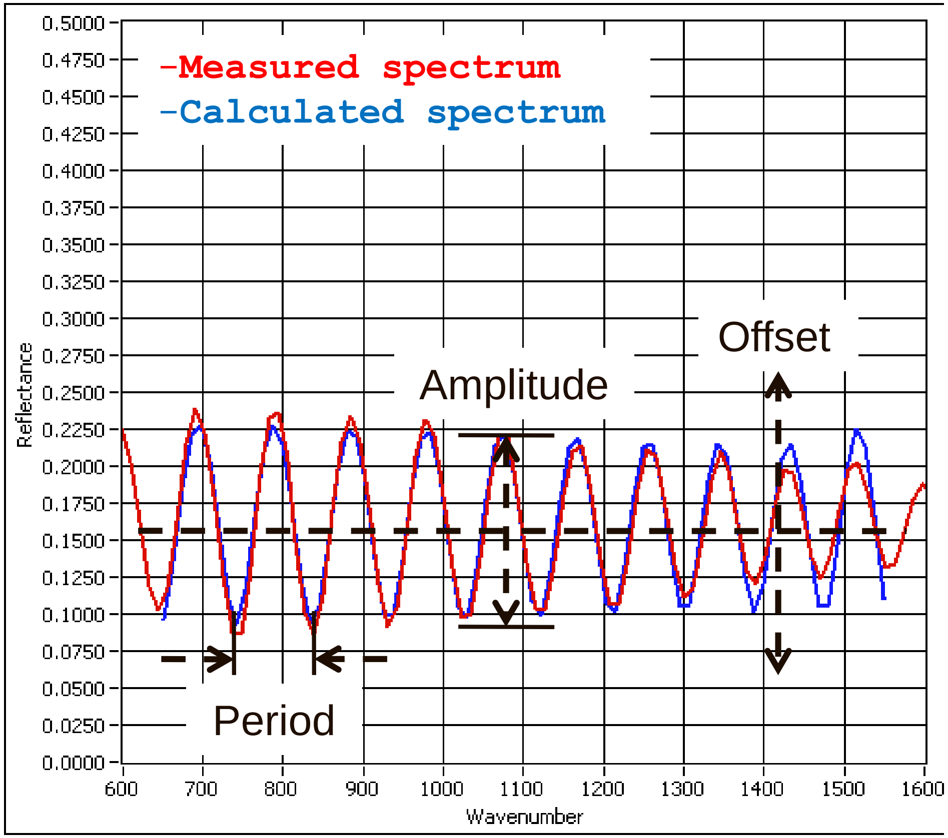
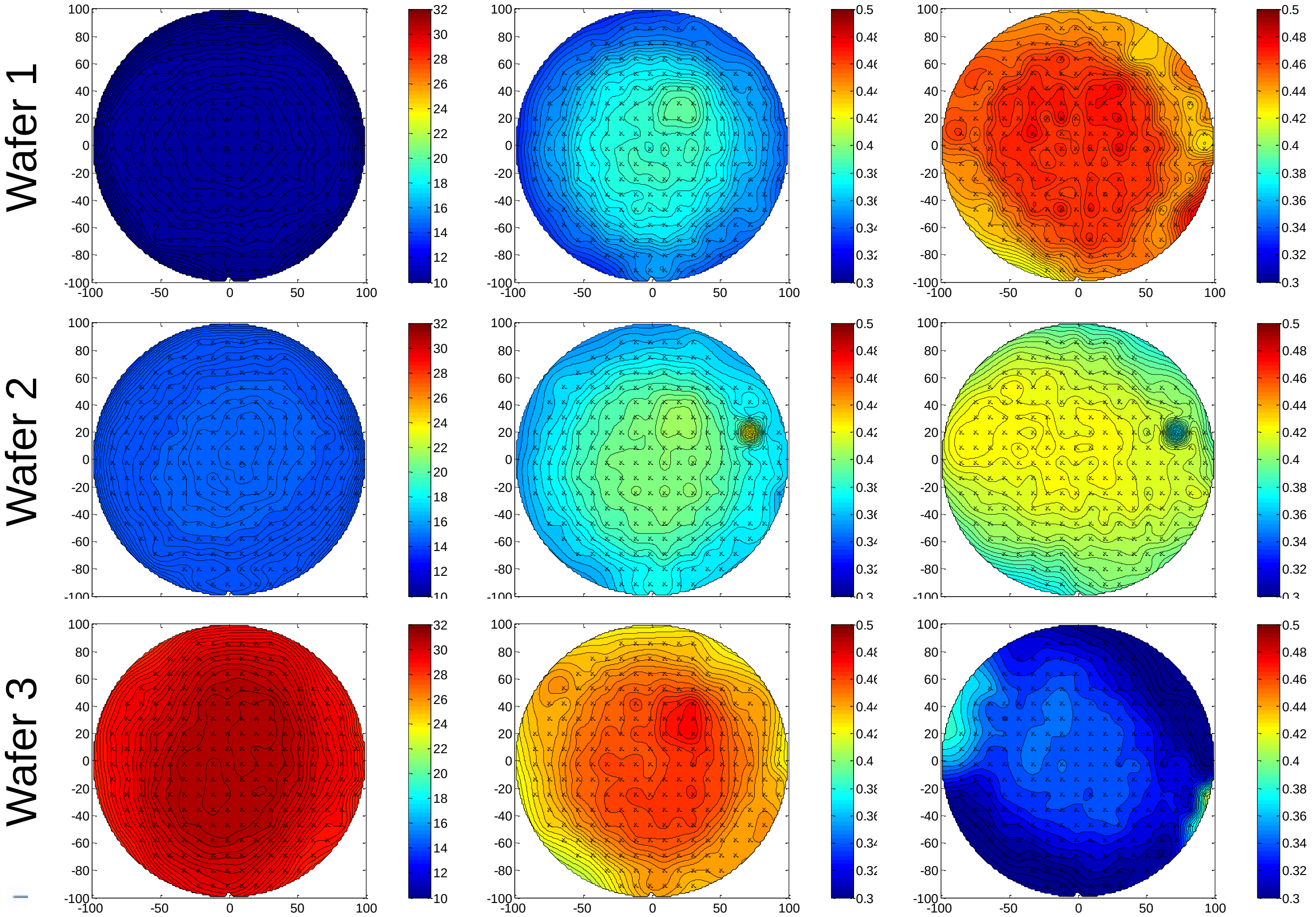


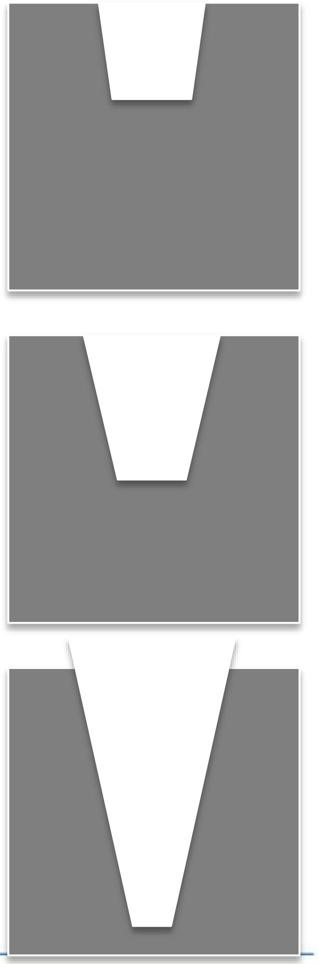
Figure - Example of spectral features

Deeper Isolation Trench Example

Etch depth [µm] Top CD [µm] Bottom CD [µm]

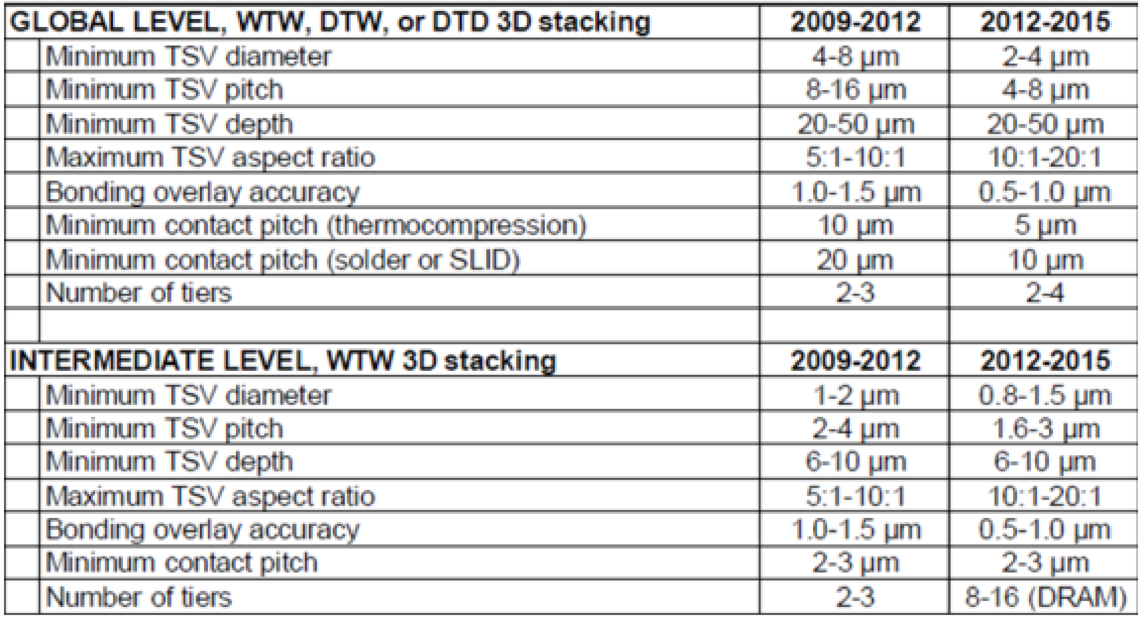


Structure Sketch
(not to scale)

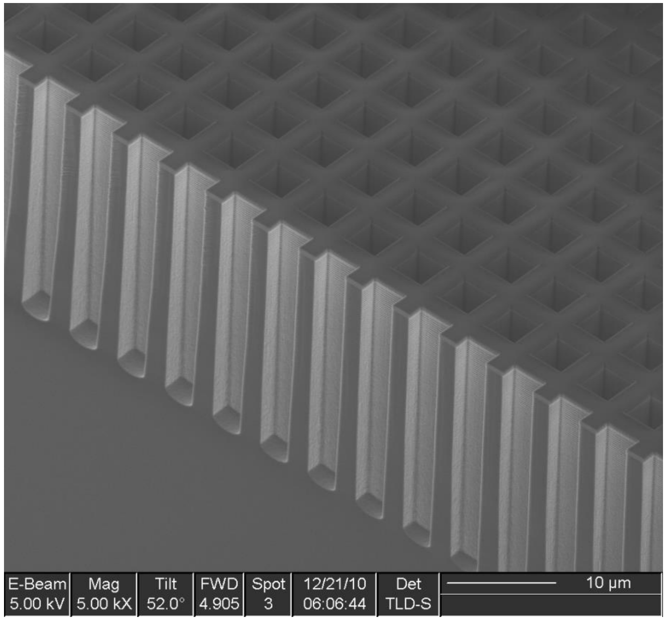


3D Integration Applications

Through Silicon Via

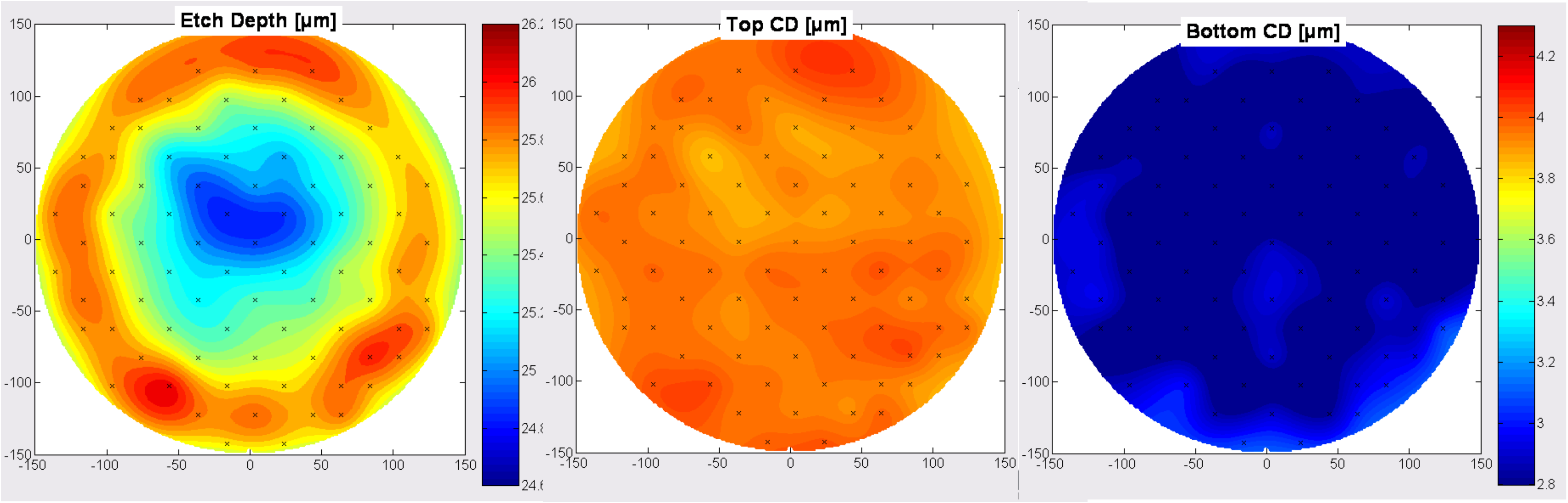


GLOBAL LEVEL, WTW, DTW, or DTD 3D stacking	2009-2012	2012-2015
Minimum TSV diameter	4-8 µm	2-4 µm
Minimum TSV pitch	8-16 µm	4-8 µm
Minimum TSV depth	20-50 µm	20-50 µm
Maximum TSV aspect ratio	5:1-10:1	10:1-20:1
Bonding overlay accuracy	1.0-1.5 µm	0.5-1.0 µm
Minimum contact pitch (thermocompression)	10 µm	5 µm
Minimum contact pitch (solder or SLID)	20 µm	10 µm
Number of tiers	2-3	2-4
INTERMEDIATE LEVEL, WTW 3D stacking	**2009-2012**	**2012-2015**
Minimum TSV diameter	1-2 µm	0.8-1.5 µm
Minimum TSV pitch	2-4 µm	1.6-3 µm
Minimum TSV depth	6-10 µm	6-10 µm
Maximum TSV aspect ratio	5:1-10:1	10:1-20:1
Bonding overlay accuracy	1.0-1.5 µm	0.5-1.0 µm
Minimum contact pitch	2-3 µm	2-3 µm
Number of tiers	2-3	8-16 (DRAM)



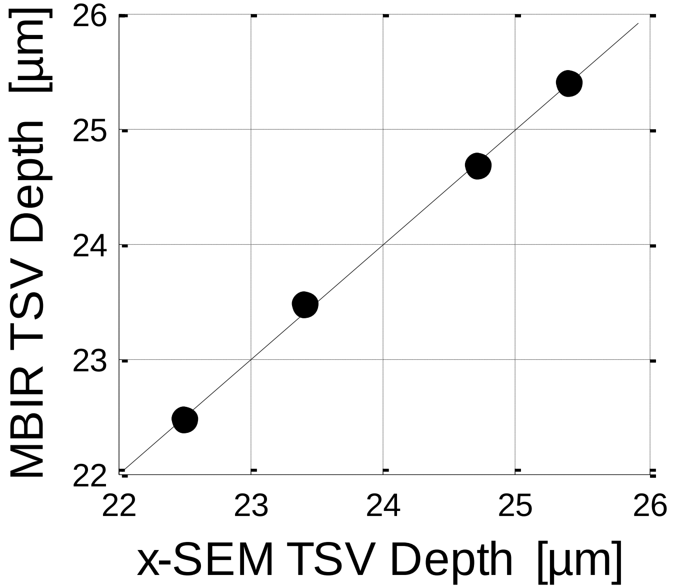
- Dimensions in ITRS specifying TSV CD shrinking.
- Shrinking pitch ≤6 µm means MBIR can be used with effective medium approximation with good accuracy.

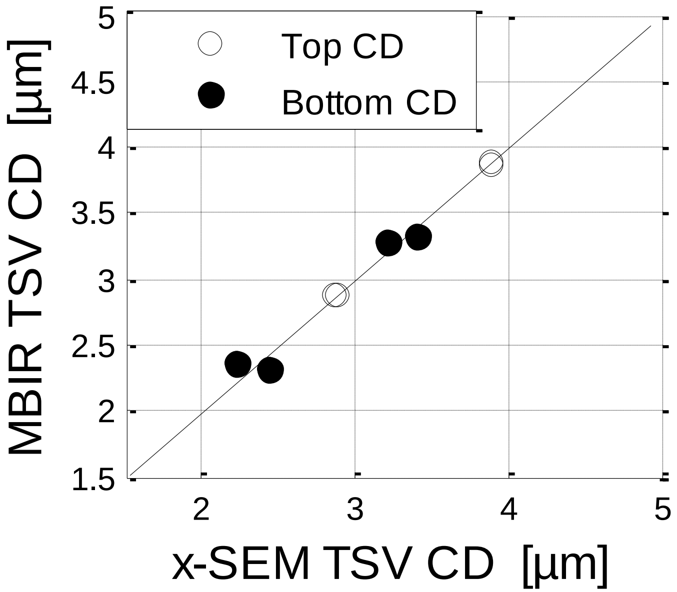
Through Silicon Via – Wafer Maps



- Wafer maps measured on 6 µm pitch / 4 µm CD TSV array are showing a concentric etch depth pattern.
- The etch profile it tapered with smaller CD towards the bottom of the vias.

Through Silicon Via – Correlation

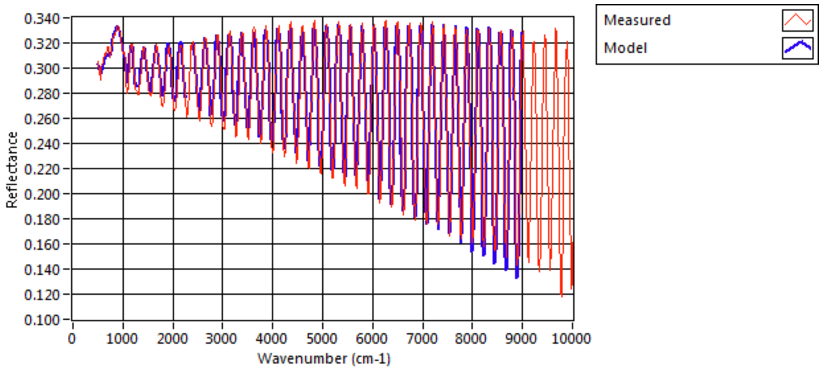




- Excellent correlation was achieved for depth, top CD and bottom CD, as shown in the plots above.

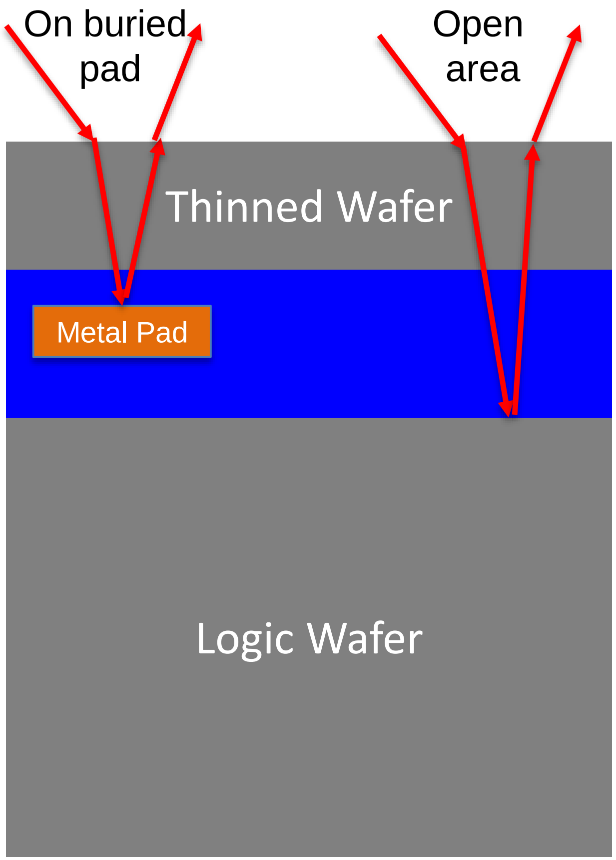
Wafer Thickness/Thinning Application

MBIR Model Fit Example



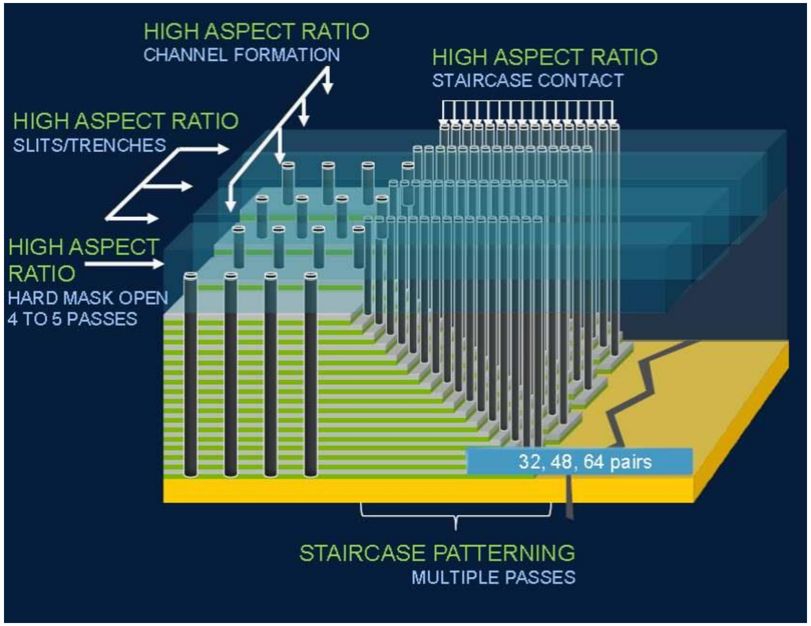
- MBIR is a good technique for monitoring the wafer thickness after the thinning process.
- As shown in the sketch to the right the measurement could be performed either with a buried metal pad or an open area.

Possible Measurement Locations



Memory Applications

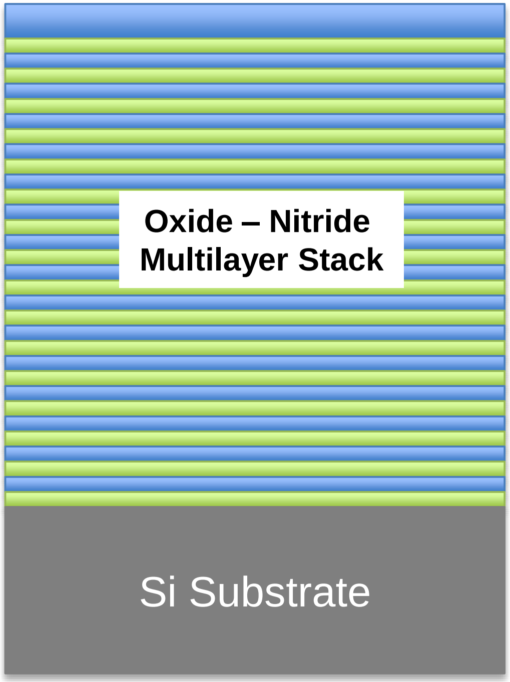
3D NAND

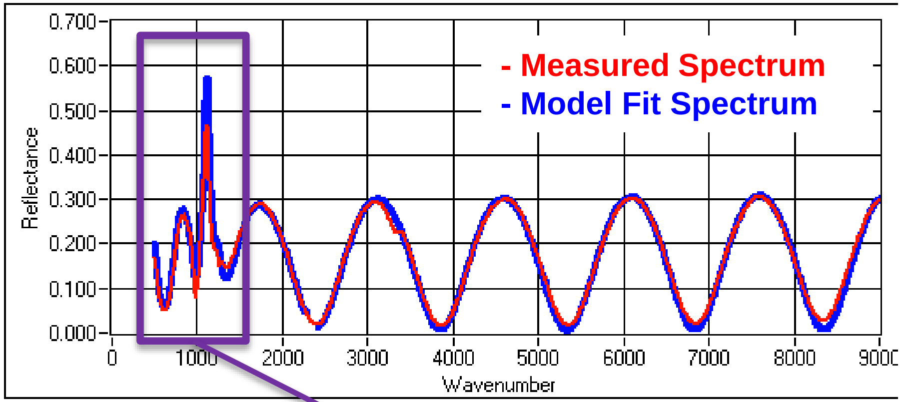


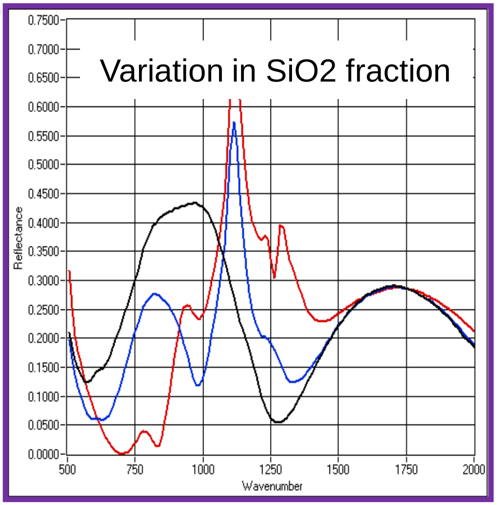
MBIR Applications for 3D NAND Device

- HAR Contact Hole Etch Geometry
- HAR Trench Etch Geometry
- Oxide-Nitride Multilayer Stacks.

3D NAND, Multilayer Stack



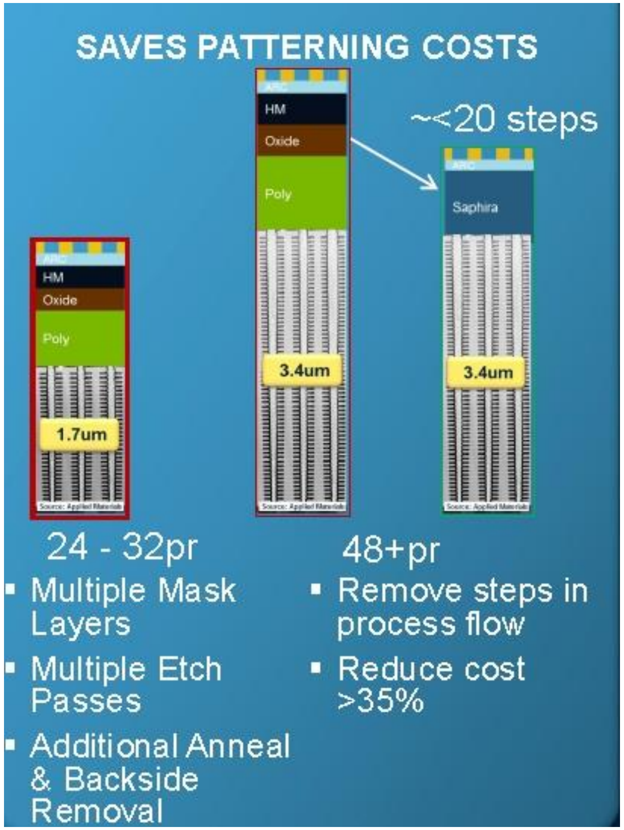




Spectral absorption features ~6-20 µm yields excellent sensitivity to characterize multilayer filmstacks by MBIR to measure:

- Total Oxide Thickness
- Total Nitride Thickness
- Combined Thickness

Amorphous Carbon



SAVES PATTERNING COSTS

24 - 32pr
- Multiple Mask Layers
- Multiple Etch Passes
- Additional Anneal & Backside Removal

48+pr
- Remove steps in process flow
- Reduce cost >35%

Source: http://semimd.com/blog/2014/11/24/applied-materials-introduces-new-hardmask-process-saphira/

Basic Background

- Applied for HAR etch processes, such as 3D NAND contact hole and trench, for which traditional photoresists are unable to withstand.
- Simplifies the process by reducing the number of process steps.
- Cannot be measured by traditional optical metrology tools, since the material is opaque in the visible range.

MBIR Measurement

- Film thickness and optical constants.
- Trench and via etch geometry.

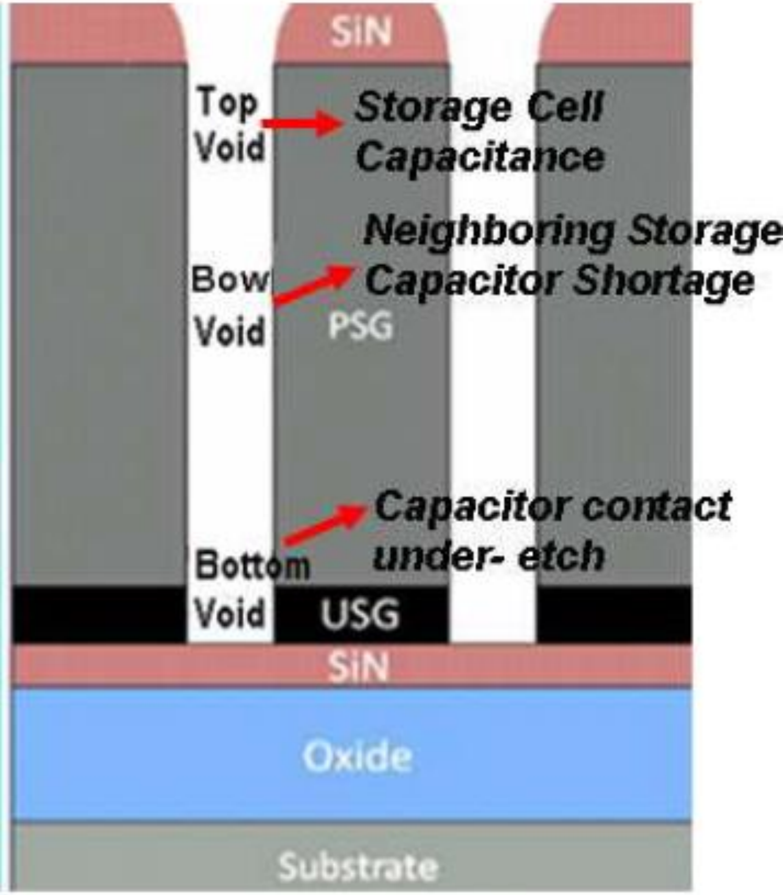
Stacked DRAM Storage Capacitor – MBIR Model

- The complex shape of the etched storage capacitor cells is easy to model using MBIR effective medium approximation.

- MBIR has good sensitivity to measure etch profile in the storage cell.

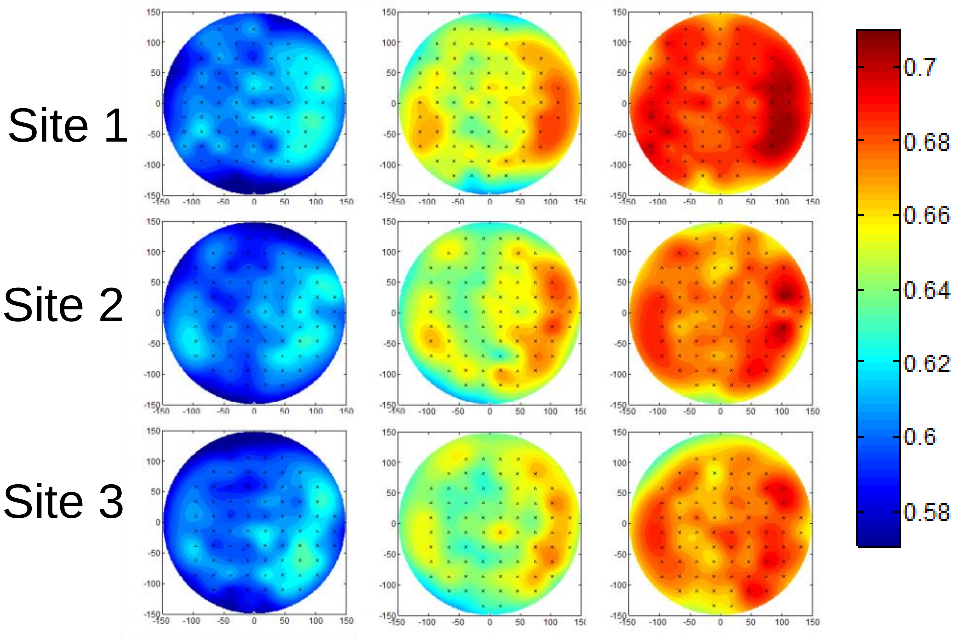
Example x-SEM

MBIR Model

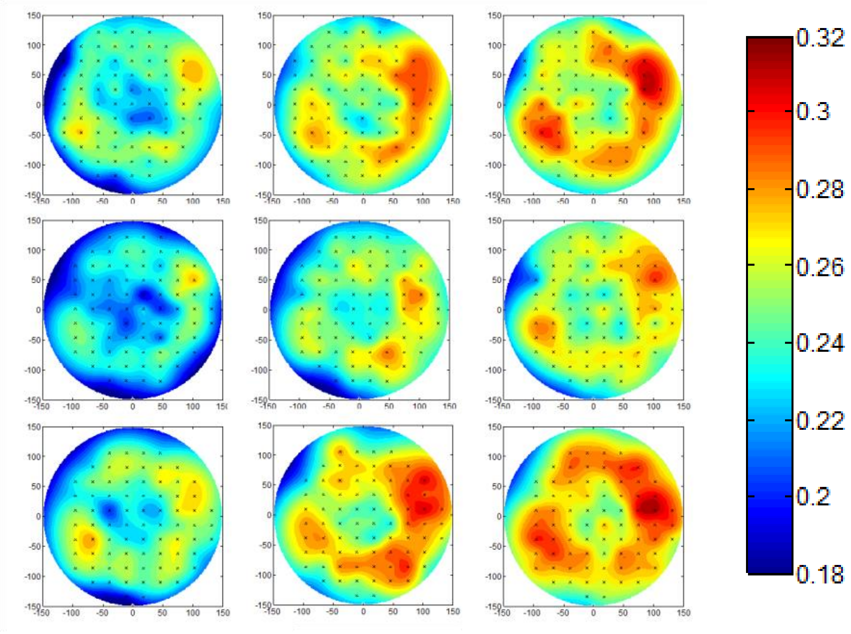


Stacked DRAM Storage Capacitor – Wafer Maps

Top Void Fraction

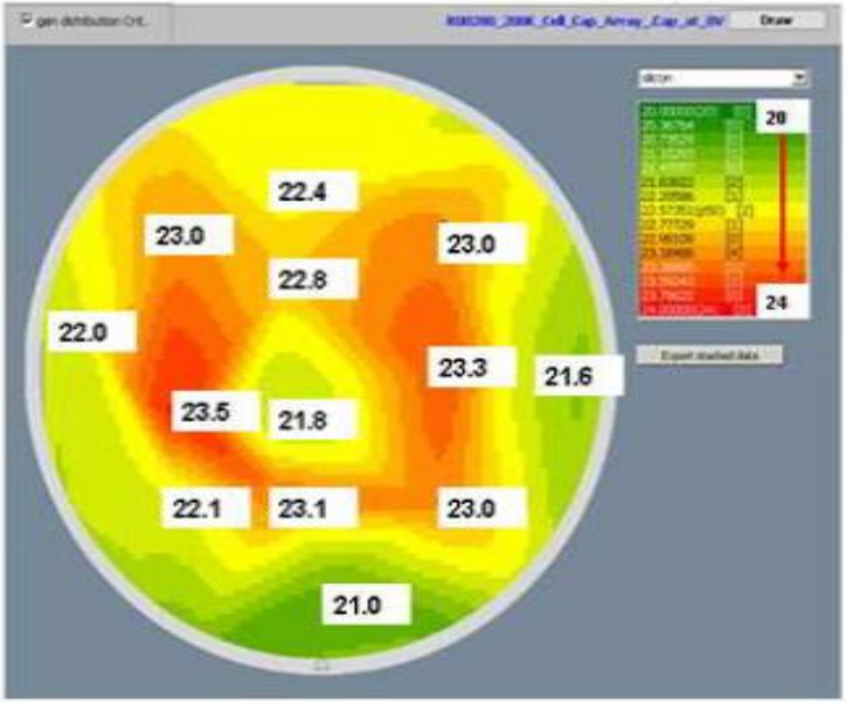


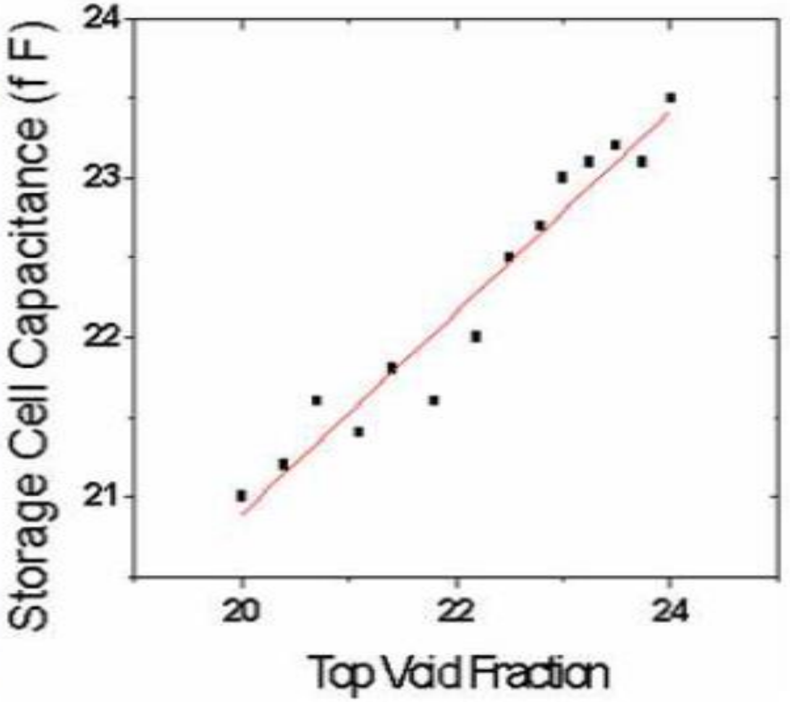
Bottom Void Fraction



- Wafer maps showing MBIR data for DOE with variation in O_2 flow in the etch process (32-36 sccm). 3 sites per die measured.
- Excellent sensitivity to process condition is observed in the measurements

Stacked DRAM Storage Capacitor – Correlation

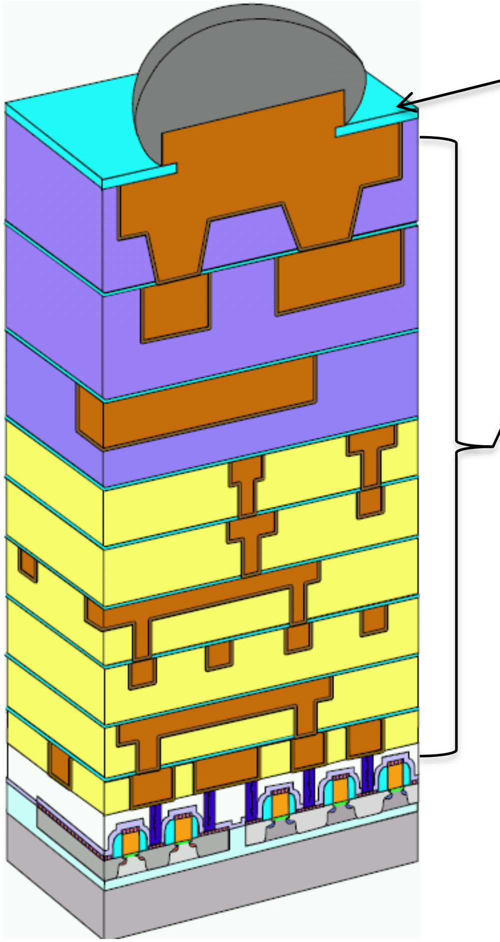




- Excellent correlation with final cell capacitance is observed.

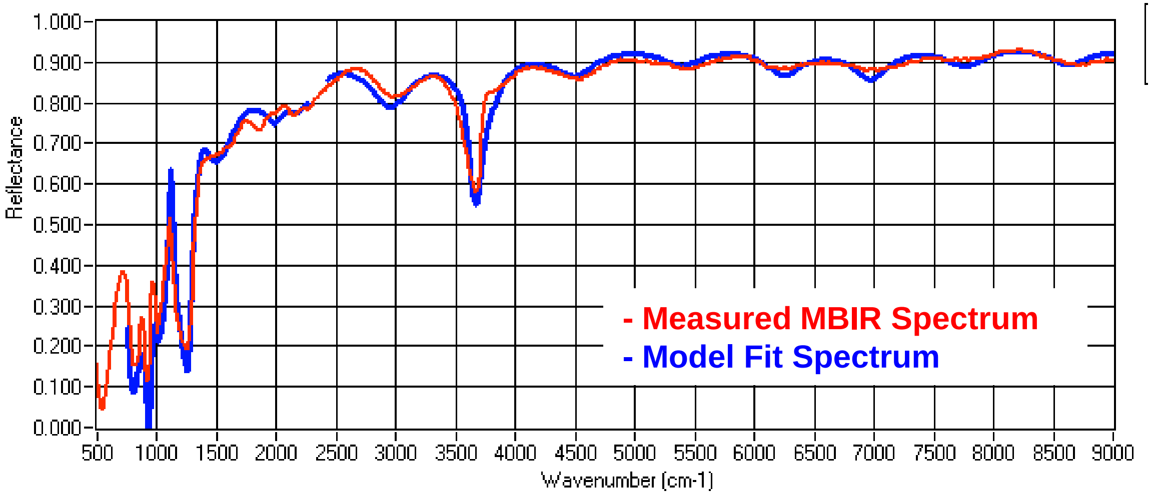
BEOL Film Applications

BEOL Thick Dielectrics and Polymers



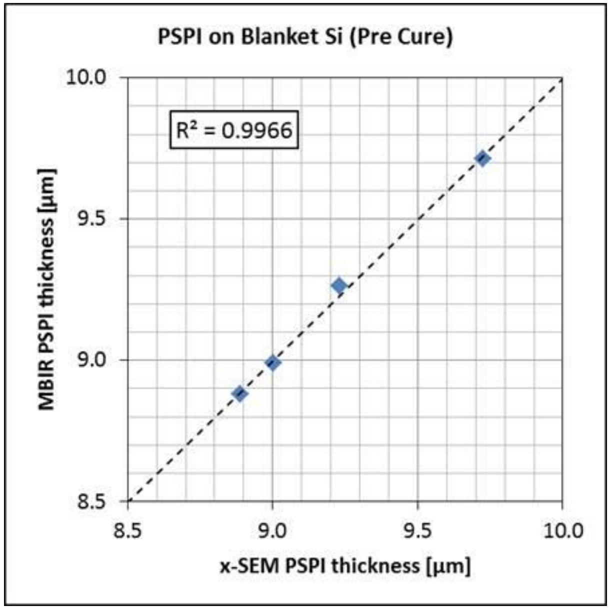
Protective polymer passivation layer (PSPI) is added before the wafer is bumped. This layer provides a stress, water, and electrical barrier. It also plays a critical role in preventing ‘chip-package interaction (CPI) failure.

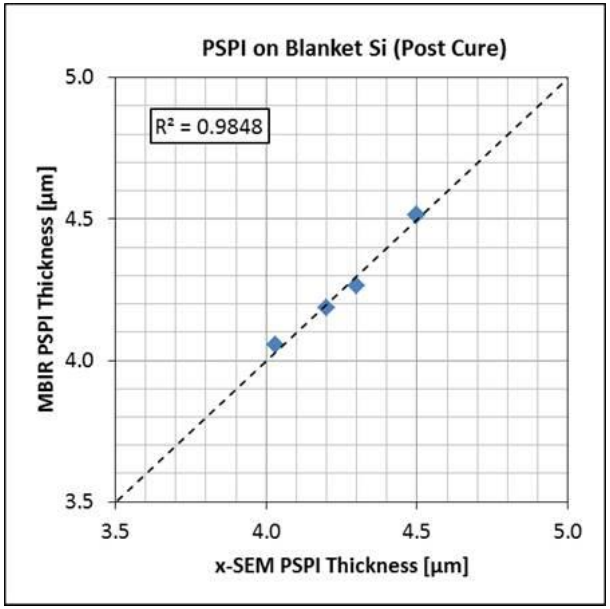
Wiring levels embedded in ultralow-*k* (ULK) and TEOS materials.



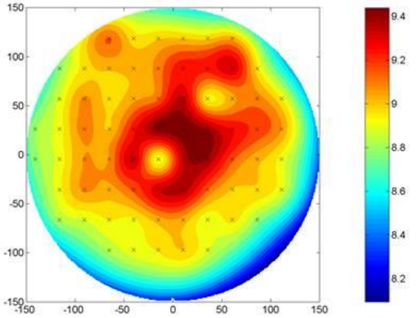
- For BEOL PSPI films and electroplated Cu, the surface roughness can be several hundred nanometers, which can be challenging to measure using traditional UV-Vis-NIR optical tools
- The longer wavelength range used by MBIR is well suited for measurements of films with this high level of surface roughness.

Photo-Sensitive Polyimide (PSPI)

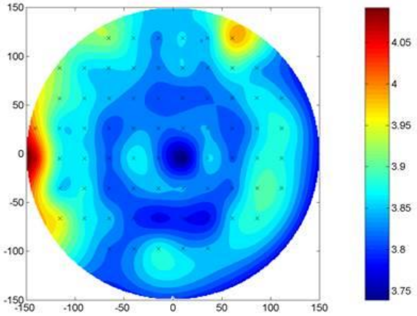




Pre-cure



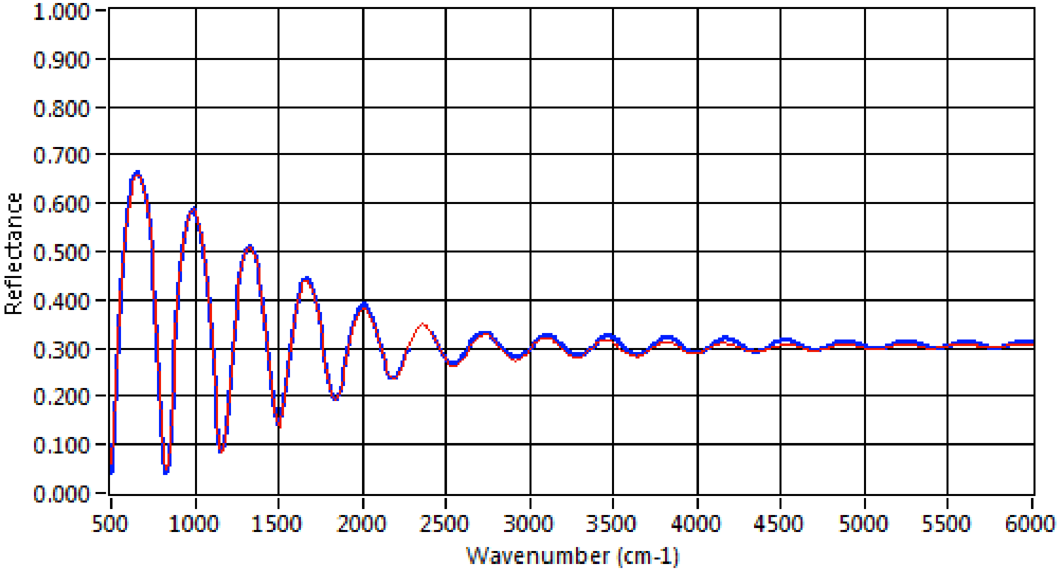
Post-cure

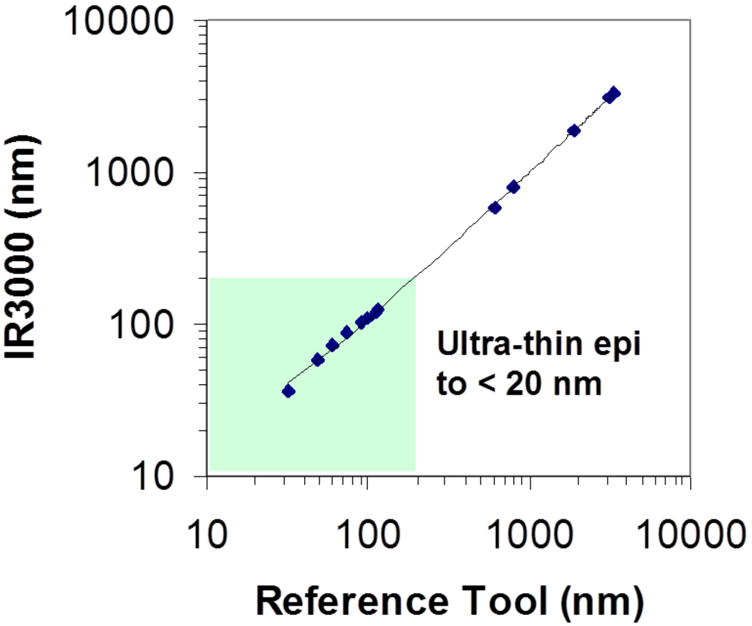


- During curing of the PSPI film the thickness can be reduced as much as 50% and the surface roughness is high.
- MBIR is capable to accurately measure the thickness pre- and post-cure and enables monitoring of the thickness and within-wafer non-uniformity.

EPI Applications

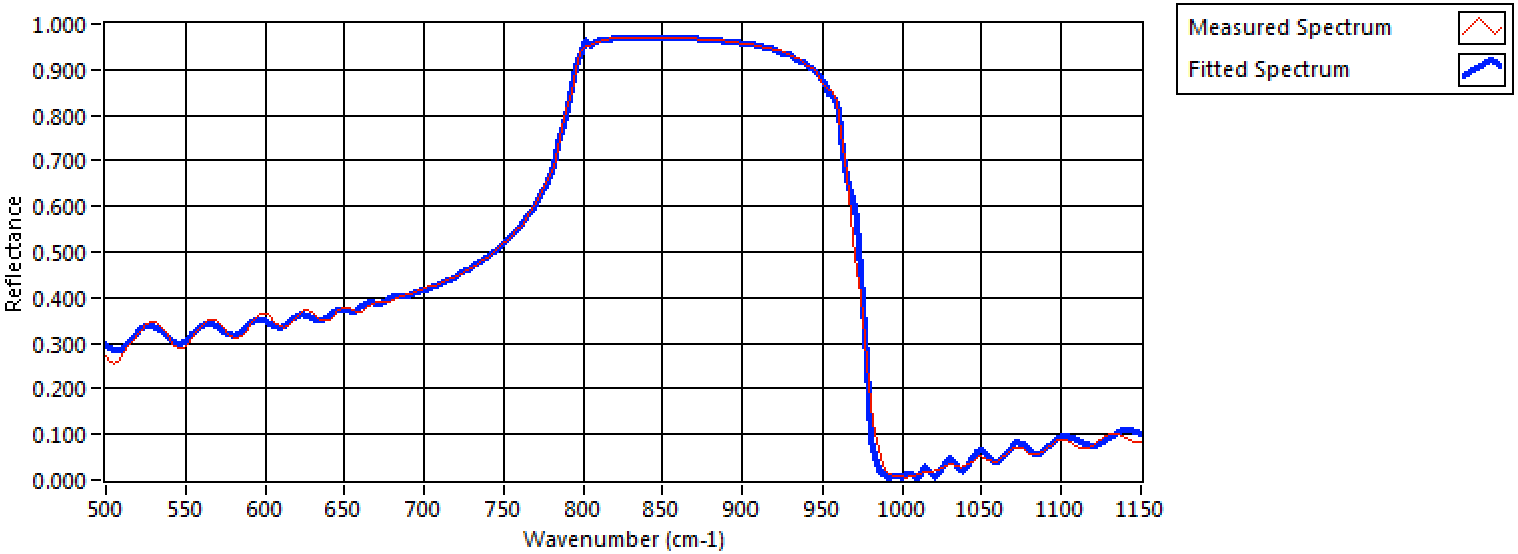
Silicon EPI





The model based technique allows accurate and highly repeatable characterization of EPI layers of a wide thickness range from > 100 µm down to ultra thin EPI < 20nm.

Silicon Carbide EPI



Similarly to silicon EPI, MBIR can measure SiC EPI using the model based approach.