Accelerating the next technology revolution

Overview of EUV Mask Metrology

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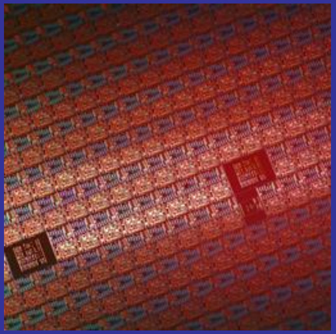
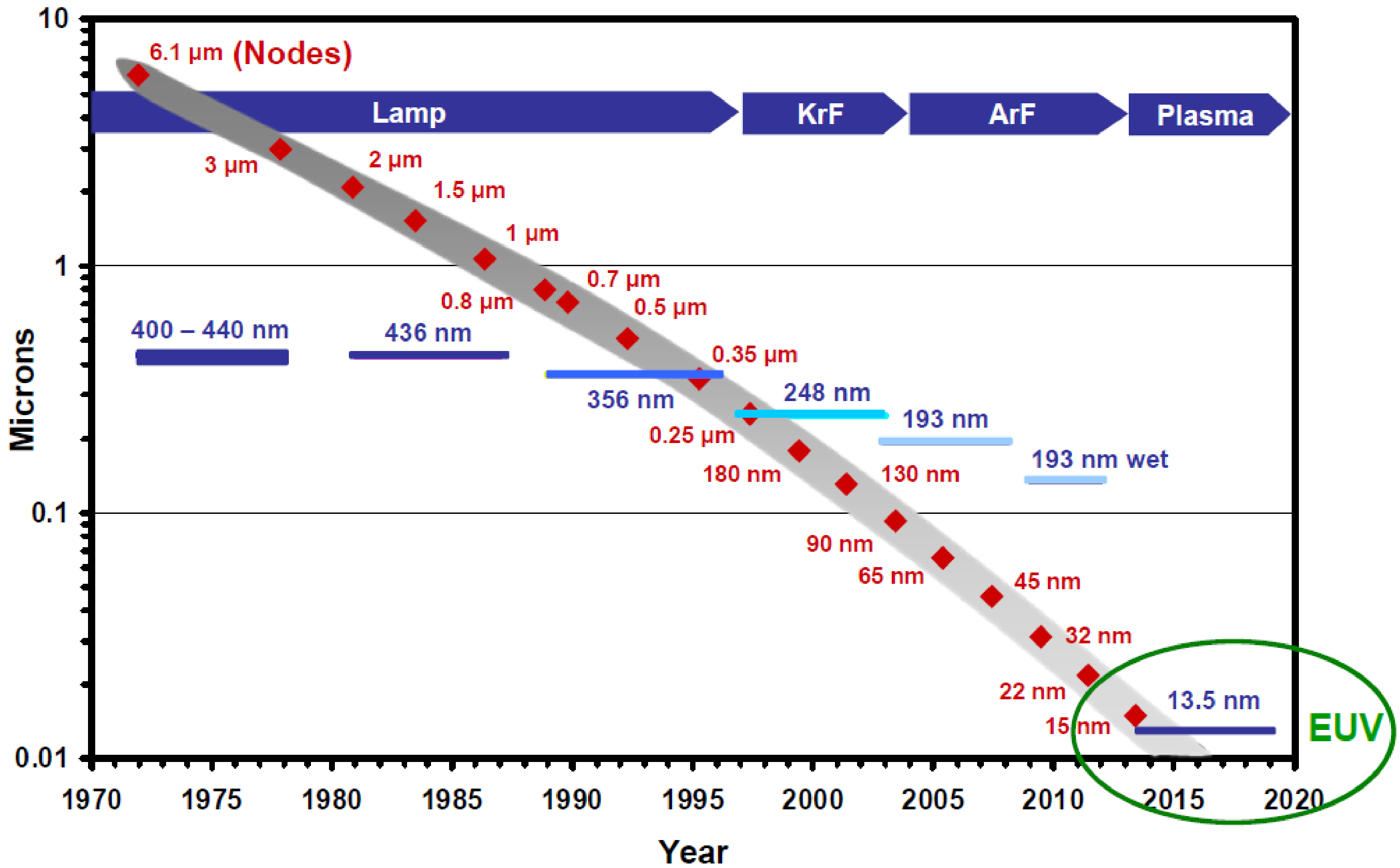
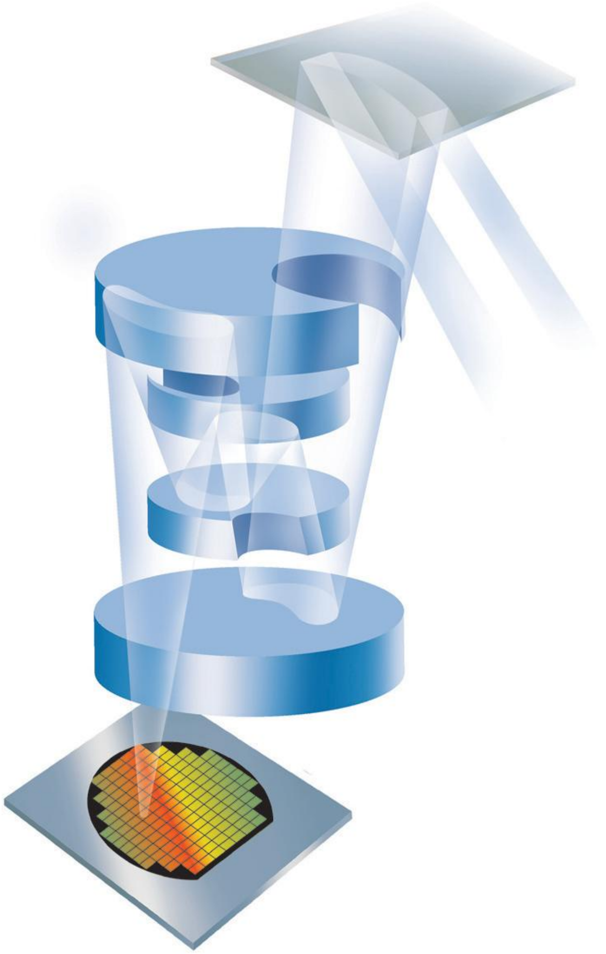
SEMATECH Inc.



Lithography Scaling



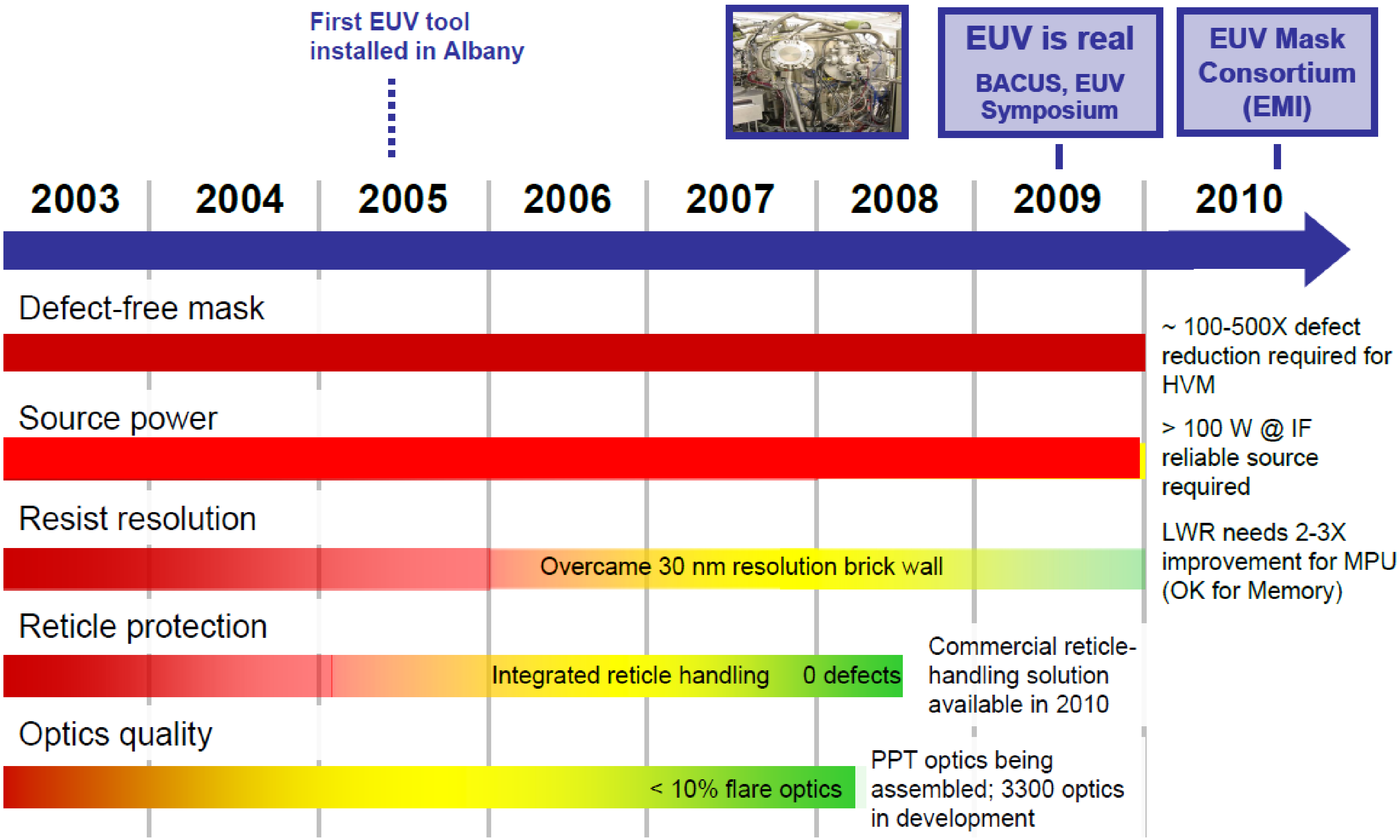
EUV Lithography



Courtesy of Carl Zeiss SMT AG

- EUV masks and projection optics are reflective
  - Differs from conventional refractive optics use in production lithography systems
  - No optical materials are transparent for EUV
- Highly sophisticated mirrors
  - Mo/Si bi-layer coatings for high reflectance
  - Low surface roughness on the order of a few atoms
  - Stringent flatness and curvature requirements
  - Mask must have no resolvable defects

EUV Lithography and challenges

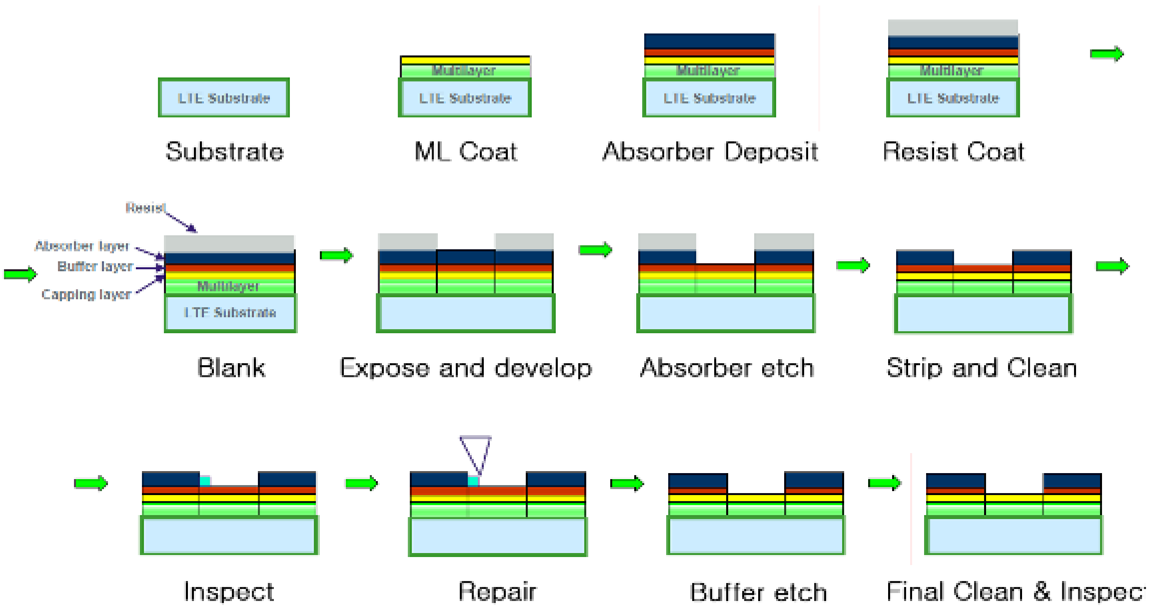


Defect Reduction Needs/Plans

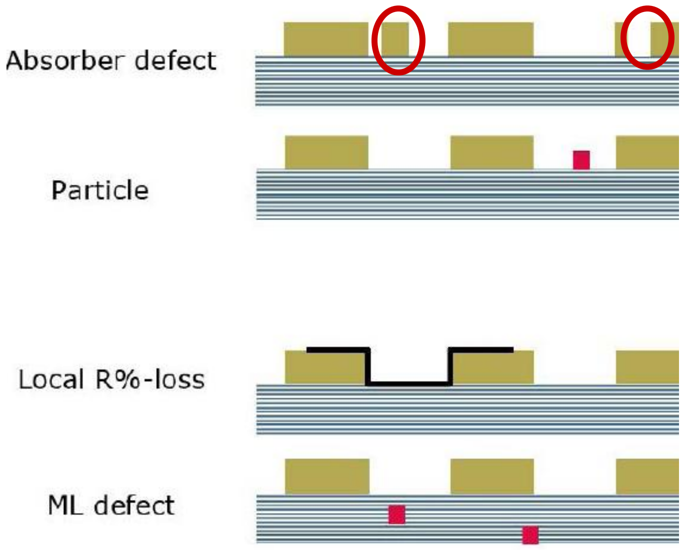
- For 22nm node:
  - Memory needs ~10 or less defects/blank @ 30nm size
  - Logic needs 0 printable defects at ~30nm size (~10 well-localized and repairable defects)
- Today, defects are at ~40 / blank @ 50nm size (defect density of 0.25/cm^2)
- SEMATECH defect reduction roadmap:
  - 2011: 0 > 150nm; 0.13/cm^2 @ 50nm < x < 150nm
  - 2012: 0 > 100nm; 0.13/cm^2 @ 35nm < x < 100nm
  - 2013: 0 > 80nm; 0.13/cm^2 @ 35nm < x < 80nm

Fabrication of EUV mask

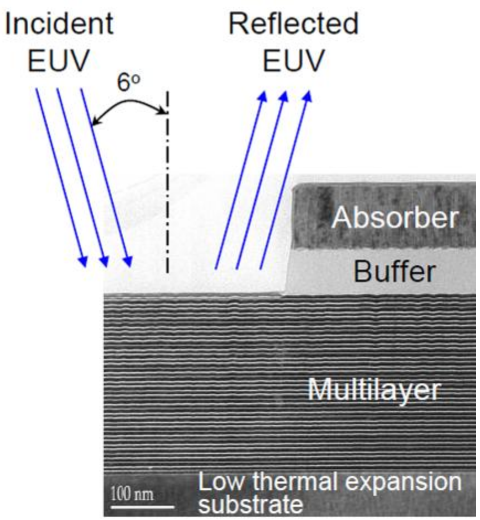
Mask fabrication process steps



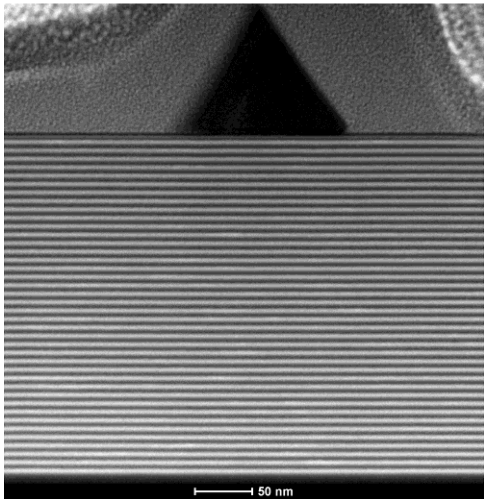
Defect types



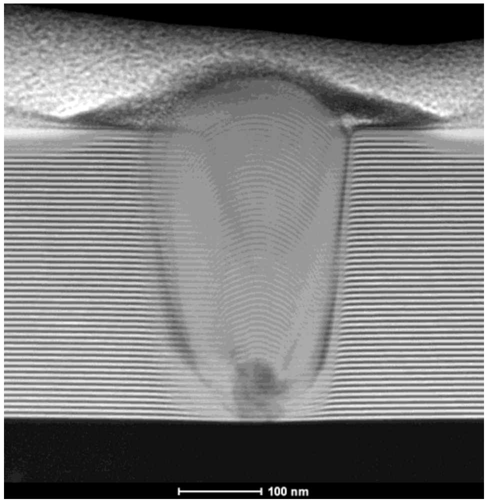
Defect categorization in EUV mask blank



TEM Courtesy: K. Nguyen, AMD

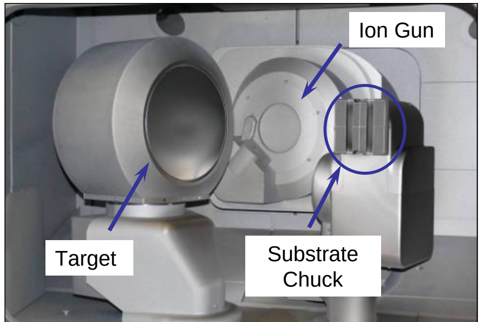


Amplitude defect



Phase defect

- EUV masks are vulnerable to different types of defects
  - Amplitude defects: surface particles/pits that generate contrast changes at the wafer
  - Phase defects: bumps/pits at the substrate which become buried below the multilayer
    - Results in a phase change of the reflected wave.
    - Phase defects as small as 1 nm in height or depth can result in printable defect



Multilayer EUV Mask Blank DepositionTool

Lasertec M1350 / M7360

Sensitivity M1350 / M7360: 55 / 40 nm on substrate and 73 / 45 nm on multilayer

EUV Reflectometer

FEI Titan TEM

MBDC

Veeco AFM

Auger: PHI SMART-Tool

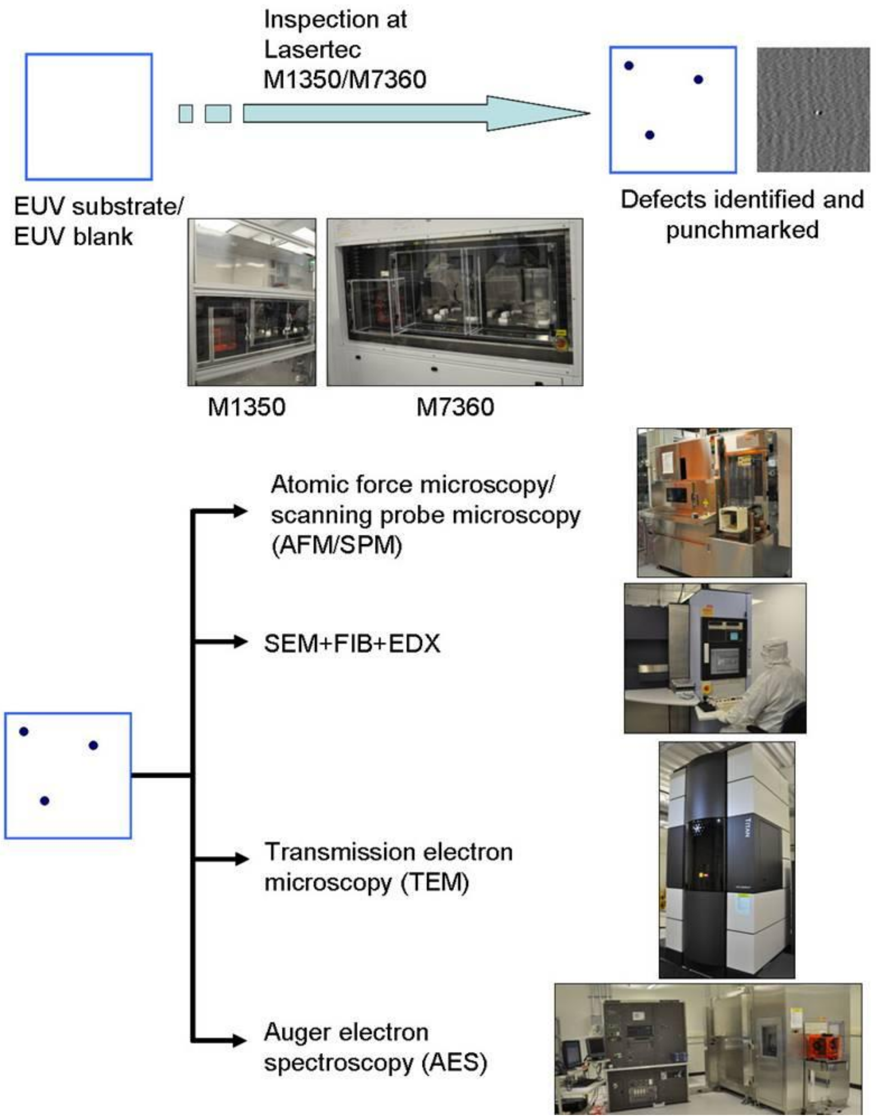
FEI FIB/SEM/EDX

Development of defect-free EUV blanks

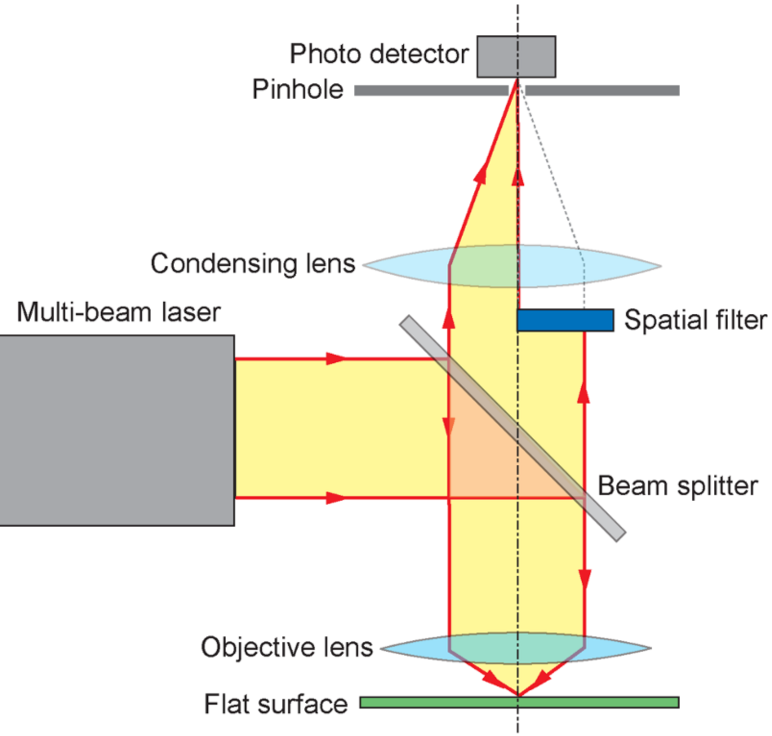
Hamatech ASC 5500

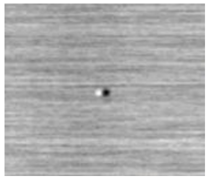
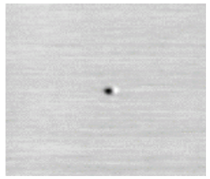
SEMATECH's EUV Mask Defect Analysis Approach

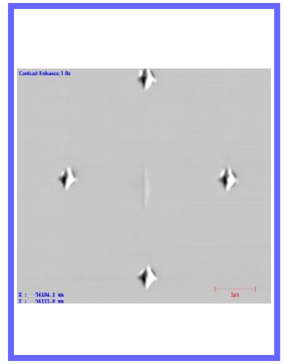
- Defect inspection
  - Inspection before and after ML deposition.
- Failure analysis
  - X-sectional and compositional analysis.
  - EDS and AFM have been the work horses for small defect analysis.
  - AES and TEM are necessary and recently established for even smaller defect sizes.
  - Enables isolation of defect source.
- Defect printability
  - Which defects will image in an exposure tool.



Substrate and Blank Inspection



Defect Shape	Bump 	Pit 
Review Image		

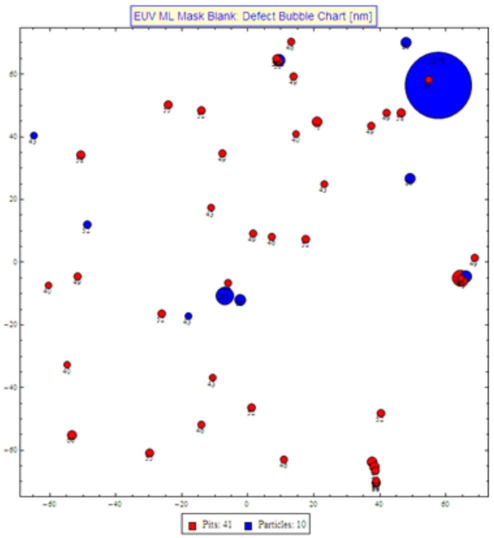


Defect Detection

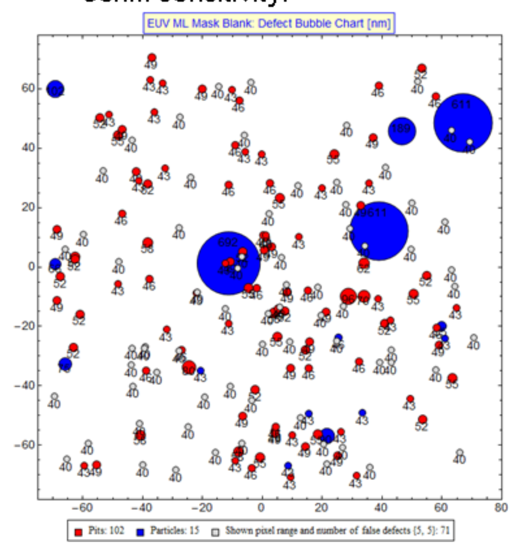
M1350 (488nm) /M7360 (266nm)

- Confocal microscope
- Defect review
- Punchmarking capability

- A champion EUV blank.
  - Few defects (41 pits, 10 particles) @ 50nm sensitivity.

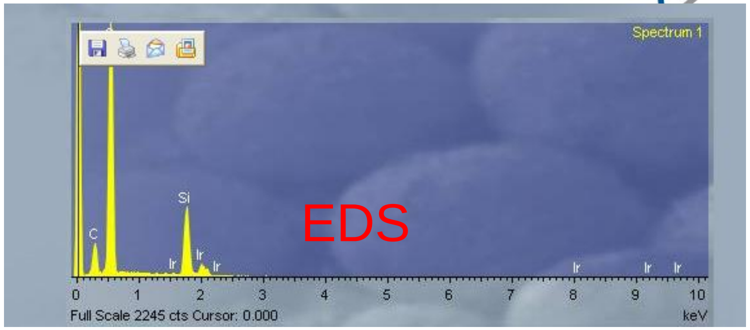


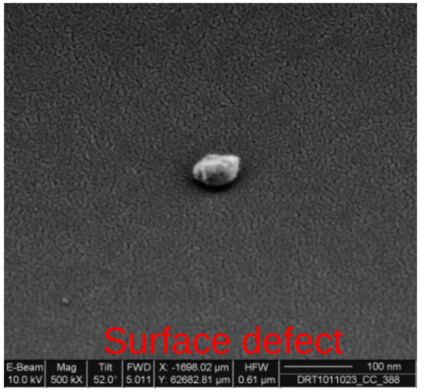
- A typical good EUV blank.
  - Many more defects (about 100 pits, 15 particles, 71 not classified) at 50nm sensitivity.

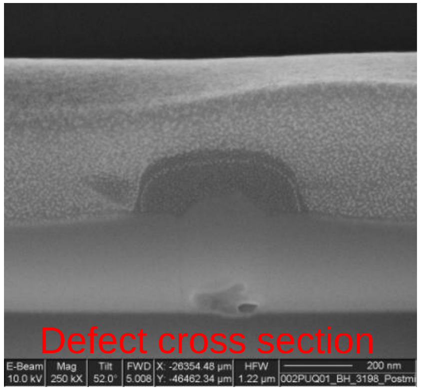


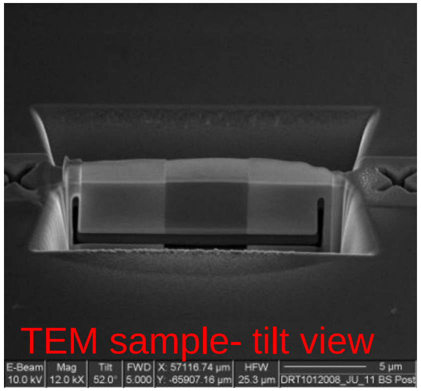
FIB/SEM

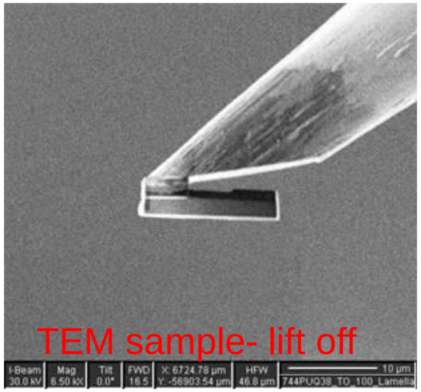
- Anchor failure analysis (FA) tool
- Tool Configuration
  - 6” mask holder, manually load.
  - Automatic navigator by KLARF.
  - Oxford Instruments EDS.
  - Focus Ga+ ion beam.
  - Omniprobe.
- Supports
  - Compositional analysis of defects >100 nm.
  - TEM sample.
  - SEM imaging.





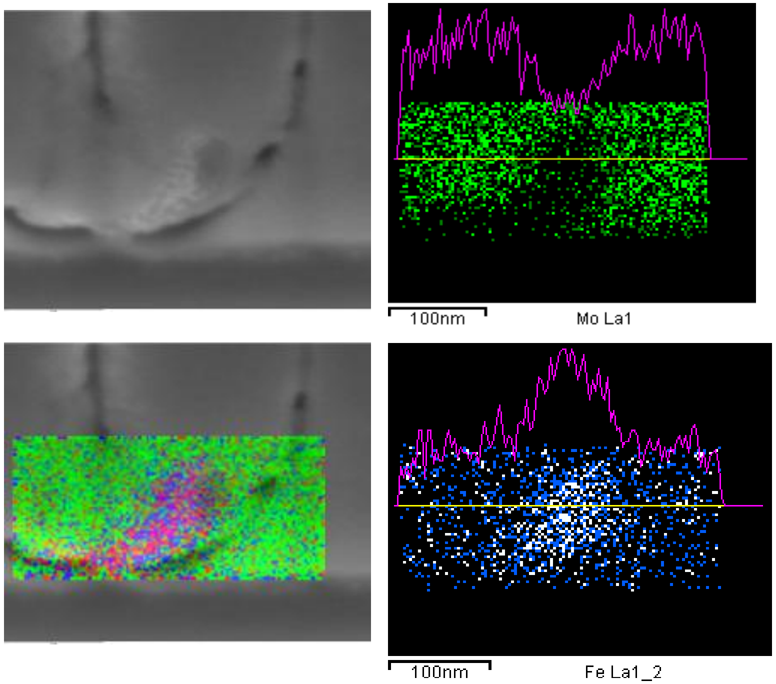


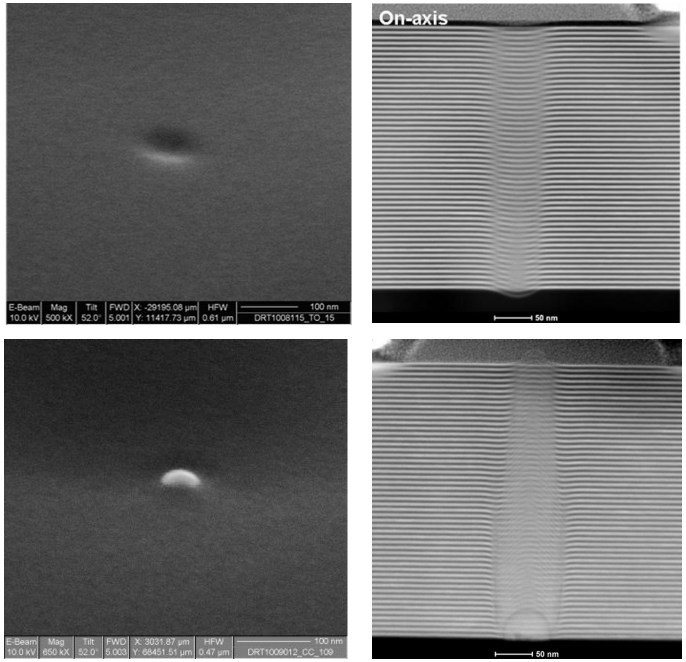




FIB/SEM and EDS Capability

- FIB/SEM EDS analysis
  - Adequate for chemical characterization of large size defects, >100nm.
  - But capability limited due to penetration depth of X-Rays.

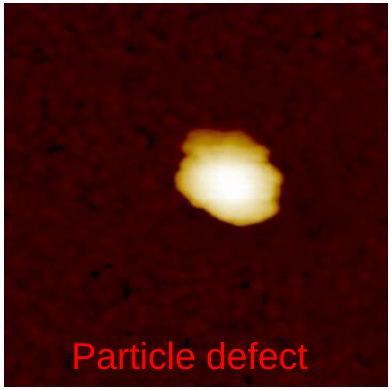


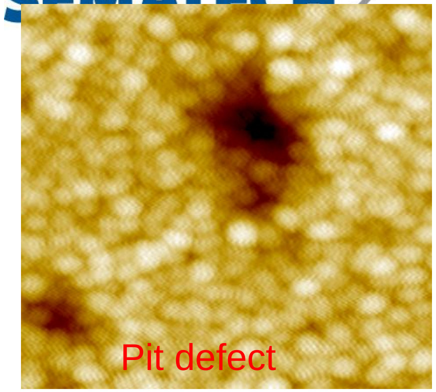


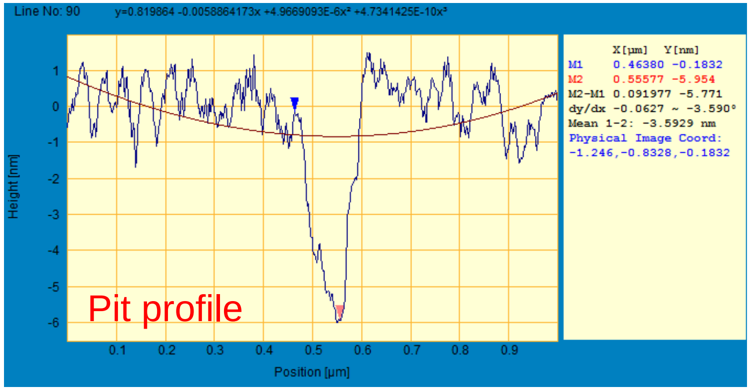
- SEM Imaging
  - Low contrast of some defects creates challenges for locating defects in SEM.
    - Although optically detected.
  - Impacts location and TEM sample prep of these defects.

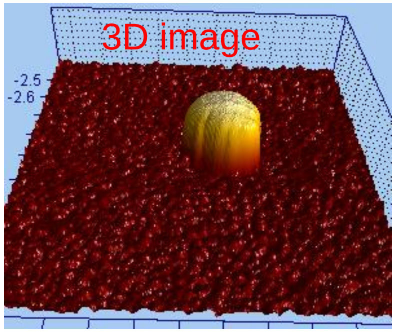
Atomic Force Microscope (AFM)

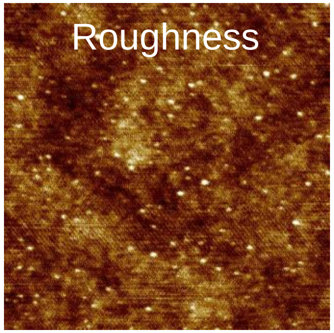
- Primarily supports
  - Imaging of particle and pit type defects on substrate and mask blank.
  - Surface roughness measurement.
  - Bonding force of particles and mask absorber.
- Capabilities
  - <0.09 nm RMS noise level
  - Depth repeatability
static – 1.0 nm (3s)
dynamic – 2.0 nm (3s)
  - Static Roughness repeatability of 0.05 nm for surface of 0.15-1.0 nm RMS







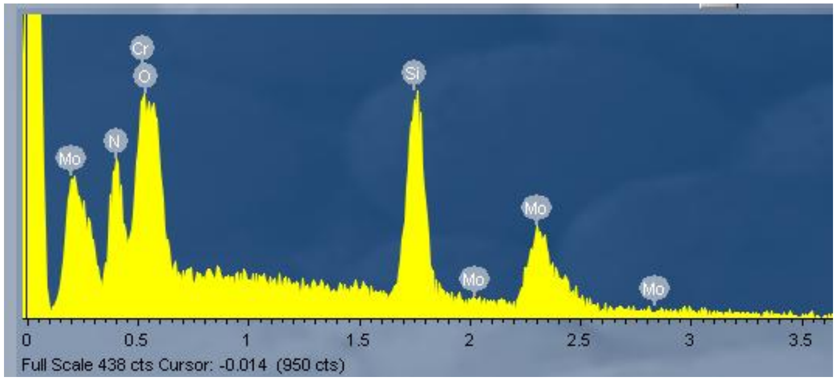




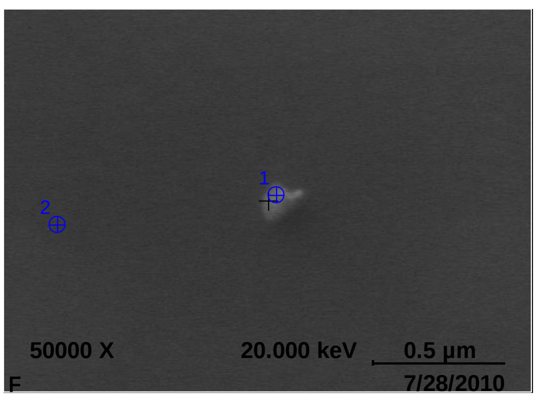
Auger Electron Spectroscopy

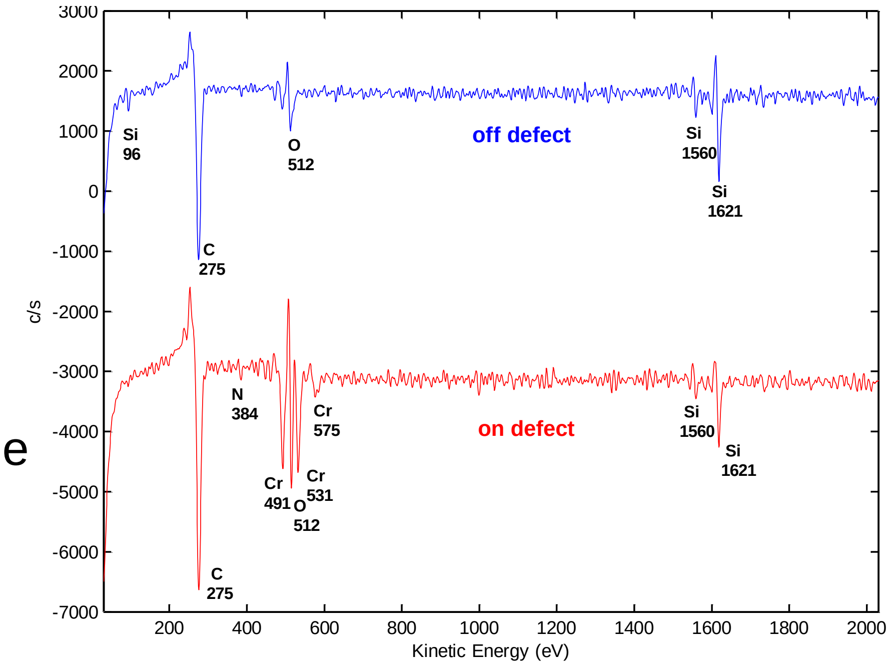
- Capacity for whole 6'' masks
  - Eliminates contamination of cutting glass
  - Preserves coordinate system from inspection tool
  - Automatic full mask navigation
- High resolution
  - 6 nm SEM resolution
  - 8 nm Auger resolution
- Tilted electron column
  - Capable of analyzing both top surface and cross section without tilting stage

AES Validation of EDS Data from FIB/SEM



- It is difficult to separate Cr from O due to overlapping EDS peaks.

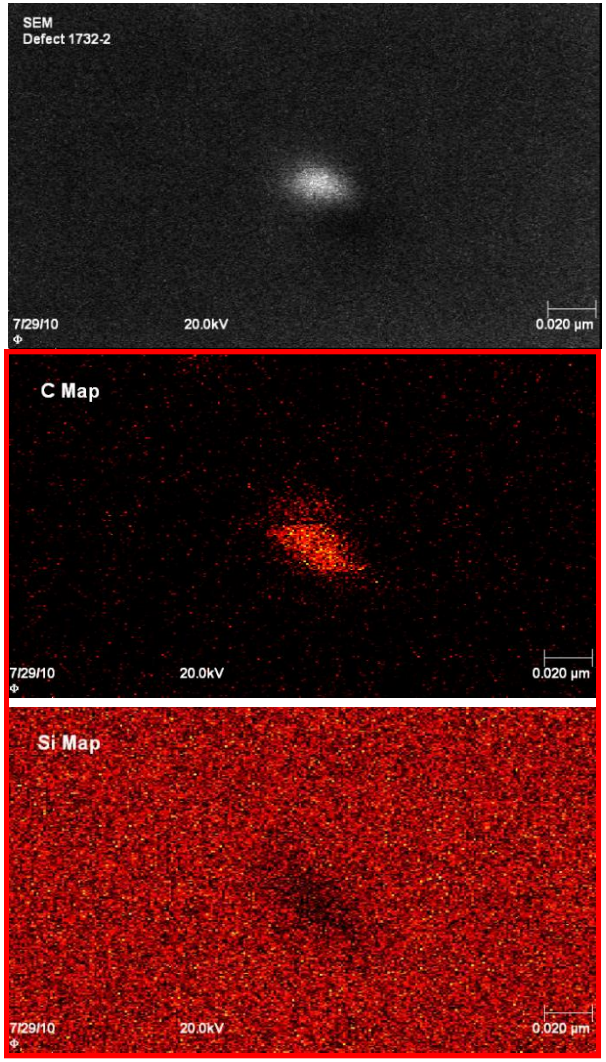


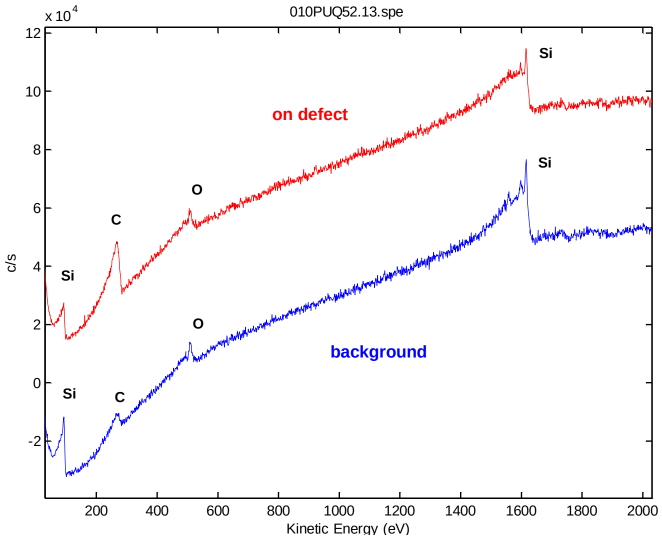


- Auger spectra confirm the defect contains Cr. They also indicate there is no Mo on the analyzed surface.

AES: Small size defect analysis

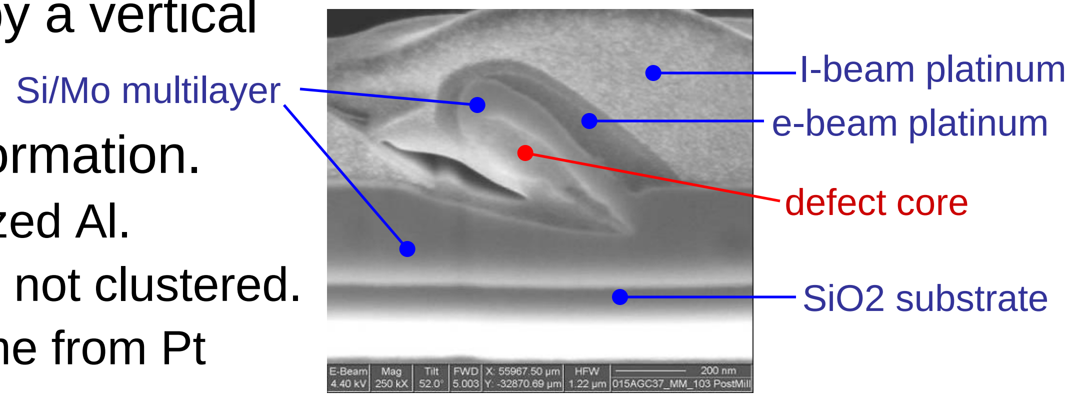
- Auger map shows the distribution of C and Si elements.
- The example confirms defects of 30 nm size can be analyzed on conductive surfaces.

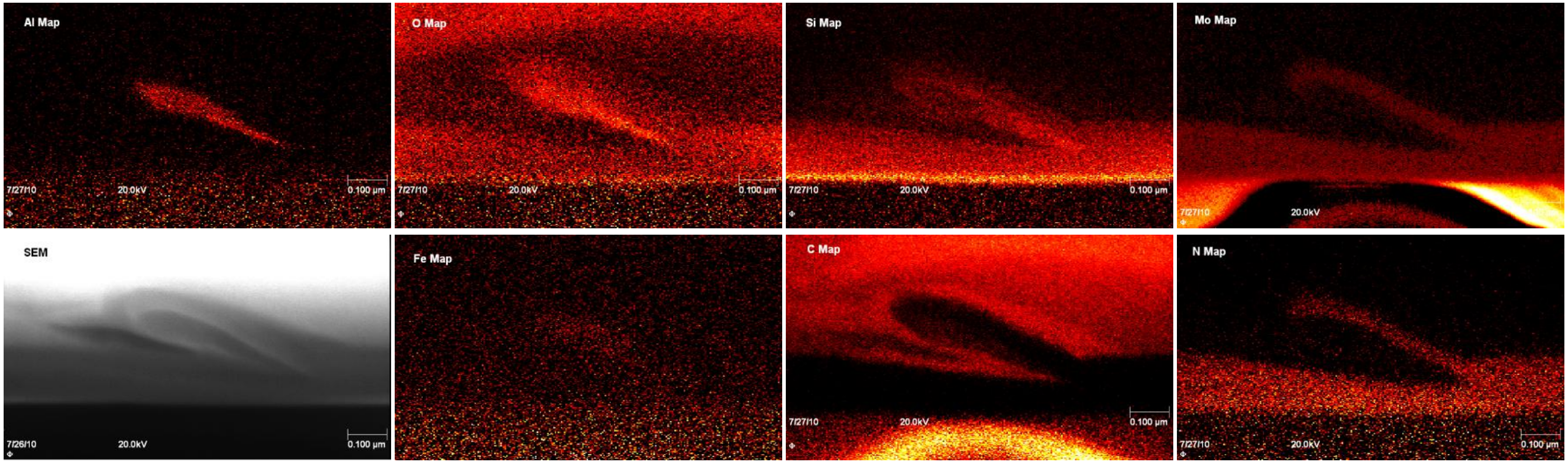




AES: Cross-sectioned defect

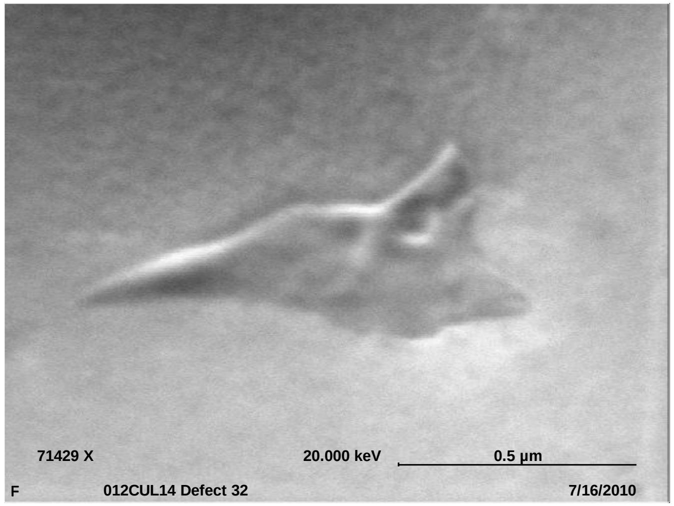
- Buried defect was exposed by a vertical FIB cut.
- Auger maps reveal detail information.
  - Defect contains highly oxidized Al.
  - Defect contains Fe, which is not clustered.
  - The C defected by EDS came from Pt deposition.
  - There is N distributed uniformly in Si/Mo film.

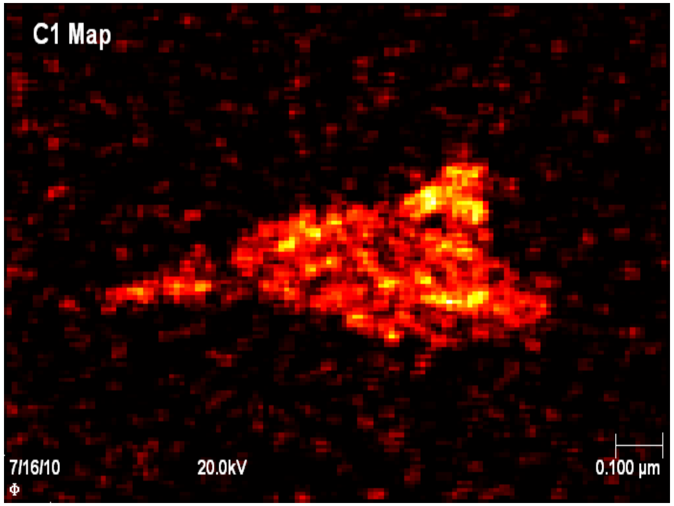




AES: Defects on non-conductive SiO_2 substrate

- Surface charging is constantly challenging for AES analysis especially when high voltage and small spot size are applied to small defects.
- A carefully controlled conductive coating is used as a counter measure.
- The example shows a defect containing C. The conductive coating is thin enough that Auger electrons can escape. Meanwhile it has to be thick enough to dissipate surface charge.

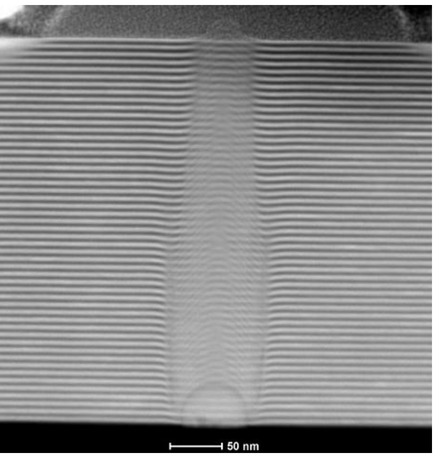


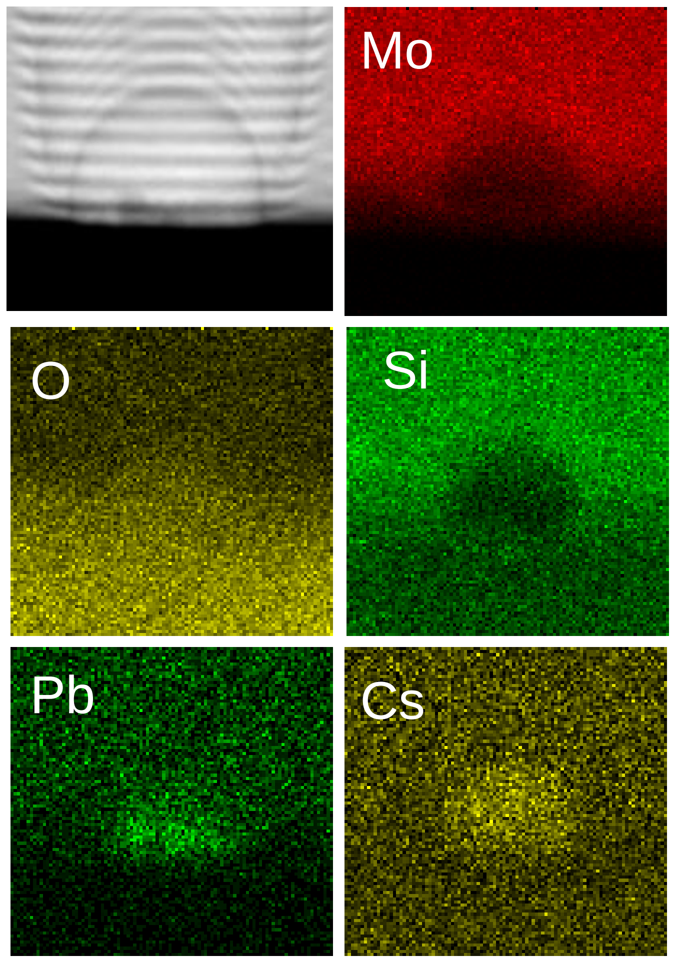


Titan S/TEM

- Increased imaging and analysis capability due to C_S probe-corrector and monochromator.
- Flexibility in accelerating voltage (80-300kV).
- Spatial resolution: 70pm.
- Point resolution: 80pm.
- Environmental closure reduces noise from environment.
- New X-FEG electron gun yields maximum source brightness and beam coherency.
- Triple condenser system for flexible illumination.
- Detectors: On-axis triple DF1/DF2/BF and HAADF.

Energy dispersive x-ray spectroscopy (STEM-EDS)





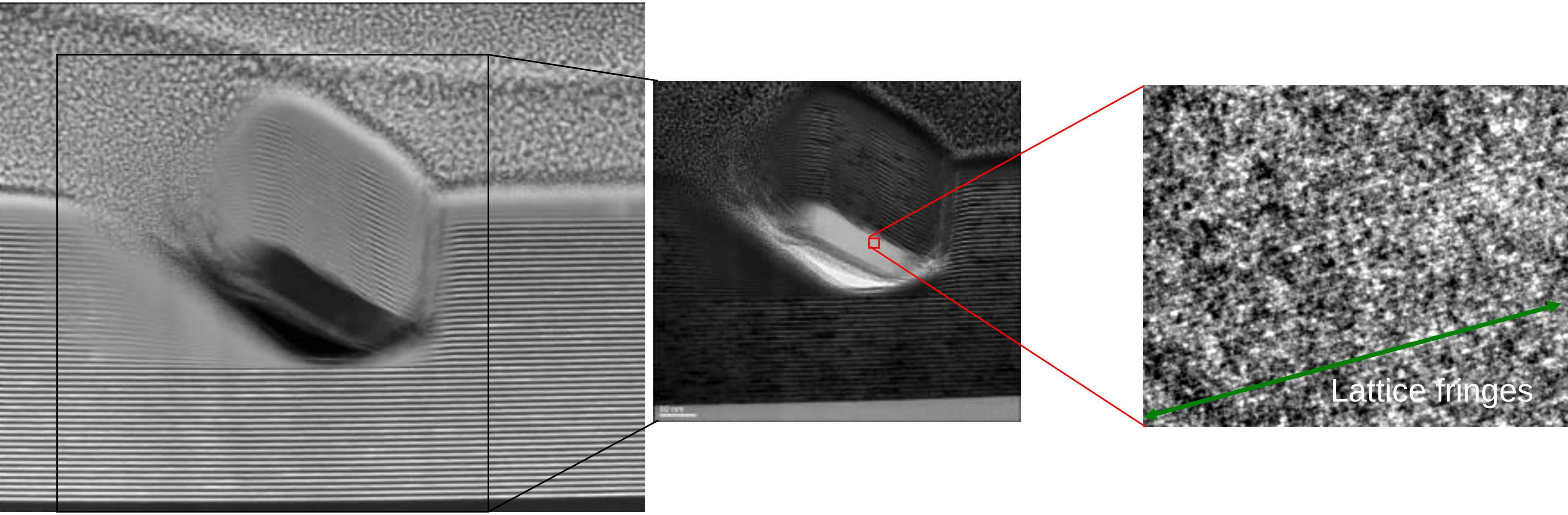
Elemental mapping through EDS provides a fast and comprehensive composition analysis of EUV mask blank defects.

FEI SuperX upgrade coming Spring 2011

- Windowless detector can detect elements down to and including Boron.
- 4 silicon drift detectors (SDDs) integrated into objective lens for large collection angle.
- High sensitivity for even low-intensity signal.
- Fast elemental mapping and spectroscopy acquisition.

Imaging modes HR-TEM

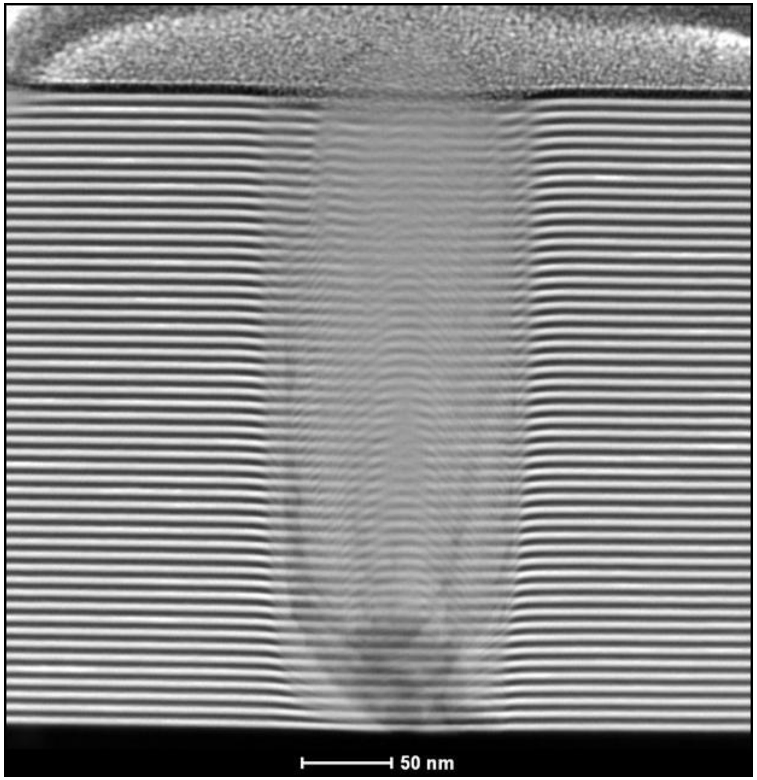
- Crystallinity information can be derived

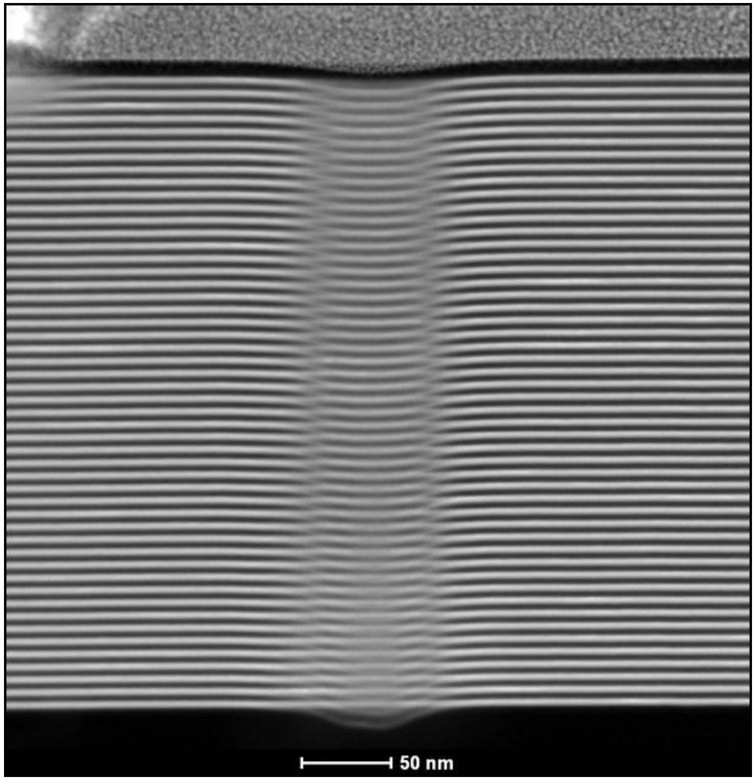


- Crystalline Si defects originated from Si target during deposition

Imaging modes HR-STEM

- High angle annular dark field (HAADF) imaging: highly scattered electrons are collected for z-contrast.
  - Provides details of multilayer film growth over substrate and embedded defects.



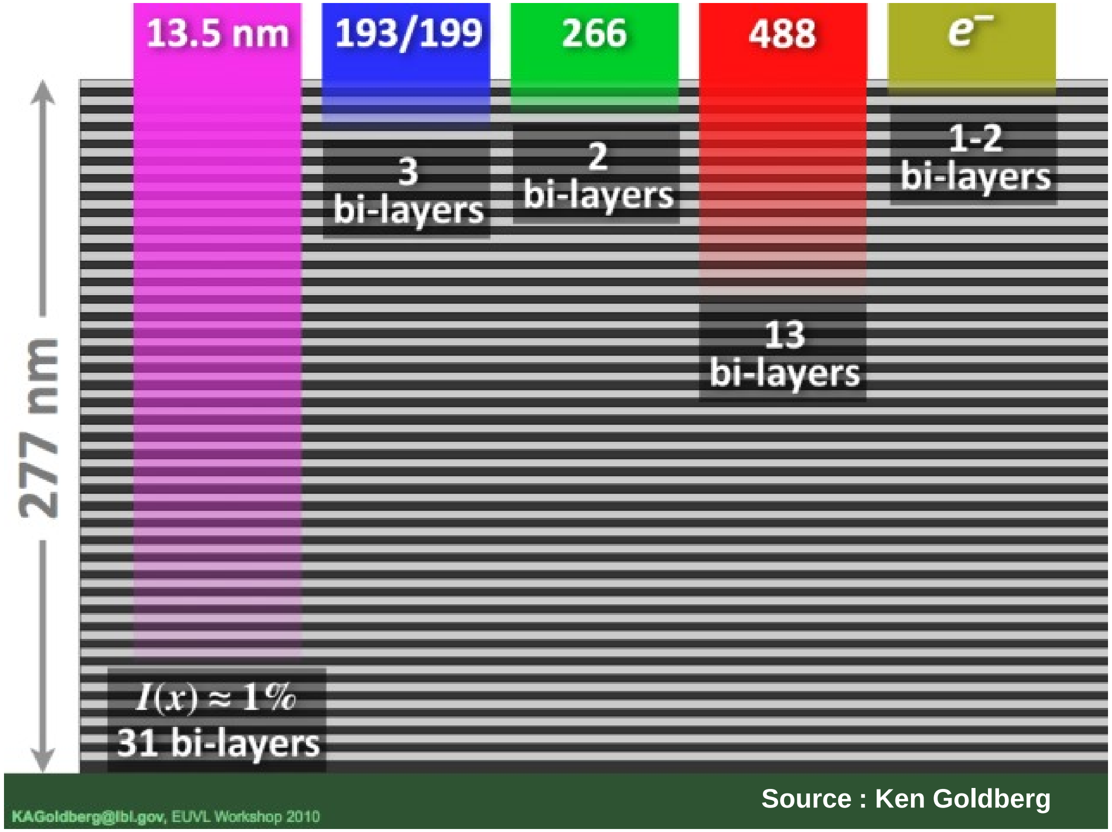


Other analytical techniques on the Titan

- Energy filtered imaging and electron energy loss spectroscopy (EELS)
  - Energy filtered imaging, EELS, and EELS mapping will provide unprecedented compositional analysis for sub-50nm mask blank defects.
  - Resolution is limited by sample thickness, so we are restricted by our current sample preparation techniques.
- 3D tomography
  - Tomography holder allows 40 rotation for accurate 3D reconstructions.
  - Shape and size information can further advance SEMATECH’s defect reduction program.

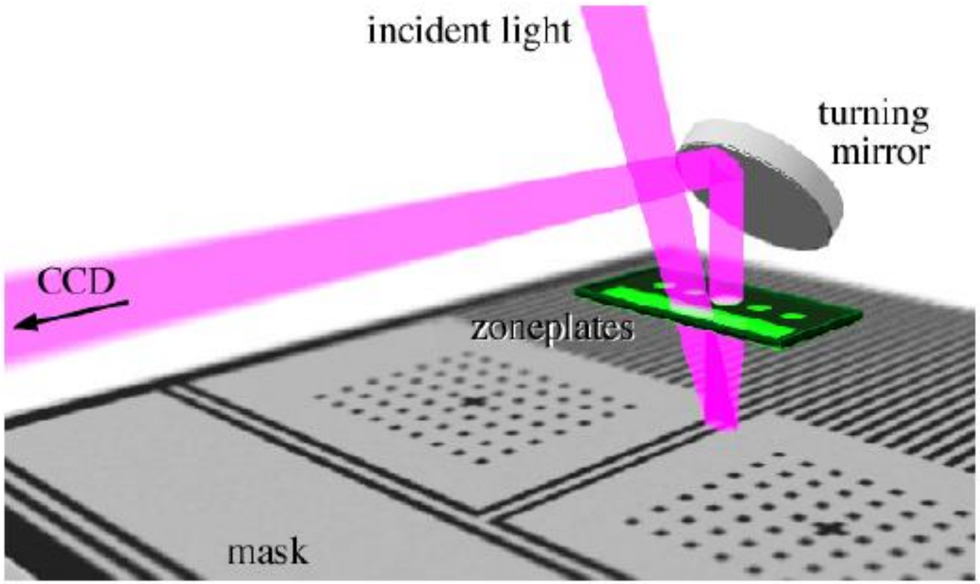
Phase Defect Detection

- Phase defects
  - Defects buried below the multilayer
  - Difficult to consistently detect using current blank inspection and mask inspection systems.

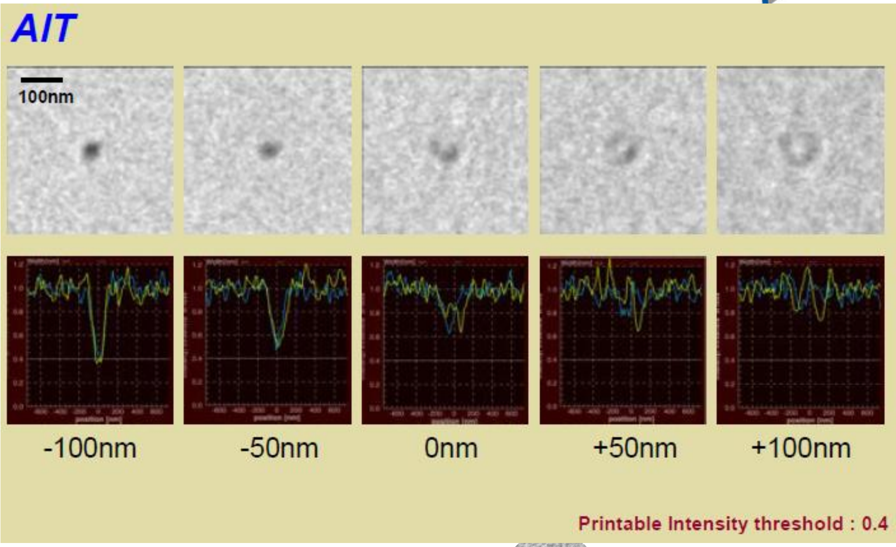


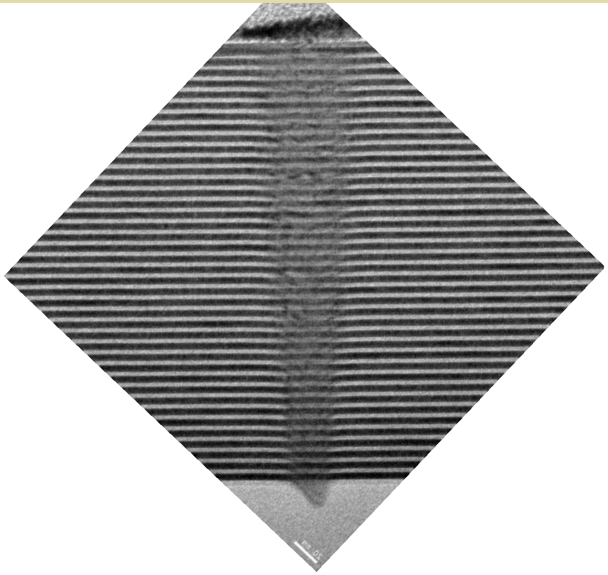
Source : Ken Goldberg

Defect printability



Actinic inspection tool (AIT)

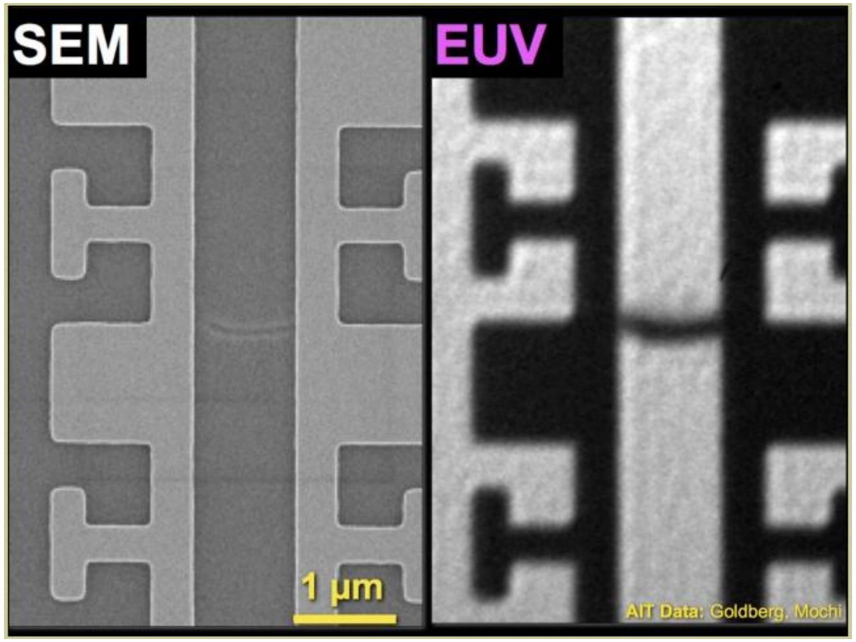




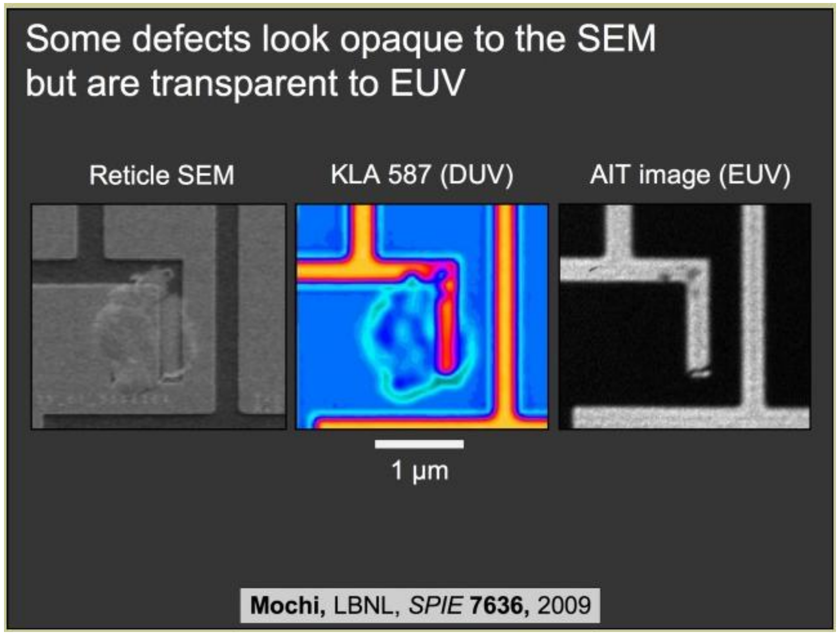
– Disruption in multilayers provide phase defects and hence intensity contrast, even though the surface on top appears smooth

Non-Actinic Tool vs. Actinic Tool

- Non-Actinic inspection will have limitations
  - Low contrast images in SEM fully resolve with EUV imaging and become printable
  - Other defects are detected but are transparent to EUV radiation



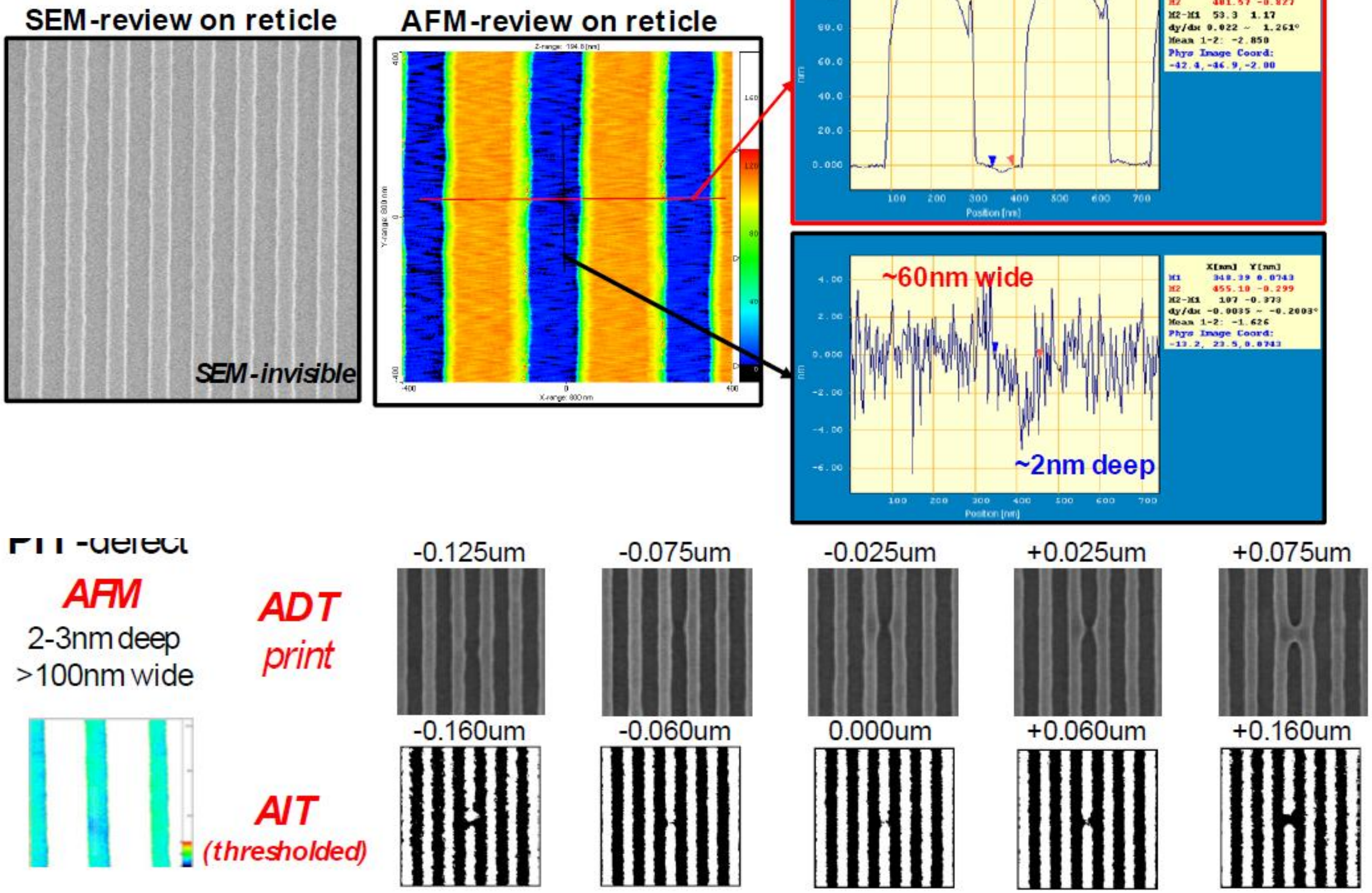
E beam vs. EUV



E beam vs. DUV vs. EUV

Defect Detection with Non-Actinic Tool

- Invisible with SEM and optical review
- But printed on wafer…and see with AIT



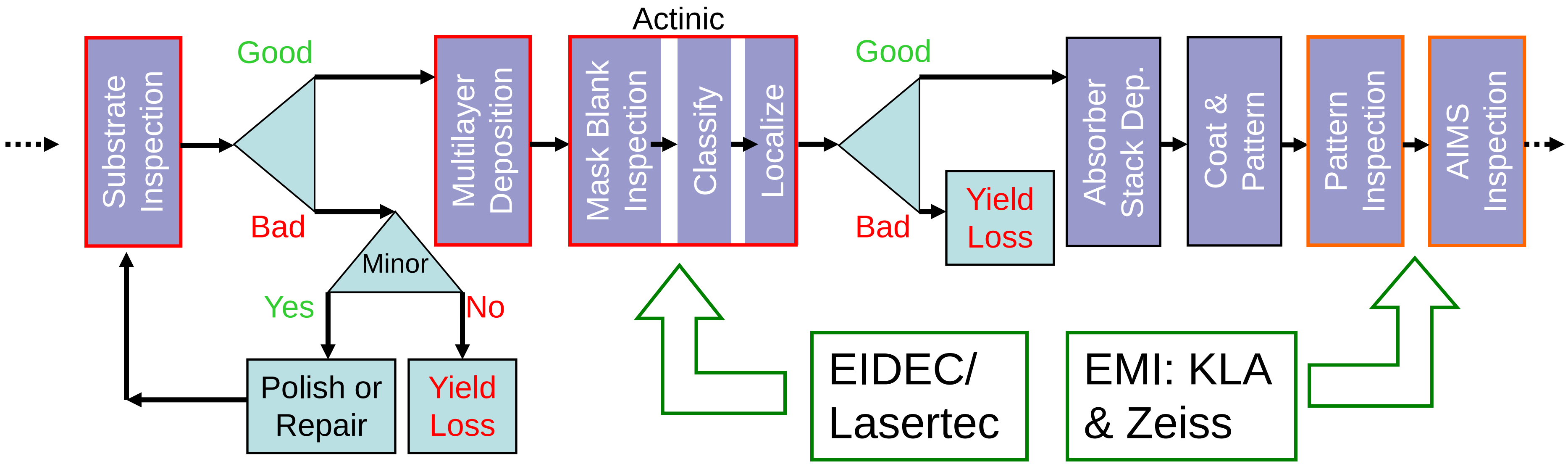
Source : Rik Jonckheere et al, EMLC 2011, SEMATECH AIT

High Level Requirements for Actinic Blank Inspection

- Inspection requirements:
  - Substrate pits/bumps (phase defects) must be detected & localized.
    - Size: ~35nm FWHM x 0.7nm height.
  - Particles, even just under the capping or top multilayers (amplitude defects) should be detected & localized.
    - Size: ~15nm FWHM x material dependant depth.
- Classification and review requirements:
  - Review should accurately localize the defects so mitigation by pattern shifting can be used.
    - Alignment needed ~15nm.
  - Defects should be classified, and near the sensitivity limit, we should review them to know if signals will print or impact patterning.
    - Diffraction limited aerial image which approximates the scanner

EUVL Mask Process Flow

- A mask process flow with gap tools shown using red outlines. Several clean steps not shown.



- Why classify/review and localize defects?
  - Localization and pattern shifting could save blanks from being scrapped.
  - We classify defects today and need to continue this when operating at the sensitivity limit where false positive/negative defects are a way of life.
  - Non-repairable substrate/multilayer defects must not cause yield loss at pattern mask inspection. Yield is a strong cost/cycle-time driver for mask shops.

Future EUV Mask Metrology Needs

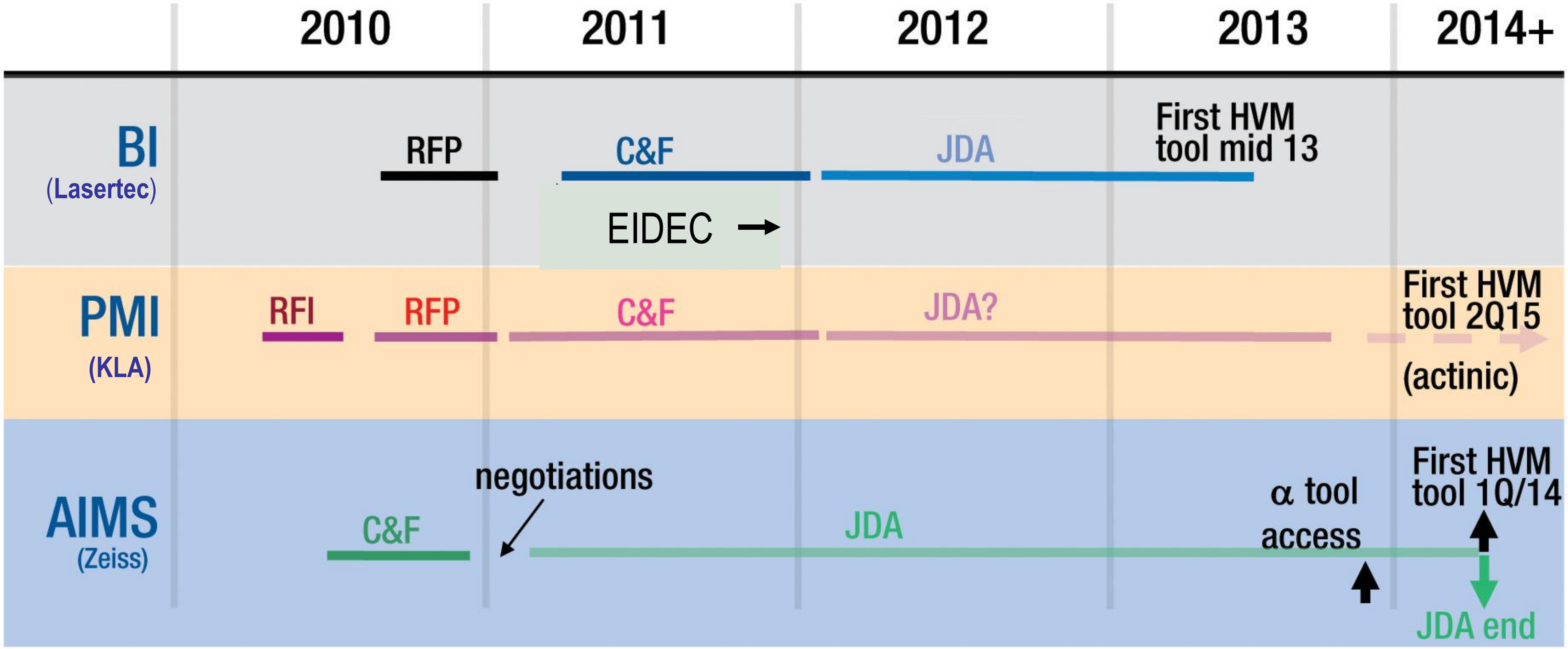
SEMATECH

- 30nm defects are relevant for the 22nm hp node, and defects as small as 10nm may print in the next few years…
- The industry needs:
  - Actinic blank inspection with defect location of ~few nm
  - AIMS review capability to support 11nm hp and beyond
  - Advanced patterned mask inspection to 11nm hp & beyond
  - Chemical characterization methods for 10nm defects

EMI status overview:

- Blank Inspection (BI)
  - Japan's EIDEC supporting with Lasertec BI effort
  - Will not meet logic manufacturers' needs, so improvement required
- Patterned Mask Inspection (PMI)
  - SEMATECH supporting KLA-Tencor actinic PMI program (7xx)
  - Multiple e-beam PMI suppliers have emerged (AMAT, HMI, others)
- AIMS
  - Program proceeding, but final signatures still needed from some members
- Metrology source development
  - EUV sources for actinic metrology require improvement from 8W mm^2 sr to ~100W mm^2 sr

EMI Program schedule overview



Summary

- SEMATECH's EUV mask defect reduction efforts are grounded in metrology
  - Comprehensive (and still growing) suite of inspection and characterization equipment
- Inspection and characterization for defects <30nm pose critical challenges for the metrology industry
- EMI is an organization creating financial pathways to support the development of infrastructure solutions for these challenges