EUV Mask Contamination During Use

(A presentation at the IEUVI Optics Contamination TWG)

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- Introduction
- Analysis of a MET-contaminated mask
  - Line width change by CD-SEM
  - Thickness by AFM
  - Composition and depth by AES
- Summary and future direction

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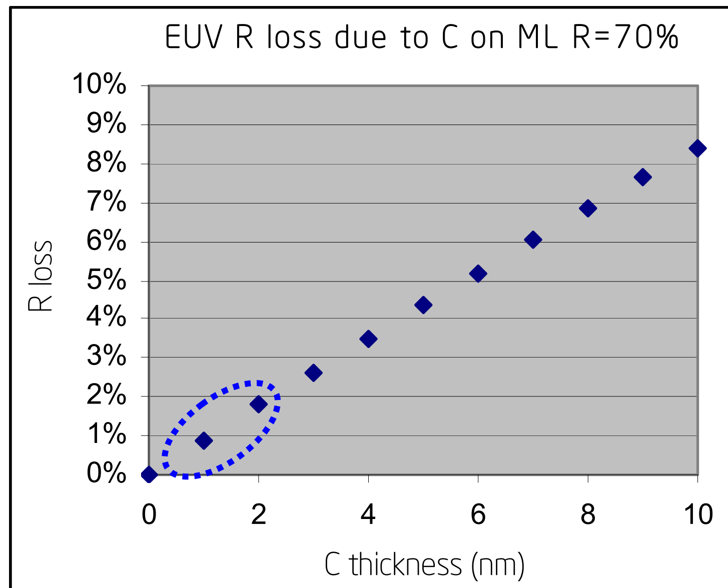
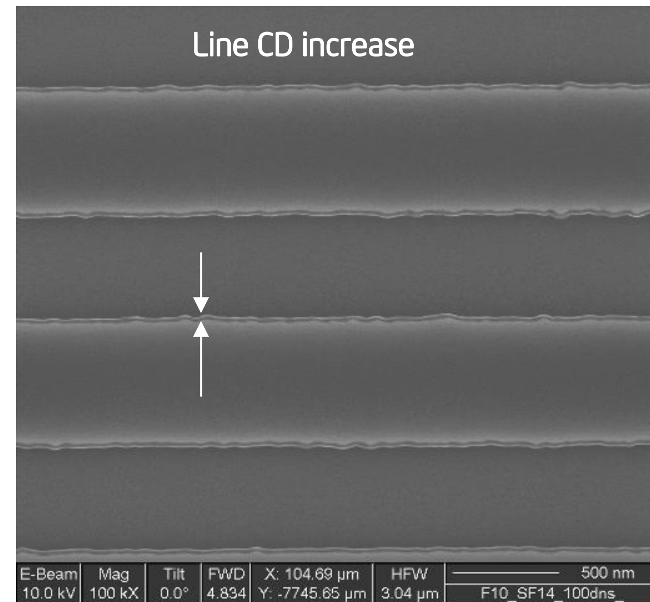
Mask Contamination

- Issue of C contamination in vacuum under EUV illumination
  - Hydrocarbons everywhere; deposit readily on most surfaces under EUV and e-beam illum.
  - Form of PID encountered today in 193nm lithography
- Multiple effects on EUV mask: Refl loss, contrast change, CD change, phase (?)





- C contamination on EUV mask relatively straightforward to understand
  - EUV absorption is atomic, independent of chemical bonding structures
  - Prevention a challenge

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Mask Contamination (cont'd)

- Complex characteristics of possible contamination make specification difficult
  - Uniform C deposition, causing global refl loss (Global CD change)
  - Structure-dependent C deposition, causing local refl loss (local CD change)
  - Material-dependent C deposition, causing pattern and side-wall change
  - Other manifestations in aerial imaging
- Current status of understanding – Some, but not enough data
  - What we know today
    - Observed heavy contamination, estimated 1nm C growth per 50 J/cm^2 (44 wafers!)
    - Patterned CD was affected
    - Contamination is non-uniform over space vs. pattern
    - Likely to be cleaned off
  - What we do not know
    - How close does this observations from MET represent reality in a full-field exposure tool?
    - What are the requirements?
    - How to monitor in-situ? Is ex-situ sufficient?
    - What is the best recovery method – wet or dry?
- Sematech's role in answering these questions
  - Baseline, testing, infrastructure, …

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Description of MET-contaminated Masks

- Mask taken off MET@Albany ~Q1'08
  - Most used mask at Albany
  - Estimated total dose ~1000J/cm^2
  - POR mask materials, jointly made by LBL and Intel for the Albany MET in 2005
    - » LBL patterned resist and Intel etched, Delivered ~ Q1'05
    - » Hoya blank: 70nm LR-TaBN on 2.5nm Ru-ML blank with quartz substrate
  - Contamination analysis done at Intel
  - Contamination: 15-20nm C build up and line CD widening
- Mask taken off MET@Berkeley ~Q2'07
  - Used about 2 years on Berkeley MET, a relatively clean system (SR source)
  - Estimated total dose ~600J/cm^2
  - Saw about 20-30% refl loss
  - Old mask materials, jointly made for MET by LBL and Intel
    - » LBL patterned resist and Intel etched
    - » Hoya blank: TAR70 Cr absorber with 20nm SiO_2 buffer and 11nm Si-cap ML/Quartz
  - Contamination analysis done by AMD (Uzo Okoroanyanwu,)
  - Contamination: ~6-10nm C build up and line CD widening

Mask off MET@Albany

- Layout
  - No repeated dies on this mask

Top right die (reference die)

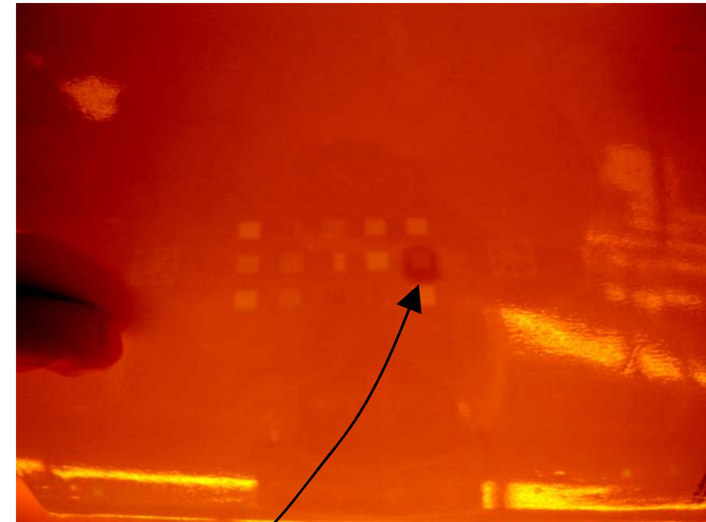
Middle right die (contaminated die)

12mm

Die size 3mm x 3mm

Distance 3mm

- Contaminated die visible



Visible dark area by naked eye

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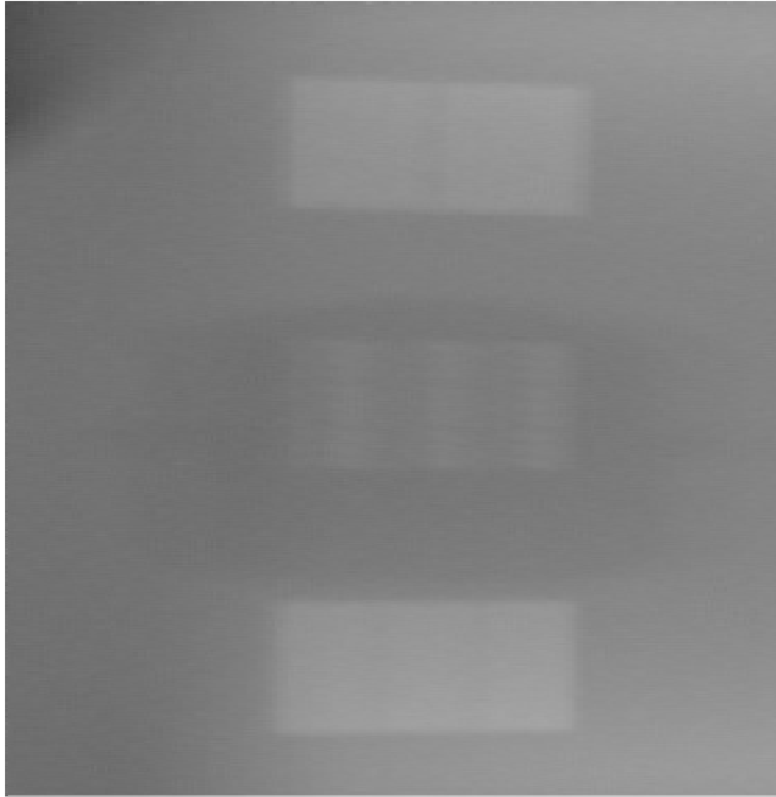
Additional Information



- MET field 10 is primary exposure field
- This field has seen 99% of EUV that has been exposed in RTC (resist test center)
- Carbon build up is evident on MET field 10
- CD's in this field compared to CD's in other fields are larger due to the carbon build up in the area

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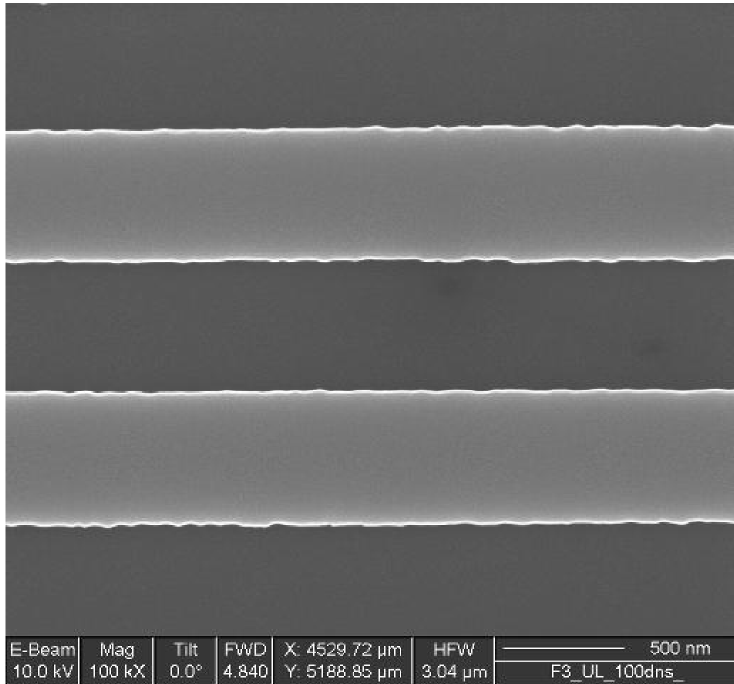
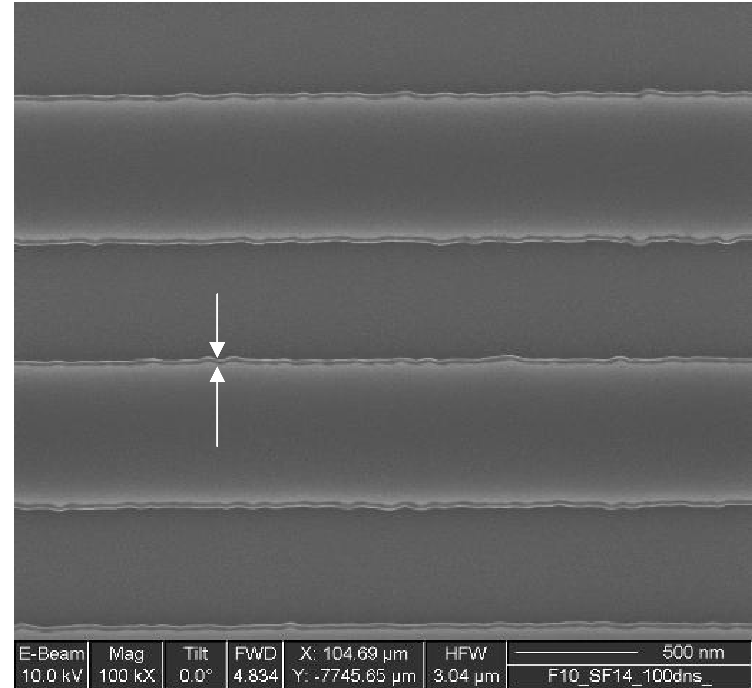
SEM Images Taken at Sematech



- Nominal 500nm (5X) 1:1 dense lines MET Field 3
- Average of 5 areas in this field measured 545.1nm.



- Nominal 500nm (5X) 1:1 dense lines from Field 10
- 500nm design CD, measured 608.9nm
- 64nm greater than 1:1 lines in other fields

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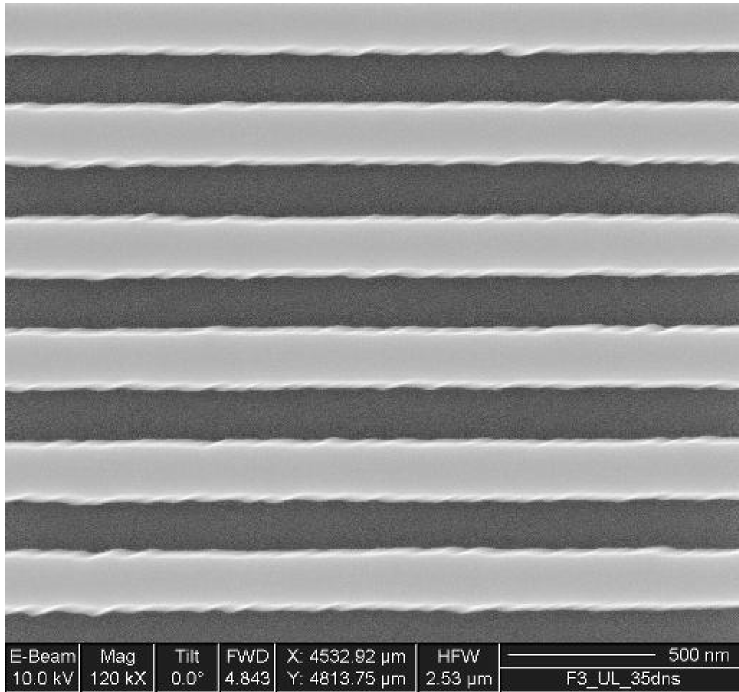
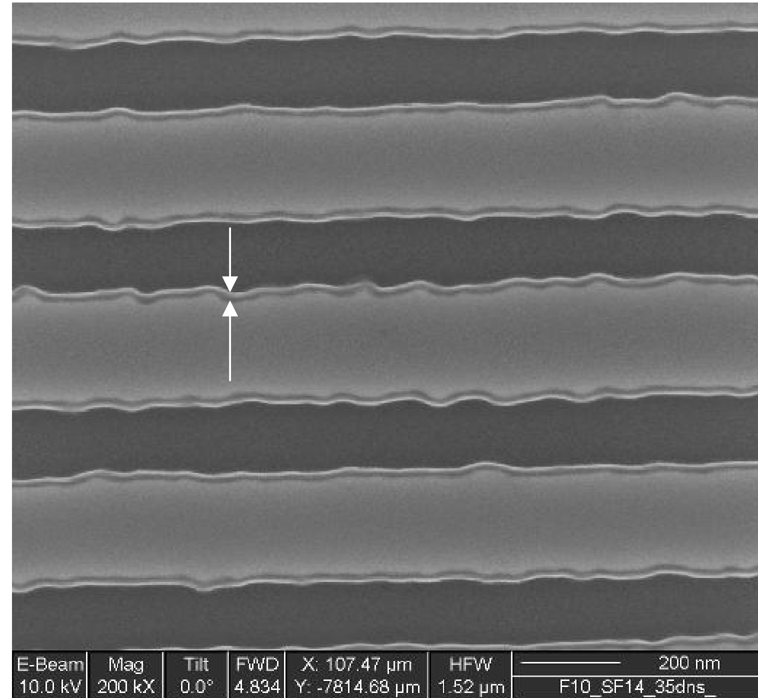
SEM Images Taken at Sematech





- Nominal 175nm 1:1 dense lines from Field 3
- Average of 5 areas in this field measured 188.5nm

- Nominal 175nm 1:1 dense lines from Field 10
- 175nm design CD, measured 233.1nm
- 45nm greater than 1:1 lines in other fields

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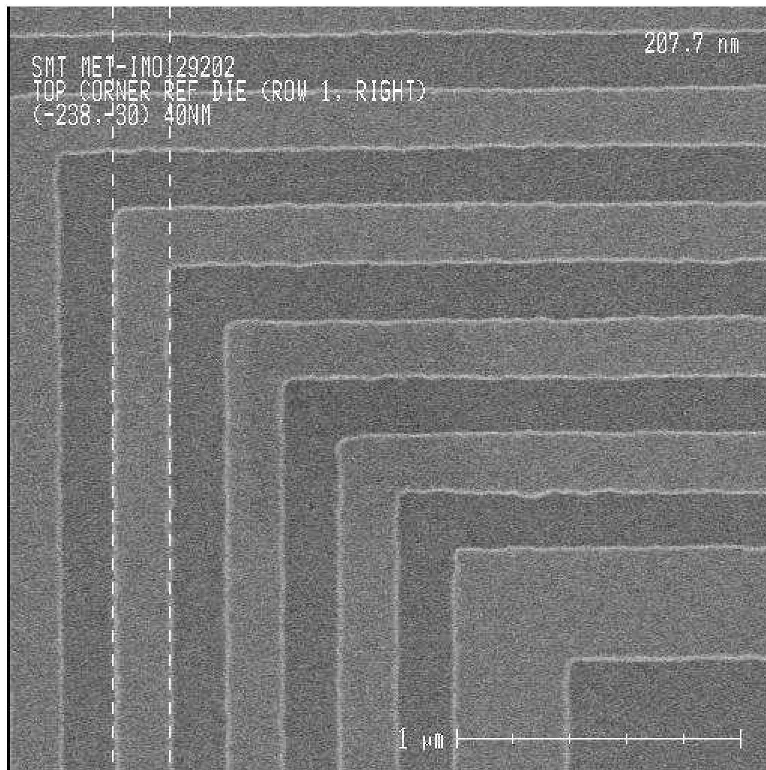
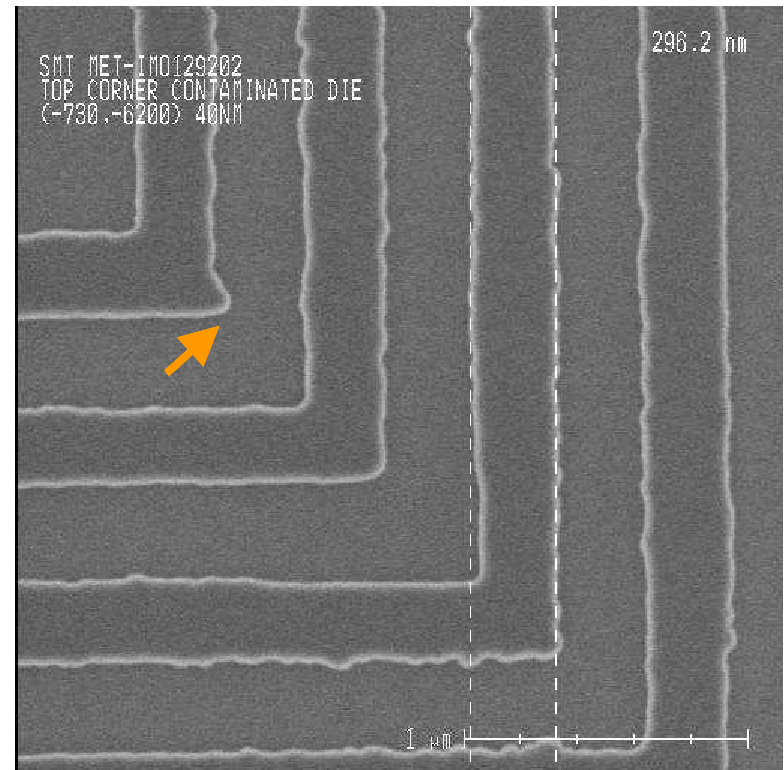
SEM Images Taken at Intel

- Since there are no repeated dies on this mask, images were taken on lines with same coding and labeling (i.e., all labeled 40nm)
- From mask as received in April 2008
- 'Dark' patterns clearly indicate carbon-containing contamination

40nm elbow on reference die



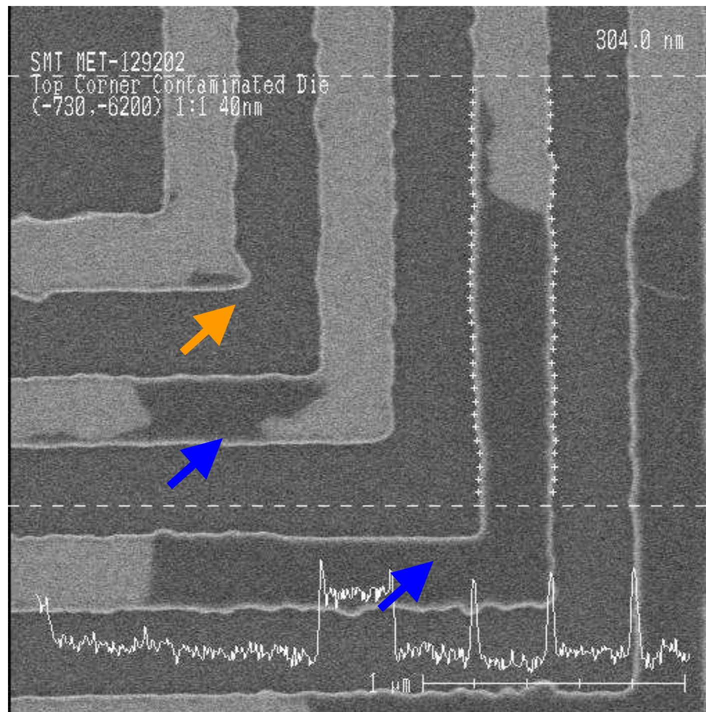
40nm elbow on contaminated die



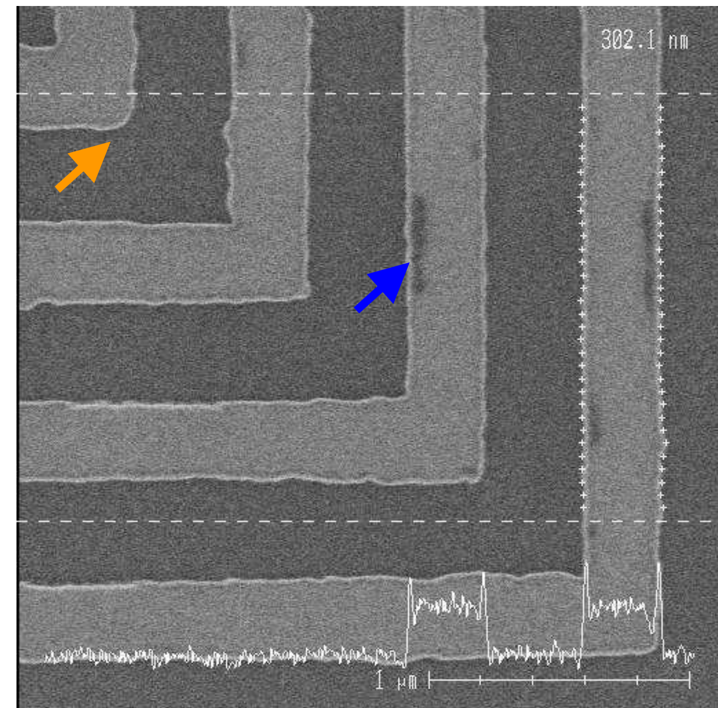
SEM Images Taken after SC1 Clean at Intel

- Extremely high level of particulates on the as-received mask
- In order to use clean room tools for measurements, mask was cleaned with SC1
  - Intended to only remove fall-on particles and maybe some 'loose' carbons
  - Did not cause significant CD change (304nm after clean vs. 296nm before clean)

Elbows patterns on contaminated die



Labeled as 40nm



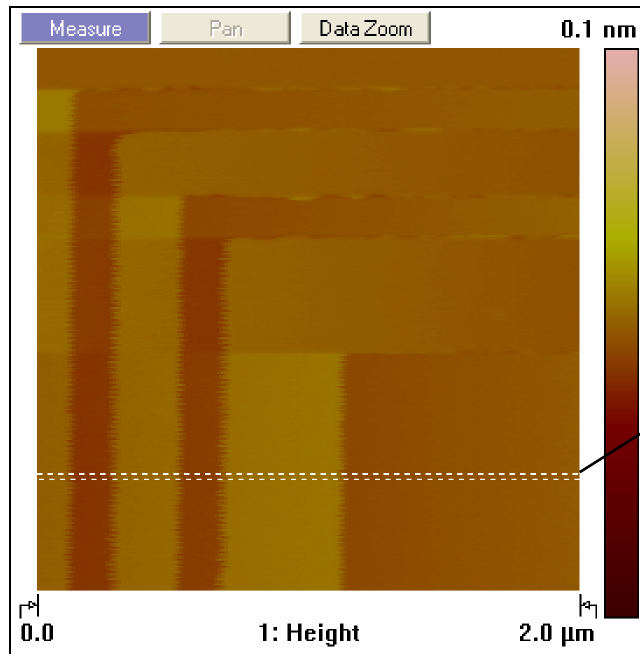
Labeled as 45nm

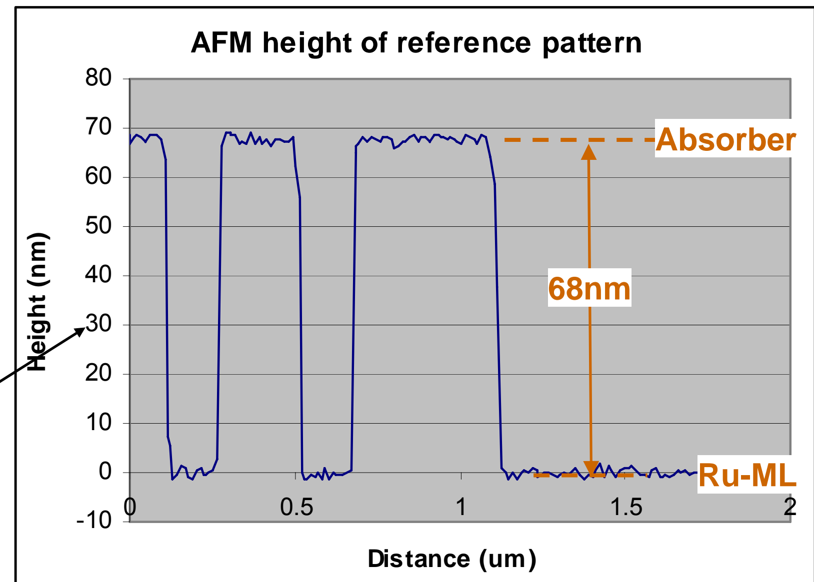
- Some contaminations were cleaned off; Some obviously remained (dark areas on lines)

AFM on Reference Die

- Pattern height ~68nm (same as incoming nominal 70nm LR-TaBN thickness)
- Pattern top is flat

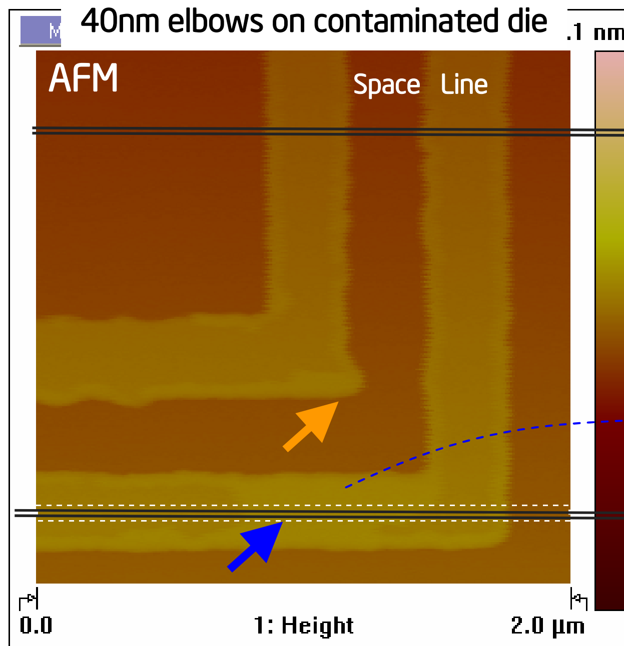
40nm elbow on reference die

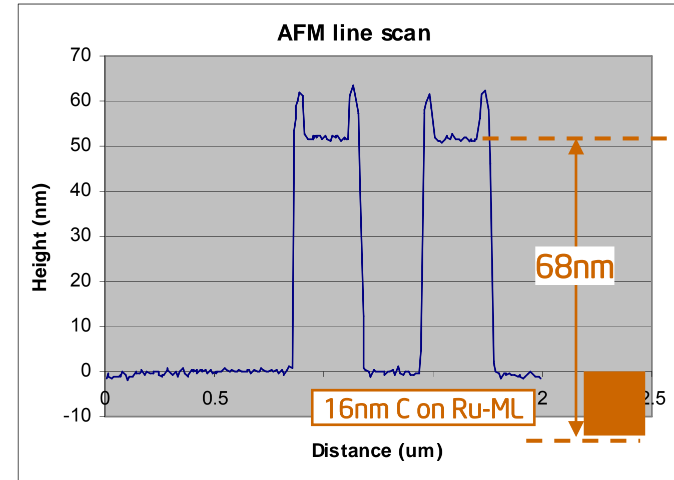


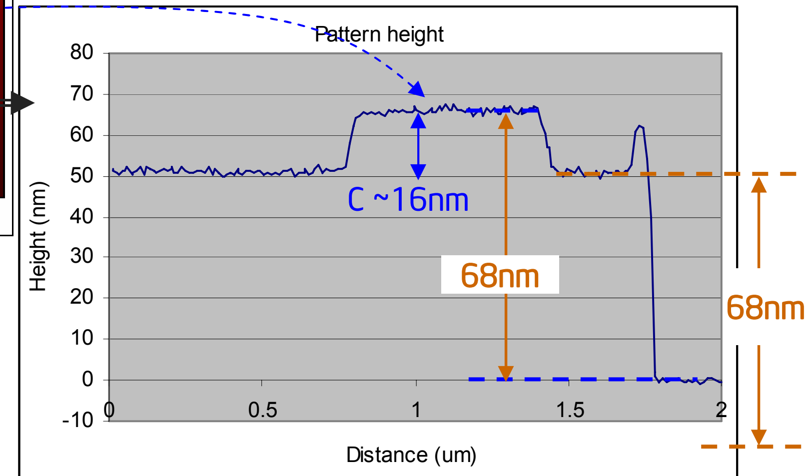


AFM on Contaminated Die – 40nm Elbows

- **At least 16nm thick C build up**
  - Pattern height ~52nm (Δt = -16nm)
  - Contamination on Ru-surface remained after SC1
  - Some contamination remained on AR-TaBN after SC1







- **'Rabbit ear' on pattern top: ~10nm (from 16nm)**
  - Contamination on pattern edge remained after SC1
  - Different characteristics? – TaBN vs. AR-TaBN, high SE
- **Contamination on pattern top**
  - Most was cleaned off with SC1
  - Remaining patches ~16nm thick

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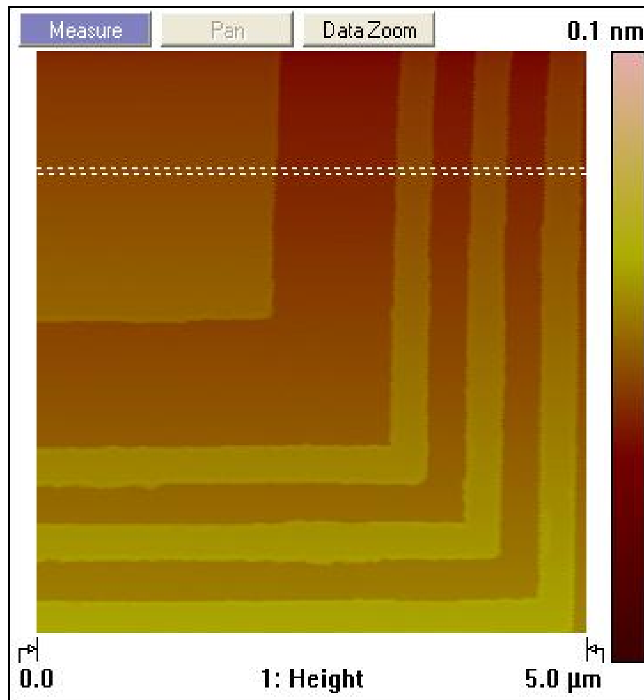
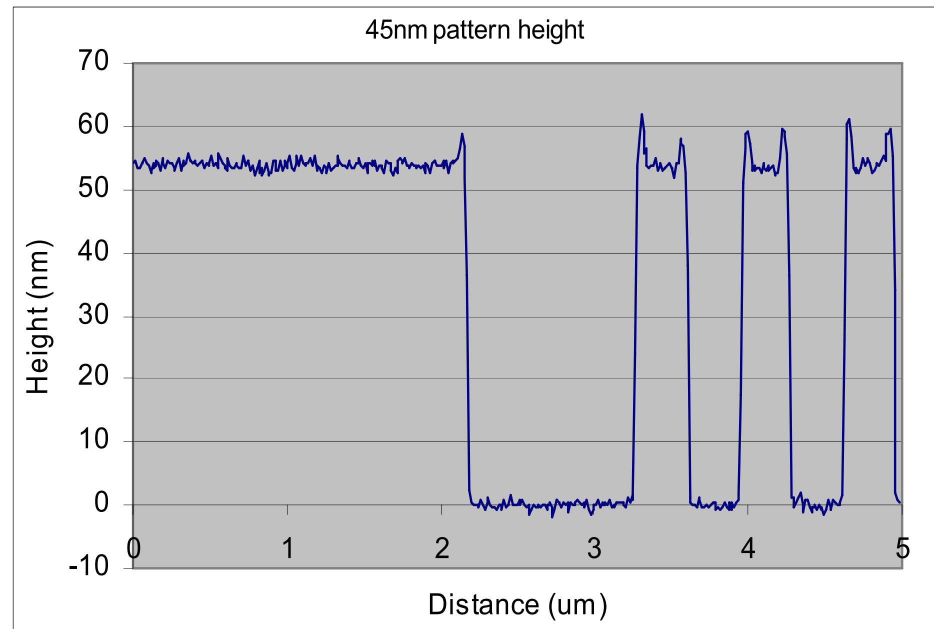
AFM on Contaminated Die – 45nm Elbows

- **Same observations**
  - Pattern height ~52nm (Δt = 16nm)
  - Same “Rabbit ear’ on pattern top

45nm elbows on contaminated die





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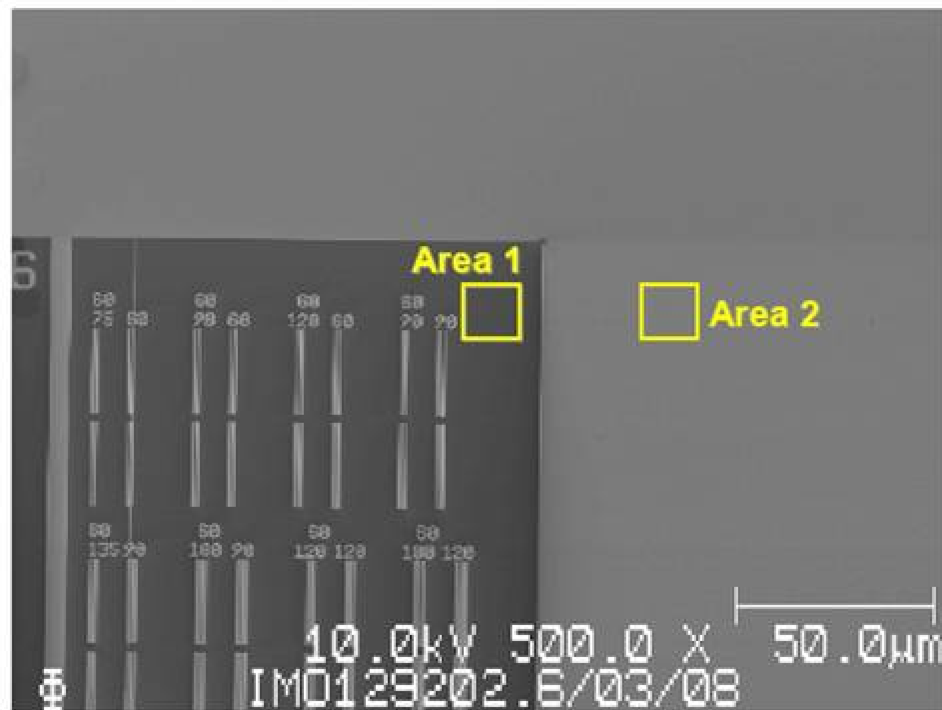
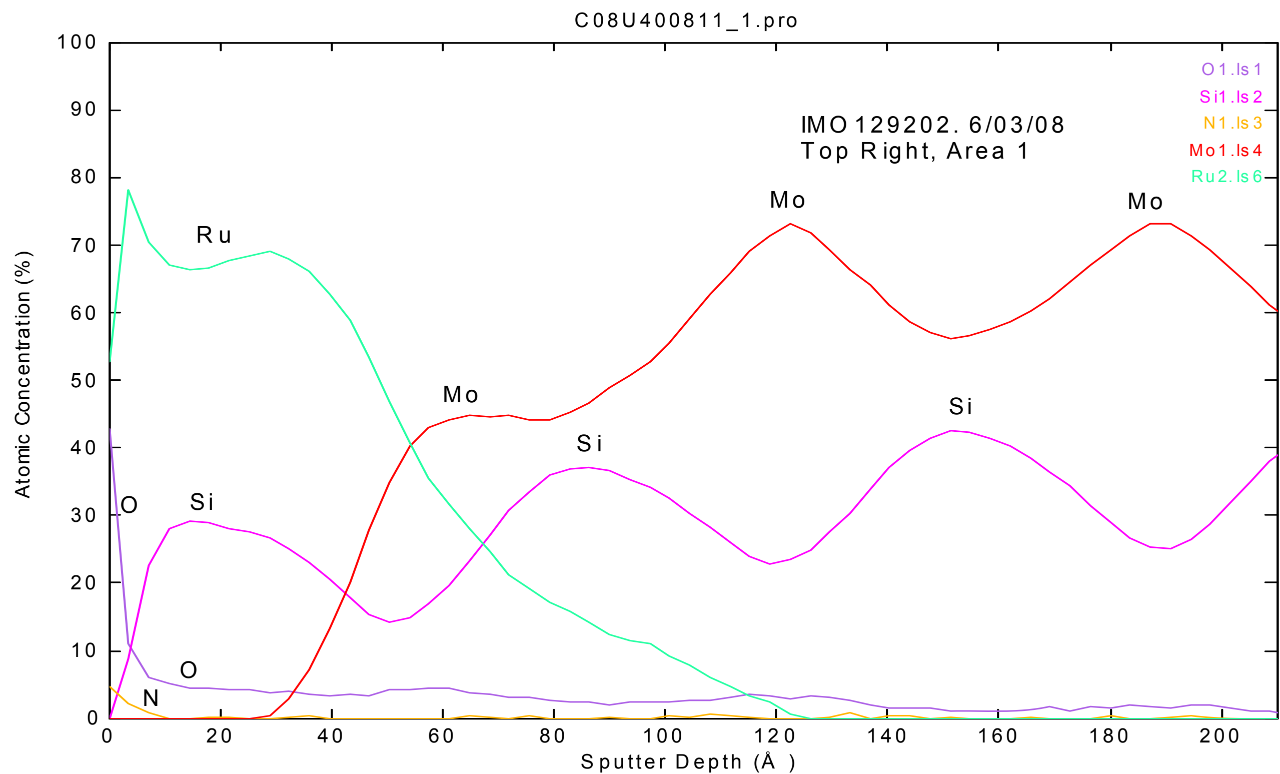
AES Depth Profiling – to Verify C Layer

- On Reference die
- Area 1 is Ru-ML, Area 2 is TaBN



AES Depth Profiling – Reference Die (cont'd)

- On Reference (non-contaminated) die, Area 1 (Ru-ML)
- Typical of a normal mask with Ru-ML blank



Note: Ru sputtering rate not calibrated

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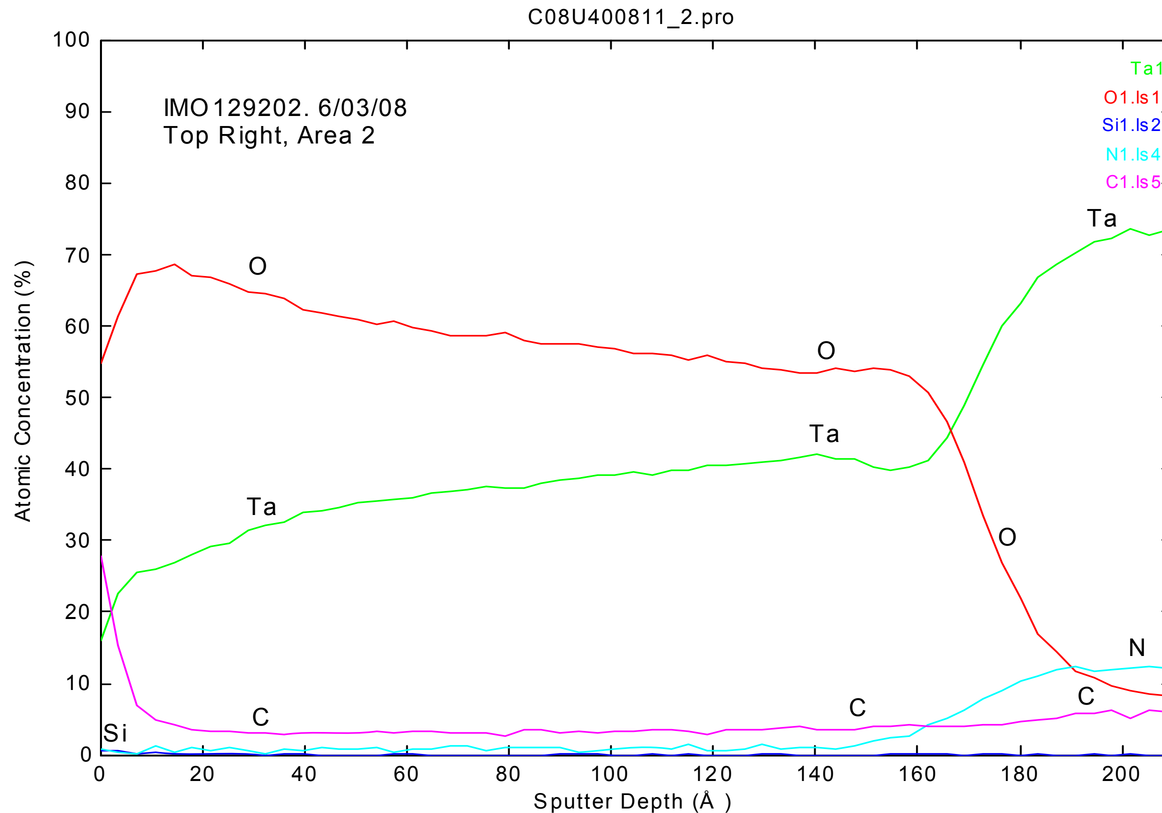
AES Depth Profiling – Reference Die (cont'd)

- On Reference die, Area 2 (LR_TaBN absorber)
- Typical of a normal mask with ARC-TaN based absorber



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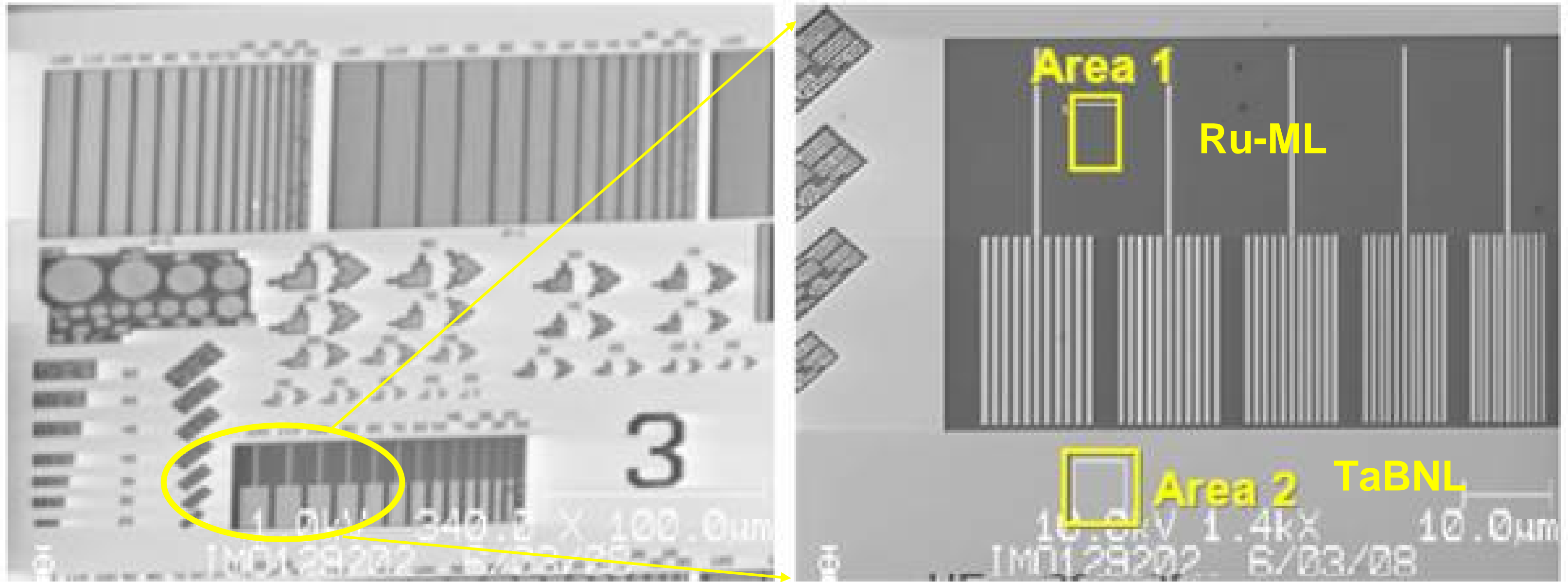
AES Depth Profiling – Contaminated Die

- On contaminated die



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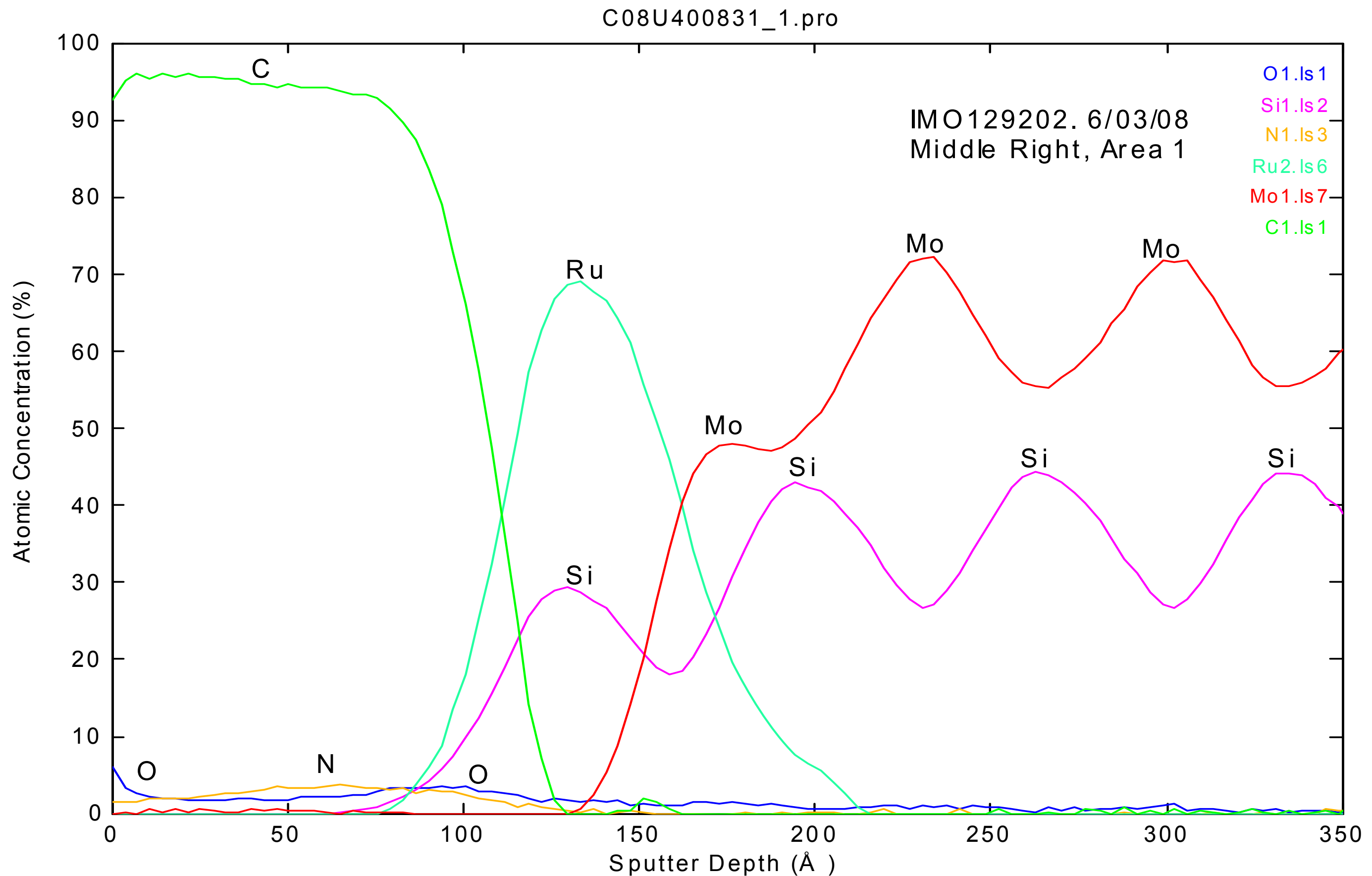
AES Depth Profiling – Contaminated Die

- On Contaminated die, Area 1 (Ru-ML)
- Surface was completely covered by C contamination
- No significant O signal increase



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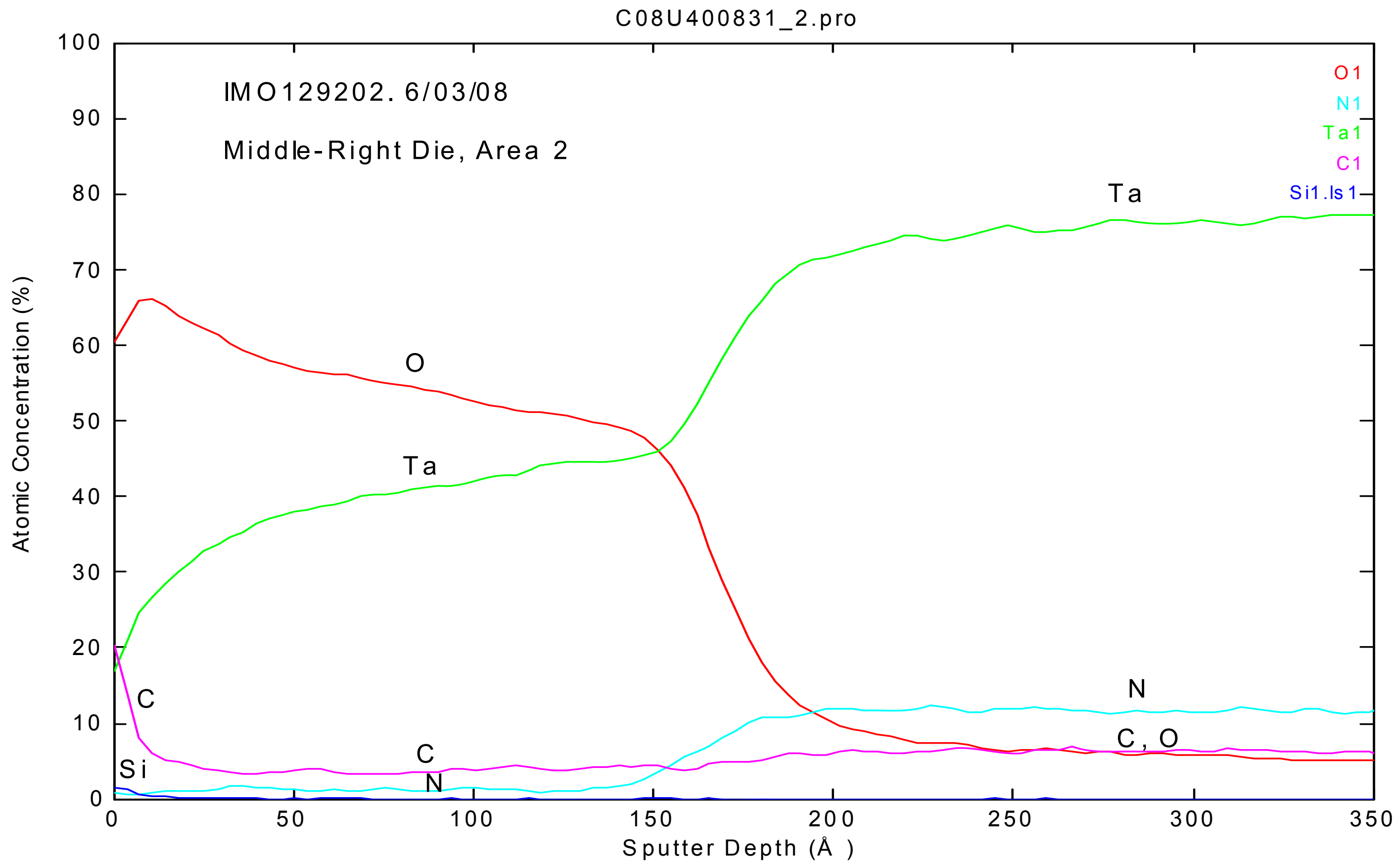
AES Depth Profiling – Contaminated Die

- On Contaminated die, Area 2 (LR_TaBN absorber)
- Very little C at this particular site (Most likely cleaned off by SC1)



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Summary and Future Directions

- **EUV exposure results in (unavoidable) carbonaceous contamination**
  - Up to at least 16nm C build up from the mask off MET@Albany
  - Contamination was not uniform: Ru vs. TaN, edge vs. top, cleanability by SC1
  - No significant oxidation was observed (a good thing - to avoid irreversible damage)
- **C contamination on Ru-ML is different than that on TaN absorber**
  - Different responses to SC1 cleaning
  - Even though this may not be entirely unexpected, further assessment needed
- **Further determination of mask lifetime due to contamination is needed in a *exposure tool with well-emulated and controlled conditions***
  - **Understand implications to manufacturability and productivity**
- **Sematech project in 2009 shall be designed to address/confirm the following, in collaboration with exposure tool suppliers and MCs**
  - Specification on contamination based on imaging requirements (Dose, CD, flare…)
  - Growth rate
  - Pattern and surface dependency
  - Monitoring – in-situ or ex-situ
  - Reduction and recovery

Ref: Roman Caudillo: Poster and TWG presentations

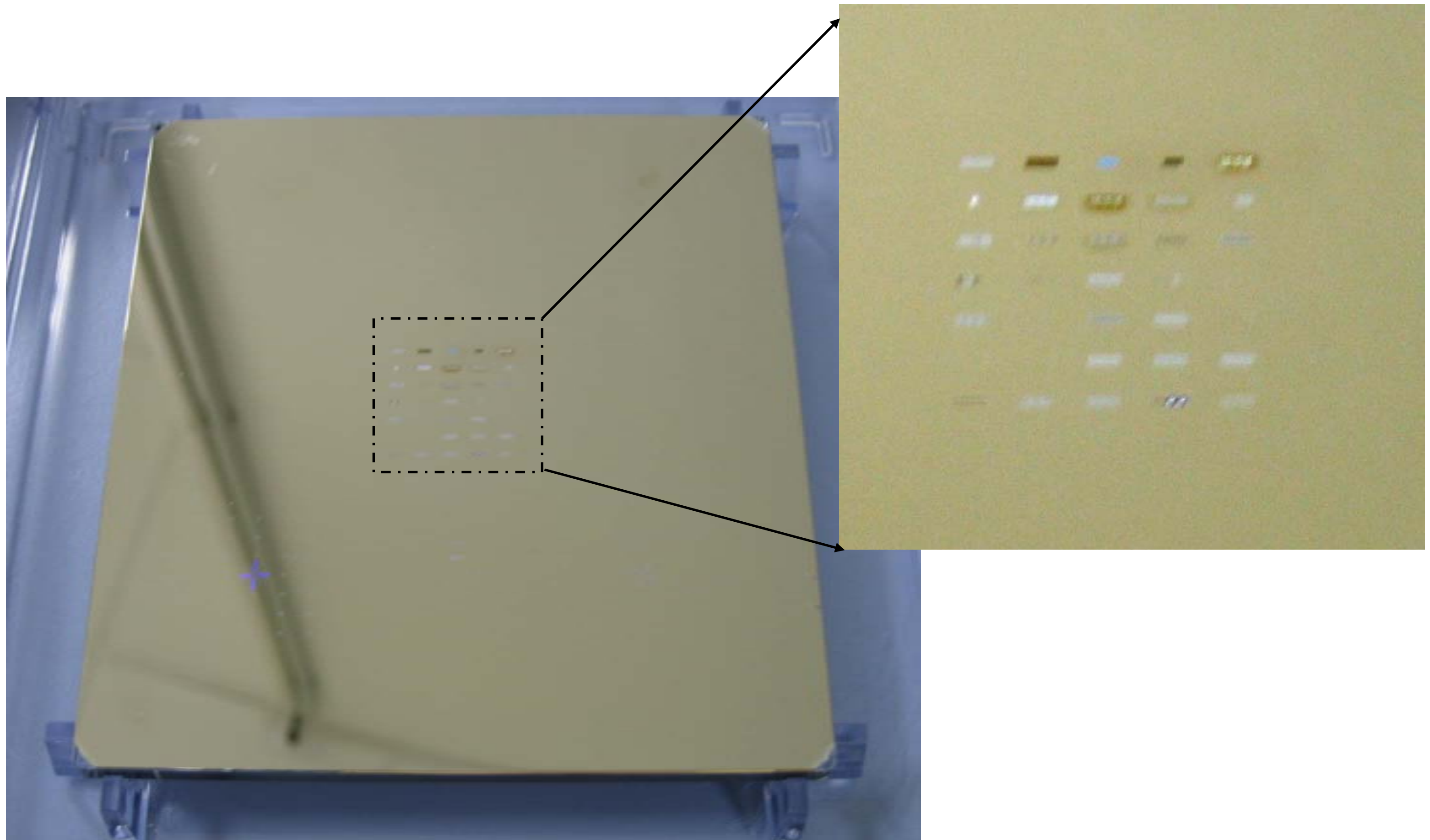
Acknowledgements

- Sematach:
  - Andrea Wüest and Co.
- CXRO – LBNL
  - Patrick Naulleau
- Intel:
  - Armando Cobarrubia
  - Joseph Rodriguez
  - Guojing Zhang
  - Roman Caudillo
  - Gilroy Vandentop

Backup

Mask off MET@Berkeley

- Similar dark regions of those exposed fields



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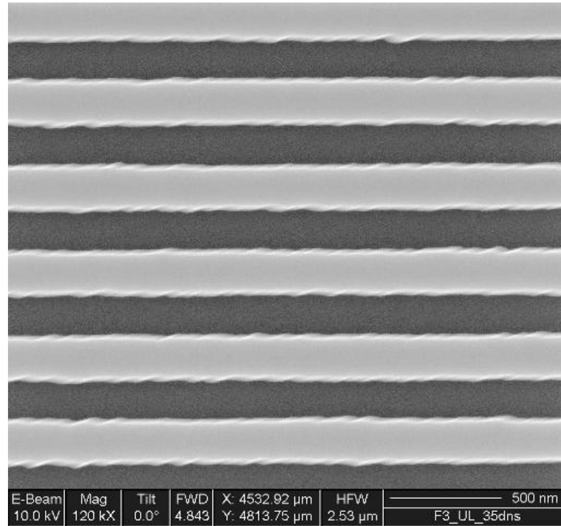
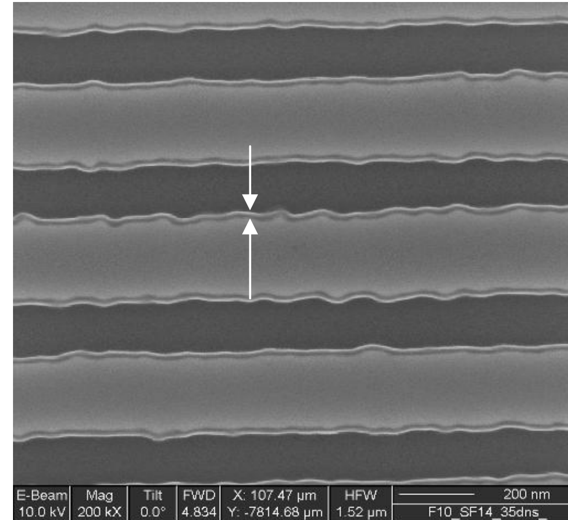
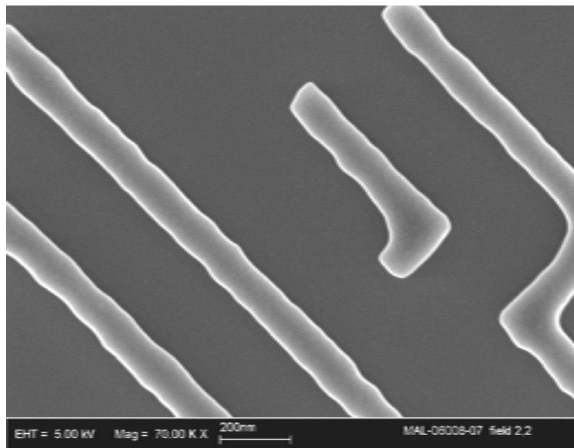
SEM Shows Same Line Edge Widening

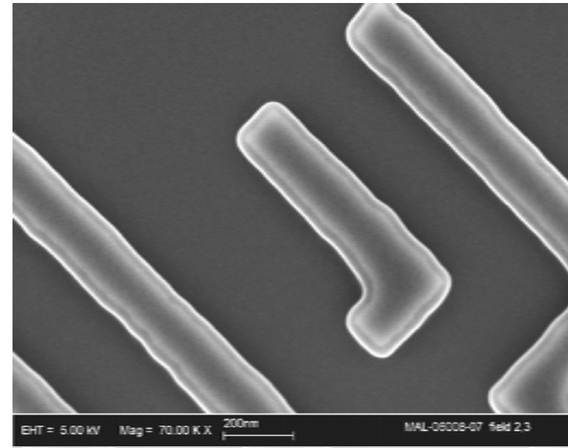
Reference



Contaminated







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