Analysis of Contaminated EUV Masks

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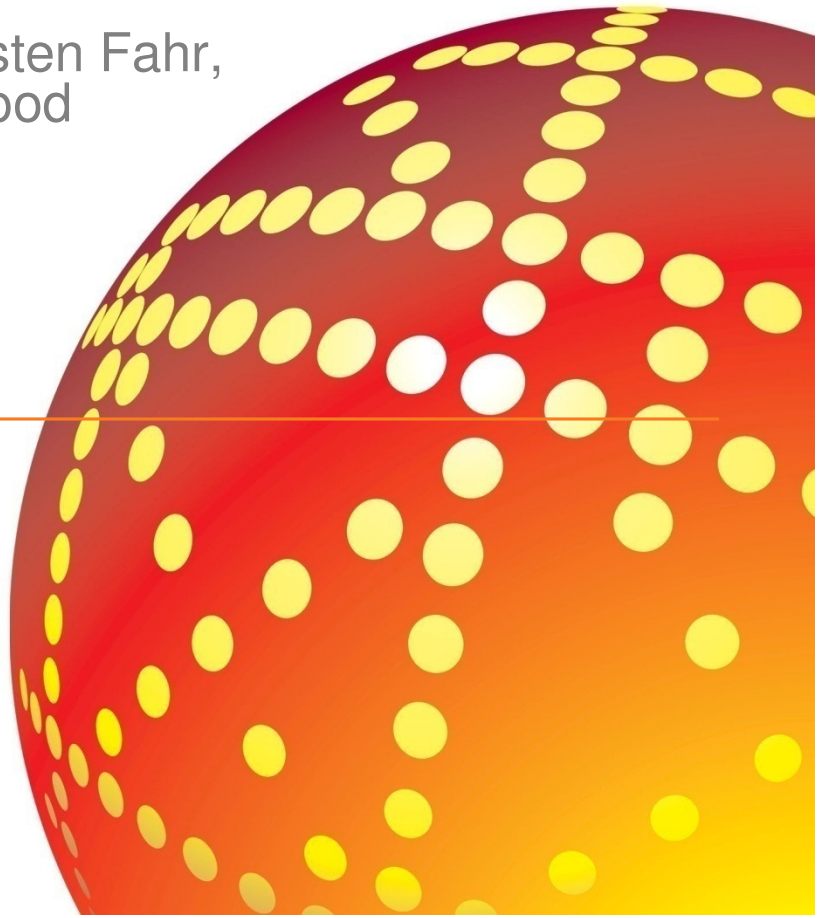
GLOBALFOUNDRIES

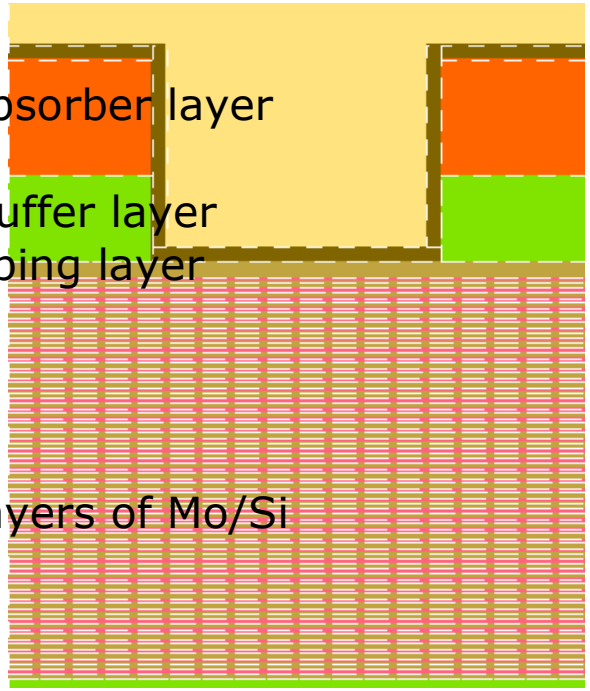


Outline

- Analysis & characterization of contaminants on 3 EUV masks
  - ❖ Imaging techniques
    - Optical photography
    - Scanning electron microscopy
  - ❖ Surface analytical technique
    - Auger electron spectroscopy (AES)
  - ❖ Chemical analytical techniques
    - Grazing incidence reflection (GIR) FTIR spectroscopy
    - Raman spectroscopy
  - ❖ Summary

About the masks

- All three masks were capped with silicon capping layer
- Mask 1 and 3 had TaN absorber layer, while mask 2 had a CrN absorber layer
- Masks 1 and 2 were used extensively on the SEMATECH EUV micro exposure tool (MET) at Lawrence Berkeley National Laboratories (LBNL)
- Mask 3 was intentionally contaminated with hydrocarbons introduced into the EUV microscope for mask imaging and contamination studies (MiMICS) tool at College of Nanoscale Sciences (CNSE) of State University of New York at Albany

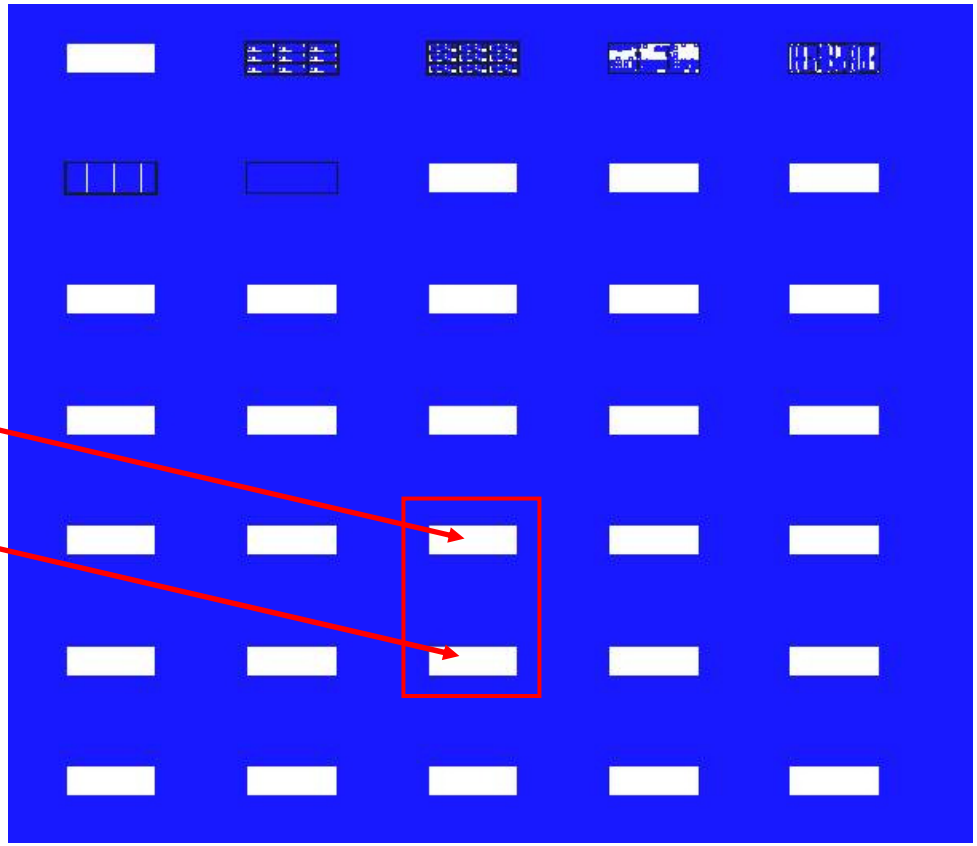


Mask 1

2 Resolution Cells of Interest:

Col 3 Row 5- more contaminated
(~ 80 hours of EUV exposure)

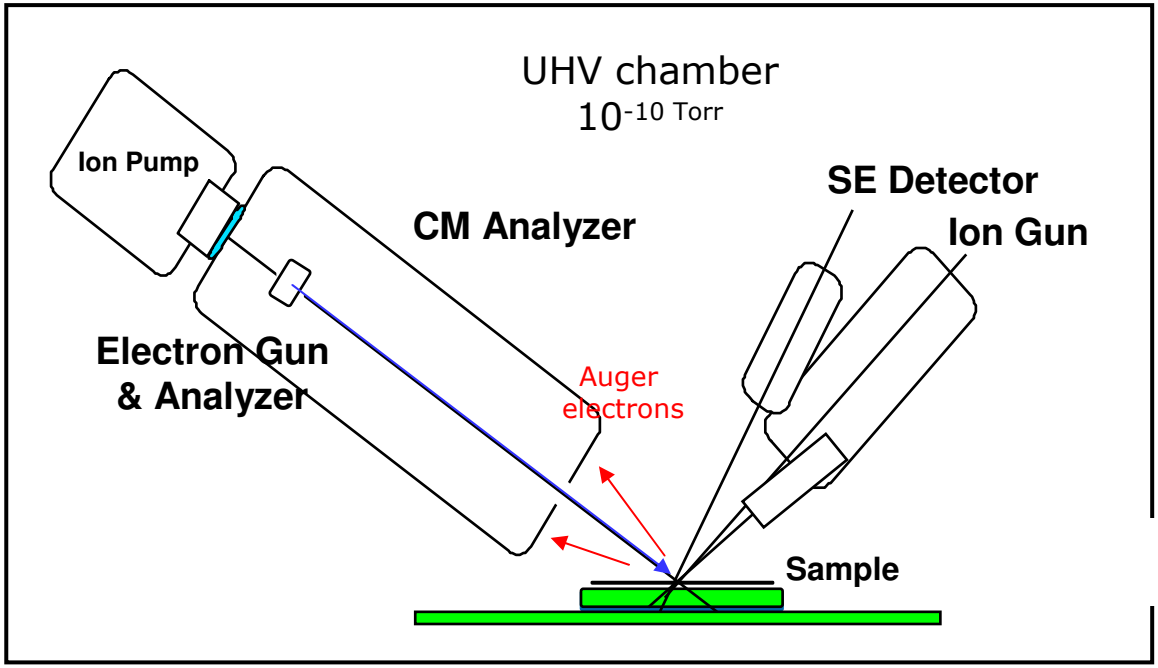
Col 3 Row 6- less contaminated
(~10 hours of EUV exposure)

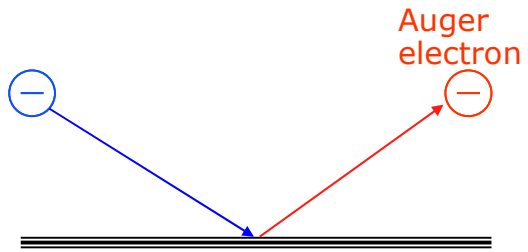


Col 3/Row 5 had 8% lower reflectivity
than Col 3/Row 6

AES analysis

Auger electron Spectrometer used: PHI Smart 200



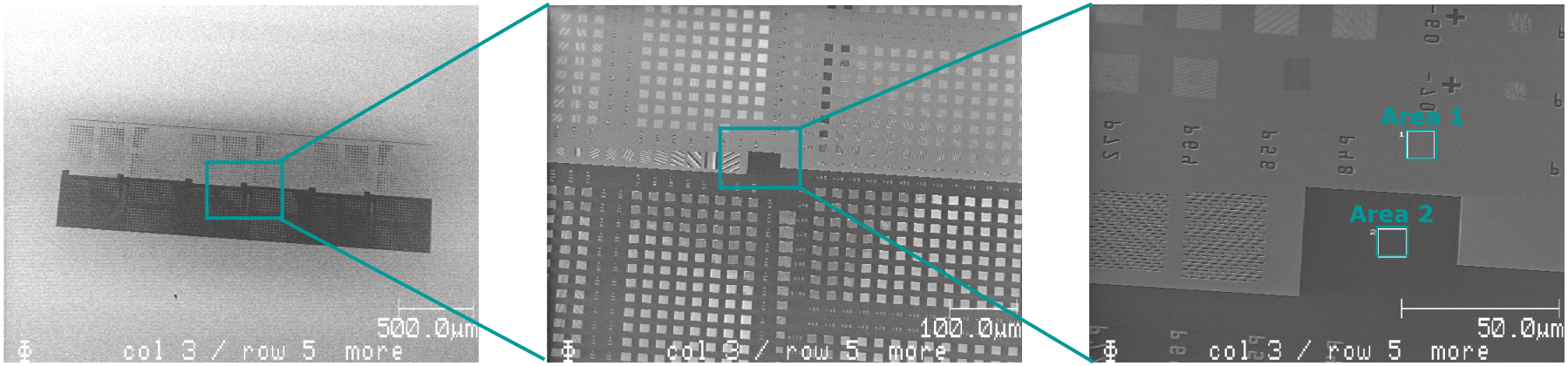


all elements (except H, He)
0.1...1 at% detection limit

- Excitation with primary electrons in the energy range 3...20 keV
- Analysis of the kinetic energy of the emitted electrons 30....3000 eV

AES analysis areas mask 1

SE images of the AES analysis area
of the exposed fields of mask 1



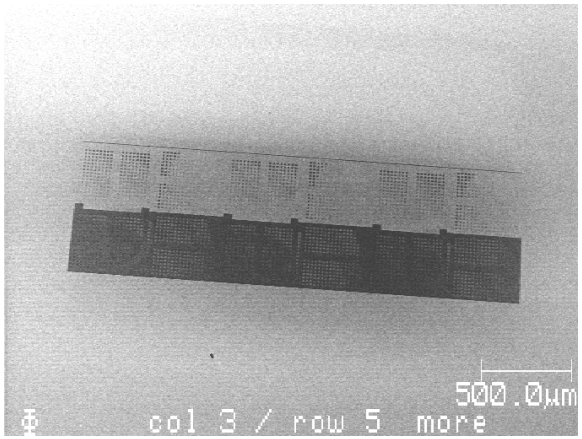
Overview @ 1kV

Detail @ 10kV

Detail @ 10 kV

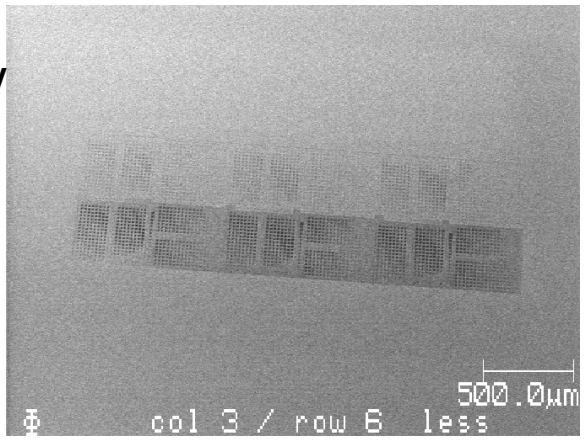
Surface AES and SEM results on mask 1

More contaminated

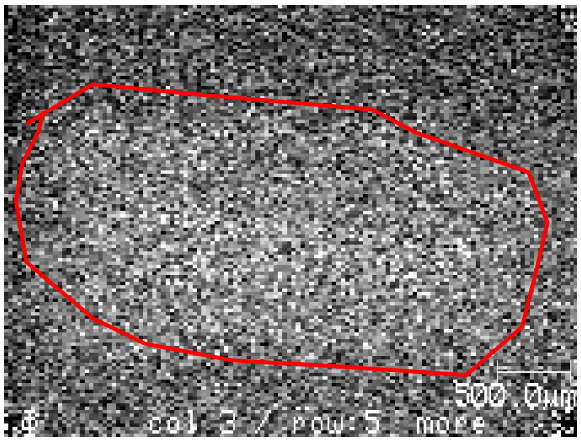


SEM @ 1kV

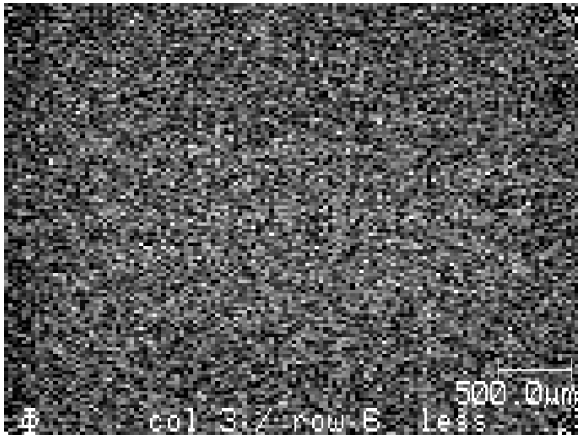
Less contaminated



Corresponding AES Carbon Maps @ 1kV

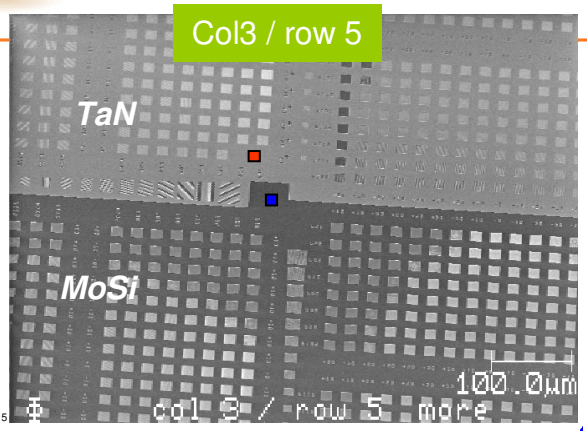


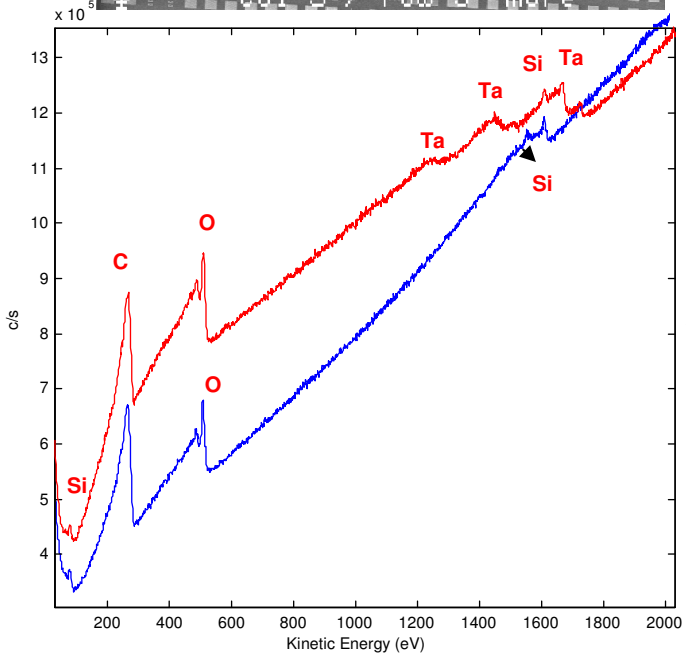
Increased carbon intensity around the more conta-minated field !



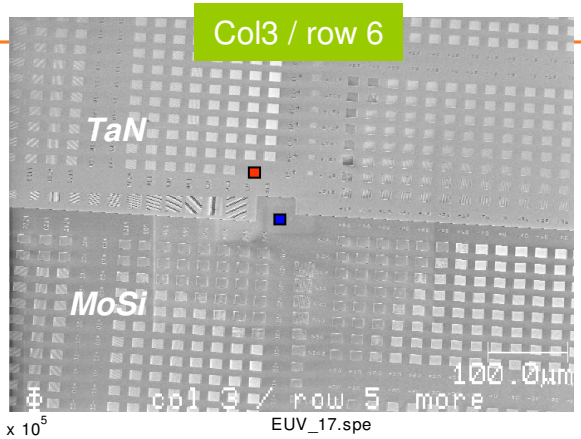
Surface AES and SEM results on mask 1

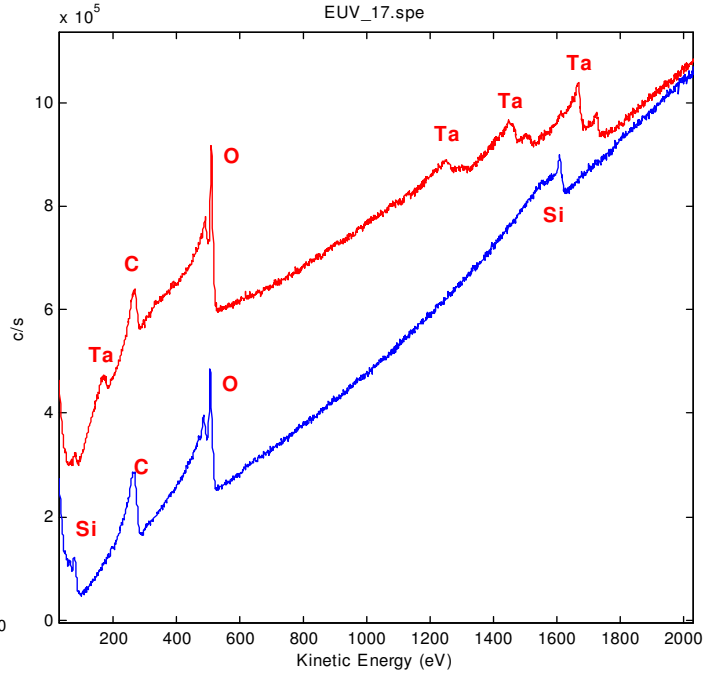
More contaminated





Less contaminated





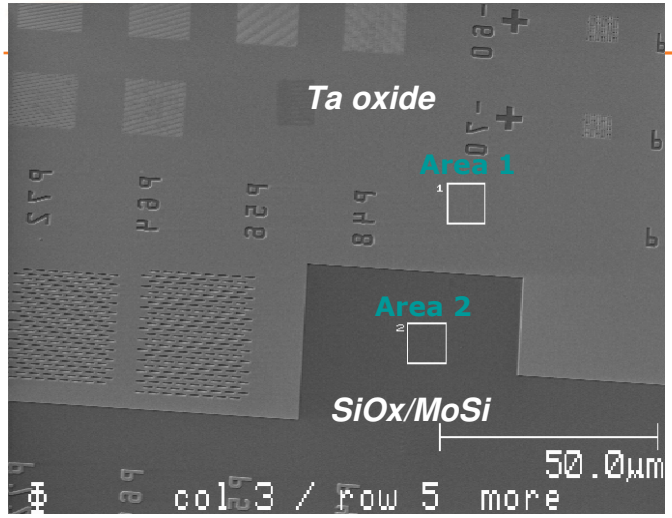
AES spectra @ 10kV10nA

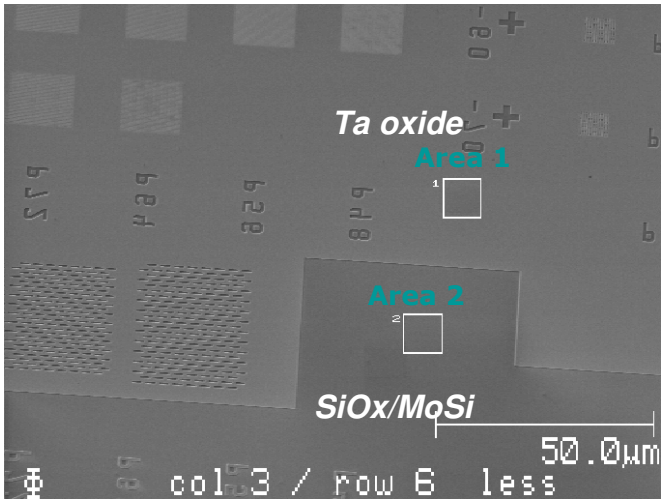
Carbon contamination observed on both areas.

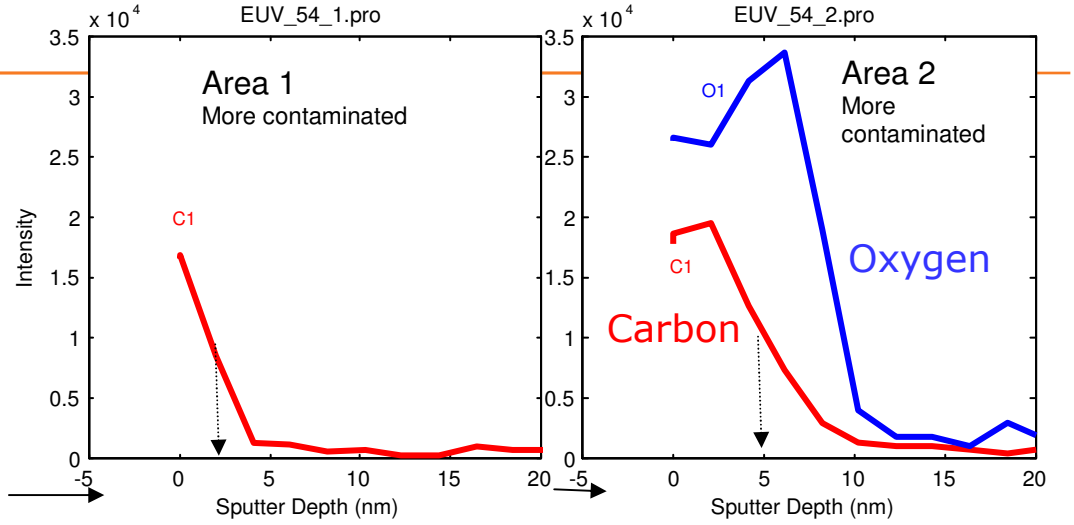
Red spectrum measured in TaN area: more C in col 3 / row 5 than in col 3 / row 6

Blue curve measured in MoSi area shows SiOx on top and carbon contamination which is higher in column 3 /row 5 than in column 3/row 6

AES depth profiles of C and O obtained on mask 1

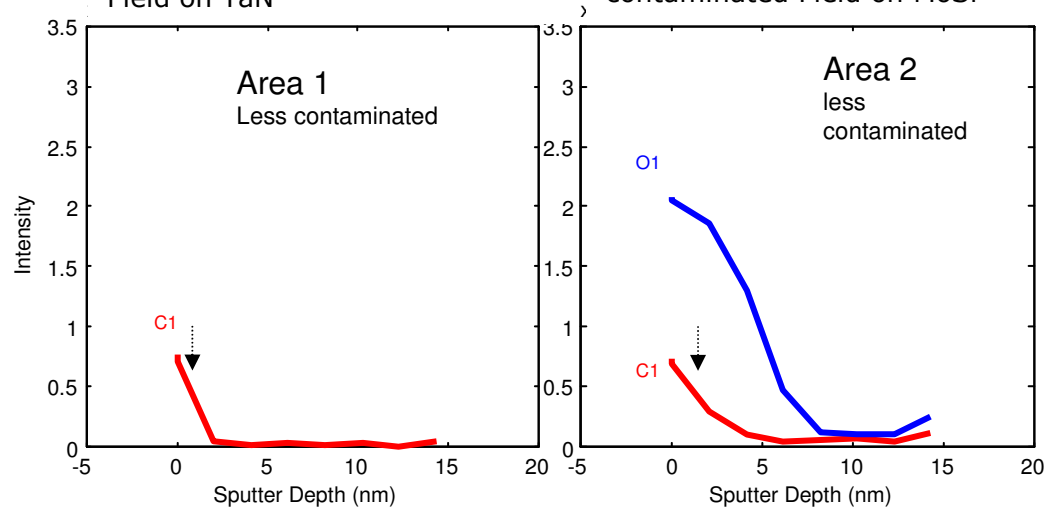






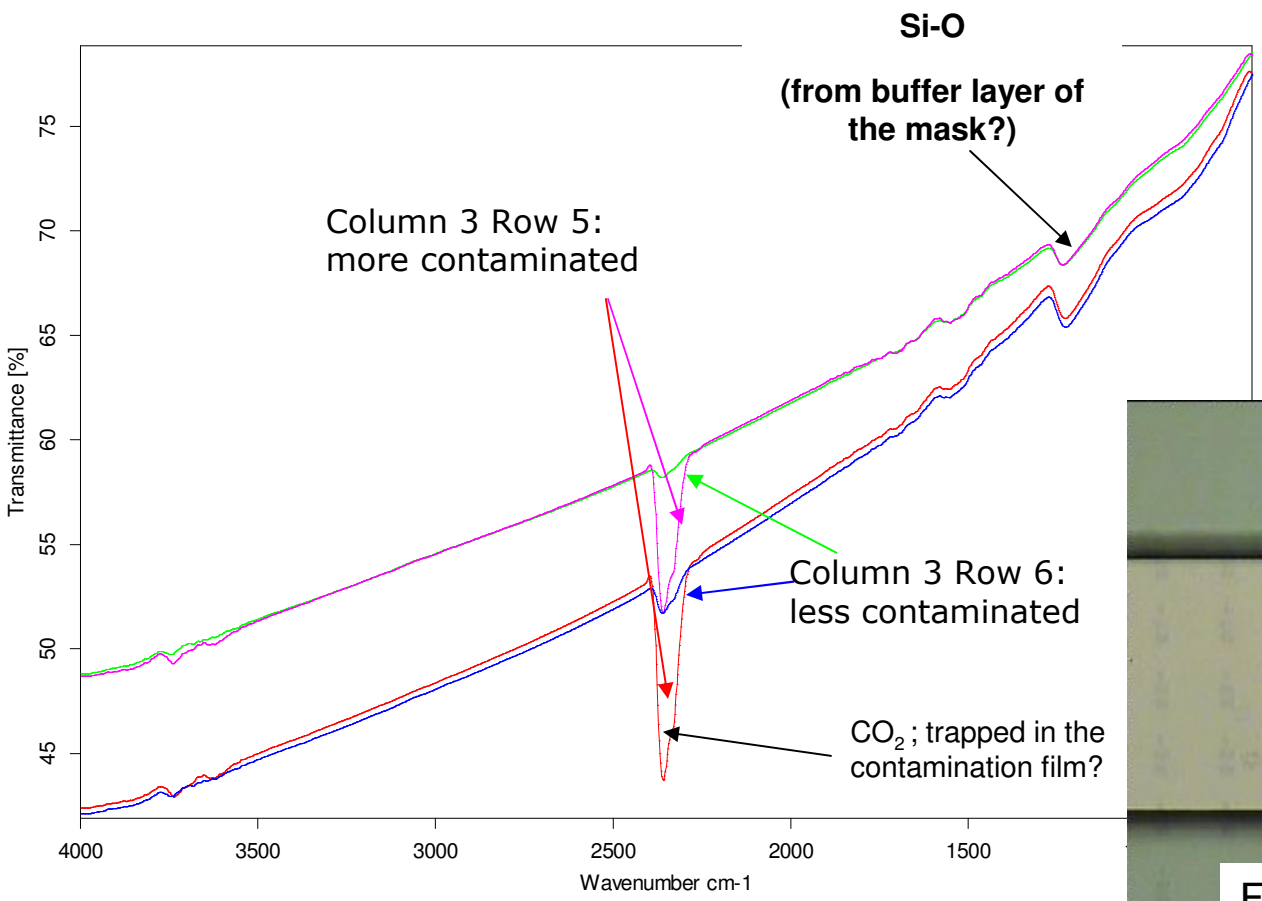
Less C in the less contaminated Field on TaN

Less C and less oxide in the less contaminated Field on MoSi

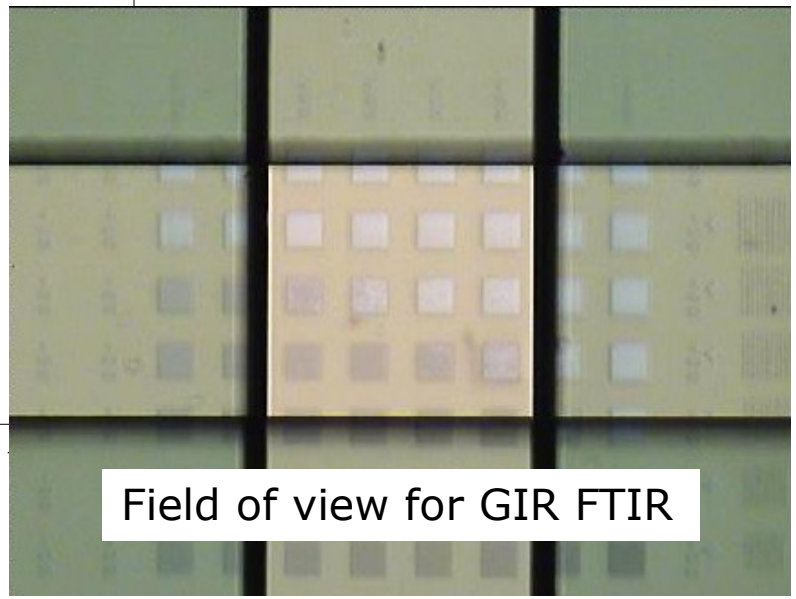


Note: The depth scale conversion is based on SiO_2 etch rate

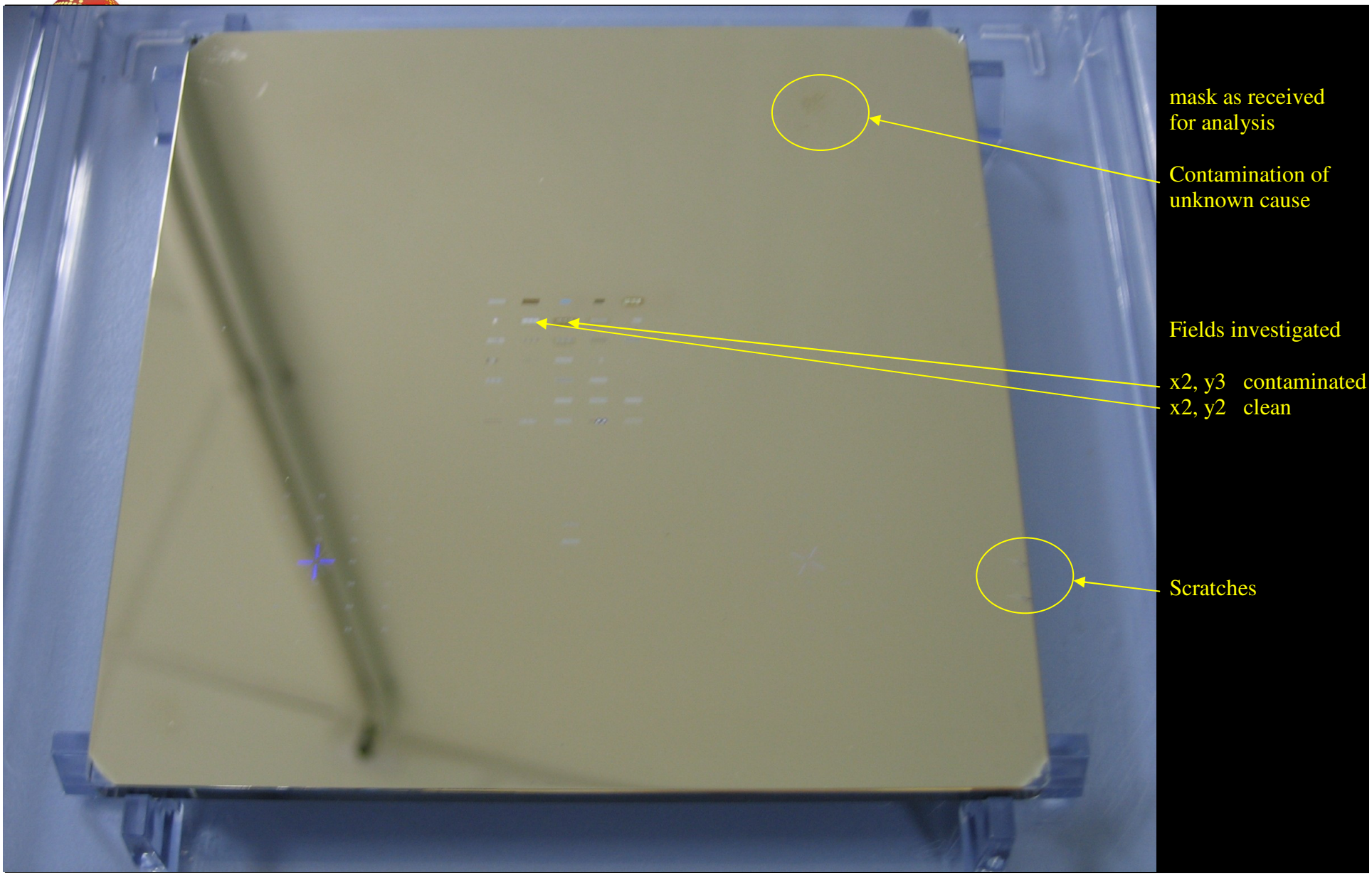
GIR FTIR microscopy @ mask 1



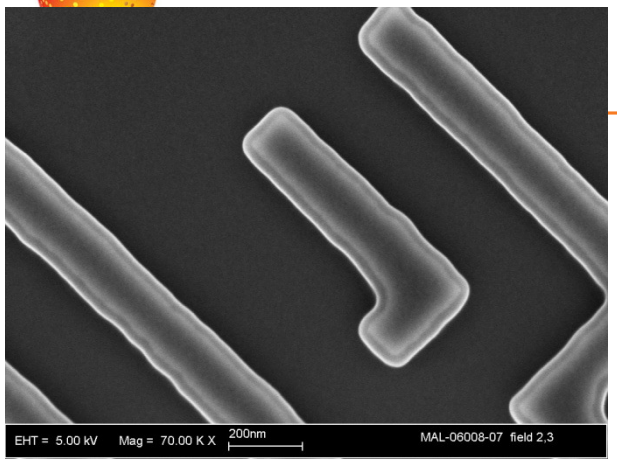
- Only Si-O and CO_2 signals are recorded
- CO_2 signal @ col3 row5 higher than @ col3 row6
- No C-H signals for organic species



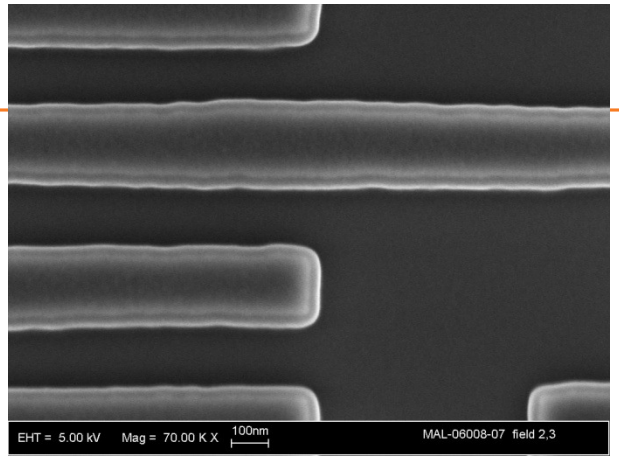
Optical picture of mask 2



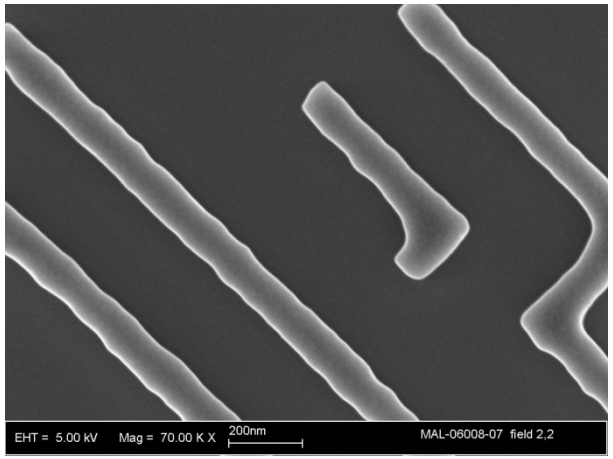
SEM images of features in contaminated & clean fields of mask 2



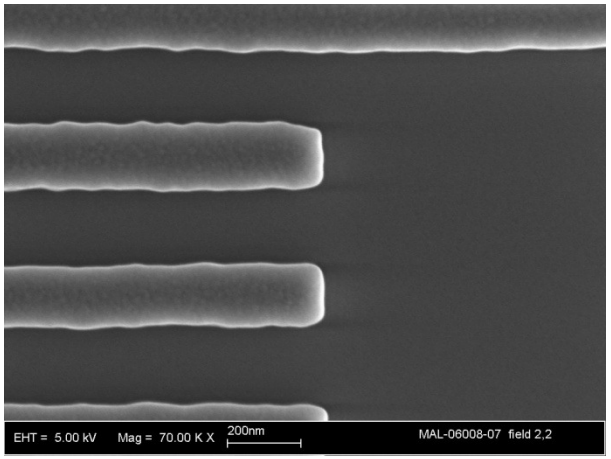
Contaminated field



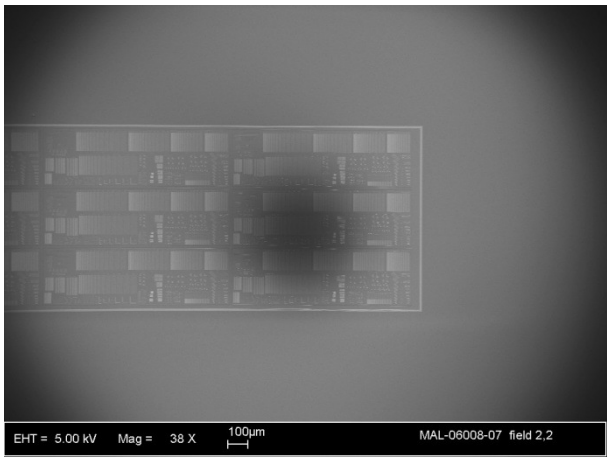
Contaminated field



Clean field



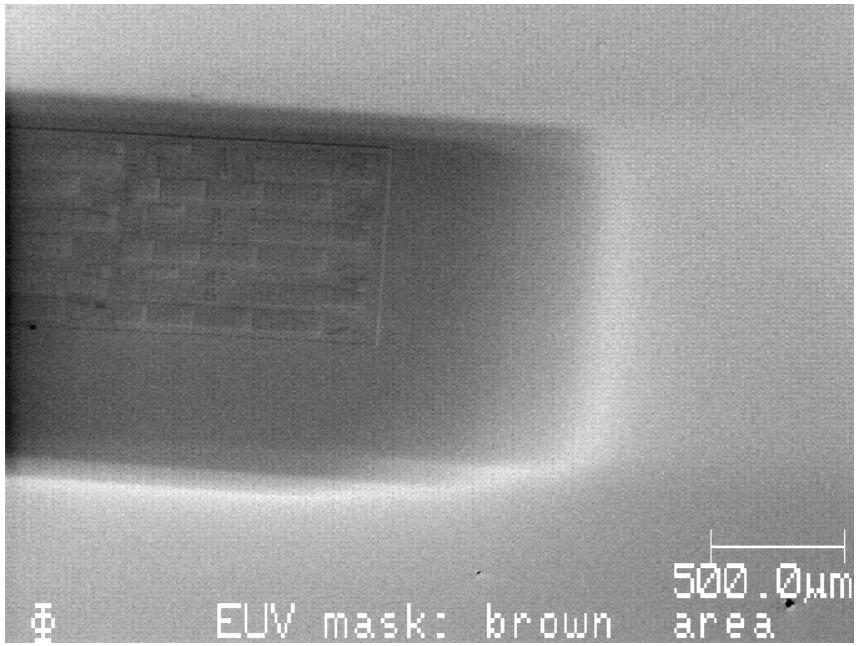
Clean field



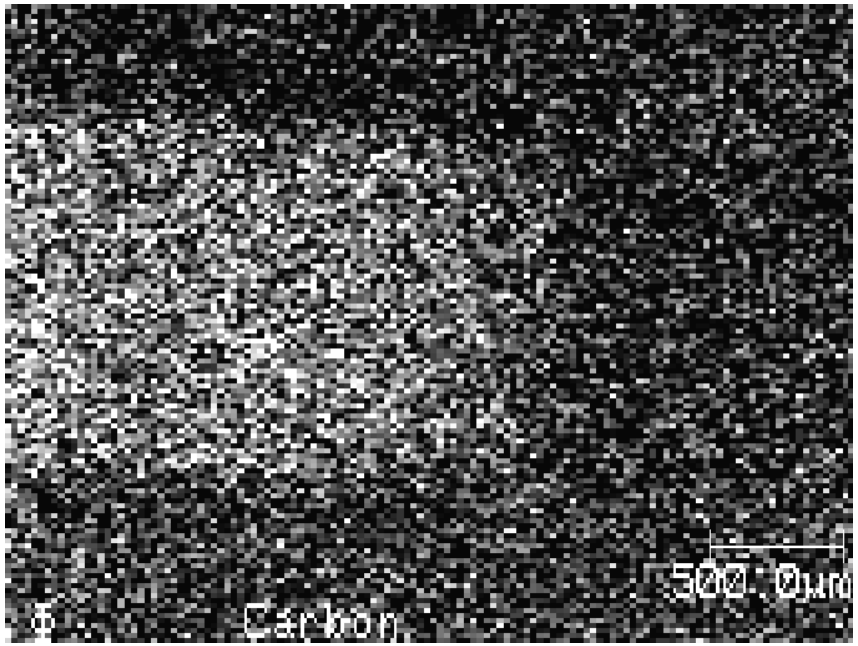
Overview of clean field

AES carbon mapping of the surface of mask 2

SE image @ 1kV

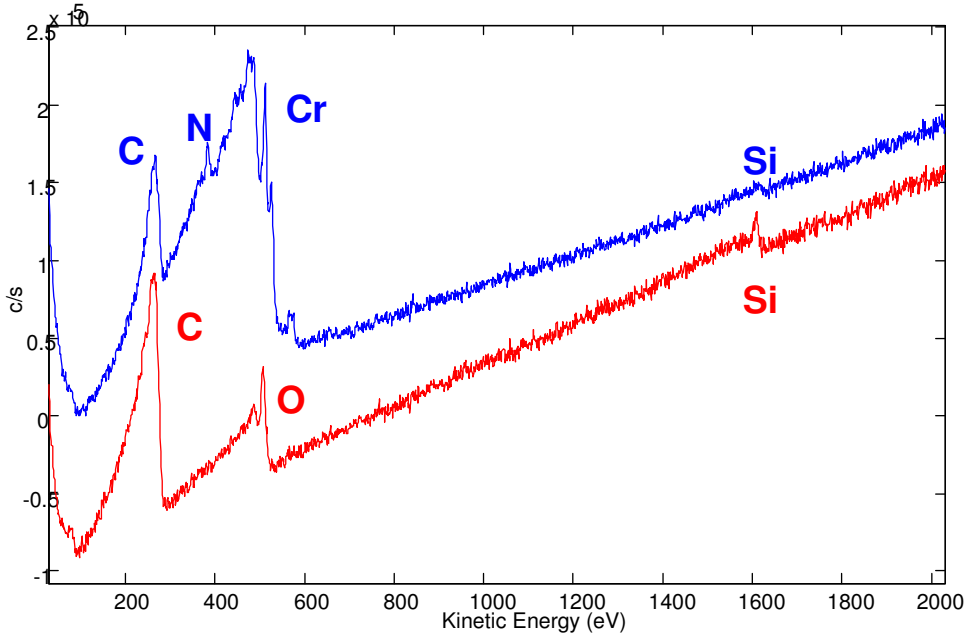


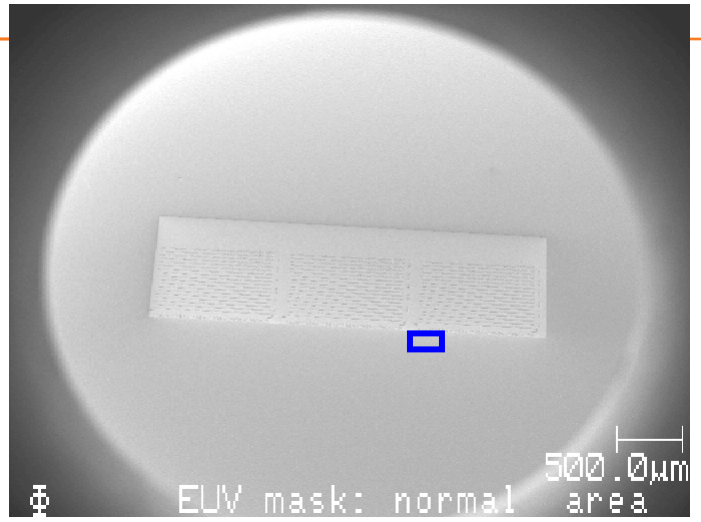
Carbon map

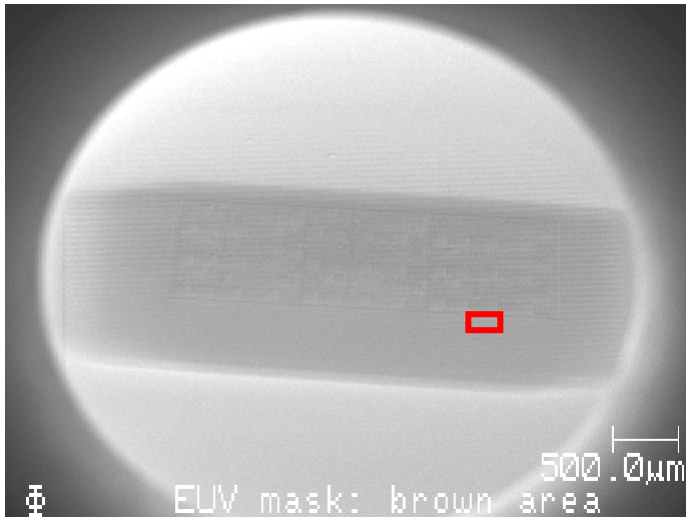


Increased carbon signal (bright spots on the map) in the dark background around the exposed field indicates high level of carbon contamination

Surface AES analysis of mask 2

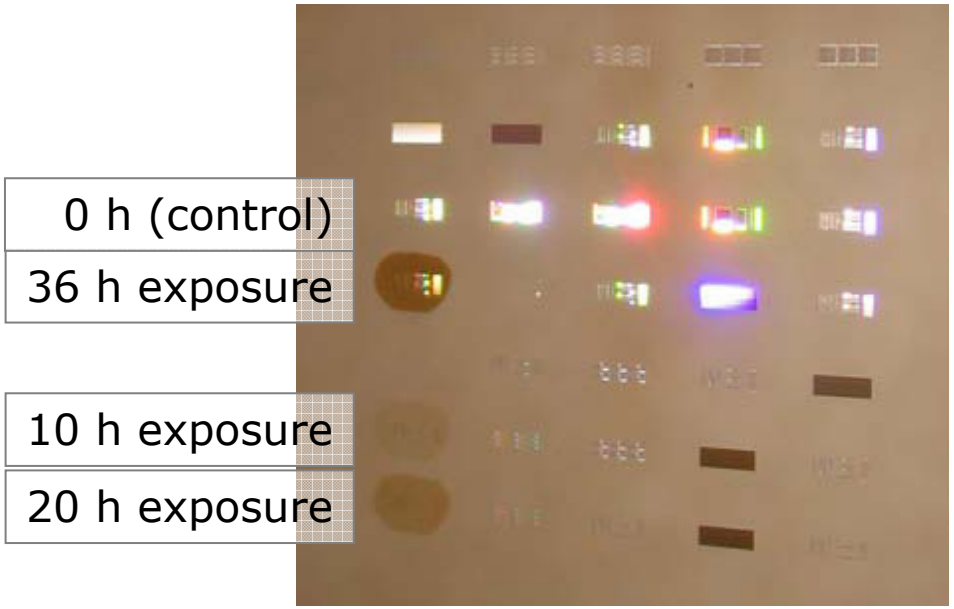






- Contamination shows clear signals of carbon on the surface
  Blue curve: control field (Cr and N come from the absorber)
  Red curve: contaminated field: C, Si, O

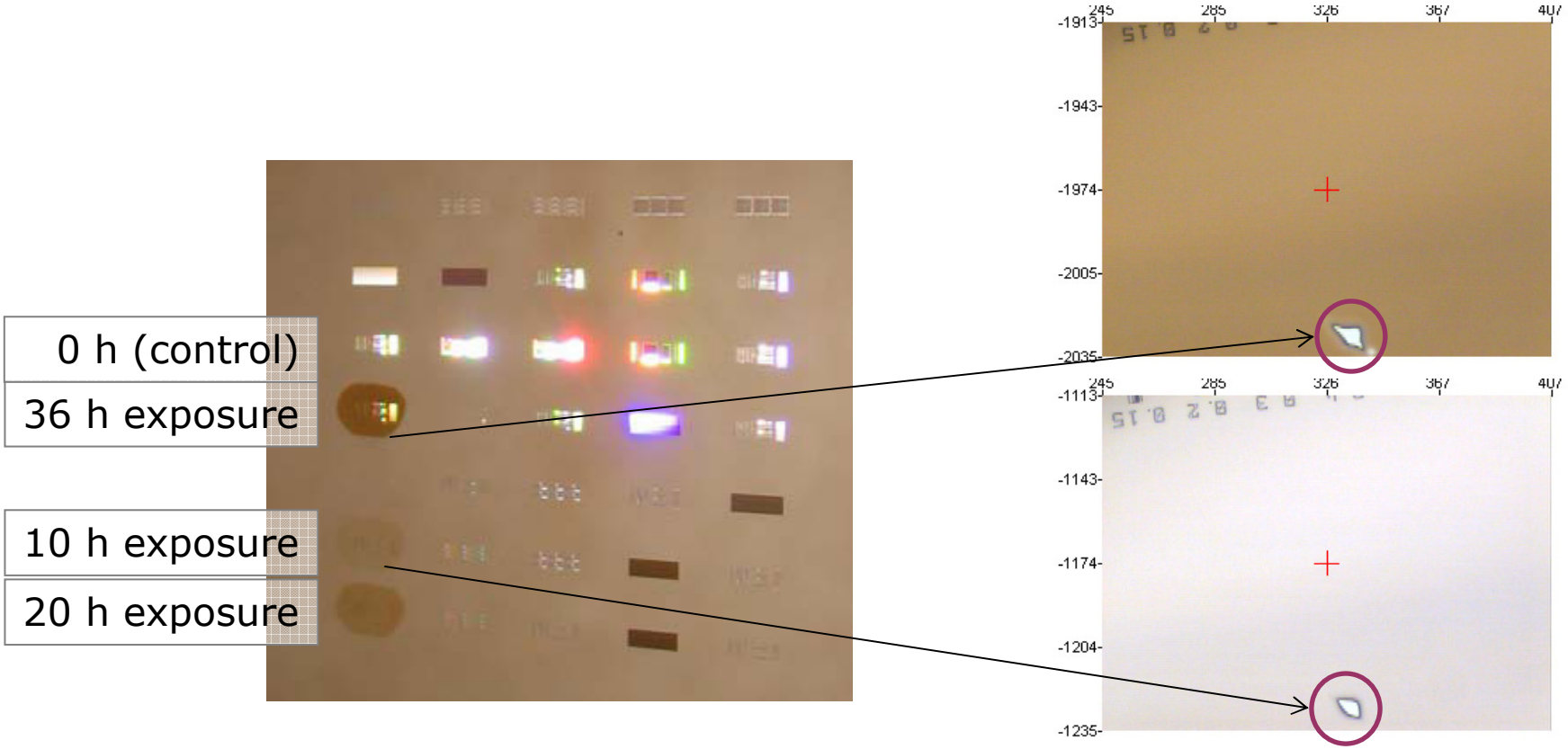
Controlled contamination of mask 3 on the MiMICS tool



- Mask was contaminated with hydrocarbons & exposed to EUV radiation for a duration of 10h, 20h, and 36h

Chemical analytical techniques: (1) Raman Spectroscopy

- Laser beam evaporated the contaminant (see)
- Raman spectrum dominated by fluorescence → no speciation
- This kind of contamination can be removed by laser cleaning



Chemical speciation techniques: (2) grazing incidence reflection (GIR) FTIR spectroscopy

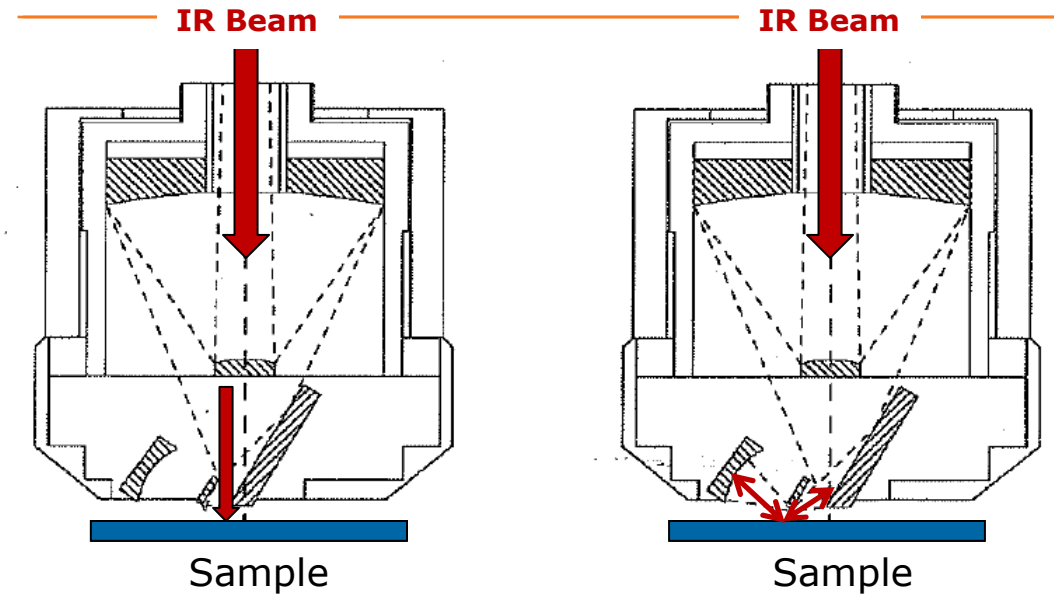


Fig 1: View (left) and measurement (right) modes in the Bruker grazing angle objective.

Instrument:

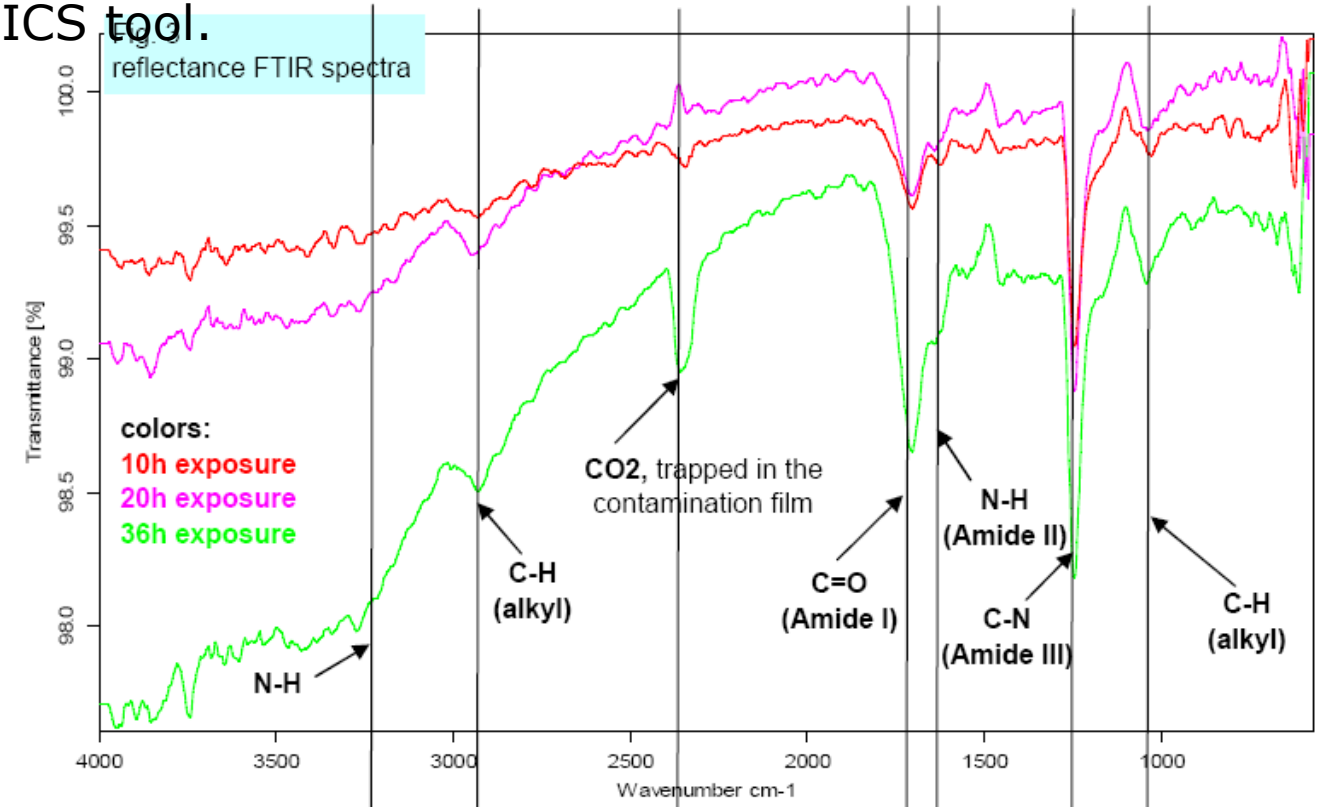
•Bruker Hyperion 2000 FTIR Microscope with Grazing Angle Objective

Courtesy of Bruker Optics, Germany

• IR beam hits the sample two times at 84° incidence angle → improved S/N ratio on thin film contamination
• No spectrum recordable at perpendicular reflection geometry on mask3

GIR-FTIR results of mask 3

- Significant increase in the intensity of the absorption bands with contamination time
- Contamination sources possibly include the introduced volatile organic compounds, as well as residual contaminants within the MiMICS tool.



Summary

- Carbon contamination was observed on the 3 masks investigated, with a thickness of around 5nm (for the moderately used mask 1), and a much higher thickness (for the heavily used mask 2).

- The uniformity of carbon contamination appears to vary, depending on substrate, vis-à-vis, CrN, TaN and Mo/Si.

- Surface oxides were observed on the masks.

- AES surface analytical technique is very sensitive for analyzing the elemental composition of thin film contaminants (a few nanometers thick) on EUV masks. It also provides spatially resolved distribution of the contaminants.

- GIR FTIR spectroscopy is sensitive for analyzing fairly thick film contaminants (≥ about 1 micrometer thick) on EUV masks.

- Raman spectroscopy was found to be not compatible with analysis of thin films of carbon contaminants because its laser evaporated the sample.

Acknowledgments

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