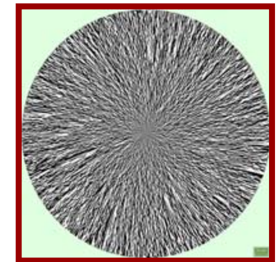
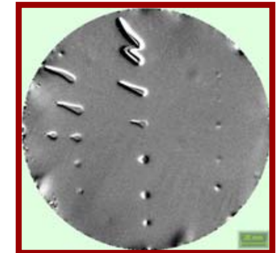
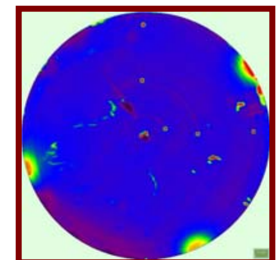
Imaging of contamination on wafers using a scanning surface potential difference measurement technique







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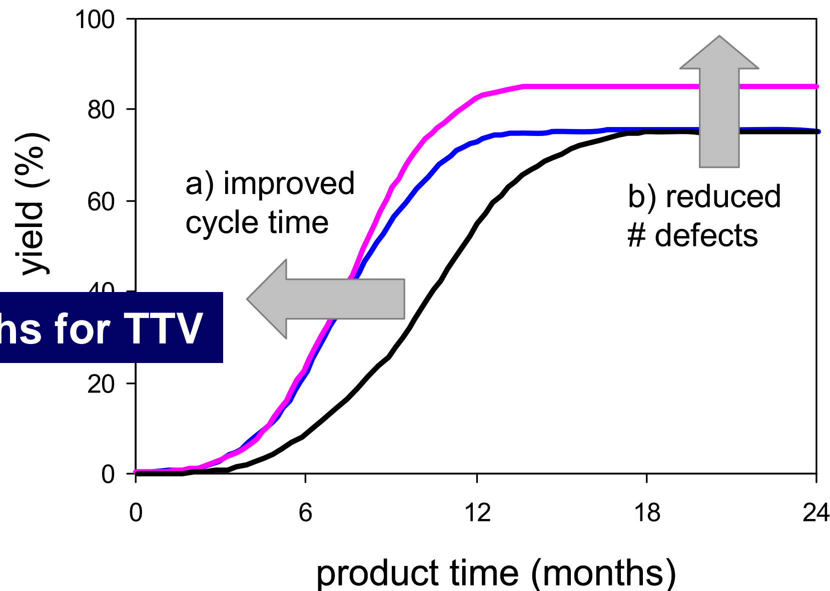
Context

- Typical competitiveness targets @ 65nm and beyond:



From 75% to 85% yield

From 18 to 13 months for TTV

- **Relevant production metrology is needed to help chip manufacturers:** non invasive, high sensitivity, fast and full imaging

Light scattering, Si lifetime … are well known examples

… introduced 2005: ChemetriQ®

C. Yang et al., *"Inspecting wafers using a potential difference imaging sensor method"*, Micro magazine, Vol. **25**, (2005)

Outline

The goal of this work is to investigate the sensitivity of the ChemetriQ method toward various contaminants

1. How ChemetriQ works
2. Experimental
   - Intentional contamination
   - Methodology of ChemetriQ analysis
   - Comparative chemical analysis: TXRF, VPD-ICPMS, ToF SIMS
3. Results
   - Sensitivity to common metals
   - Ions on metal films
   - Wafer edge contamination
4. Conclusion

1) How ChemetriQ works

A probe scans the wafer and is sensitive to work function variations

- With an electrical coupling between the probe and the wafer, a charge builds up, with regard to the Surface Potential Difference (when WF 1 ≠ WF 2)

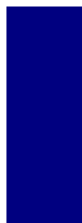
- When moving the probe over the wafer with a constant capacitive coupling (air gap), the current into the probe is: $i = \frac{dQ}{dt} = C_{air}\frac{dV_{SPD}}{dt} = C_{air}\frac{dV_{SDP}}{dx}\frac{dx}{dt}$

$$i_{probe} = C_{air} v \frac{dV_{SDP}}{dx}$$

relative velocity between probe and wafer

How ChemetriQ works (2/2)

Probe: metal with Work Function 1



Chemical non-uniformity: WF 3 (> WF 2)

Wafer: WF 2 (> WF 1)

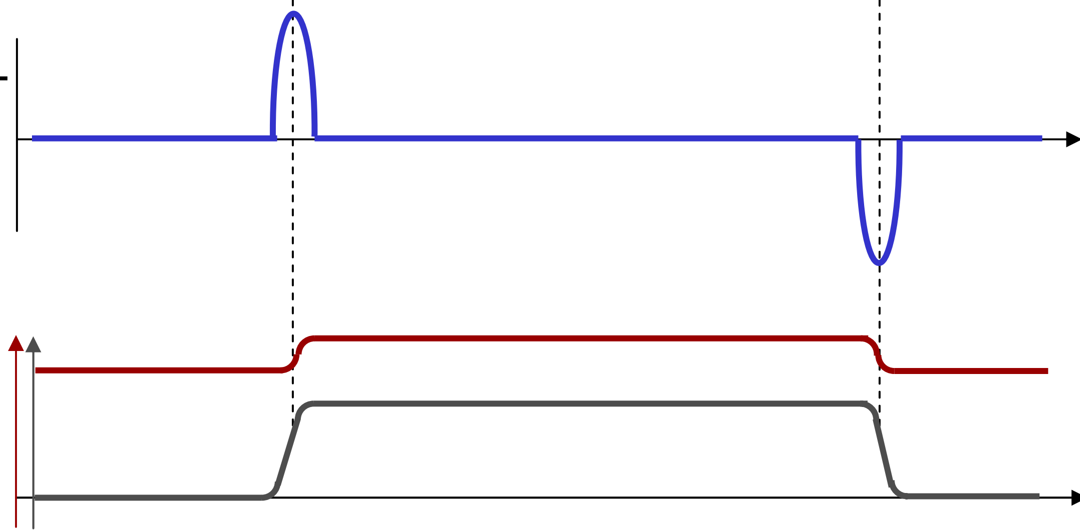
The probe scans the wafer and software creates an image proportional to work function variations

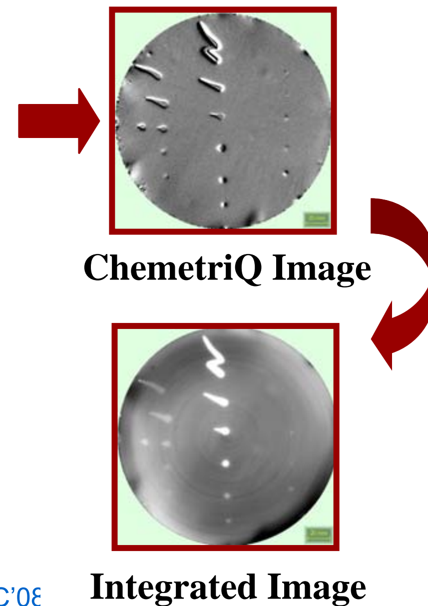
ChemetriQ SPD Signal

$$\propto \frac{dWF}{dt} \propto \frac{dV_{SPD}}{dx}$$

Surface WF

Integrated signal



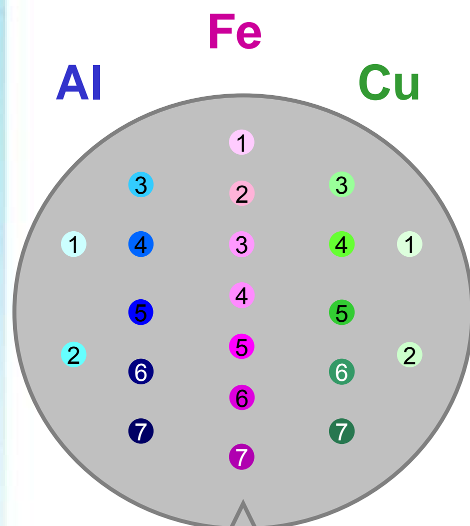


ChemetriQ Image

Integrated Image

2) Experimental: intentional contamination

- Localized spots of metallic contaminants



✓ Si wafer with clean chemical oxide
✓ Dried droplets of solvent + controlled amount of metals
✓ Range [10^{10} – 10^{13}] at/cm^2 targeted

- Full sheet contamination

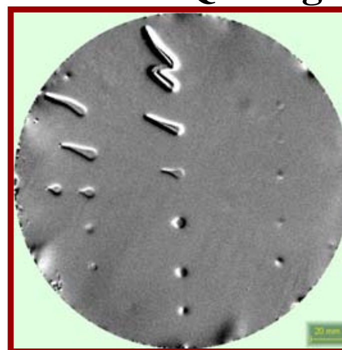
✓ Metals: SC1 bath, spin coating on chemical oxide and prior thermal oxide
✓ Ions: exposure of Cu films to air contaminated by HF

Experimental: ChemetriQ analysis

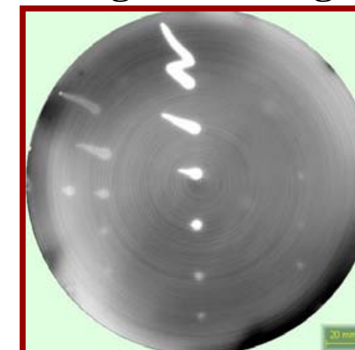
Parameter	Value
Sensor	660µm
Spin Speed	1009rpm
Radial Resolution	375µm
Samples / Track	10078
Scan Height	50µm
Averaging	3x
Edge Exclusion	0mm
Ionizer	On
Time per wafer	4min. (300mm)

- Images: all wafer are orientated with the notch down (6:00 position)

ChemetriQ Image



Integrated Image



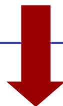
- **Quantitative analysis from images:**
  - **Delta between clean and contaminated areas**
  - **Sum of defective areas**
  - **Absolute ChemetriQ Measurements (ACM) after scaling**

Experimental: Chemical analysis

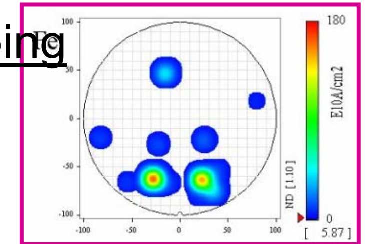
- VPD-ICPMS (metals) and LPE-IC (F) for full sheet contamination
- TXRF and ToF SIMS for localized contamination

✓ Direct-TXRF on spots

- Fe, Cu : set time per point = 100sec.
  - ND(Fe): 2.5×10^{9} at/cm^2
  - ND(Cu): 1.9×10^{9} at/cm^2
- Al: 500sec. and 2000sec. for low levels
  - ND(Al): 18.4 and 9.2×10^{10} at/cm^2

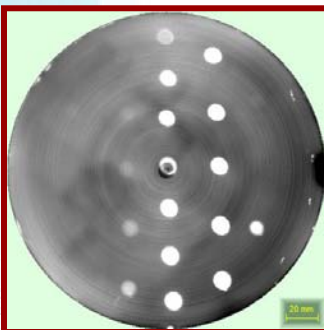


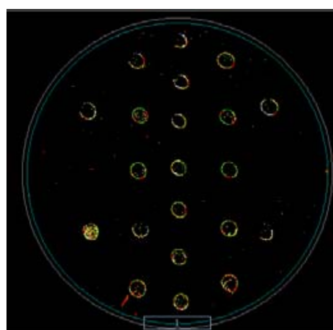
✓ SP-TXRF for 'full' mapping



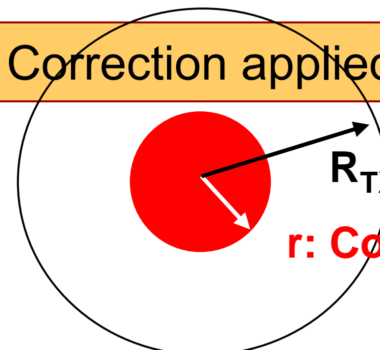
- 93 points, 5sec. / point
  - ND(Fe): 1.1×10^{10} at/cm^2
  - ND(Cu): 9×10^{9} at/cm^2
  - ND(Al): 1.8×10^{12} at/cm^2

Coordinates of spots determined from ChemetriQ and/or SP1 KLARF files





Correction applied to quantification

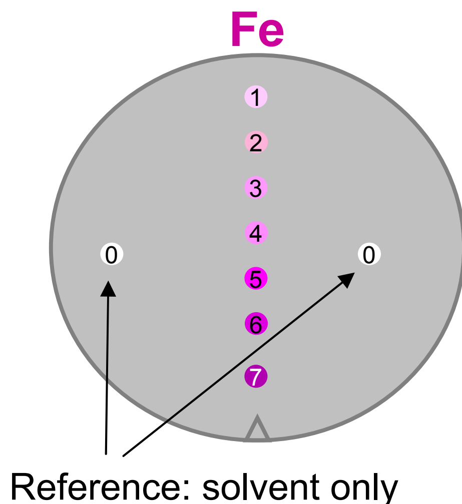


R_{TXRF}: TXRF spot size = 12mm

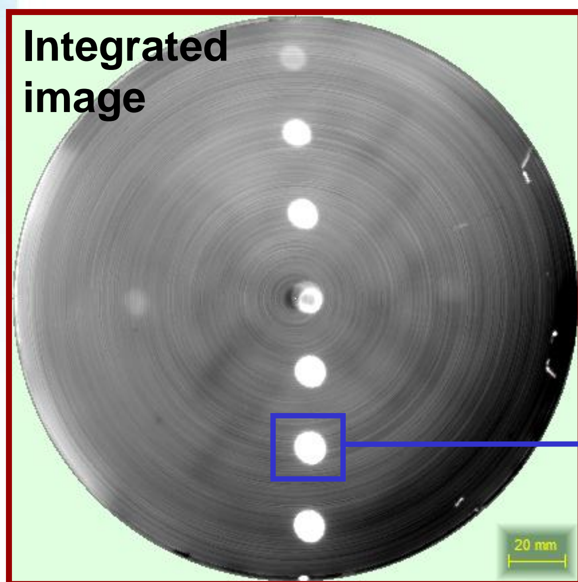
r: Contamination spot size < 12mm

3) Results: sensitivity to various metals

Spots on p-type CZ wafer



Reference: solvent only

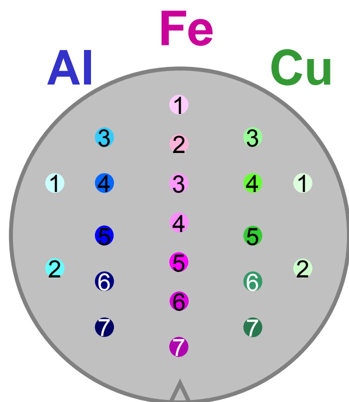


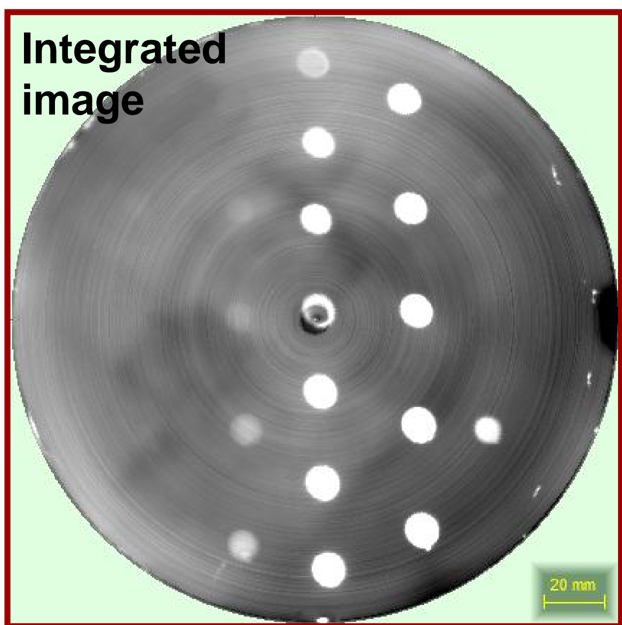
(x,y)	Level	TXRF (raw data, E10 at/cm2)	TXRF corrected (E10 at/cm2)	Delta in integrated image (V)
(-56,1)	ref	2.7 (Fe)	6.8	0.305
(54,2)	ref	< 0.25	< 0.63	0.308
(0,85)	Fe 1	5.5	14.3	0.463
(3,59)	Fe 2	4.8	12.5	1.241
(4,30)	Fe 3	3.9	8.6	1.8
(4,1)	Fe 4	15.9	35	2.376
(4,-26)	Fe 5	31.0	62	3.139
(4,-53)	Fe 6	151	302	3.728
(3,-80)	Fe 7	317	634	4.106

Range of integrated signal in region of interest: Delta (V) between contaminated spot and clean Si

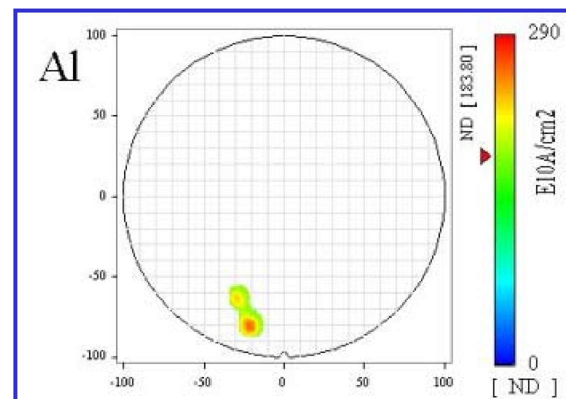
ChemetriQ: comparison to TXRF mapping

Spots on p-type CZ wafer

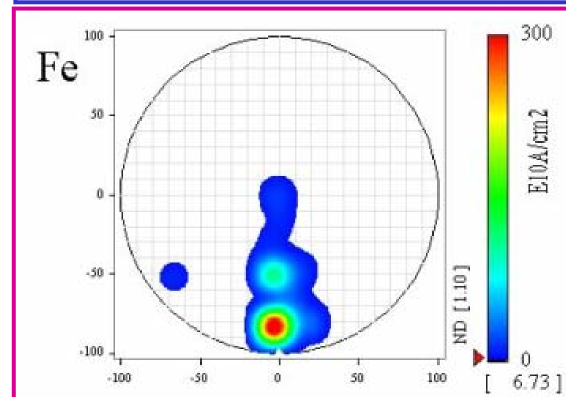




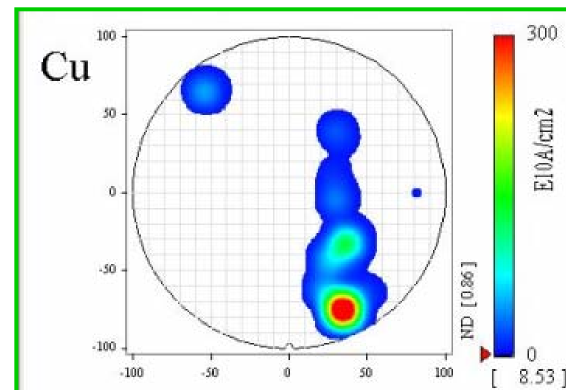
Only level #7 detected



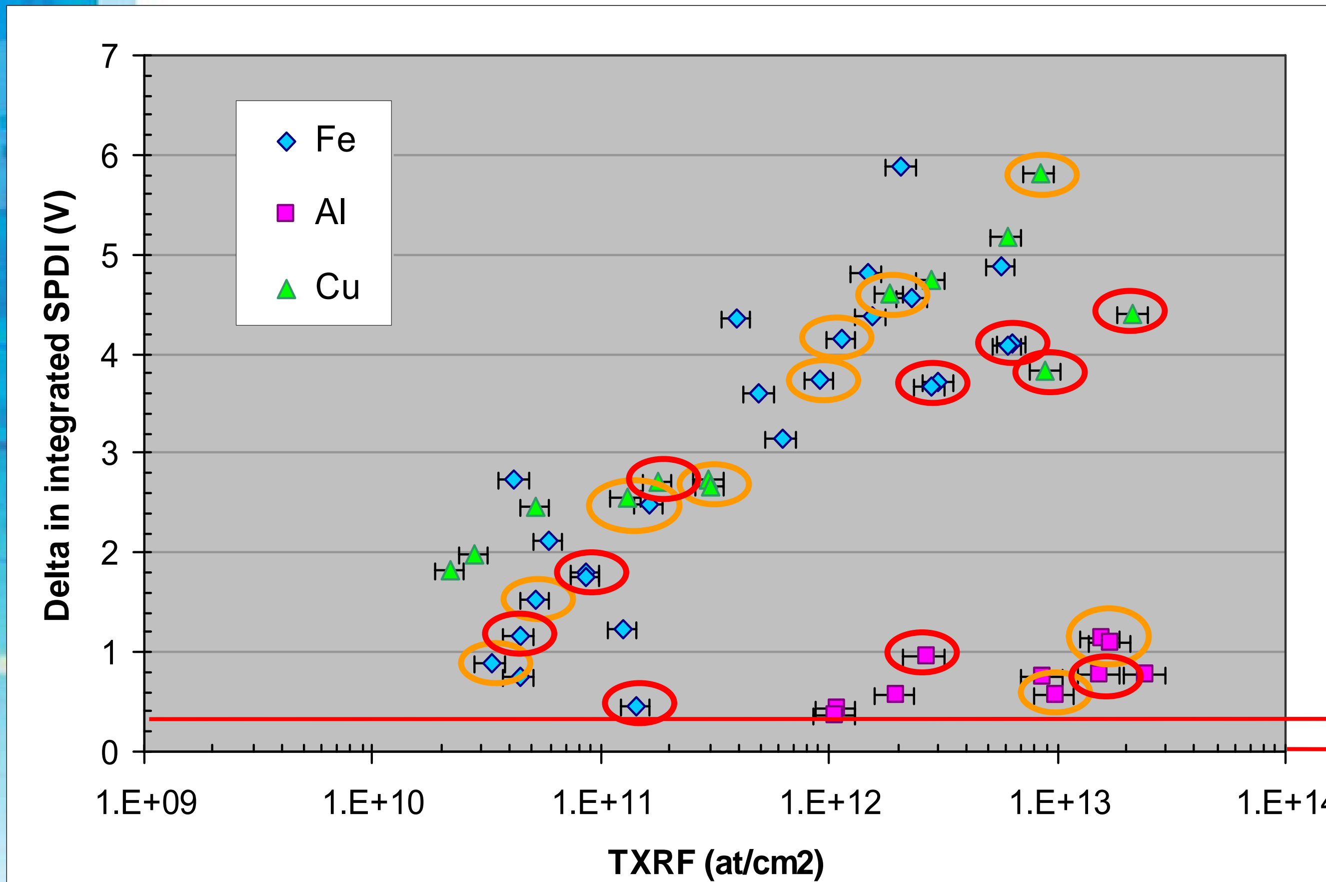
Levels #5;6;7 detected



Levels #4;5;6;7 detected



ChemetriQ sensitivity to various metals



- CZ p-type, 8 Ohm.cm
- CZ n-type, 6 Ohm.cm
- SOI p-type 8 Ohm.cm, 70nm Si / 145nm SiO_2

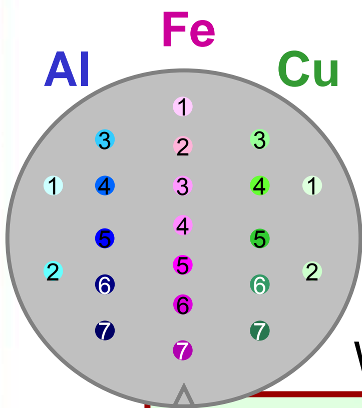
Delta < 0.3V: sensitivity to 'solvent only'

Different sensitivity element to element, not obviously correlated to Δ(WF)

At first order, sensitivity to the chemical element does not depend on substrate type

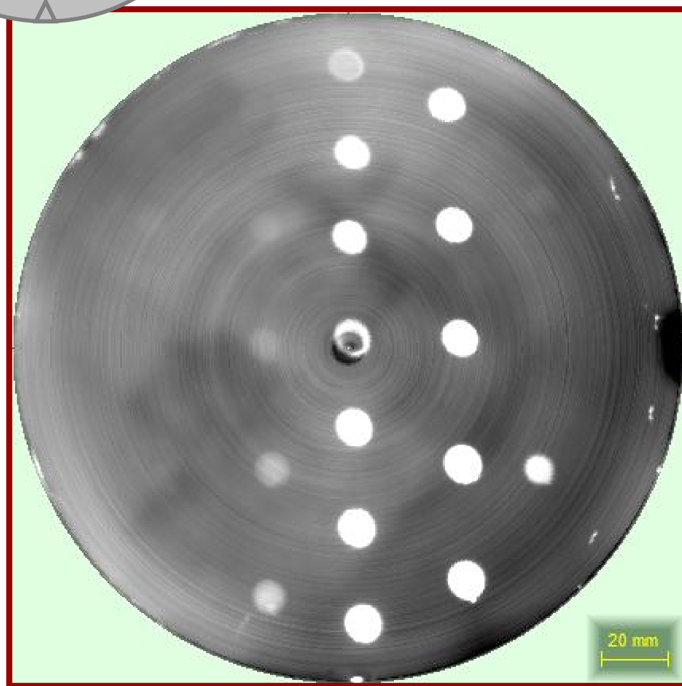
Detection of contaminants in the E9 at/cm² range for Fe and Cu, E11 for Al

Backside and frontside results similar



2 CZ, 200mm, p-type wafers
similar spots of contamination

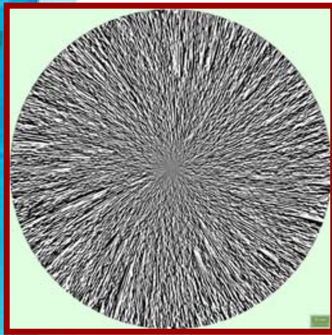
Wafer #1: Front side



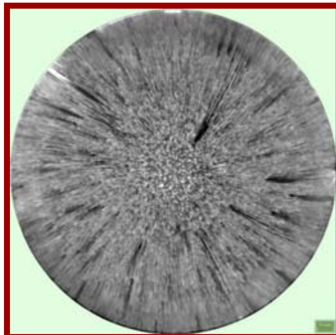
Wafer #2: Back side

Fe sensitivity: spin coating contamination

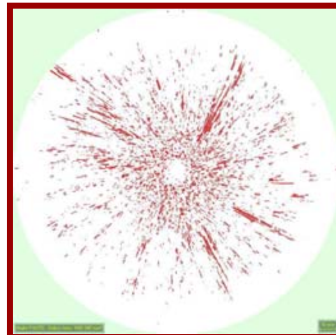
- Contamination on clean p-type CZ wafers
- ChemetriQ threshold analysis



ChemetriQ Image

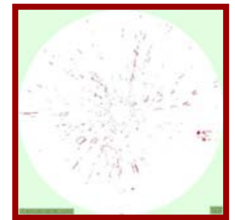


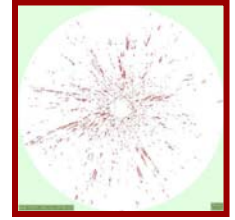
Integrated Image

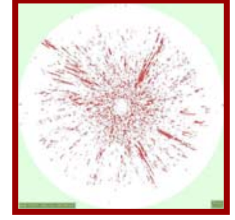


Threshold Image @70mV

Sum of ‘defective’ area (mm^2)

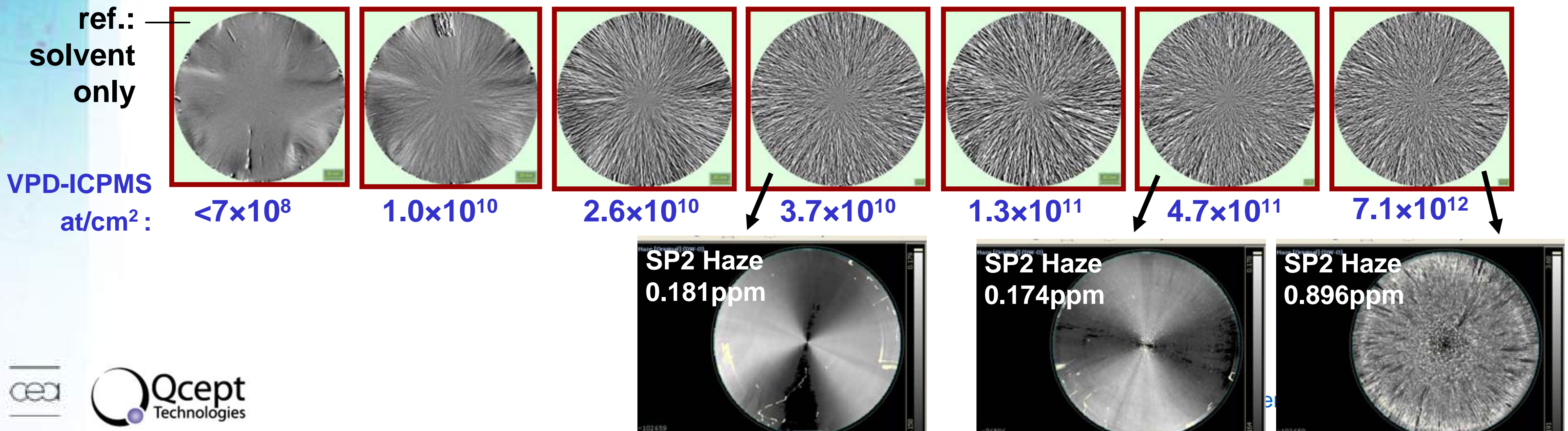






Dynamic becomes visible

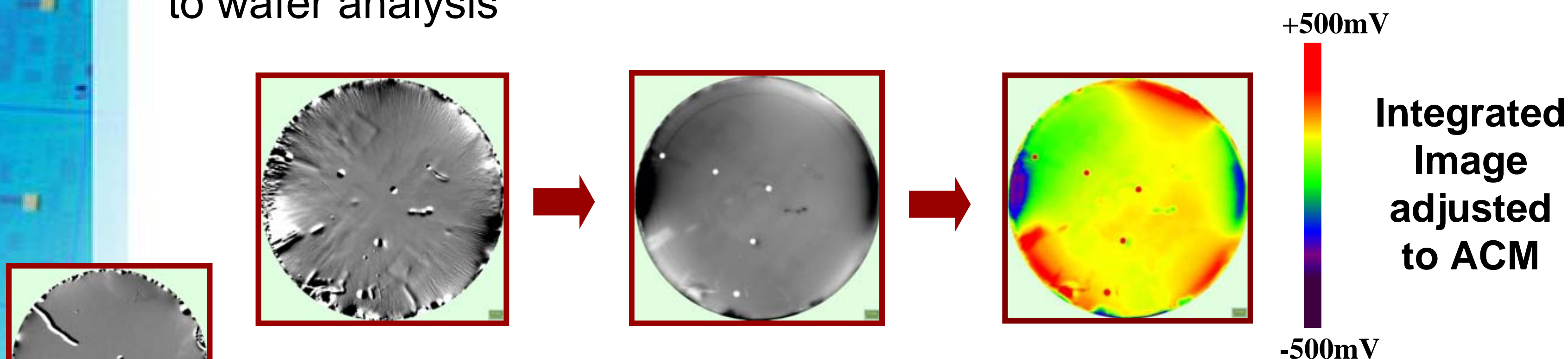
- Comparison with light scattering and correlation to VPD-ICPMS

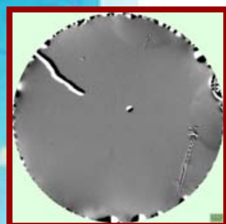


Absolute ChemetriQ Measurements

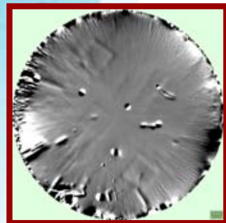
✓ The probe is used under vibrating mode (Kelvin probe) to get an absolute measurement of the Work Function difference between the sensor and several points of the sample

✓ Then, these ACMs are used to scale the integrated images and allow wafer to wafer analysis

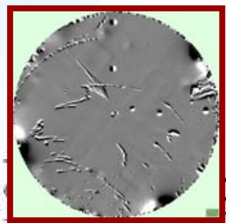




Wafer #1
ref. 20nm SiO_2

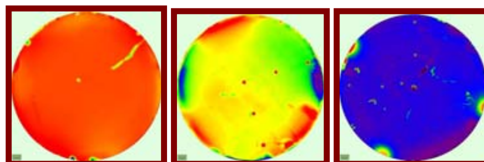


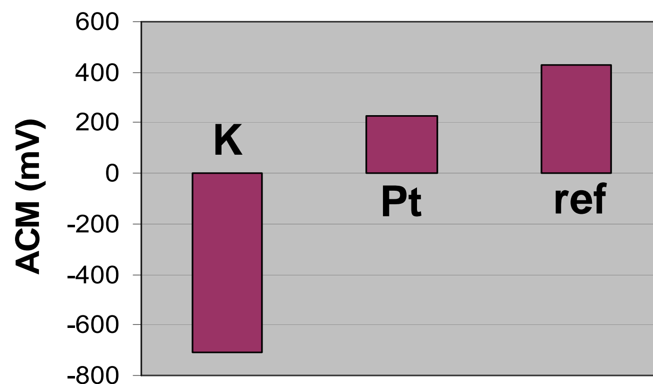
Wafer #2
20nm SiO_2 with Pt contamination (1.2^e12)



Wafer #3
20nm SiO_2 with K contamination (1.9^e12)

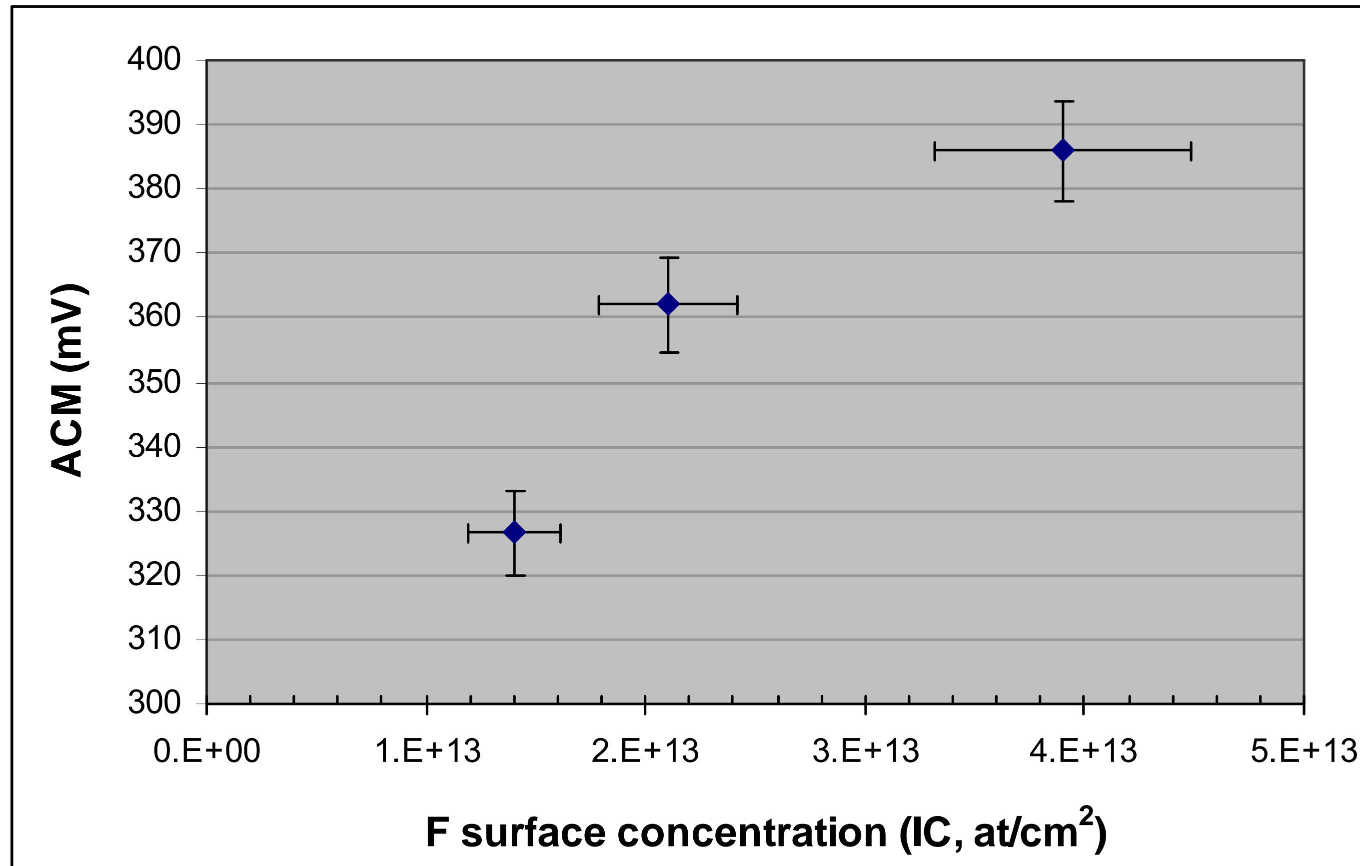
- **ChemetriQ and integrated images make non uniformity across the wafer well visible**
- **ACM needed to compare wafers and see impact of contamination**





Sensitivity to ionic contamination

- Exposure of Cu PVD films to air contaminated with HF



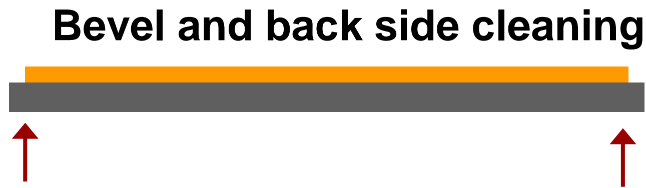
✓ Suggests possibility for monitoring surface impacts of Airborne Molecular Contamination (AMC)

✓First statement, further investigation necessary

Sensitivity to edge contamination

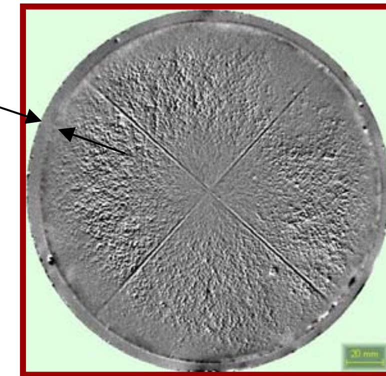
Metal film deposited on front side with bevel and partial back face coverage

Bevel and back side cleaning

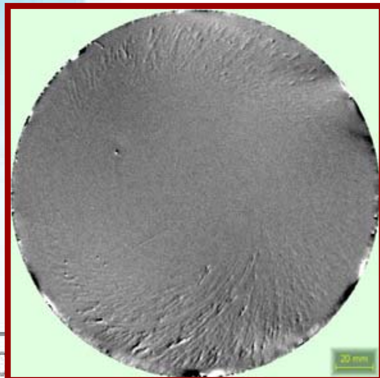


ChemetriQ inspection to evaluate cleaning efficiency

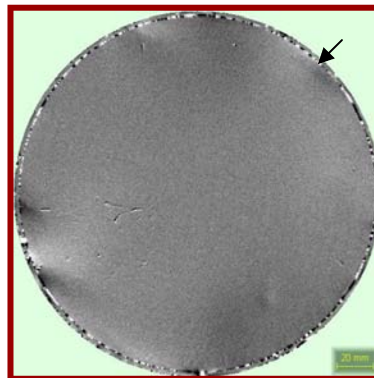
- No clean: about **6mm** ring with Mo giving a signature on images

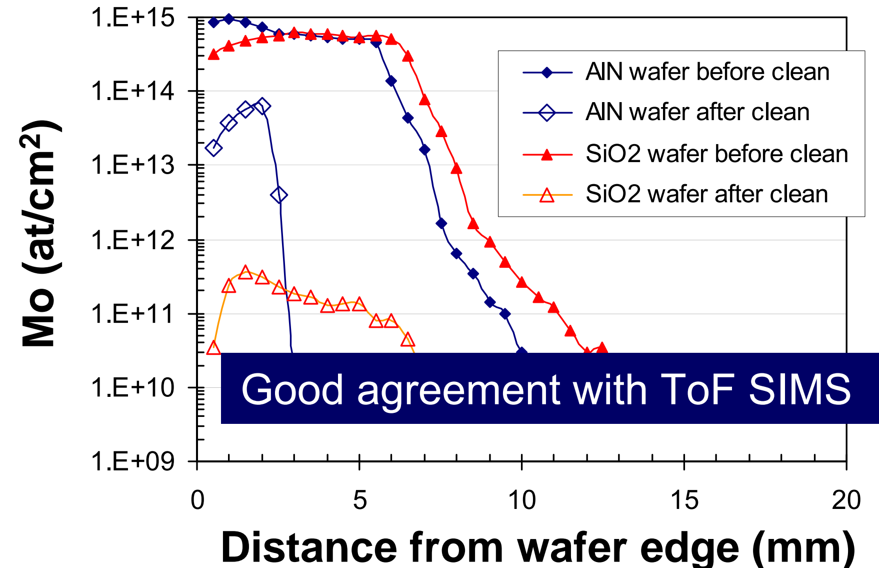


- Clean on Mo/SiO_2: almost no edge residues



- Clean on Mo/AIN: about **2mm** edge residues related to an AIN ring



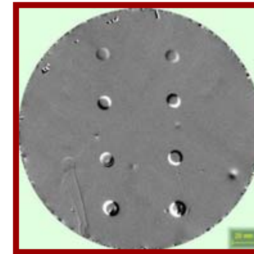


Good agreement with ToF SIMS

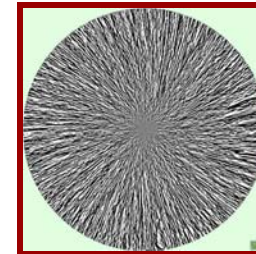
4) Conclusions

Sensitivity to contaminants demonstrated

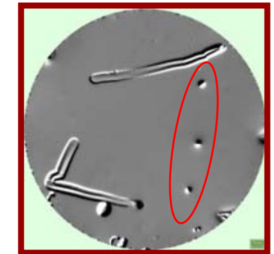
- ✓ Differences element to element: understanding under progress
- ✓ Good sensitivity for a given element whatever the type of contamination
  - Localized spots
  - Global (SC1, rinse and spin dry)
  - Precipitates



Fe spots



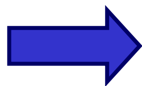
Fe spin coated



Fe traces and aggregates

Fast, non invasive, sensitive, versatile method

- ✓ Full mapping in a few minutes, full sheet and patterned wafers
- ✓ Detection of defects in the < 10^{10} at/cm² range shown
- ✓ Different ways to extract information from images
- ✓ Absolute measurement for wafer to wafer comparison



Very promising production monitoring method

Acknowledgements

✓ This work was performed in the frame of a Qcept technologies – LETI collaboration

✓ Thanks to G. Hamaide, SOITEC, for the support on experiments on SOI wafers and to V. Enyedi, LETI, and Y. Borde, STM, for the support on intentional contaminations

Thank you for your attention

Questions ?