Non-uniform contamination results in sub-ppm fail rates

analytical challenges

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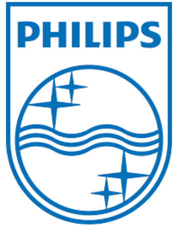
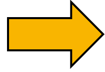
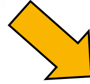
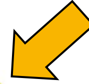
SECURE CONNECTIONS
FOR A SMARTER WORLD

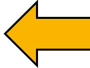
History & Future



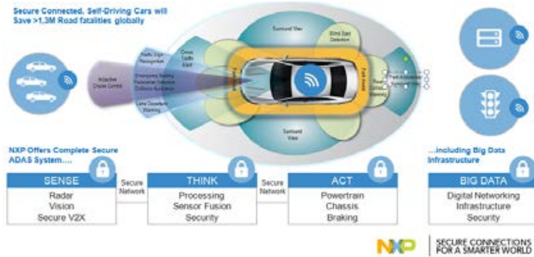








freescale



Expected end of 2017.

One of the reason is **Automotive Quality**

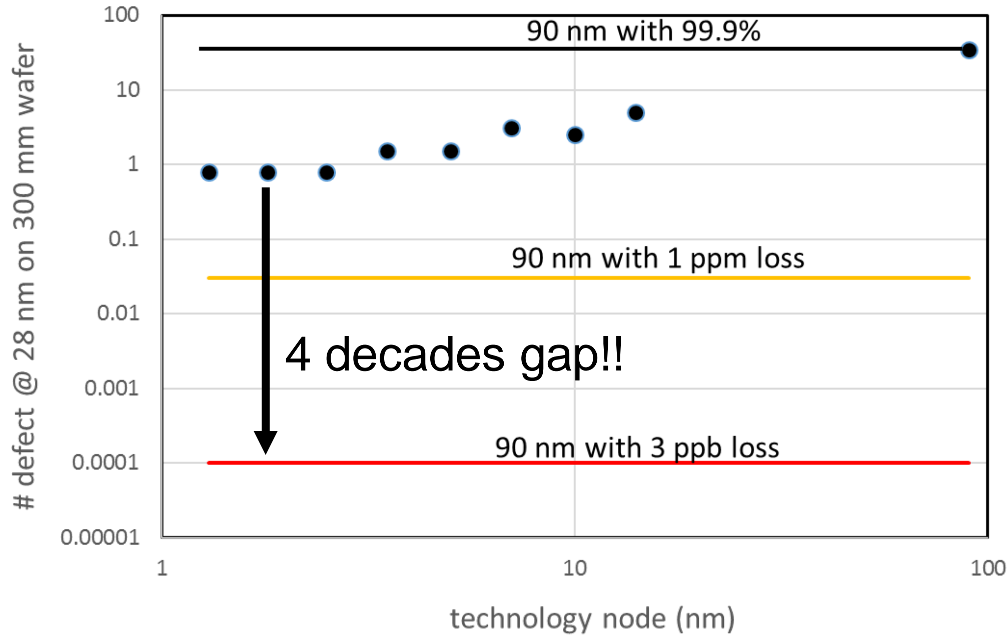
What is automotive quality for surface preparation

- ITRS FEP road map was also based on 99% yield — 10000 ppm
- Most customer applications have 99.98% — 200 ppm
- A few years ago we had 1-ppm mind set: 99.9999% — 1 ppm
- Today we have zero-ppm: 99.999998% — 20ppb
- Goal is to have per failure mode > 99.9999997% — << 3 ppb!

With 1 ppm and 1000 IC's in a car 1 of 1000 will fail due to one IC failing
With 200 ppm 18% of the cars will fail

ITRS Roadmap surface preparation

Road map was base on 99% and in ITRS 2.0 99.9% calculation are given



ITRS 2.0

Used equations:

$$Y = e^{-DpRpAeff}$$

Defects on critical gate oxide area

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Yield: failures in the field

- Many opportunities to fail with a chance, p_x

$$Y_{loss} = \sum_{x=1}^{n} p_x$$

- For many failure modes there is a detection with a chance to detect (d_x)

$$Y_{loss\ at\ customer} = \sum_{x=1}^{n} d_x p_x$$

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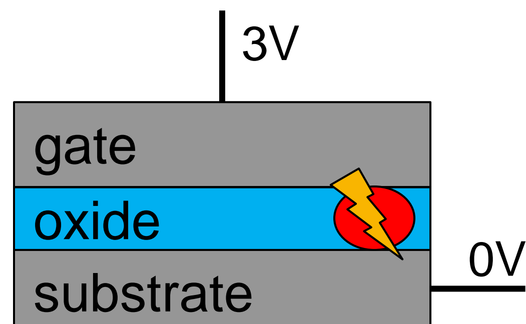
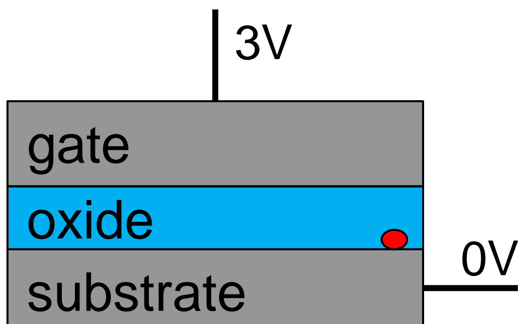
What is going to the customer?





Wafer test or Final test

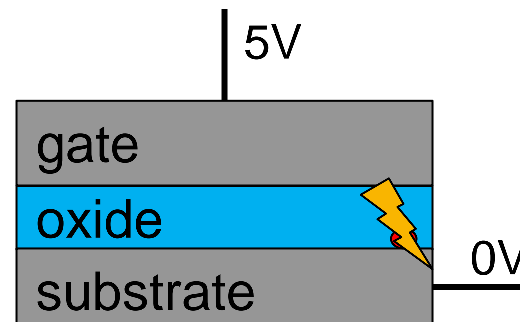
$p_x d_x$

Fail on short

$p_x(1-d_x)$

Product pass

Defect is screened out



Product fails at customer

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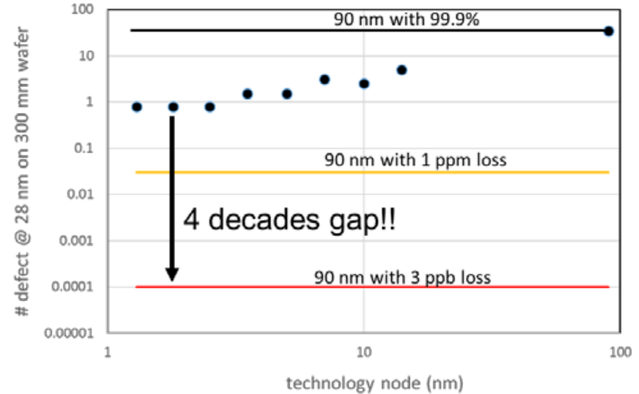
What is going to the customer?

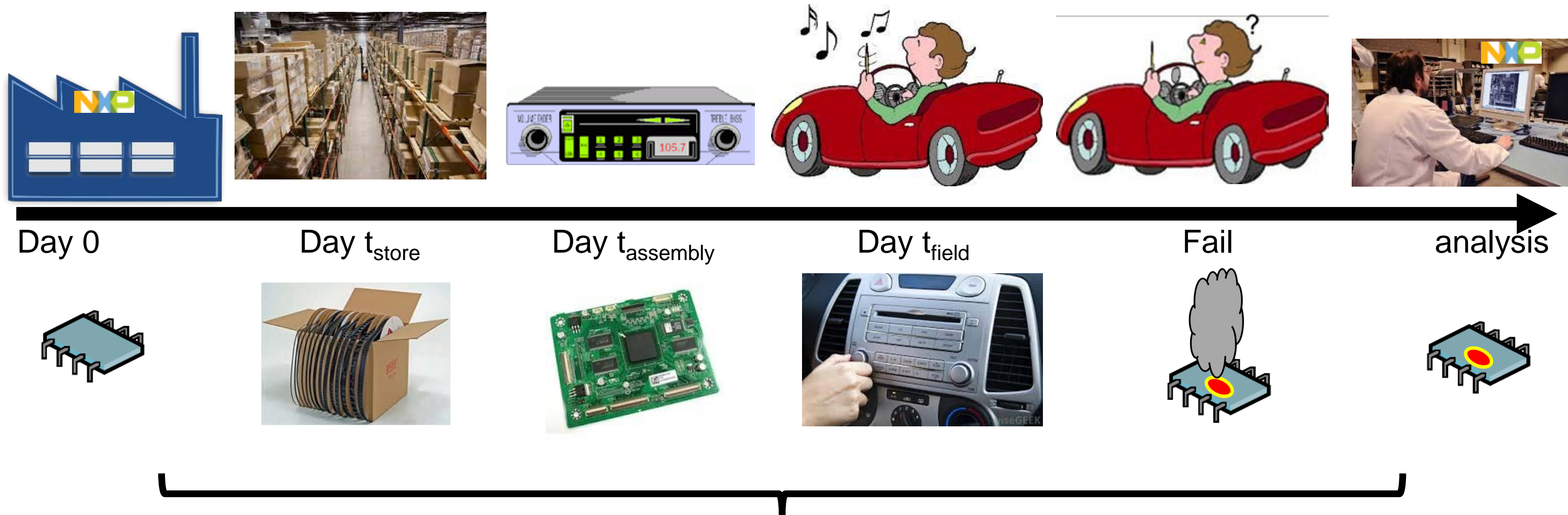
- Gap is large, but is bridged by:
- Improving processes
  - Reduce defect addition
  - Improve cleaning
- Filter out by advanced detection methods



What are we doing to focus on the problems…

OUR TOOLS

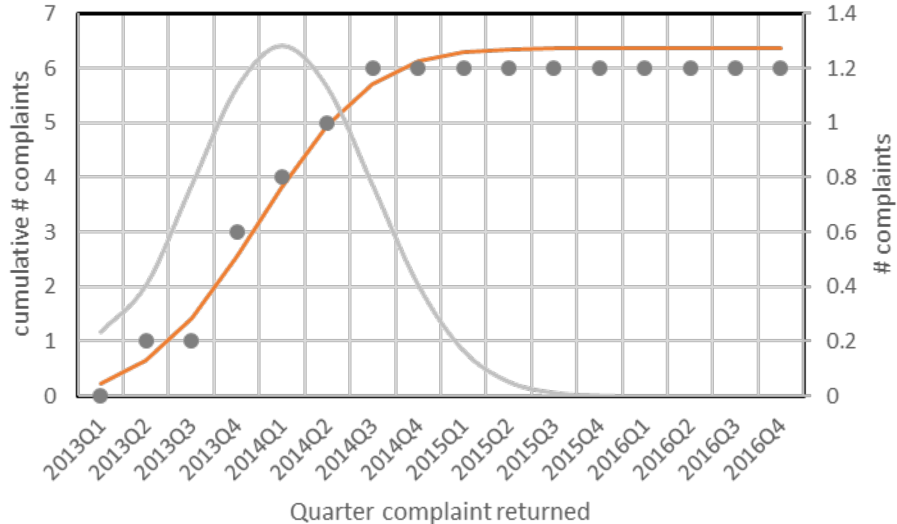
Manufacturing to field failure



Return Time has lot of variation

Forecast of severity: crawl chart

Return profile of products manufactured in 2013 Q1

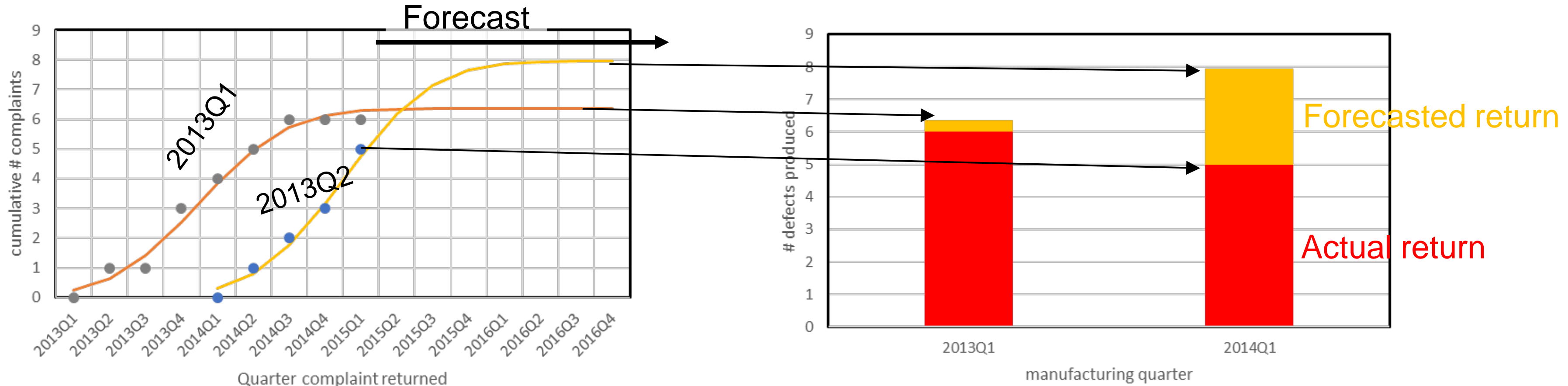


No real data

After Failure Analysis, the root cause is known and such charts can be made for, i.e. gate oxide fails

Crawl Charts: extrapolation

- Forecast using Crawl Chart



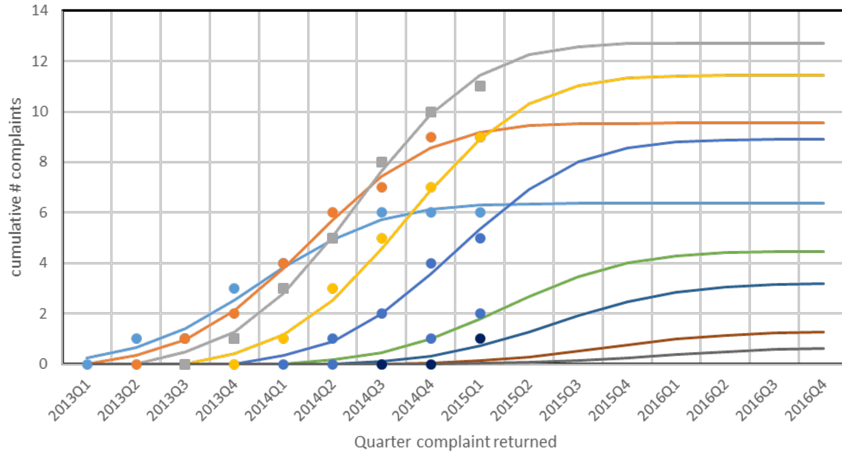
No real data

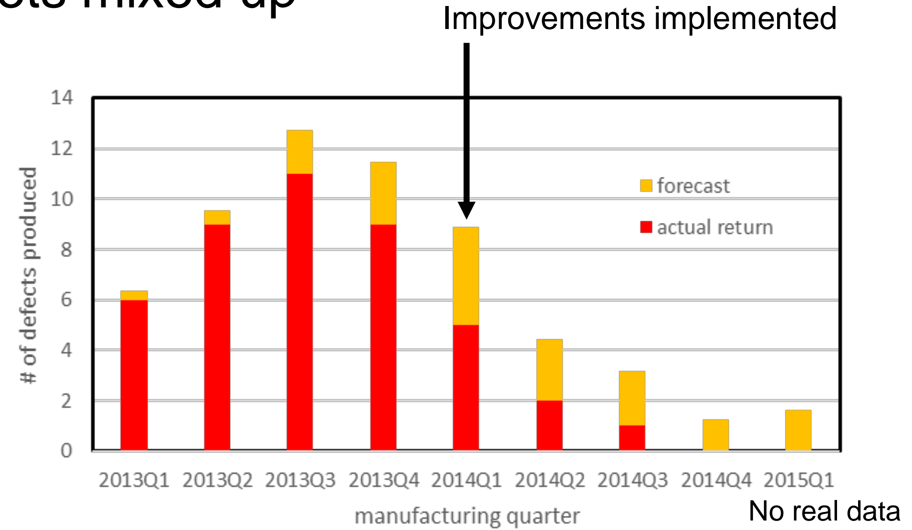
Crawl charts of failing products produced in 2013Q1 and 2014Q1 based on the return date 2015Q1

Since the shape of crawl chart is assumed to be constant, the maximum CQC can be forecasted by scaling the curve to fit the known points

Crawl Charts: trends and extrapolation

- Multiple Crawl Charts information gets mixed up





Summary of multiple crawl charts

Problem is solved

Failure Analysis (FA) with full traceability

- Samples are rare
- Physical FA: Many tricks to investigate reason and root cause of fail preferably non destructive.
- Process reason investigation:
  - Die ID or batch ID
  - Test-yield check (e.g. escaped product, $p_x(1-d_x)$, of large group found in test $p_x d_x$)
  - Trace back the full process history.
    - On which tool it has been on which time including rare events.
    - If more defective products returned: Communality studies: e.g. all 3 defects were processed on the same wet bench (of the four that are in use for this process step)

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#1 failure mode in FE

- Gate oxides blown up (root cause evidence is gone)
- There are many reasons for gate oxide fails
- In some cases there are communalities such as with clean, wet etch,or dryer. Containment:
  - Golden flow
  - Make changes in process
- What is the root cause?
- Do we have defects outside our vision?

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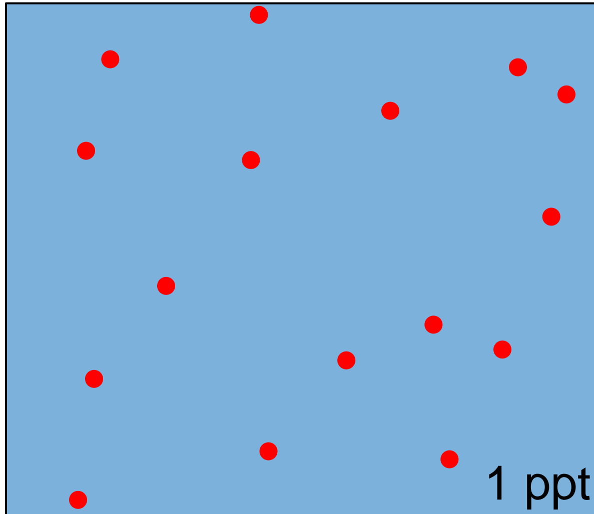
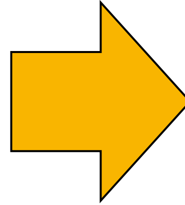
POTENTIAL FAILURE MODE

Non uniform contamination: hypothesis

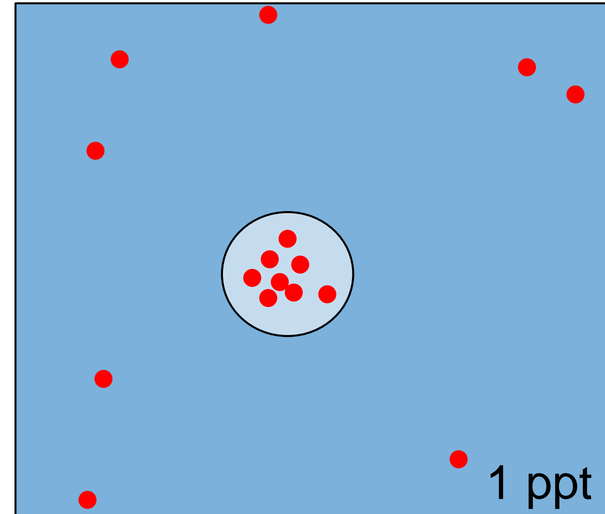
In spec:



Deposition by adsorption and carry-over layer



But potential defect



Deposition by adsorption, particle deposition, and carry-over layer

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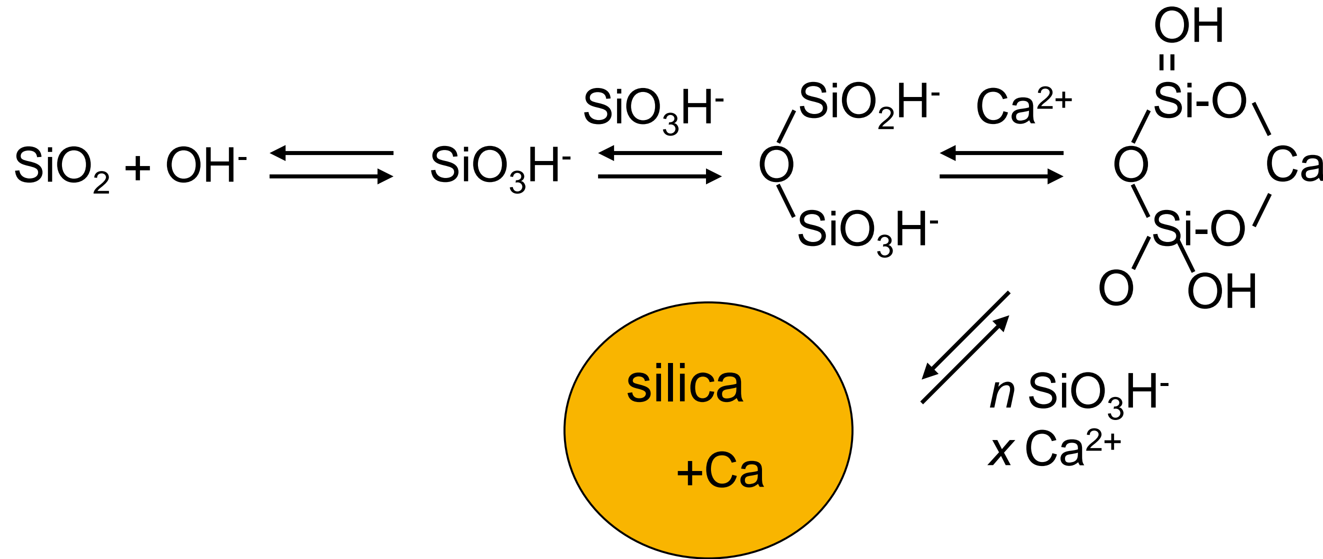
Known reaction



We are able to make these particles (but >> 50 nm)
These cause defects, while similar Ca-free silica particles cause no defects.
What determines kill ratio of particle?

Impact of Metal-Ion Contaminated Silica Particles on Gate Oxide Integrity by I. Rink, F. Wali, D.M. Knotter in Solid State Phenomena 145-146:131-134

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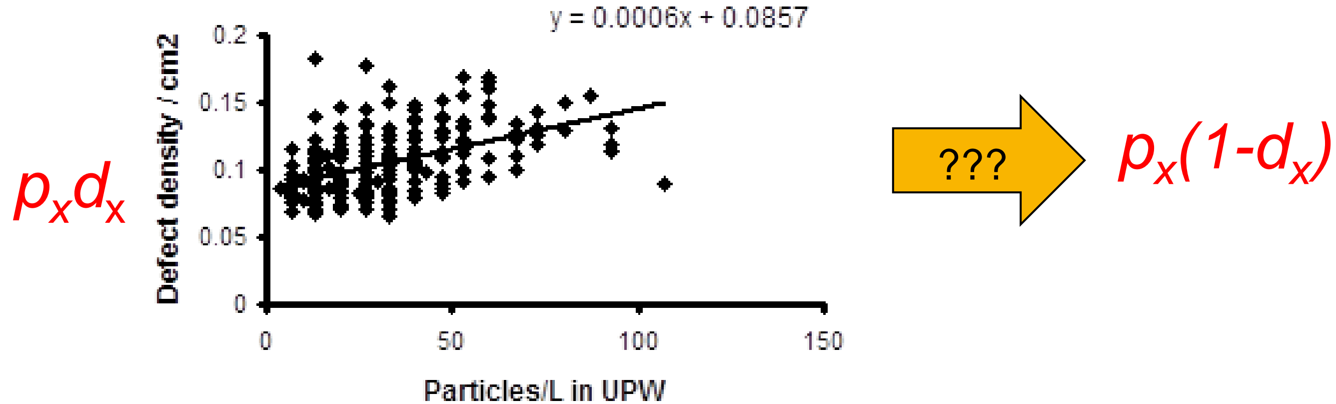
Weak responses: particles in water



Particles do not account for all defects, but slope is significantly different from 0.

Impact of particles in ultra pure water on random yield loss in IC production F. Wali, D. M. Knotter, A. Mud, F. Kuper Microelectronic Engineering 86(2):140-144

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Challenge FE analysis

- We have circumstantial evidence for particles having high M contamination can result in fails
- We lack analytical methods for a full prove.

- By the way: Solution is <u>not</u>:
  - Reduce silica in water (it will etch wafers)

- In BE we have an example….

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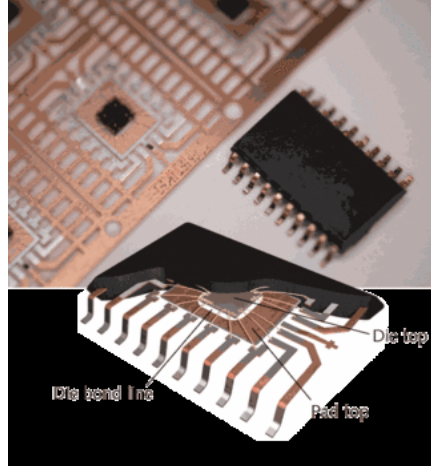
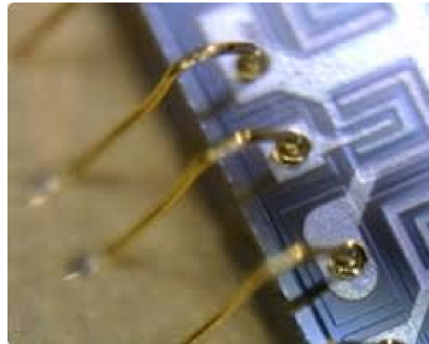
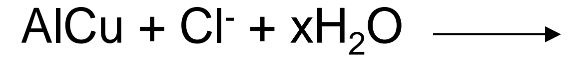
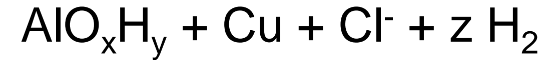
Contamination in mold compound

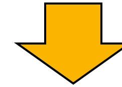




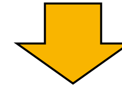




$$AlCu + Cl^- + xH_2O \longrightarrow AlO_xH_y + Cu + Cl^- + z\,H_2$$

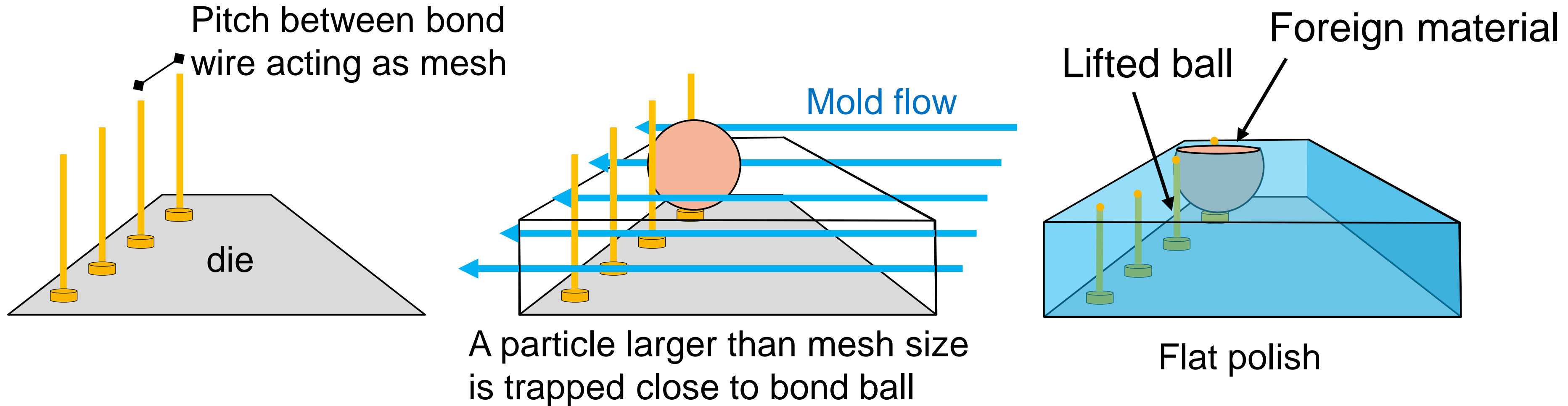


Ball lift and defective product



Specification Cl in mold compound
< 35 ppm

Contamination in mold compound: particle



Evidence of root cause of failure is still present

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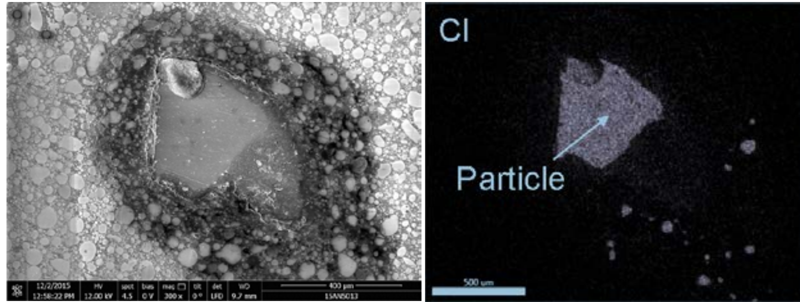
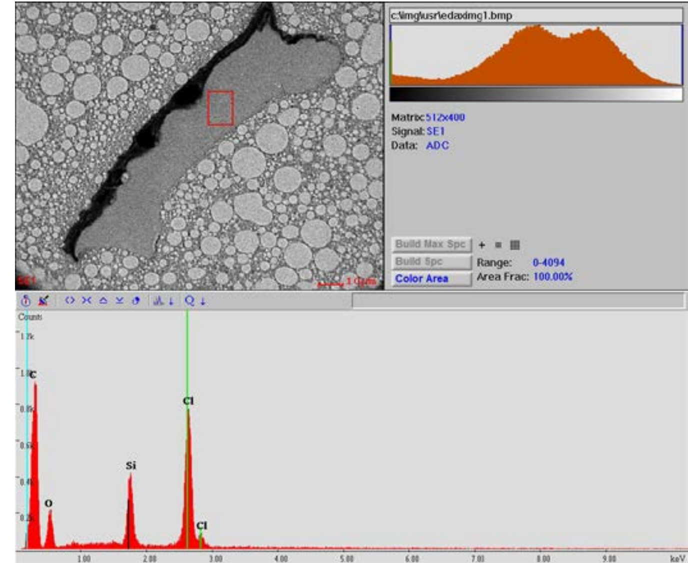
Cl-containing particle in package

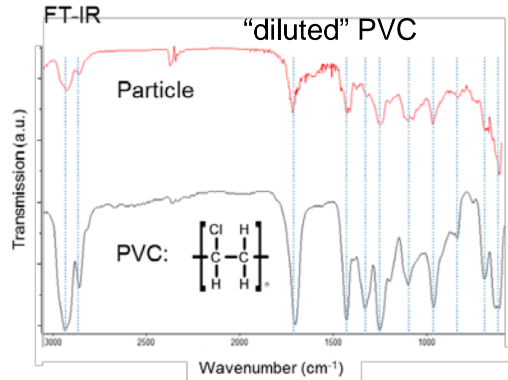
SEM-EDX

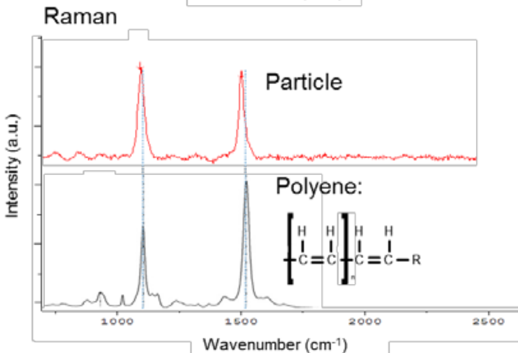




Rik Otte, Rob Fonville and Martin Knotter ": Identification of Foreign Particles in Packages of Failed Products" ESREF 2017 submitted to : E - Packaging and Assembly Reliability and Failure Analysis

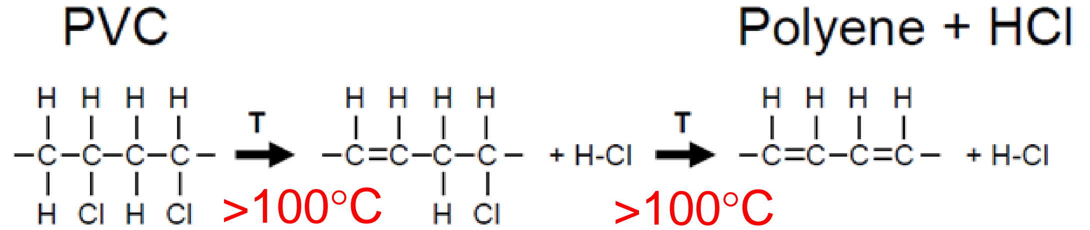
Confirmation of PVC particle





Note that XPS would also differentiate between $CaCl_2$, NaCl

XPS:
Organically bonded chloride is at 200eV and chloride salts typically 198.5eV.



Hjertberg T and Sörvik EM. Thermal degradation of PVC. Degradation and Stabilisation of PVC. Springer Netherlands, 1984, pp 21-79

Rik Otte, Rob Fonville and Martin Knotter ": Identification of Foreign Particles in Packages of Failed Products" ESREF 2017 submitted to : E - Packaging and Assembly Reliability and Failure Analysis

Summary of BE problem

- Bulk material is well within specification for Cl content and particles
- Product fails because of a particle generating locally a contamination level higher than specification.
- In this case we succeeded in the development of
  1. An analytical method to measure local high contamination levels and the composition of this material
  2. An Analytical method (not in this presentation) to determine this in the bulk material
- This enables us to find root causes and improve our processes.

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Conclusion

- We need to develop analytical methods to determine the distribution of contaminants within a bulk material.
- We need analytical methods to determine contamination levels at the location of failure.

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