Endpoint Detection of Low Open Area Contact Nitride Etches by Use of Optical Emission Spectroscopy in an APC Compatible Multi-Sensor Platform

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Content

1. **Context**
   - ALTIS & HORIBA Jobin Yvon
   - The JY instrument platform
   - Contact Nitride Etch
2. **Optical Emission Spectroscopy**
   - Data handling
   - Wavelength selection
   - Endpoint detection
3. **Results**
   - SEM validation
   - Statistics : tool impact, first wafer effect ...

ALTIS Semiconductor

Joint Venture (1991)
50% IBM, 50% Infineon
2000 people
10000 wafers per week
504 M€
CMOS logic, eDRAM & mixed signal

HORIBA
JOBIN YVON

HORIBA Group

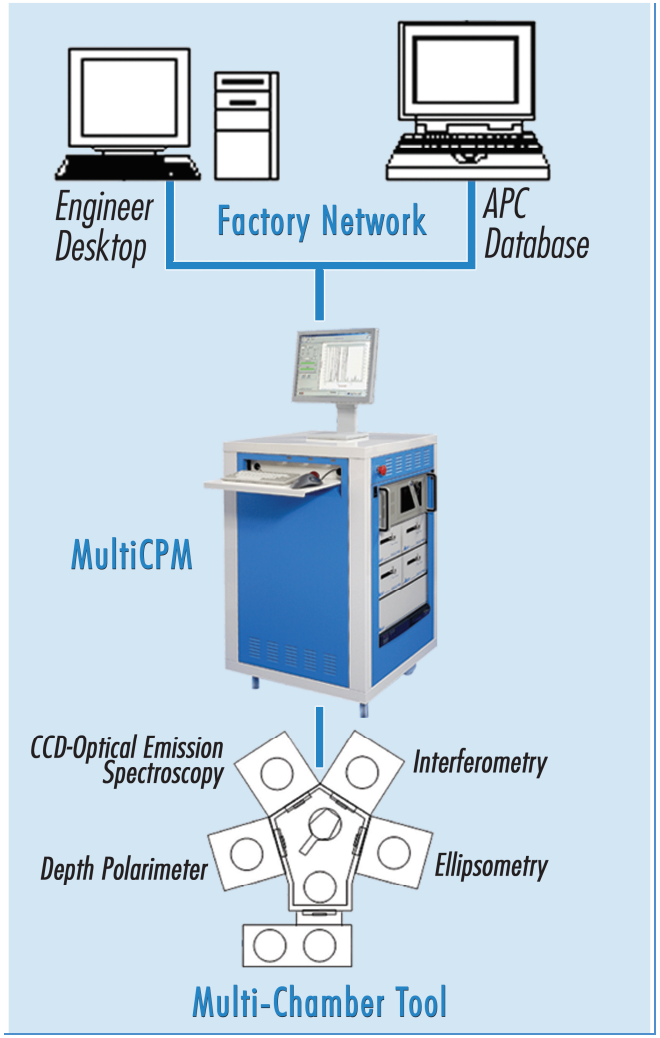
3700 people worldwide
750 M$
► **Jobin Yvon** (joined HORIBA 1997)
550 people worldwide
98 M€
► **Thin Film Division** (50 people)
Optical metrology (ellipsometry, APC)

MultiCPM Platform

- **In-situ multi-sensor and multi-chamber monitoring**
  - *OES Optical Emission Spectroscopy*
  - *LEM Camera Interferometry*
  - *TDM Depth monitoring*
- **Designed for fab**
- **Compatible with all etchers and OEMs**
  - *LAM Alliance*
  - *AMAT AME 5000 & 5200*
  - *TEL Unity 2 & M*

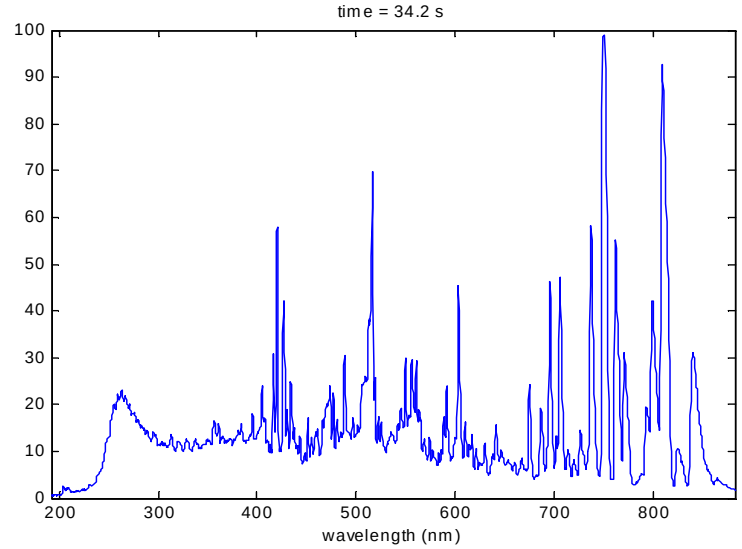
ALTIS

- **Common Windows based software platform**
- **More than 50 production chambers equipped at ALTIS**

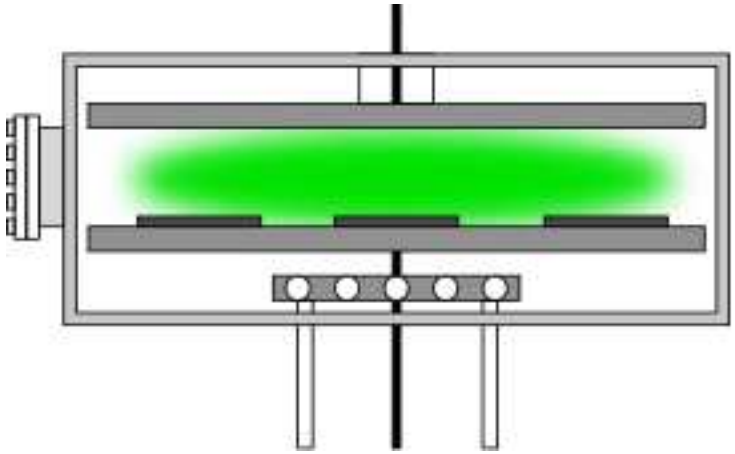


Optical Emission Spectroscopy

- **Principle**
  - The relaxation of plasma excited species produces light.
  - Emission wavelengths are caracteristic of the species in presence.

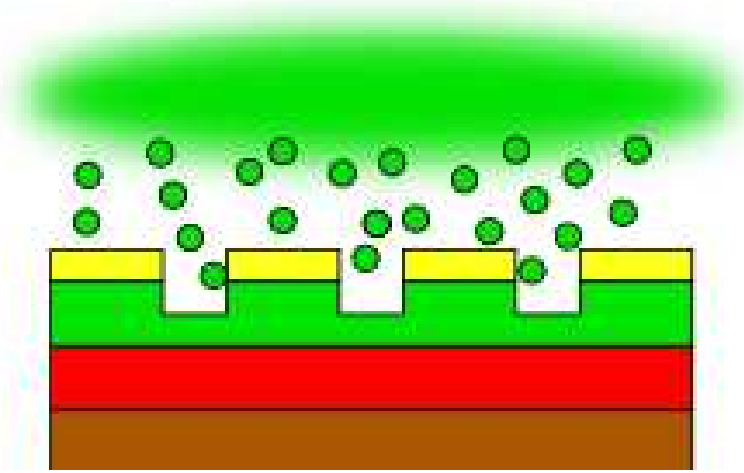


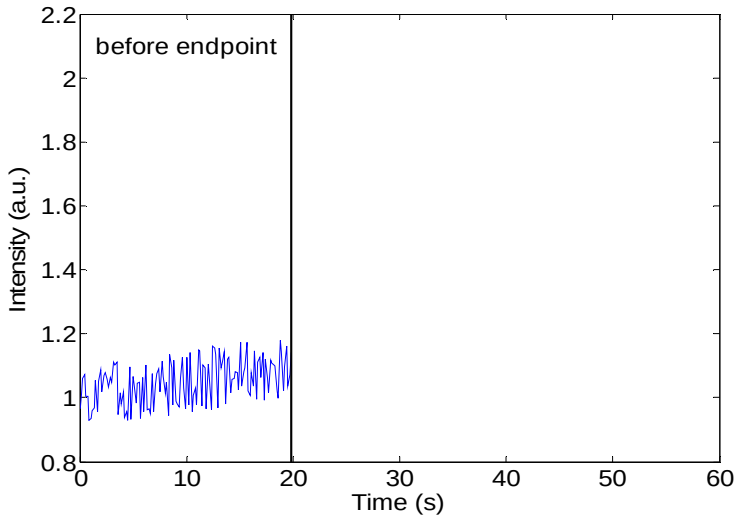
- **Instrumentation**
  - Light is guided towards a diffraction grating by a fiber optic
  - Light intensity is measured as a function of wavelength
  - Real time



Application to Plasma Etching

- **Plasma / etched layer interaction**
  - Plasma emission is modified by the nature of the layer being etched
- **Plasma emission change**
  - Interface
  - Change in the chemical reaction in the plasma
  - Appearance / disappearance of emission lines
- **Interface signature**
  - Rupture





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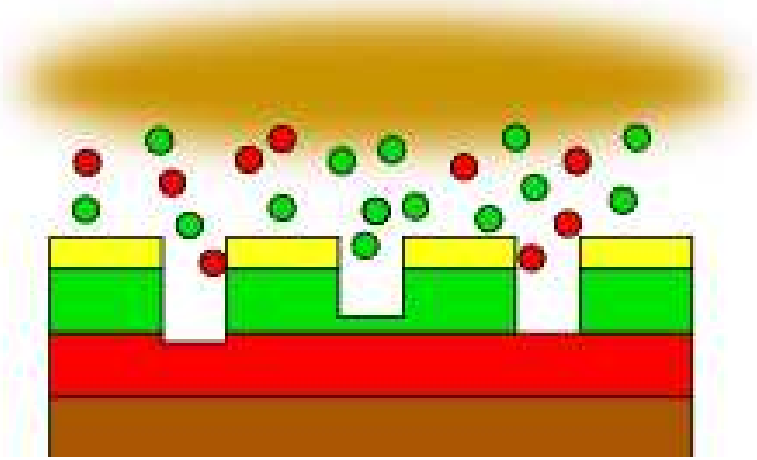

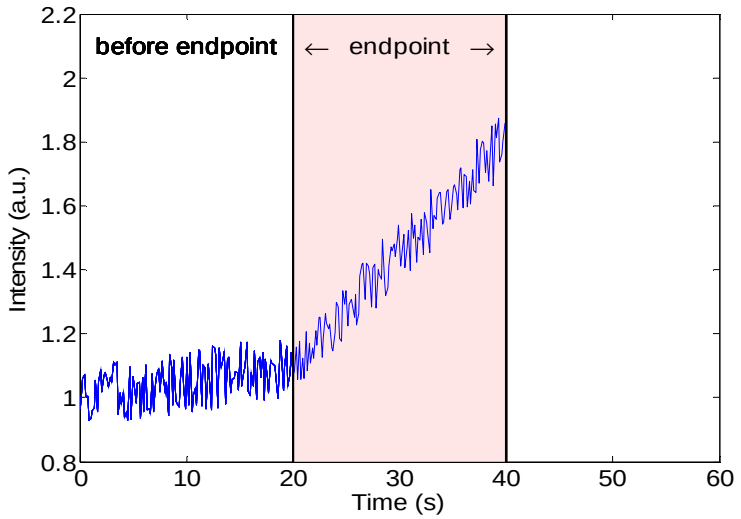

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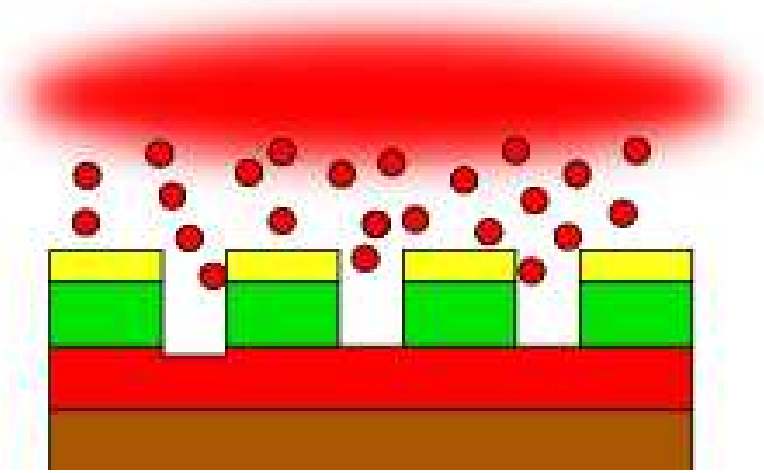
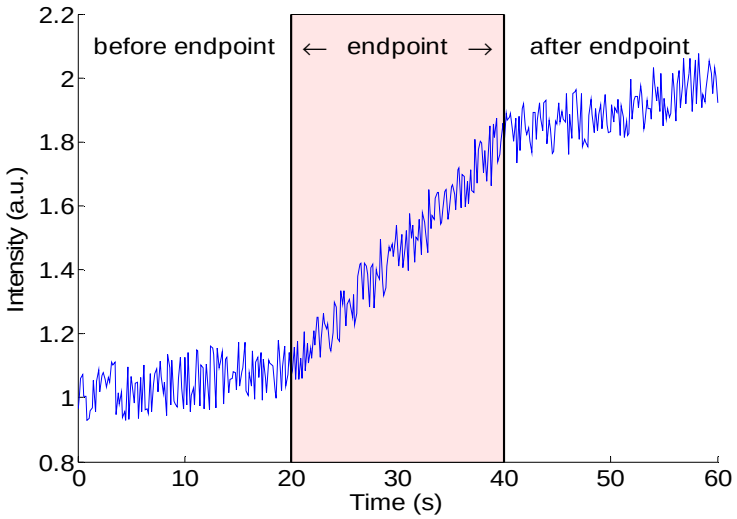
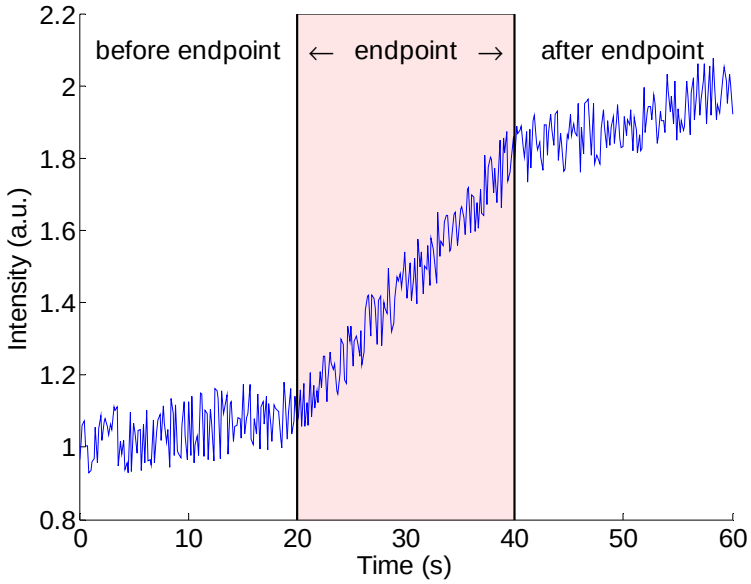




The Endpoint Transition

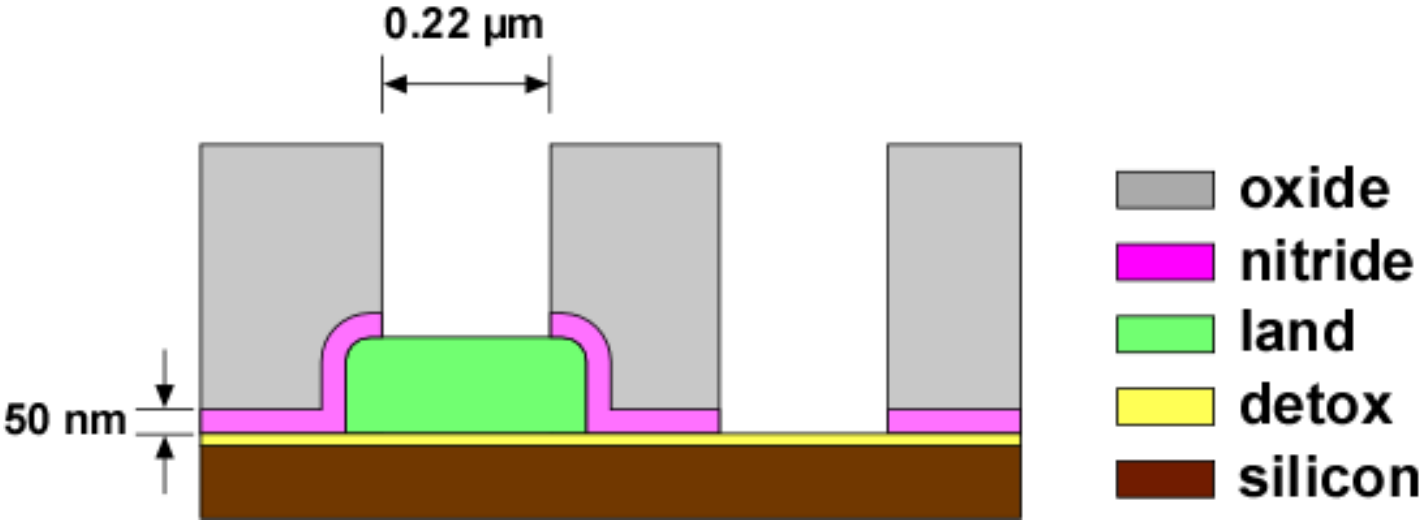
- Transition between 2 levels
- Transition time length is related to the etch rate inhomogeneity
  - ➔ **Non-uniformity from the center to the border of the wafer (layer thickness ...)**
  - ➔ **Non-uniformity in pattern density**
- Only certain wavelengths are concerned



Contact Nitride Etch

Flash Memory

- 0.22 µm technology, open area 2.5 to 5%, non-uniform pattern density
- 5 steps involved : Nitride dep / oxide dep / CMP / (litho mask) / oxide etch /nitride etch
- Nitride etch monitored by OES



The Process Engineer's Work

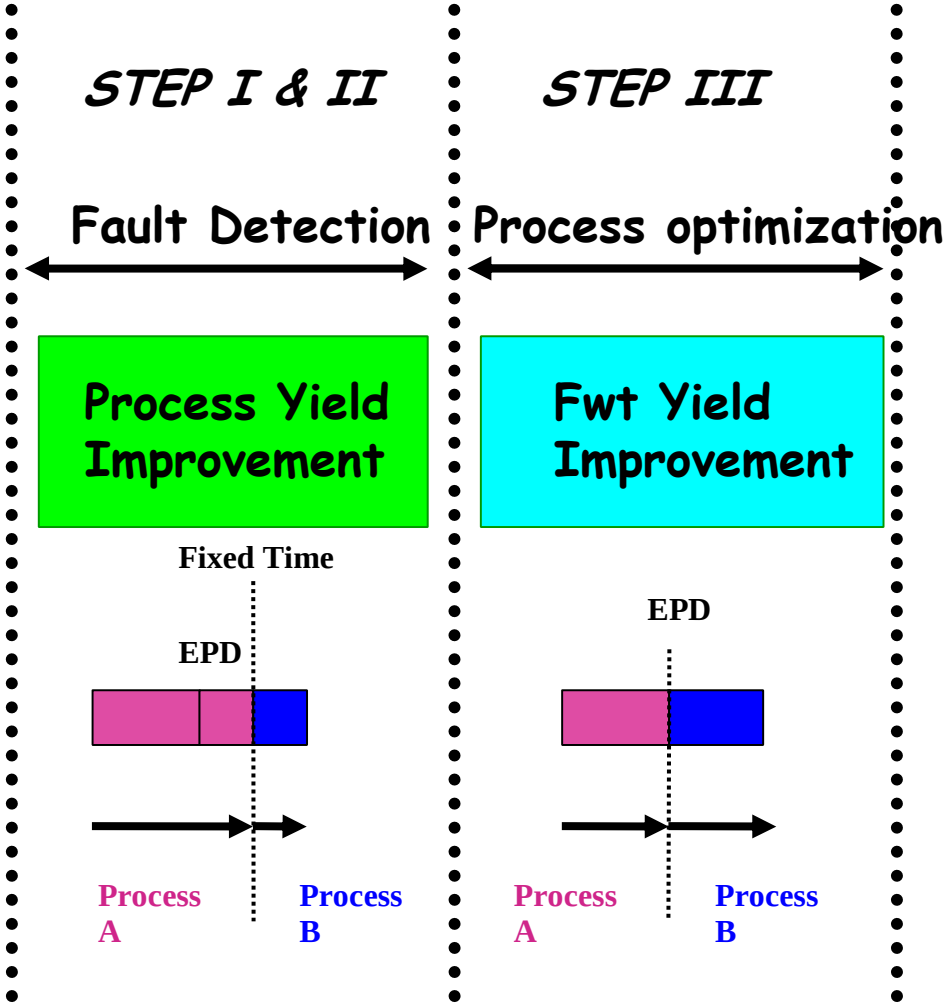
Step 1: endpoint detection setting

- Collect & understand the data
- Select wavelengths & parameter endpoint detection algorithm
- Perform test on a few lots

Step 2: validation

- Process monitor (still in fixed time)
- Statistics and correlation with electrical tests

Step 3: production and yield improvement

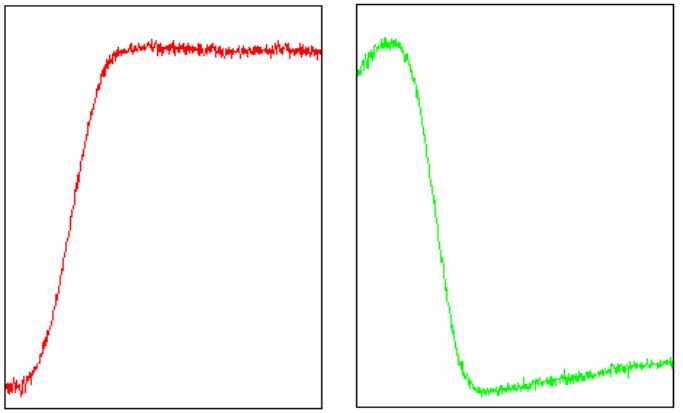


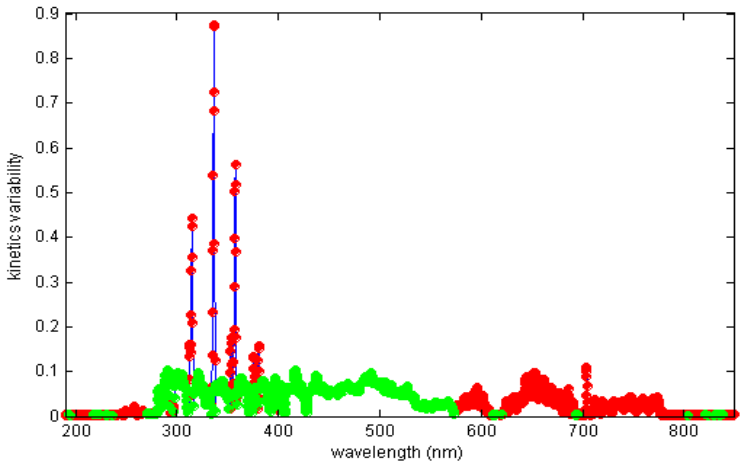
JY solutions

1. **Understanding the data**
   - Quick navigation
   - Classification
2. **Select Wavelength**
   - The software selects the best wavelengths from a series of runs
3. **Parameter setting**
   - Easy and intuitive algorithm parametering
4. **Validation**
   - Statistics in a database
   - Reprocessing on the saved spectra (change the algorithm parameters)

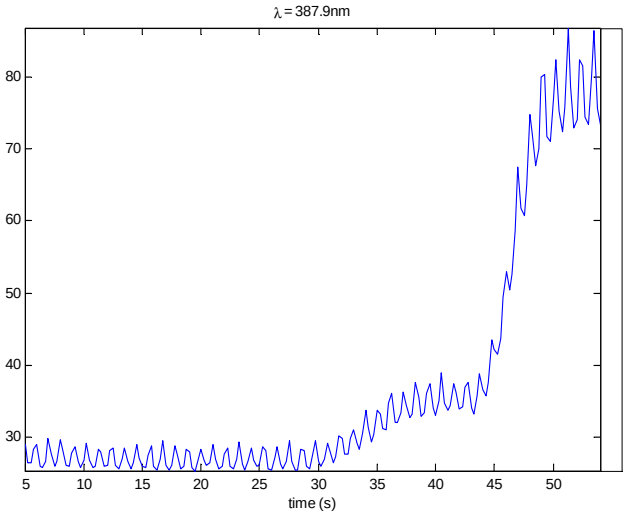
Classification

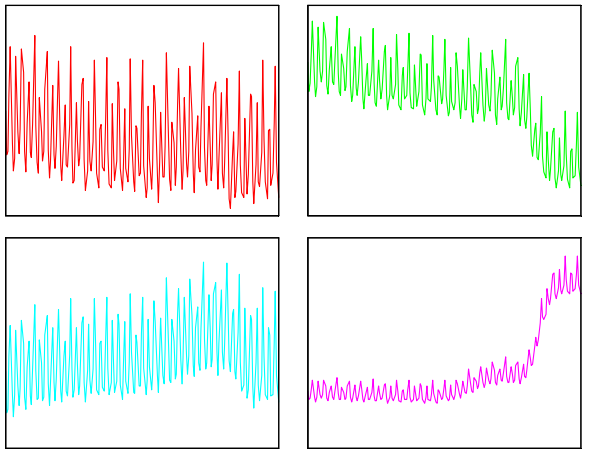
- **Principle**
  - Bring together wavelengths that behave in a similar manner and make groups with them
- **Result**
  - The classification offers within a few seconds a summary of the 2048 wavelengths
  - The user can understand quickly what is happening in the process, where it is happening and when

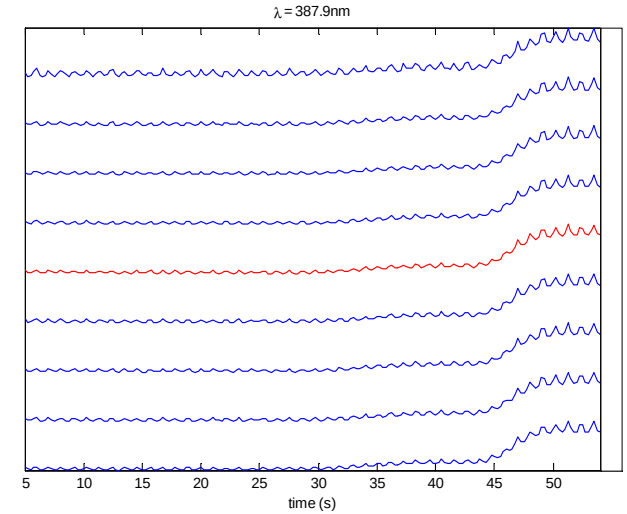


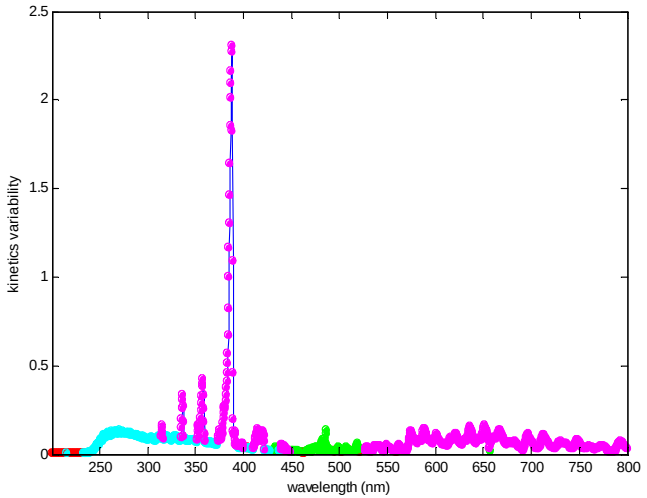


A classification example ...







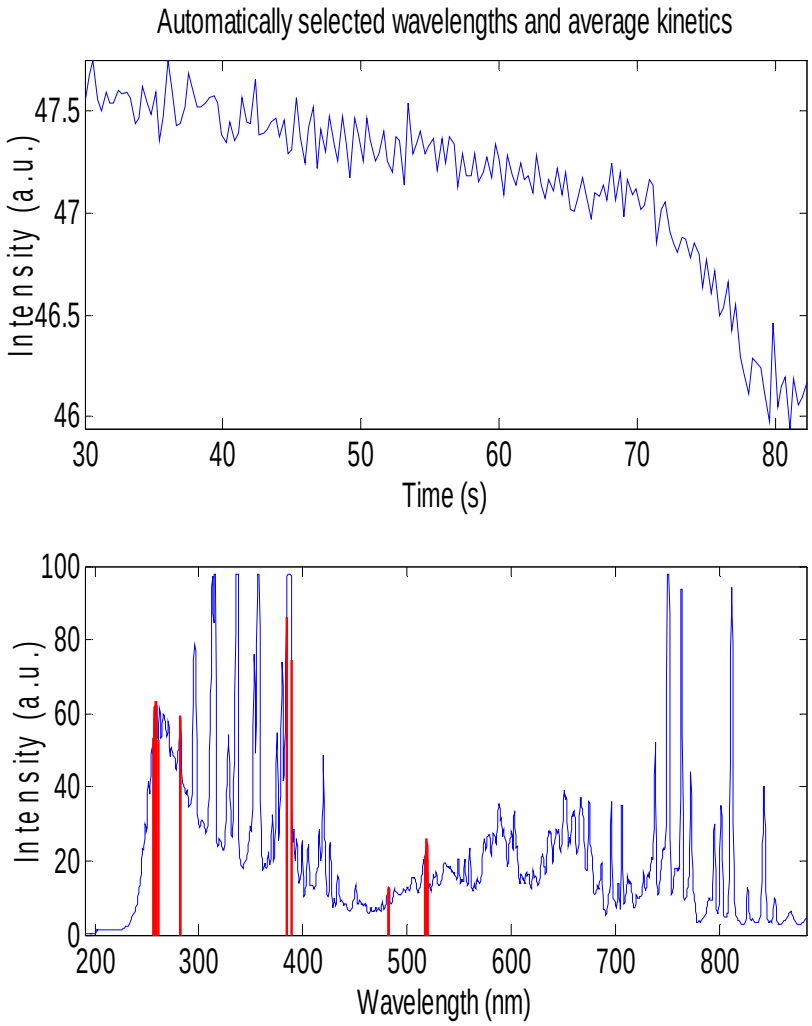


Wavelength selection

User inputs
•Time range
•Wavelength range

►The algorithm automatically selects the best wavelengths

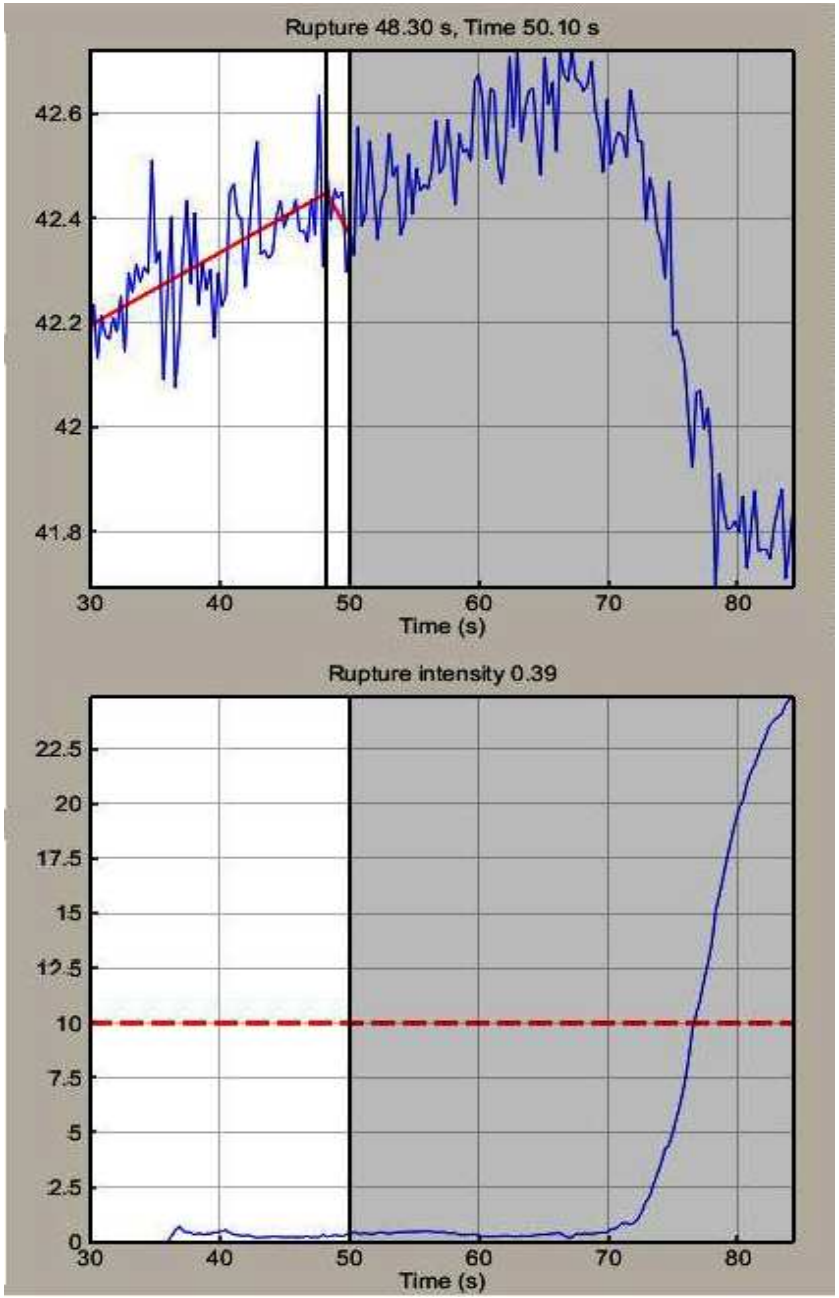
►Image
Bottom : selected wavelengths are in red
Top : average kinetics over selected kinetics



Real-time Endpoint Detection

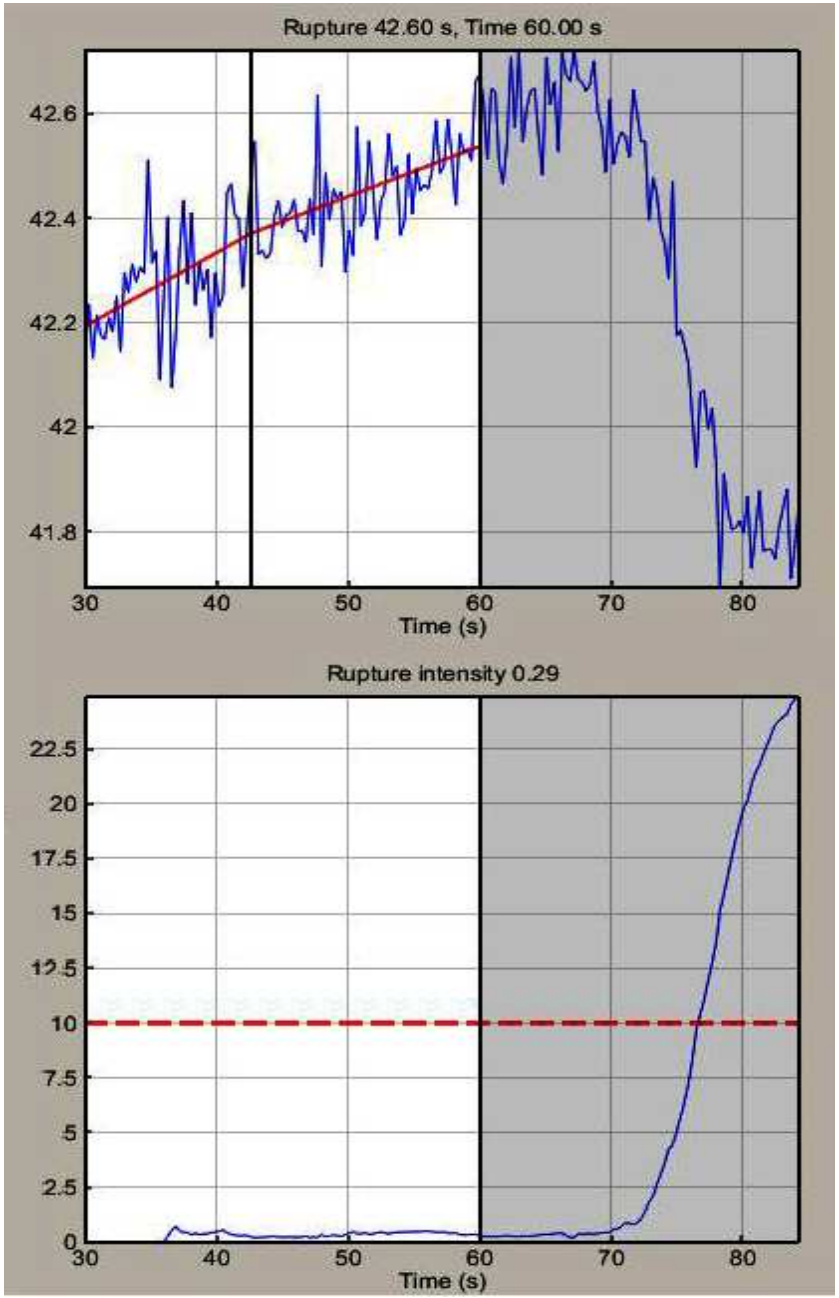
The endpoint detection algorithm in sequence

- The top curve is the average kinetics
- The bottom curve tells if the rupture is well defined
- The left vertical black line on top points to the most highly probable rupture time
- The right vertical black line is the time



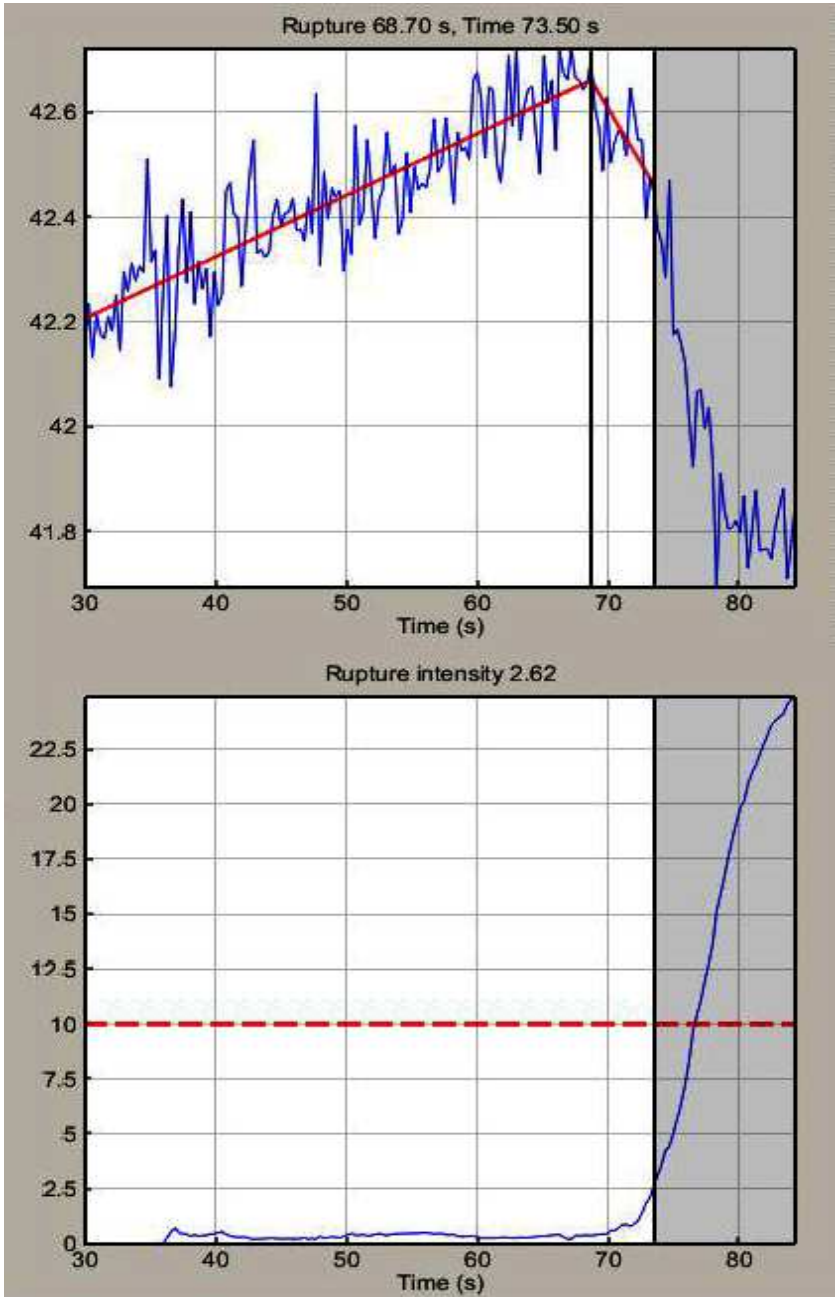
Real-time Endpoint Detection

The endpoint is not reached yet, the probability to find an rupture (bottom curve) is still low.



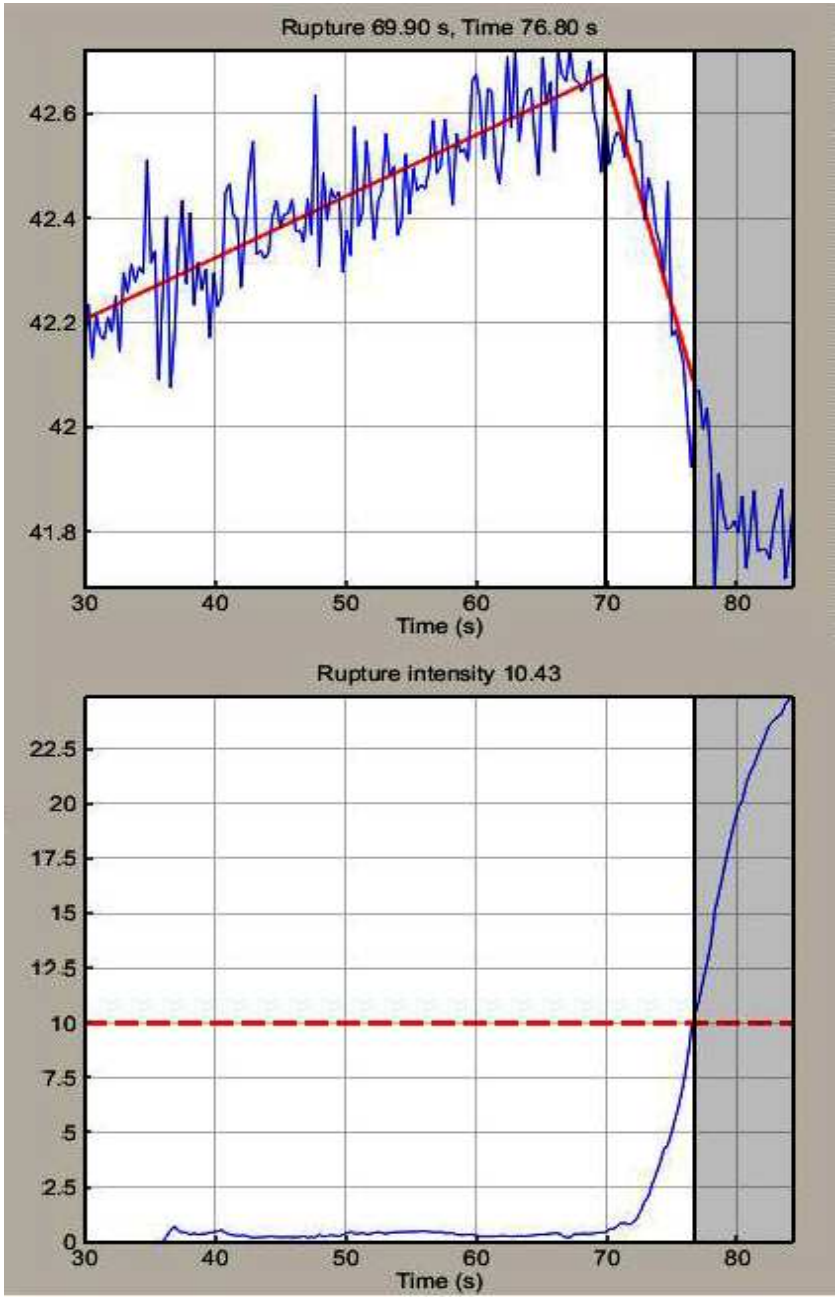
Real-time Endpoint Detection

The endpoint is being reached. The probability start to grow but it is still low: the endpoint can be detected but it is *not robust !*



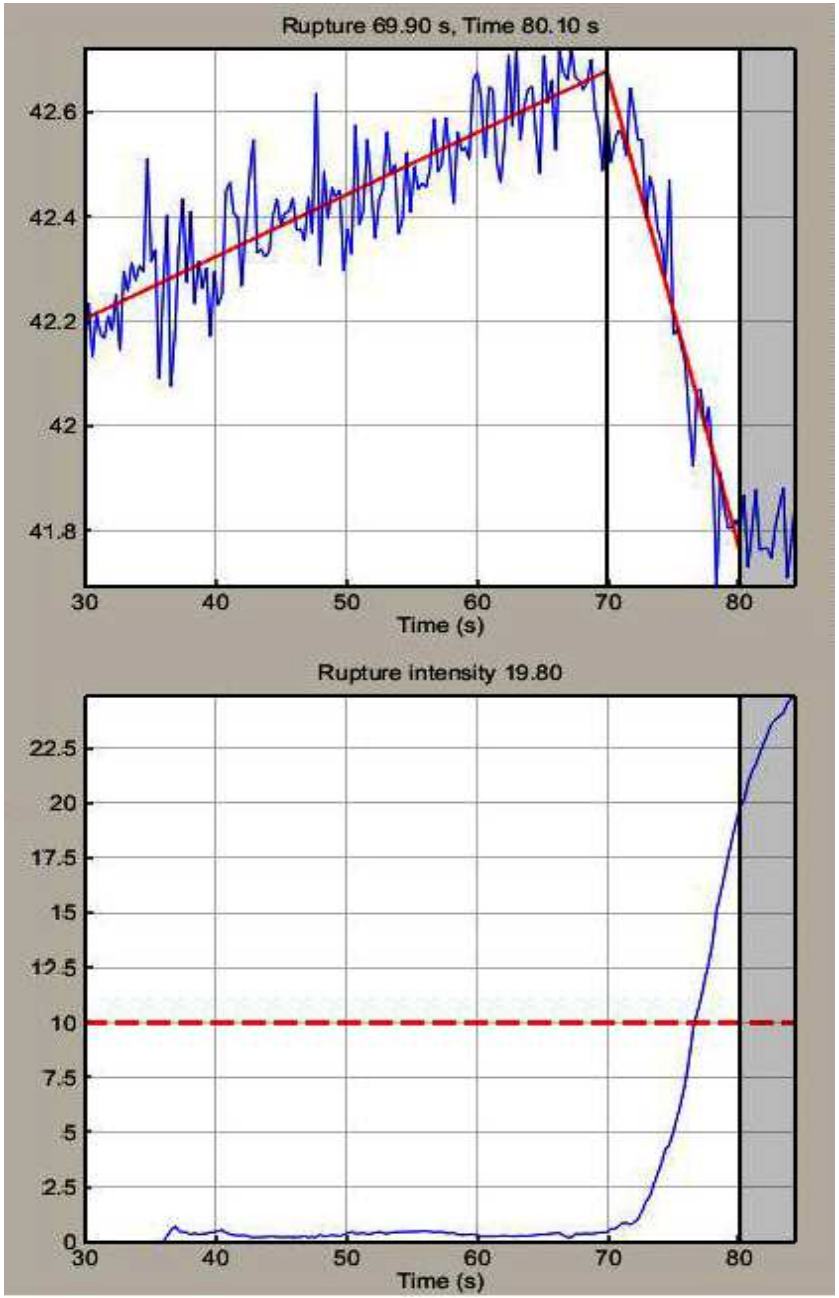
Real-time Endpoint Detection

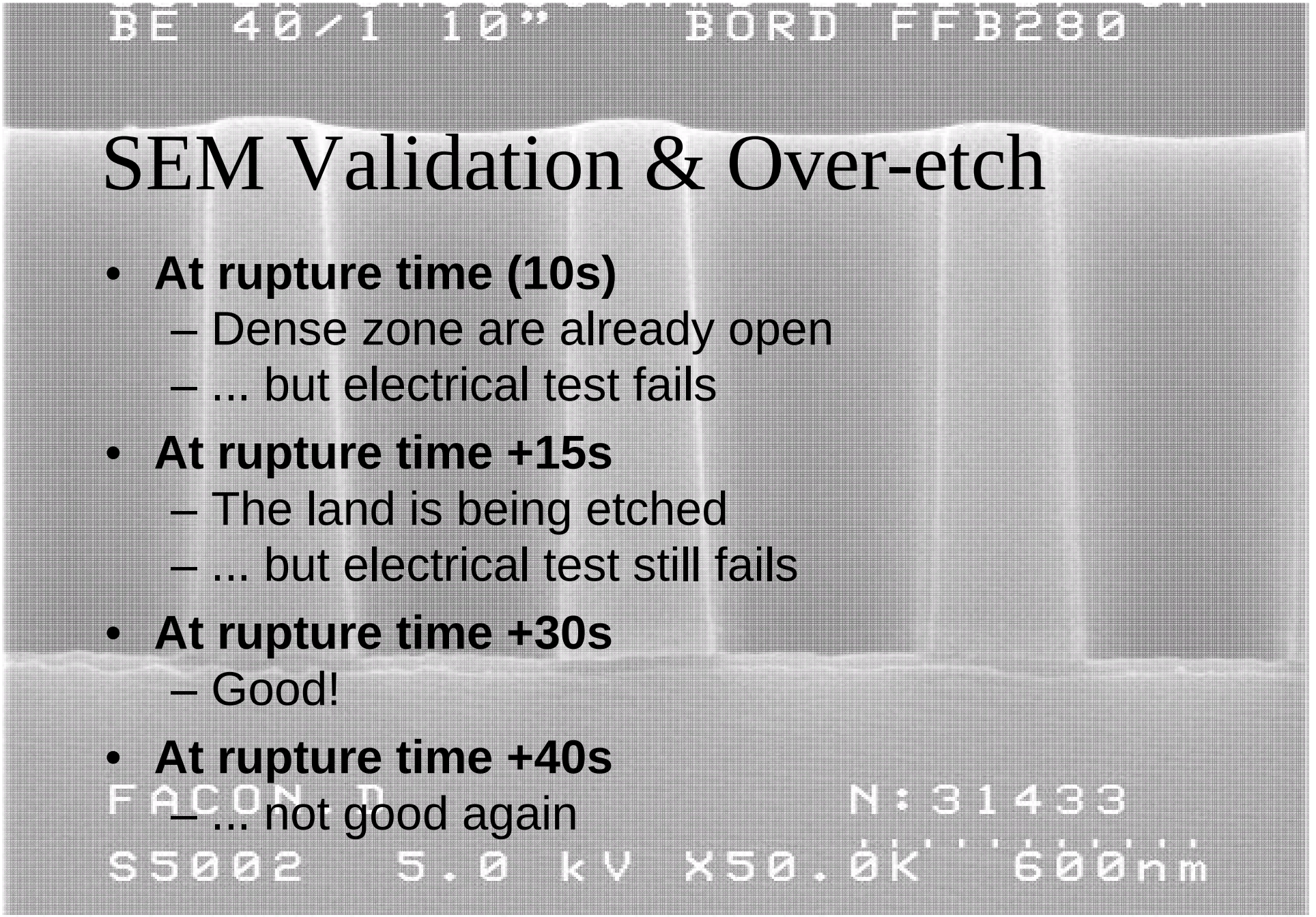
The endpoint is detected.
The probability is high and has reached the user defined threshold (value 10).
The endpoint detection robustness has increased.



Real-time Endpoint Detection

The endpoint has long been reached. The algorithm still points towards the rupture point at 70 seconds.





SEM Validation & Over-etch

- **At rupture time (10s)**
  - Dense zone are already open
  - ... but electrical test fails
- **At rupture time +15s**
  - The land is being etched
  - ... but electrical test still fails
- **At rupture time +30s**
  - Good!
- **At rupture time +40s**
  - ... not good again

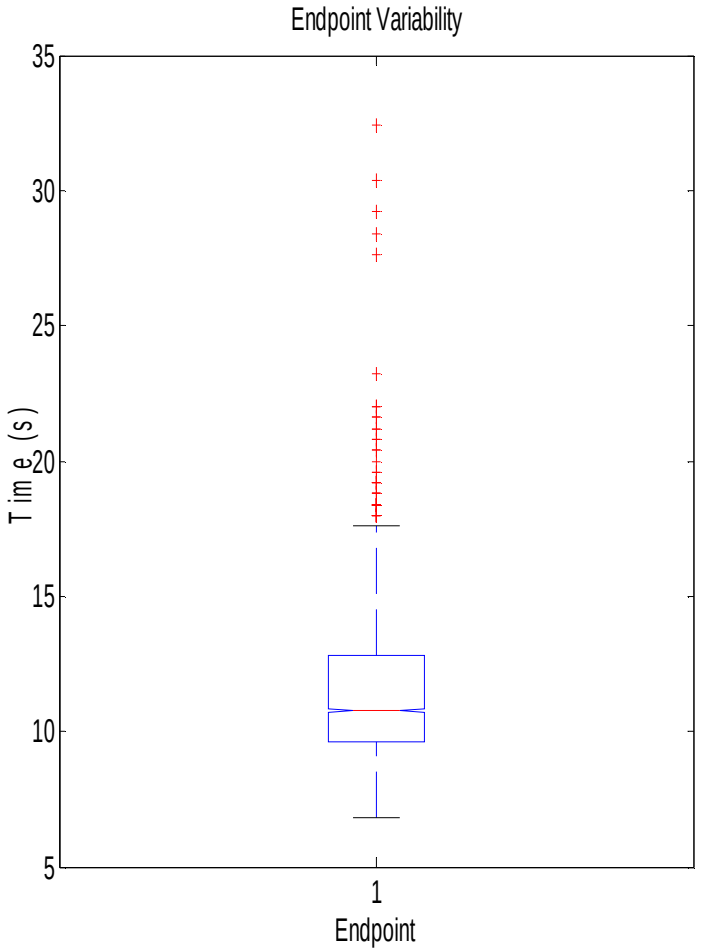
Statistics

- **Collected data**
  - Monitoring (endpoint not in production yet)
  - 10000 runs (1 month)
  - SECS II
  - Chamber names for the previous steps
- **Study**
  - Endpoint "normal" variability
  - Tool or chamber impact on endpoint variability
  - Maintenance operation

Endpoint variability

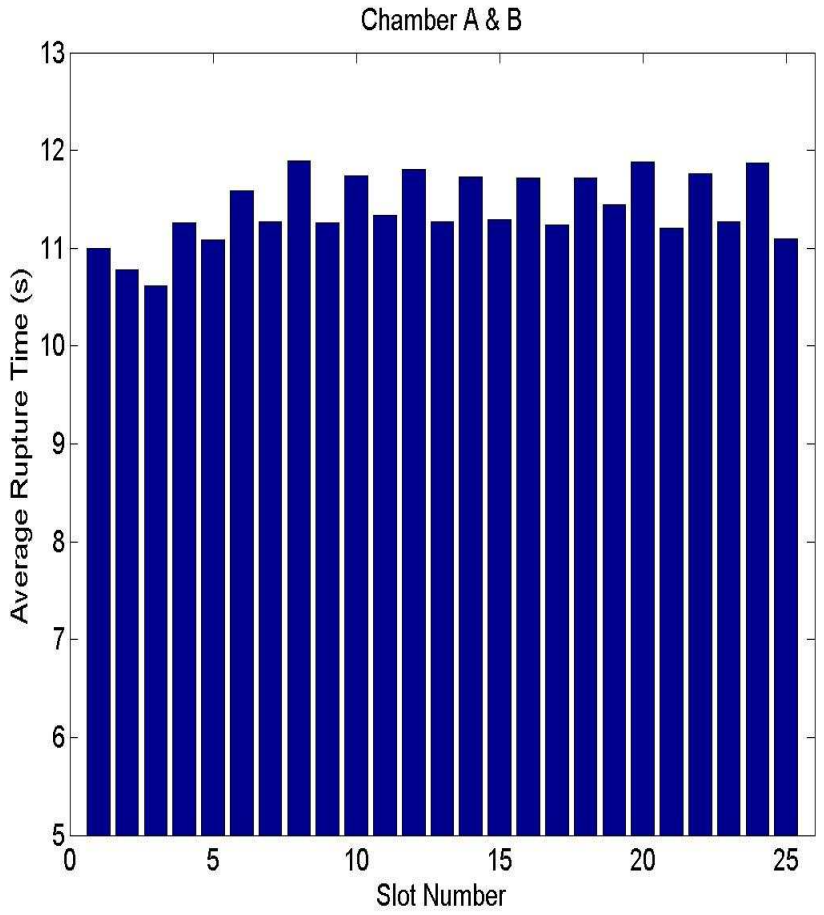
- Average 12 s
- Standard deviation 2.3 s
- 50 % between 6.8 and 17.6 s
- Some outliers above 20 s (under investigation)

The endpoint can vary within a range of 10 s. This is to be related to the wafer to wafer nitride layer thickness variability



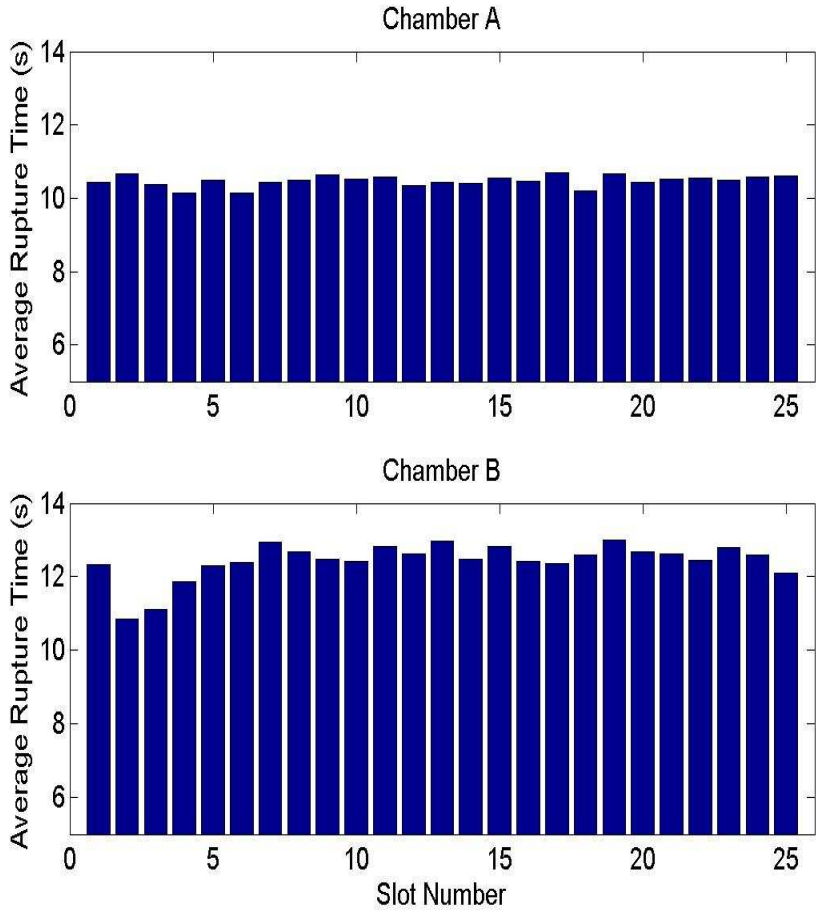
First wafer effect 1/3

- **Nitride layer etch**
  - One tool, two chambers (A & B)
  - Average rupture time vs slot number
  - Two populations : odd and even slots



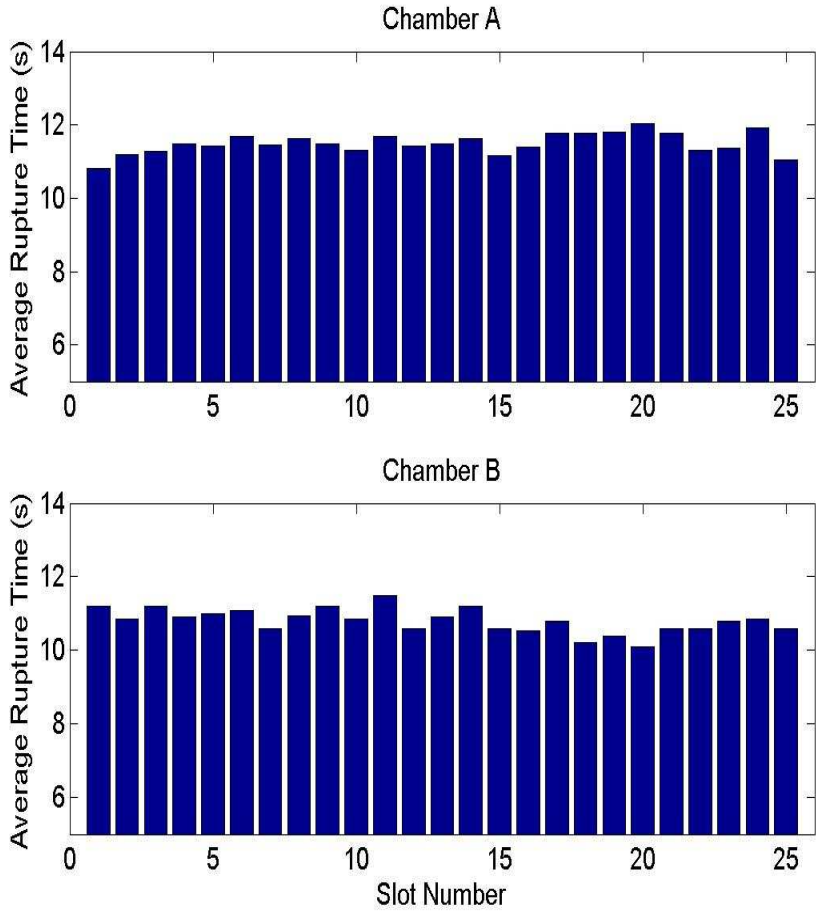
First wafer effect 2/3

- **Nitride layer etch**
  - One tool, two chambers (A & B)
  - Average rupture time vs slot number
  - Two populations : odd and even slots
  - Chamber effect ! Odd slot numbers are usually processed by chamber A
  - Problem ?



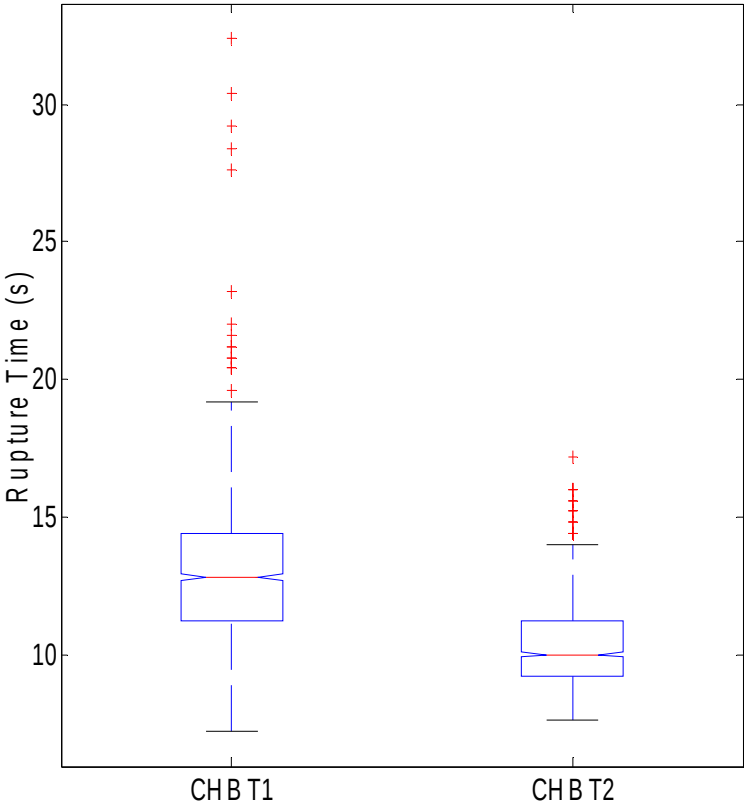
First wafer effect 3/3

- **Nitride layer etch**
  - One tool, two chambers (A & B)
  - Average rupture time vs slot number
  - Two populations : odd and even slots
  - Chamber effect ! Odd slot numbers are usually processed by chamber A
  - Problem ?
    - temperature and flow correction in the tool cooling system



Tool Matching

- **Previous step : oxide layer etch**
  - 2 tools : T1 and T2
  - Separate study on nitride etcher chamber A and B
- **Results**
  - Significant difference between T1 and T2
  - T1 is more selective than T2 : T2 starts to etch the nitride layer so the endpoint comes sooner on T2 than on T1.



Advanced Process Control at ALTIS

- **Process monitoring**
  - Increase process stability
- **Equipment monitoring**
  - Increase equipment uniformity and performance
  - Tool matching
- **Module monitoring**
  - Control the inter-dependent steps of a module
- **HORIBA Jobin Yvon is a key partner for the OES process control at ALTIS**