# Low-Open Area Endpoint Detection using a PCA-based $T^2$-Statistic on Optical Emission Spectroscopy (OES) Measurements

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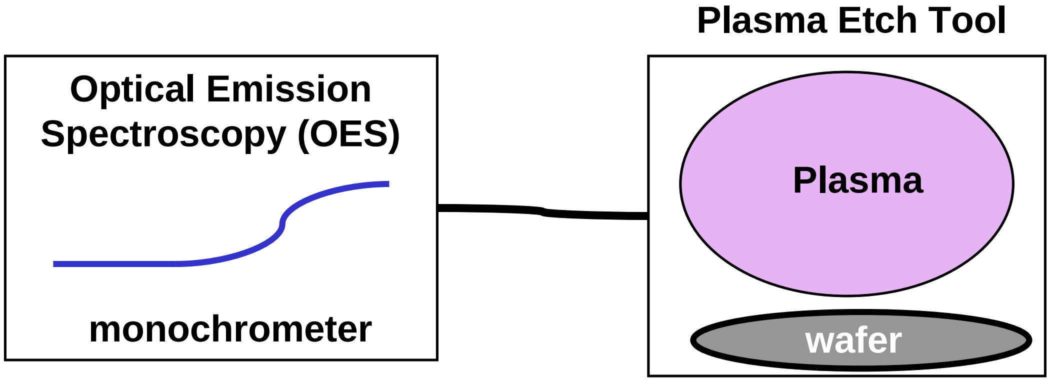
*Acknowledgements - This research has been supported by the MIT Leaders for Manufacturing Program and Digital Semiconductor.*

# Overview

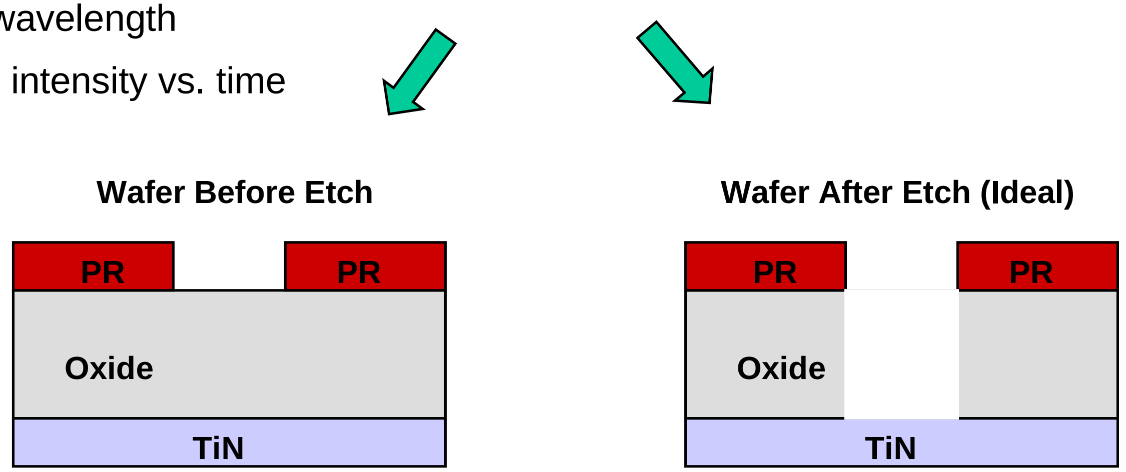


**Etch Process:**

- Energetic species react with wafer
- Selective removal of material

**Conventional Monochrometer**:

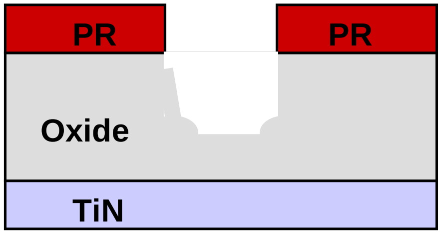
- Monitors a single wavelength
- Measures spectral intensity vs. time



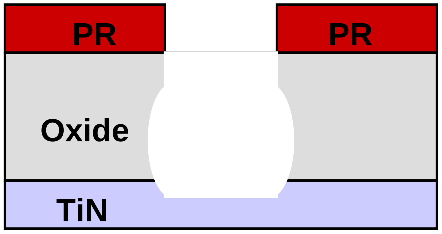
**Research Goal:** Develop methods that utilize the OES sensor to improve the etch profile and determine when to stop etching.

# Terminology

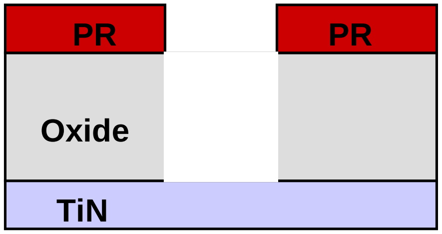
## Under-Etch



## Over-Etch

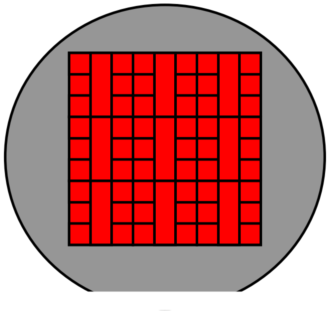


## Ideal Etch



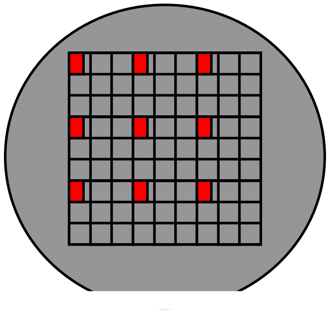
## Blanket Etch

100% Etch

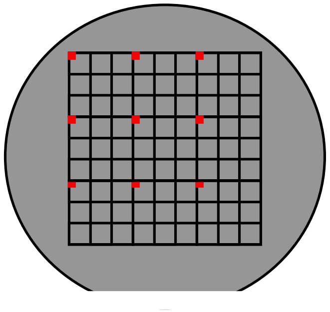


## Low Open Area Etch

10% Etch



1% Contact Etch



# 10% Open Area Etch, More Spectral Channels are Required

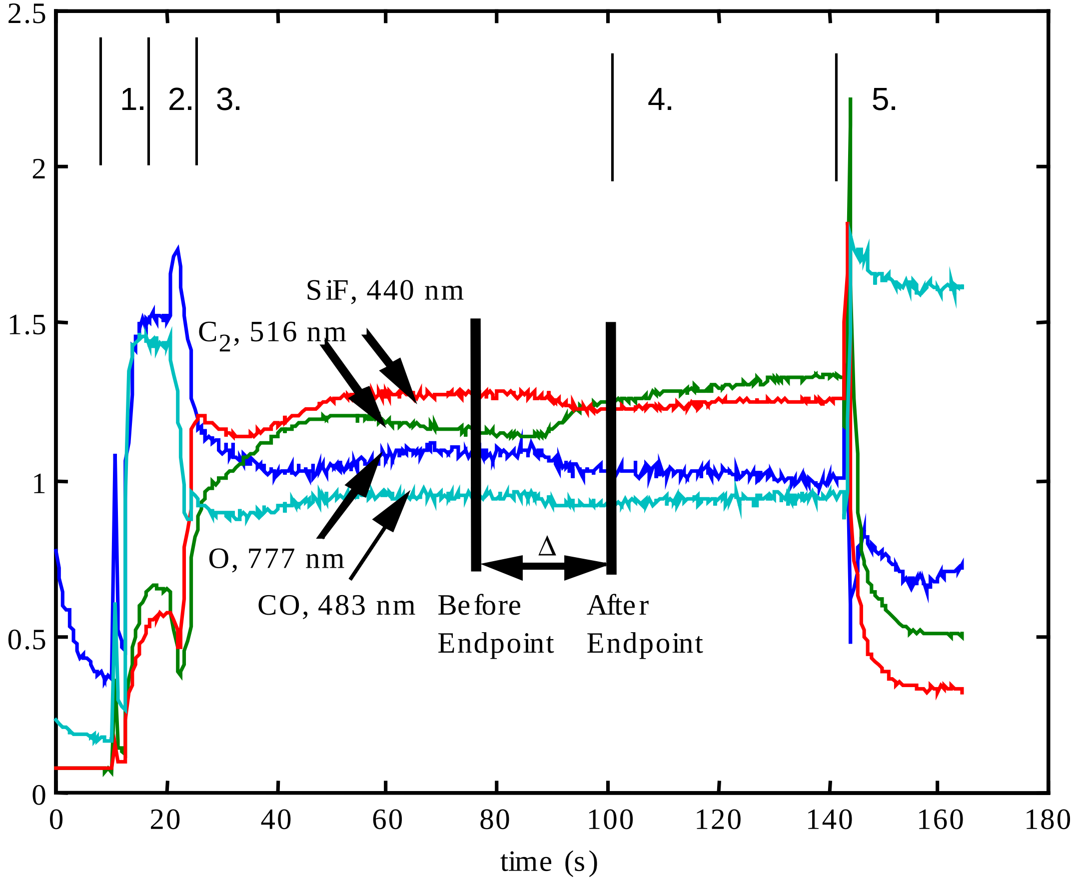
1. Ignition
2. ARC Etch
3. Main Oxide Etch (overetch)
4. Post-etch Treatment
5. De-chuck

**For 10% Etch,**

**Multiple Spectral**

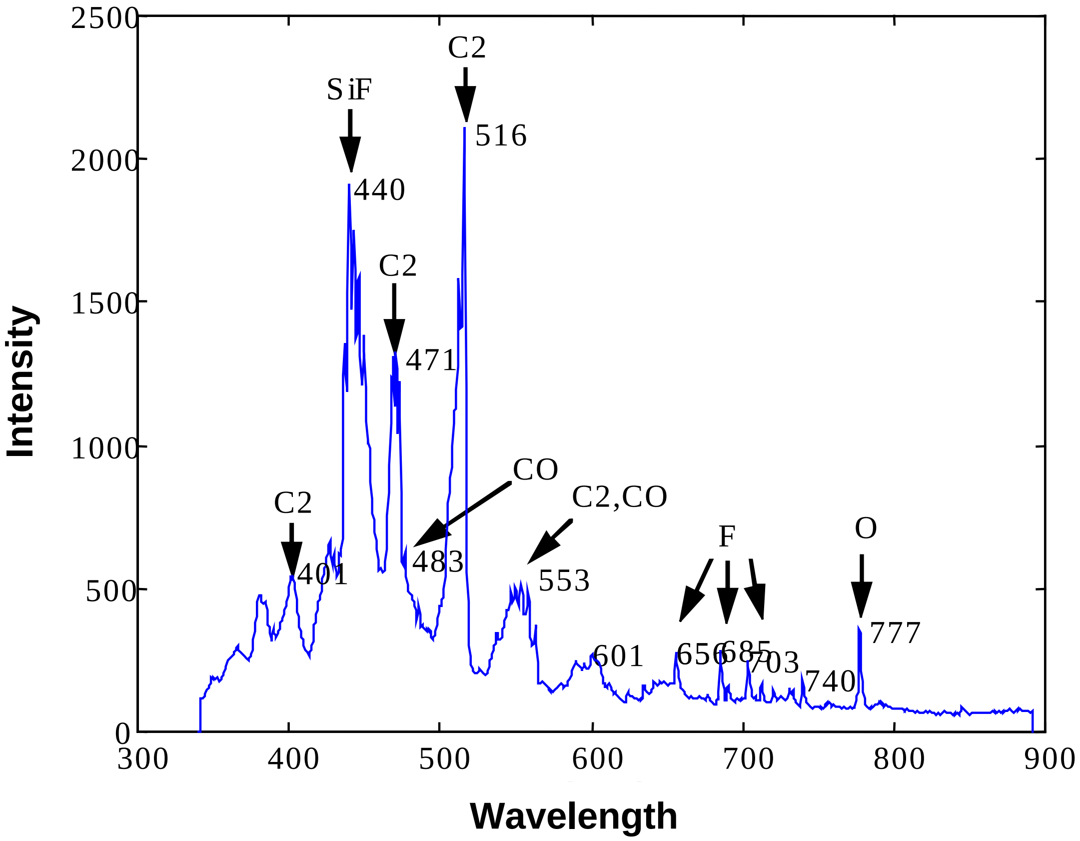
**Lines are Necessary**

**to Determine Endpoint**



# Optical Emission Spectroscopy Sample During a Contact Etch

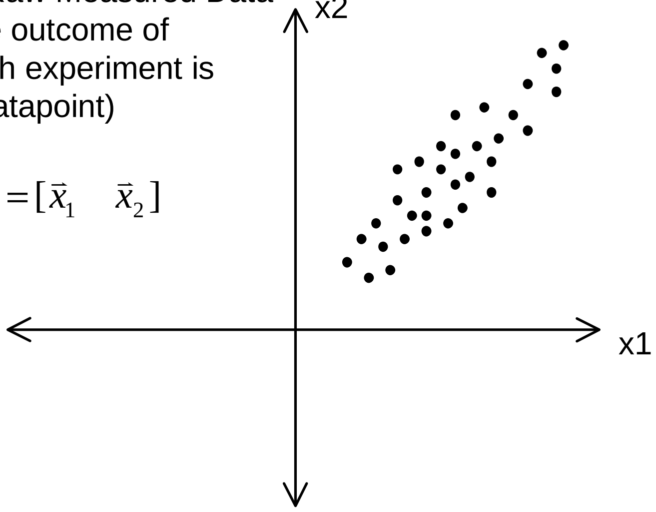
- 1100 spectral channels from 350 to 850 nm
- Dominant spectral channels are labeled
- Methods are needed to extract correlations



# Graphical Description of PCA Decompostion

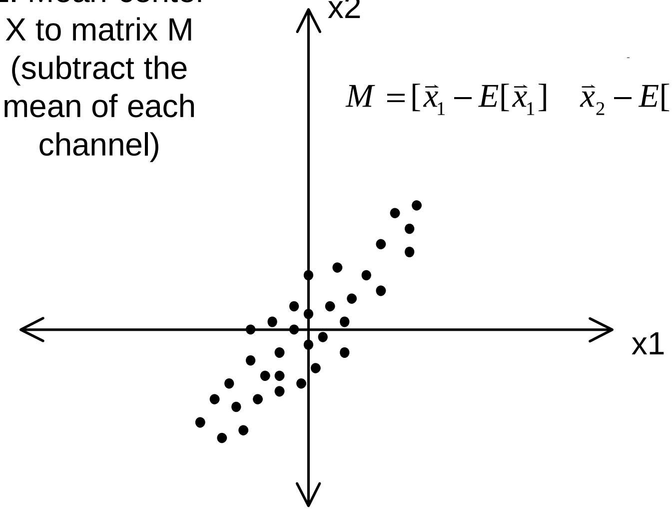
1. Raw Measured Data (the outcome of each experiment is a datapoint)

$$X = [\vec{x}_1 \quad \vec{x}_2]$$

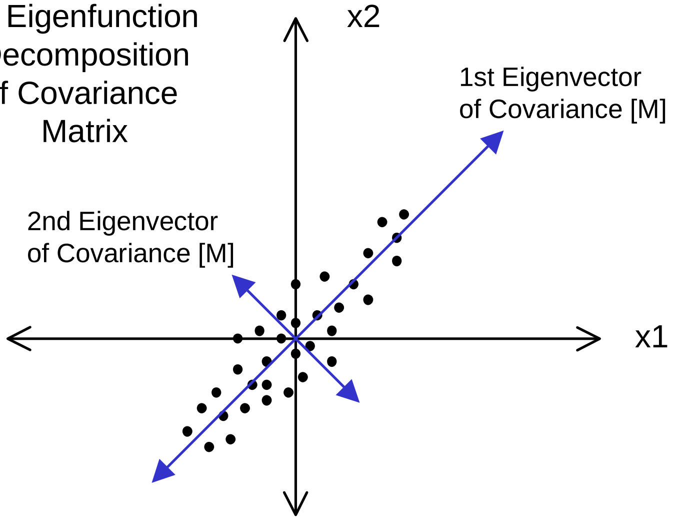


2. Mean-center X to matrix M (subtract the mean of each channel)

$$M = [\vec{x}_1 - E[\vec{x}_1] \quad \vec{x}_2 - E[\vec{x}_2]]$$



3. Eigenfunction Decomposition of Covariance Matrix

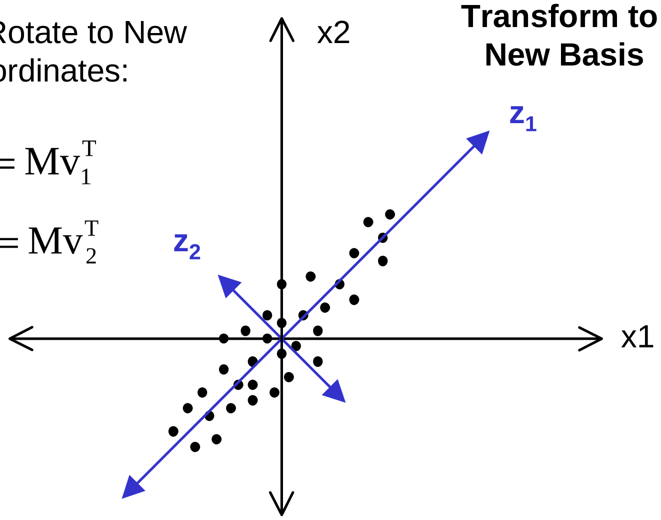


4. Rotate to New Coordinates:

$$z_1 = Mv_1^T$$

$$z_2 = Mv_2^T$$

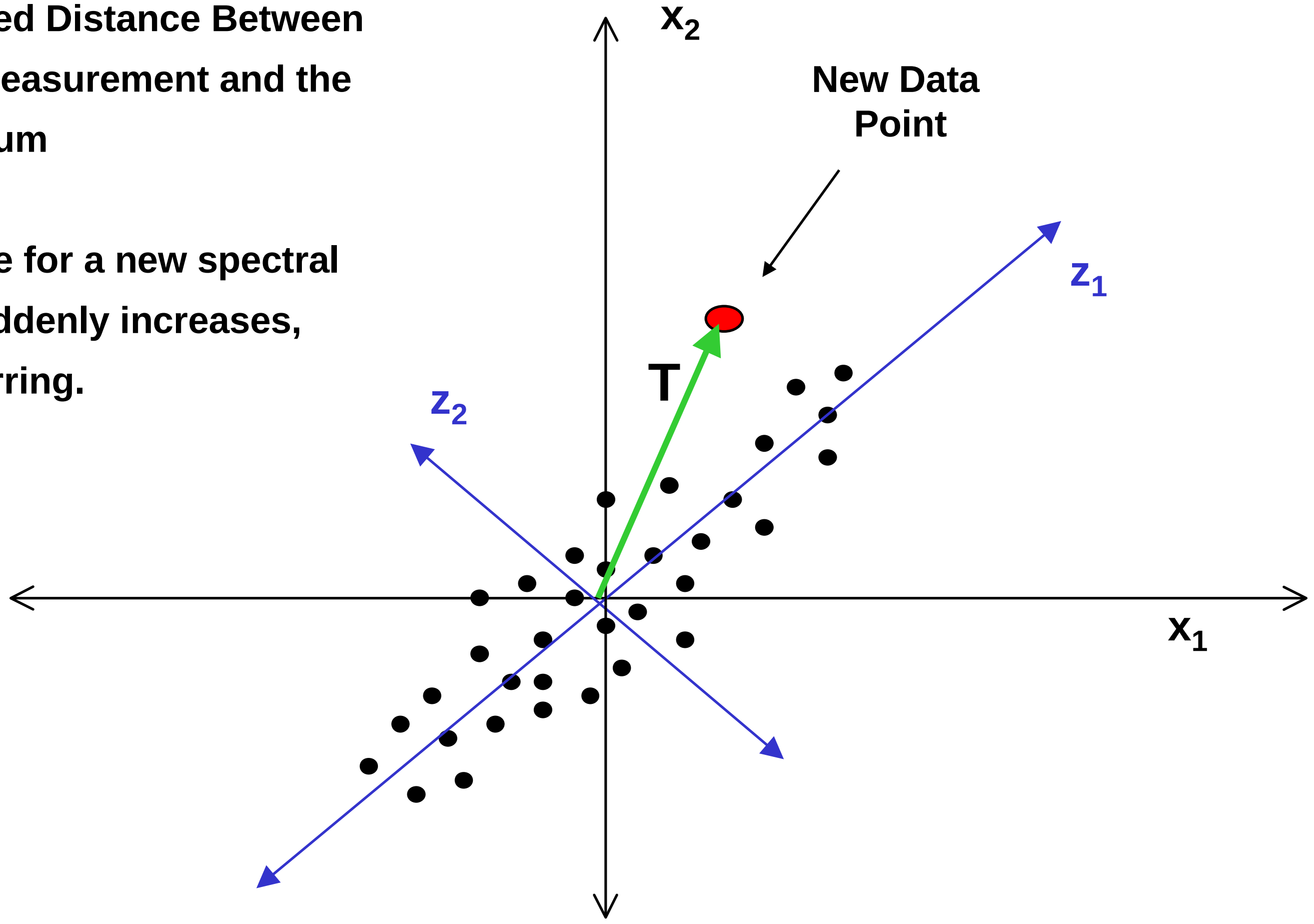
**Transform to New Basis**



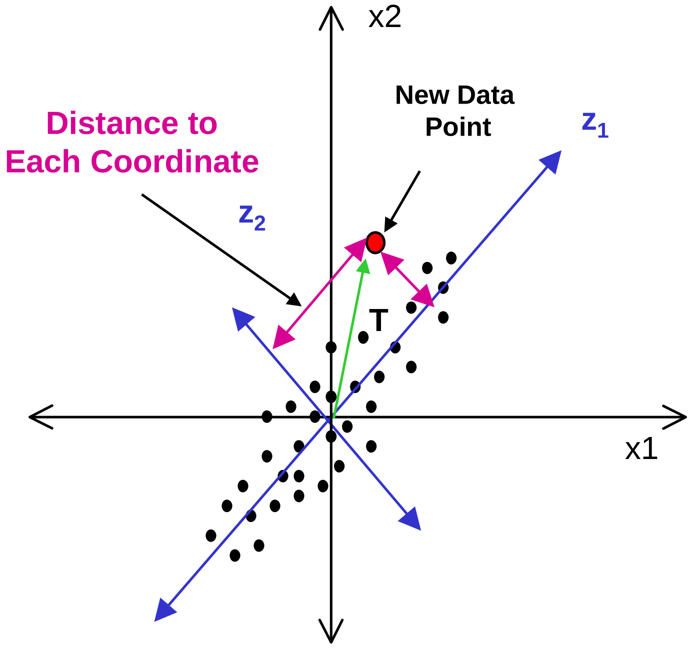
# Graphical Description of PCA based $T^2$ Statistic

**T is the Normalized Distance Between a New Spectral Measurement and the Bulk Etch Spectrum**

**When the $T^2$ value for a new spectral measurement suddenly increases, endpoint is occurring.**



# Graphical Description of PCA based $T^2$ Statistic



**From the Application Perspective:**
We are determining whether a new spectral measurement varies considerably from nominal etch. If so, then we classify that variation (with regard to the selected principal components) endpoint.

$T^2$ statistic provides a distance metric for comparing a new measurement to prior data observed.

Conventional use of Hotelling's $T^2$ statistic would retain all the spectral channels which would result in an inflation of the statistic due to adding the variance due to noise.

The use of PCA allows us to filter this noise and work with only that data that is correlated with a particular event such as endpoint.

In continuing the two dimensional case, it can be expressed as:

$$T^2 = \begin{bmatrix} z_1 \\ z_2 \end{bmatrix}^T \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix}^{-1} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} = \frac{z_1 \cdot z_1}{\lambda_1} + \frac{z_2 \cdot z_2}{\lambda_2}$$

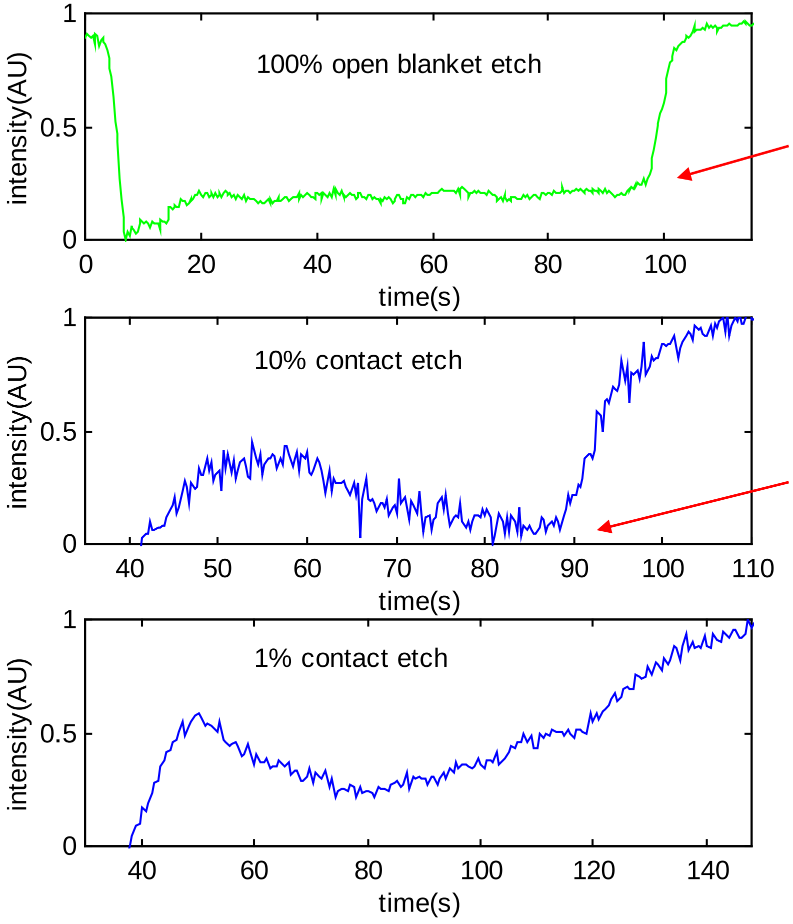
which is the projected variance of the new data point on first and second principal components, respectively. In other words, the lower the $T^2$ value the more likely the new data point is correlated with that particular principal component.

# Plot of the Dominant Spectral Channel for the 100%, 10%, and 1% Etch Cases

**100% Etch**

**10% Etch**

**1% Etch**



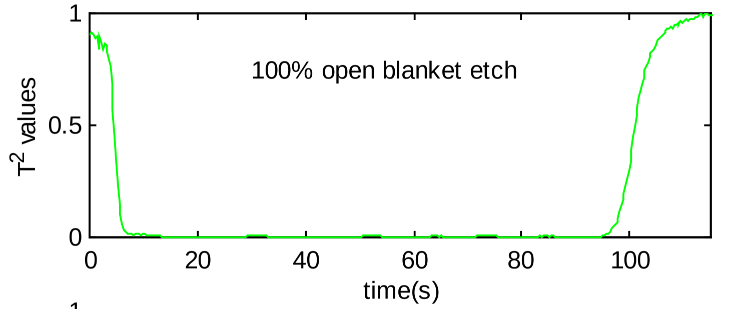
**Endpoint**

**Endpoint**

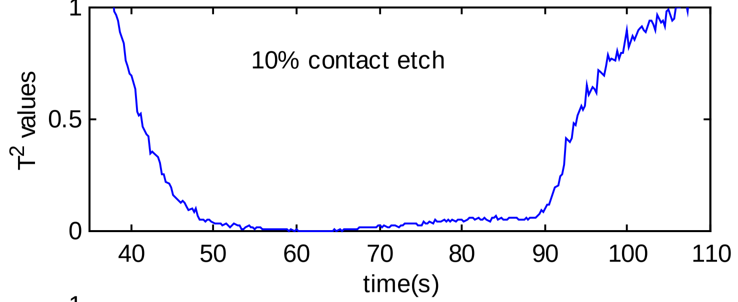
**Endpoint ?**

# Plot of the PCA based $T^2$ Statistic for the 100%, 10%, and 1% Etch Cases

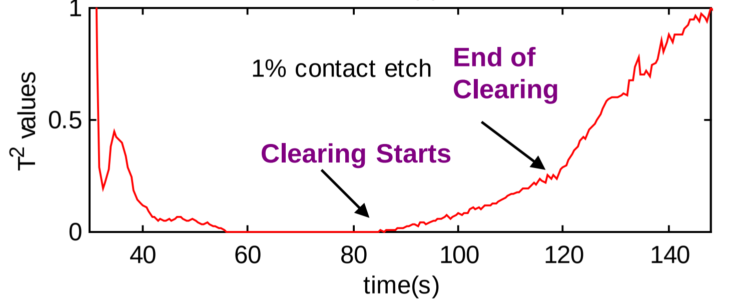
**100% Etch**



**10% Etch**

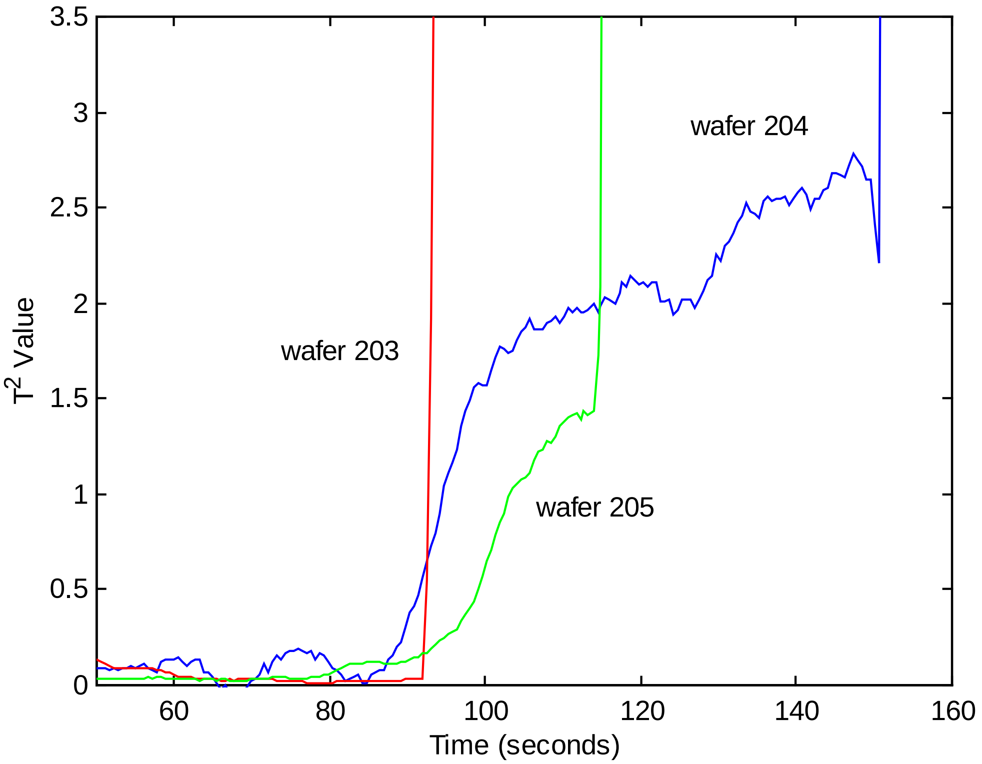


**1% Etch**



# Demonstration of Endpoint Detection at Digital Semiconductor

- Wafer 203 is purposely stopped short of endpoint
- Wafer 204 is the current timed etch recipe for Alpha wafers
- Wafer 205 was stopped at the end of endpoint



# Scanning Electron Micrographs (SEMs) for Wafers 203, 204 and 205

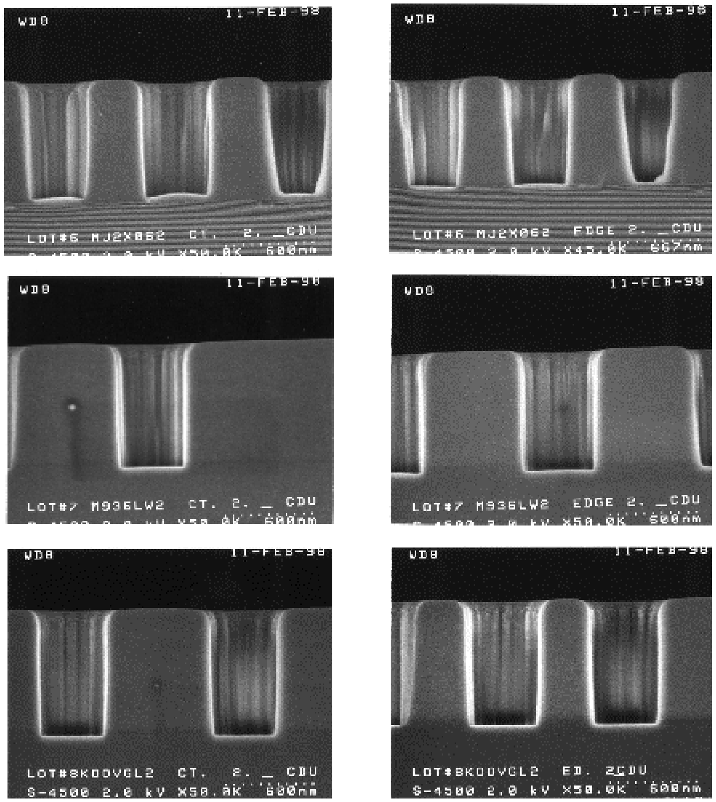
## Center and Edge Positions of the Smallest Critical Design Units of an SRAM Structure

**Center** **Edge**

**Slight Under-etch** — **Wafer 203**

**Slight Over-etch** — **Wafer 204**

**During Endpoint** — **Wafer 205**



## Conclusions

- Successfully Demonstrated Endpoint for 1% Contact Etch
- Robustness Tested for One Month of Operational Use

## Future Work

- Investigate Methods to Automate Endpoint Detection
- Examine Approaches that Better Capture Time Behavior