CMP Process Monitoring and System Interoperability using Acoustic Emission

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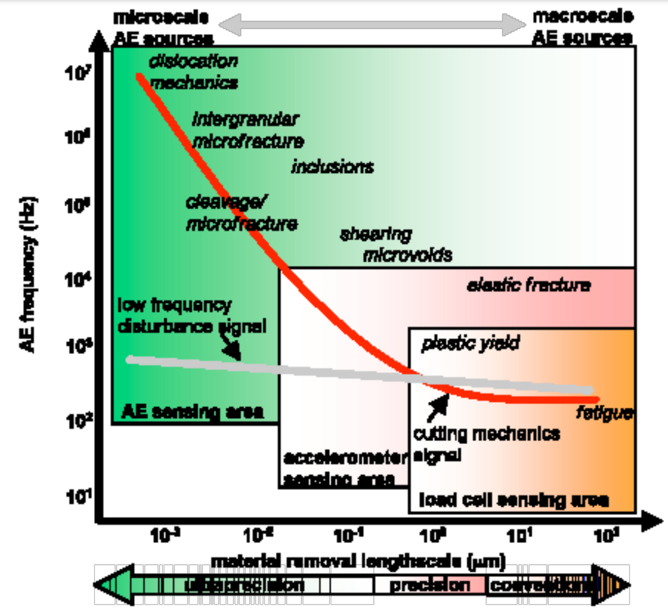
Outline

1. Acoustic Emission (AE) Background
2. CMP Monitoring using AE
3. Endpoint Detection (EPD)
4. Scratch & Defect Detection (SDD)
5. Real-Time Implementation
6. System Interoperability & MTConnect
7. Summary

Acoustic Emission (AE)

1

- Propagation of elastic waves generated by:
  - Solid-solid elastic interaction
  - Plastic deformation
    - Dislocation movement
    - Elastic energy release due to creation of new surfaces
- Ultrasonic frequency range, typically ~20 – 2000 kHz
- Advantages:
  - In-situ – non-destructive /non-evasive
  - Unaffected by many noise/error sources
- Disadvantages:
  - Relatively expensive
  - <u>Difficult to integrate</u>



Signal/noise characteristics and sources of AE signal at different lengthscales (Dornfeld & Lee 2008)

Energy of AE signal ~ hardness
➔ More energy needed to initiate material removal in harder materials

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Sources of AE in CMP

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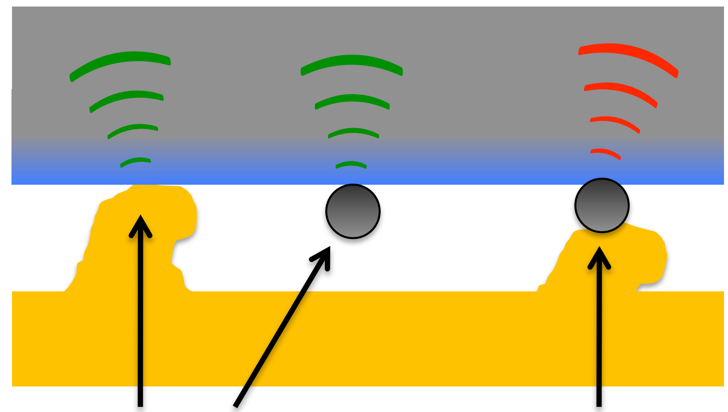
- Dominated by sources at pad asperity/wafer interface
  - Abrasive/wafer interaction (primary)
  - Pad asperity/wafer interaction
- Macroscale sources:
  - Friction between two surfaces (wafer/pad/retaining ring)
- Potential sources as yet unknown:
  - Solid/fluid interaction
  - Internal fluid turbulence



Very sensitive indicator of degree and nature of contact between surfaces in CMP

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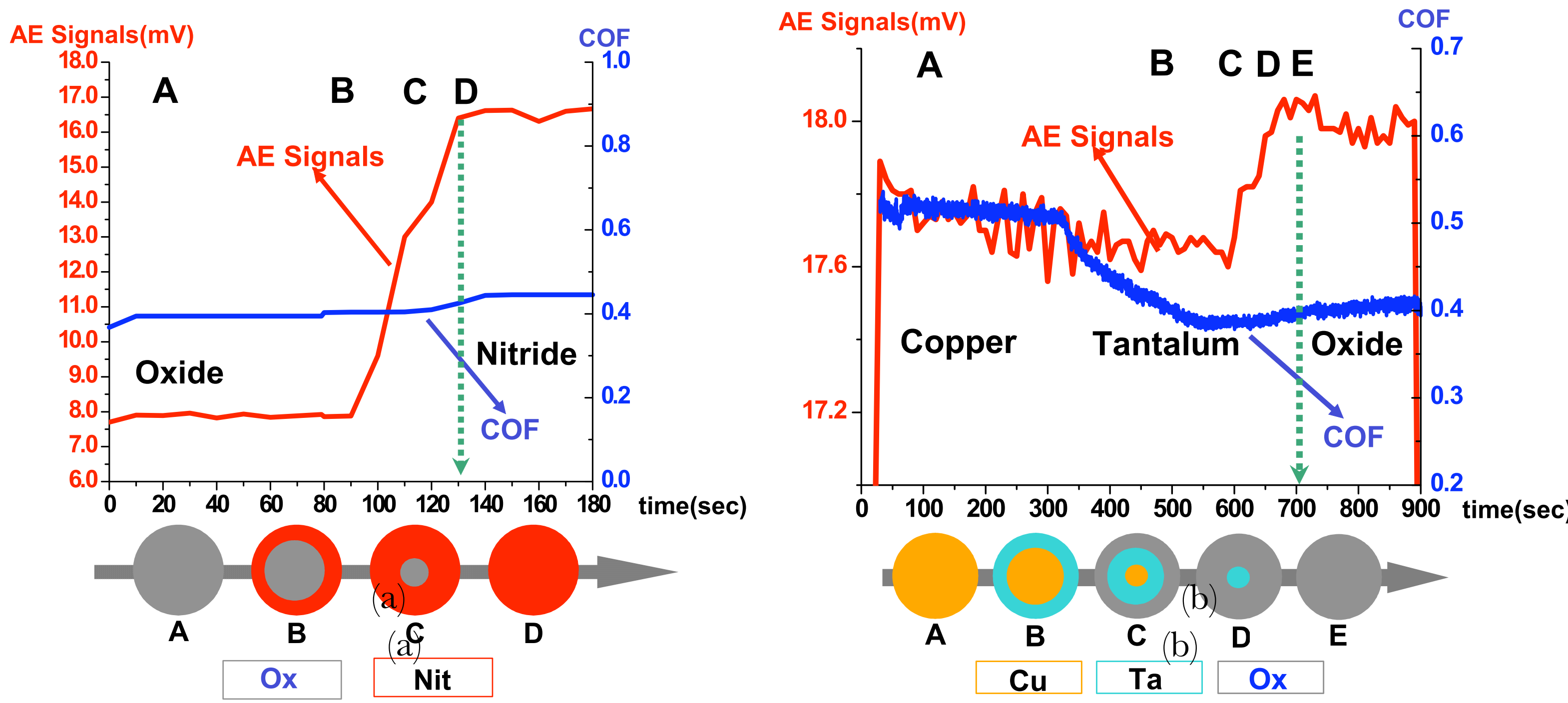
CMP Monitoring using AE

- Endpoint detection (EPD)



AE RMS endpoint detection for STI CMP (left) and Cu damascene CMP (right) (Lee, et al. 2006)

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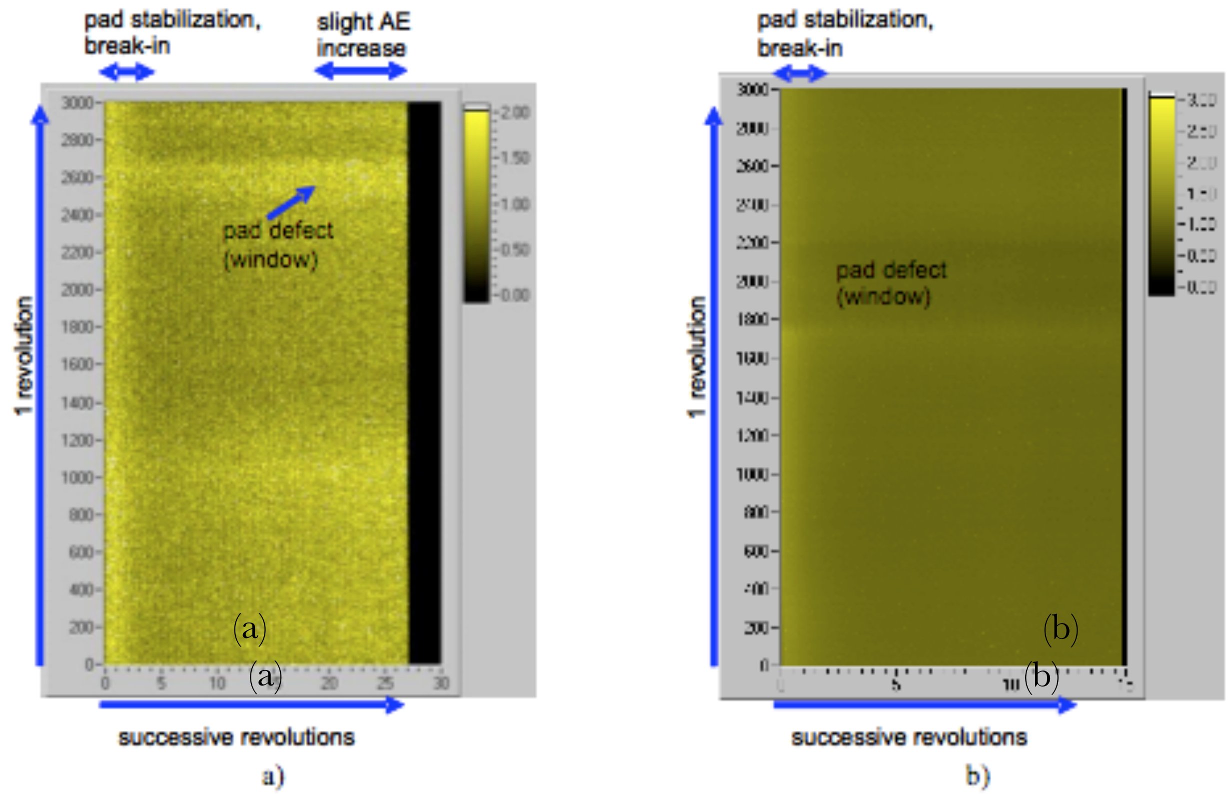
CMP Monitoring using AE

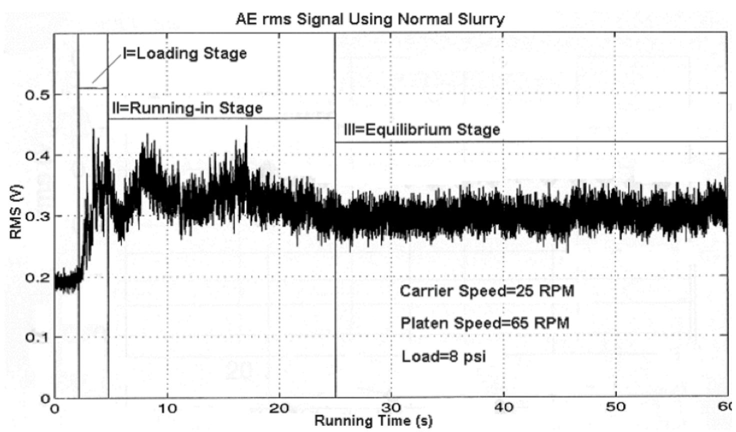
- Pad condition monitoring



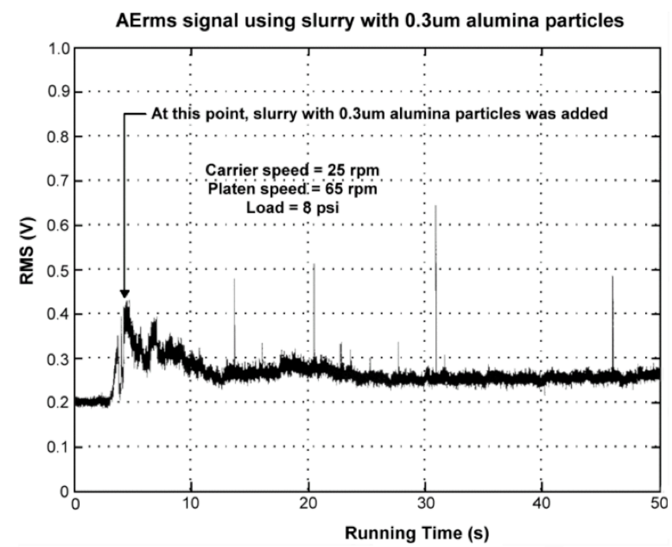
Intensity mapping of (a) AE RMS, and (b) friction force measurements for extended Cu polishing (Lee, et al. 2005)

CMP Monitoring using AE

- Microscratch detection



(a)

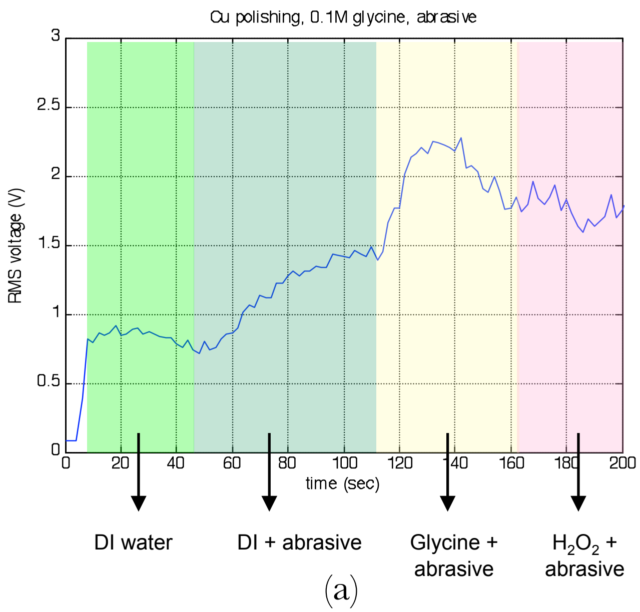


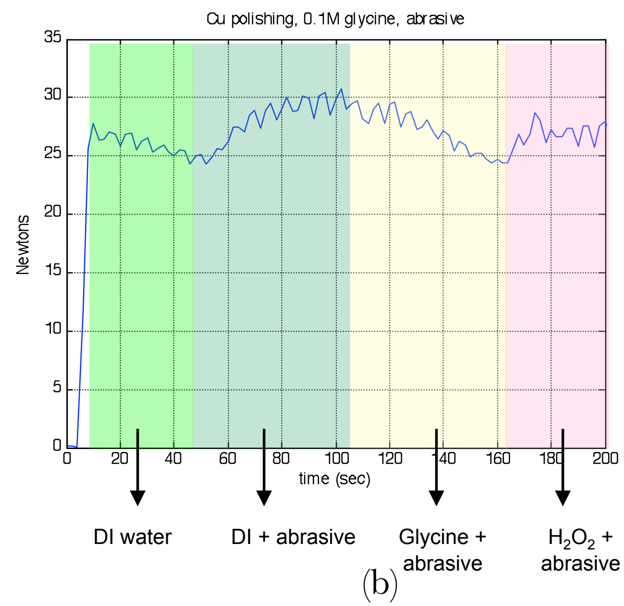
(b)

AE RMS signal for typical oxide CMP process with (a) standard slurry, and (b) slurry with fine Al_2O_3 particles (Tang, et al. 1998)

CMP Monitoring using AE

- Slurry condition monitoring

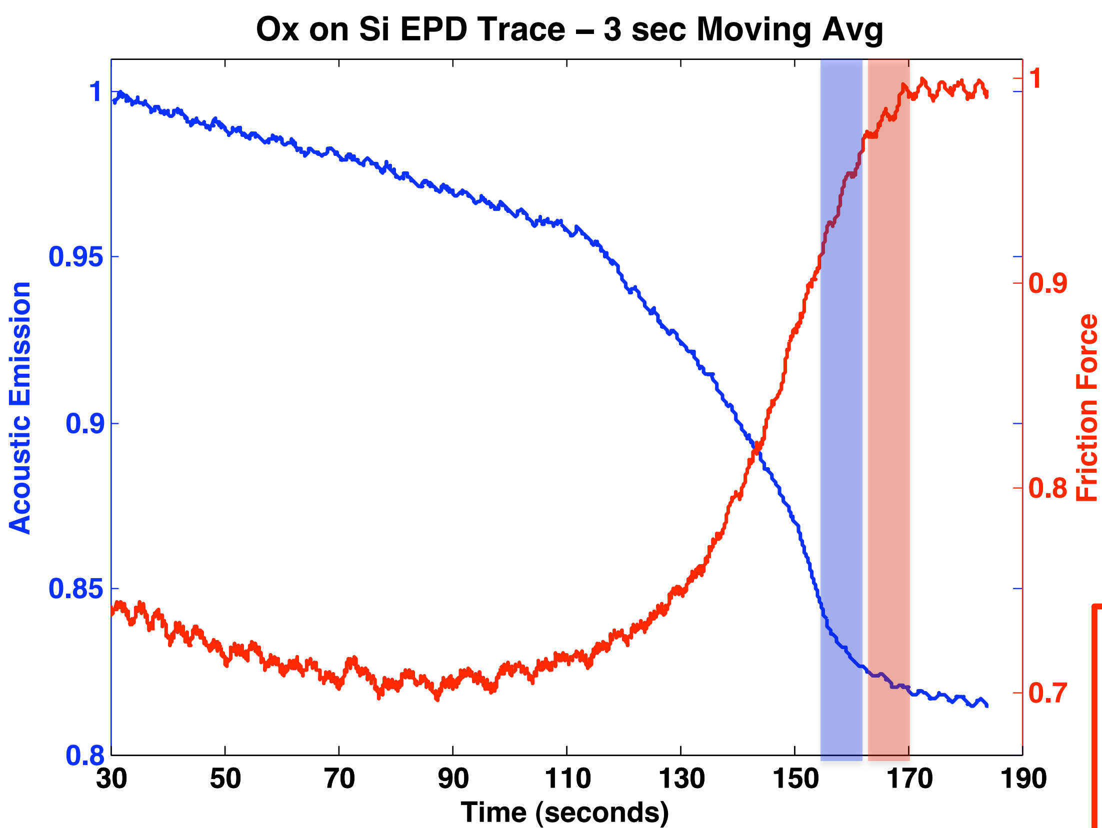




(a) (b)

AE RMS intensity mapping for variations in slurry type for Cu CMP (Lee, et al. 2005)

Endpoint Detection Using AE



- G&P Poli-500 CMP Machine with built-in Friction Force Monitoring System
- 4” 1µm LPCVD Oxide wafer
- R&H IC1010 pad
- Cabot D7000 Slurry
- 6psi Down Force
- 90 RPM Platen Rotation
- **1 RPM Head Rotation**
- DECI AE Sensor (50kHz-500kHz)
- AE high-pass cutoff @ 100kHz
- AE and Friction 100ms sampling

- AE used to detect change in high-frequency energy → faster response
- AE Signal detected EP more precisely (~6% sooner than Friction Force)

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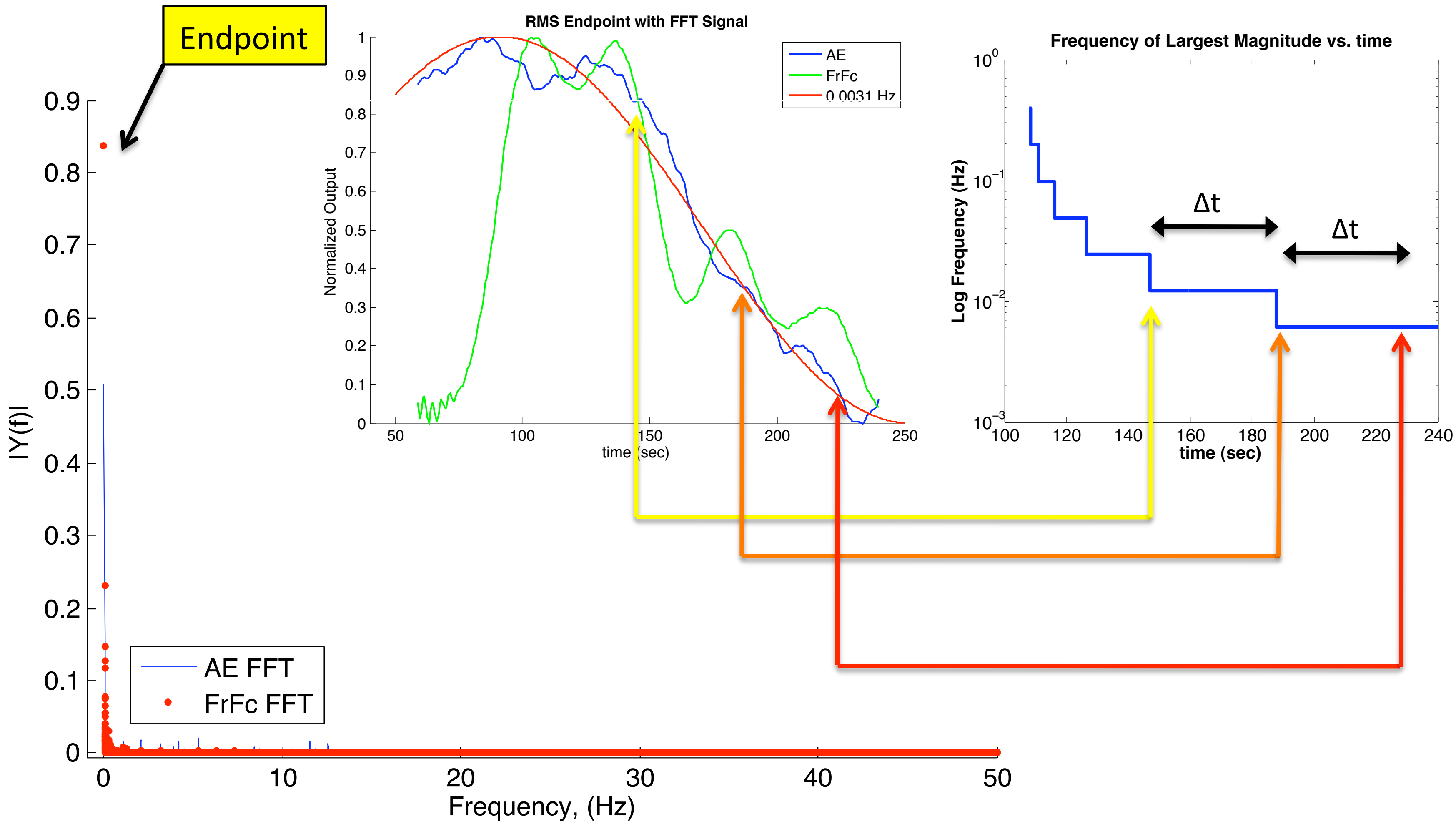
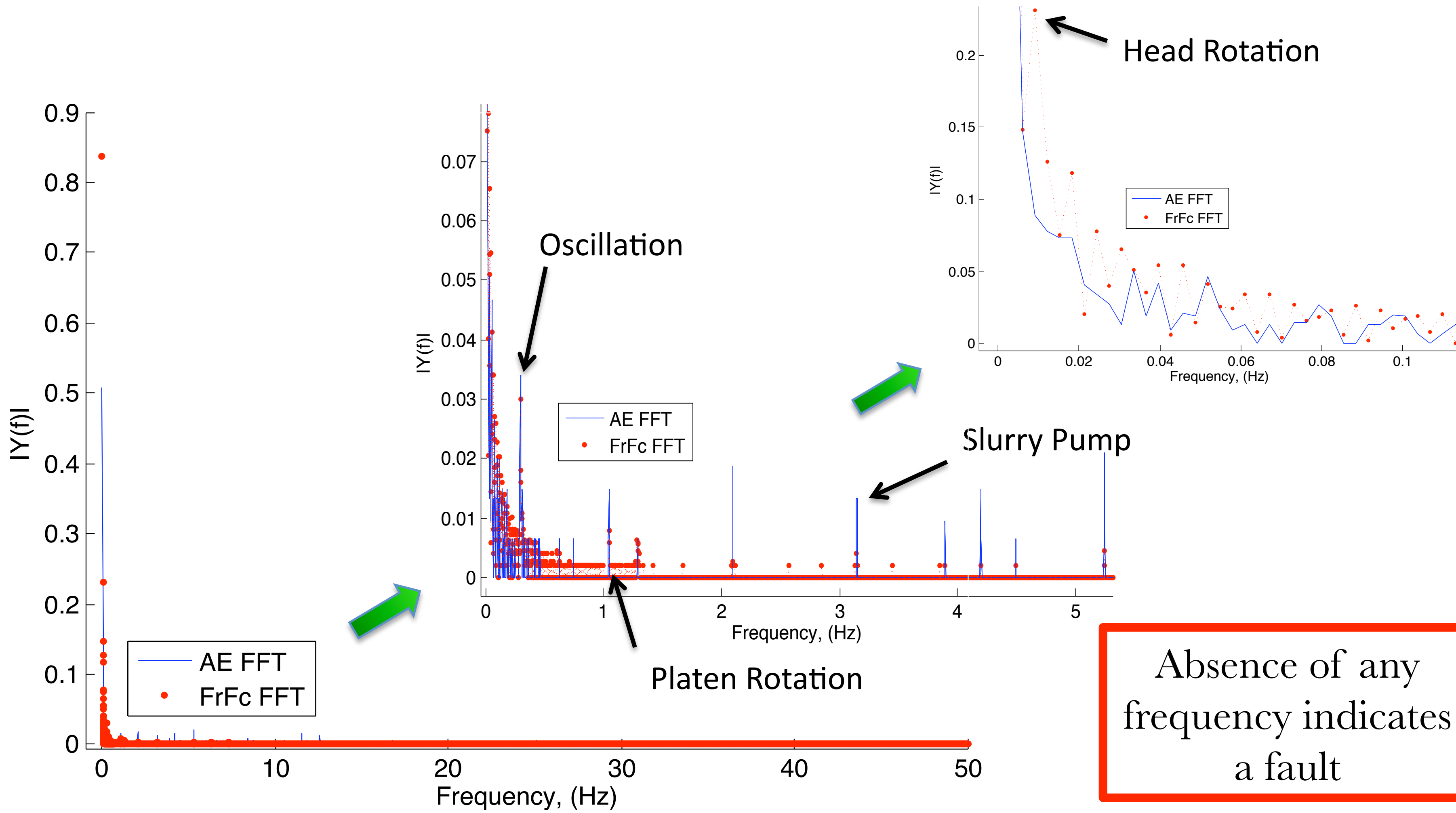
Fast Fourier Transform (FFT) Analysis

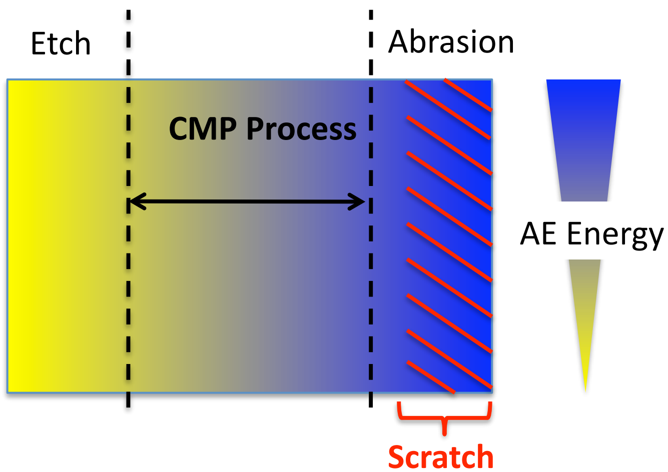


In-situ Fault Detection



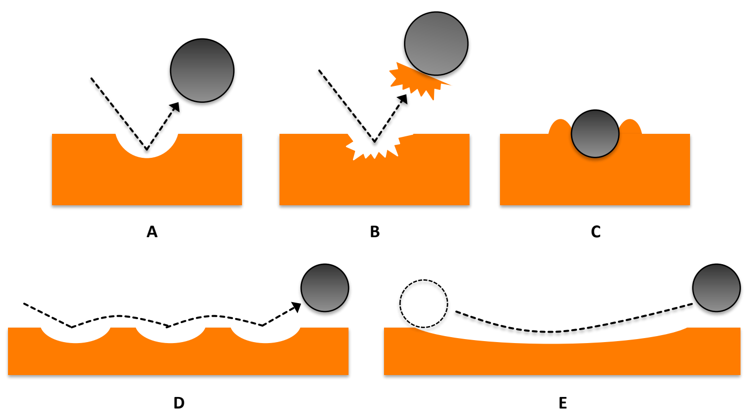
Absence of any frequency indicates a fault

Scratch & Defect Detection (SDD) 4



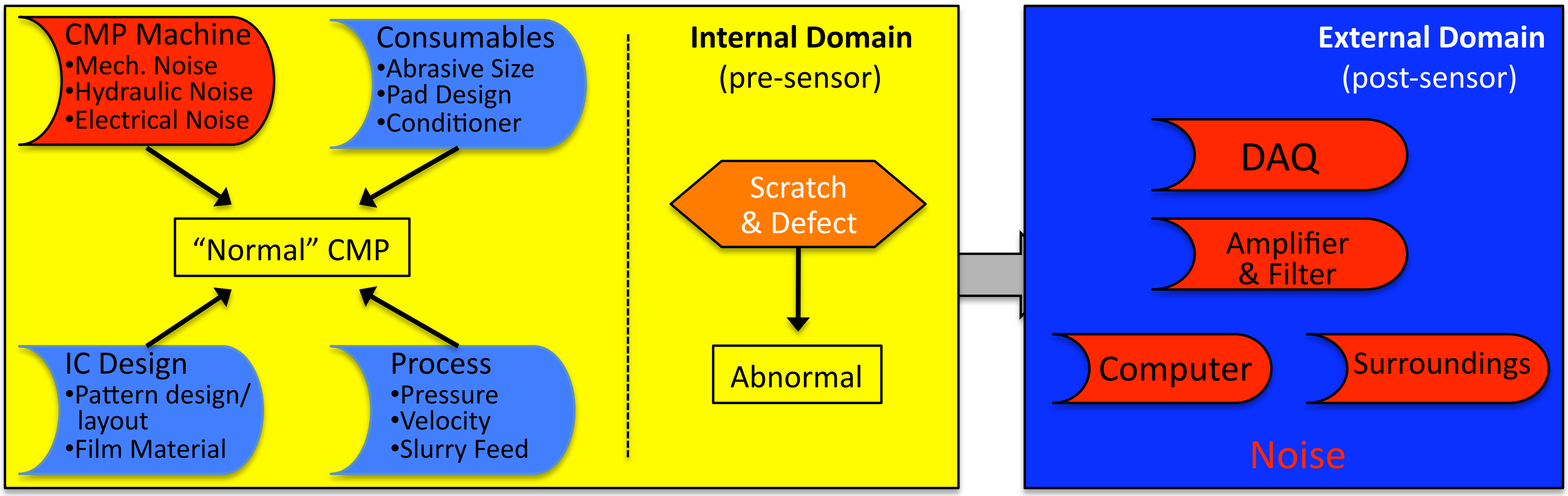
Scratch Domain

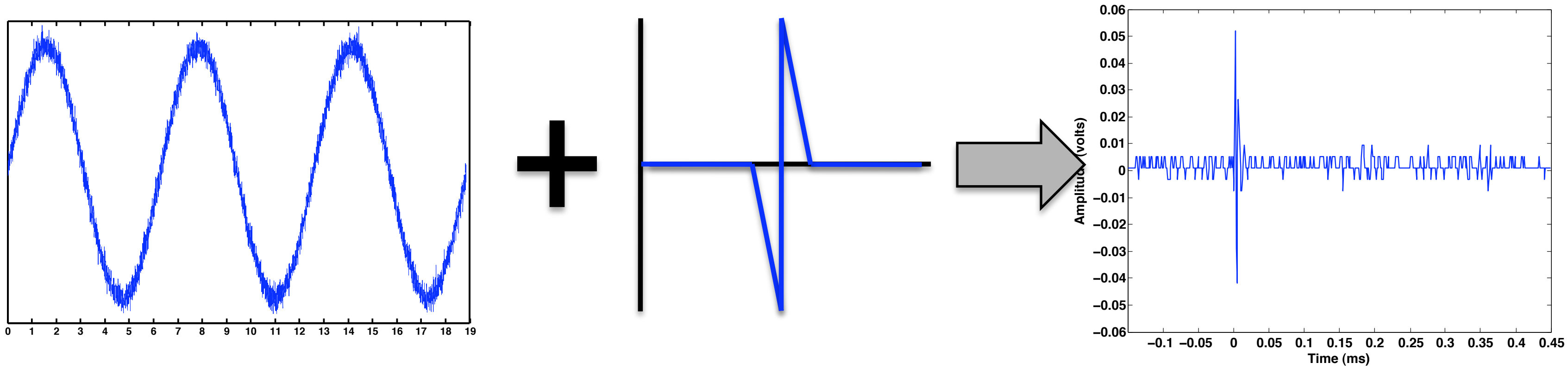
Looking for irregularities in acquired AE signal



- A: Indentation
- B: Rip-out
- C: Embedded
- D: Skipping/Chatter Scratches
- E: Plow Scratch
- Various combinations A-E

SDD AE Signal Domain

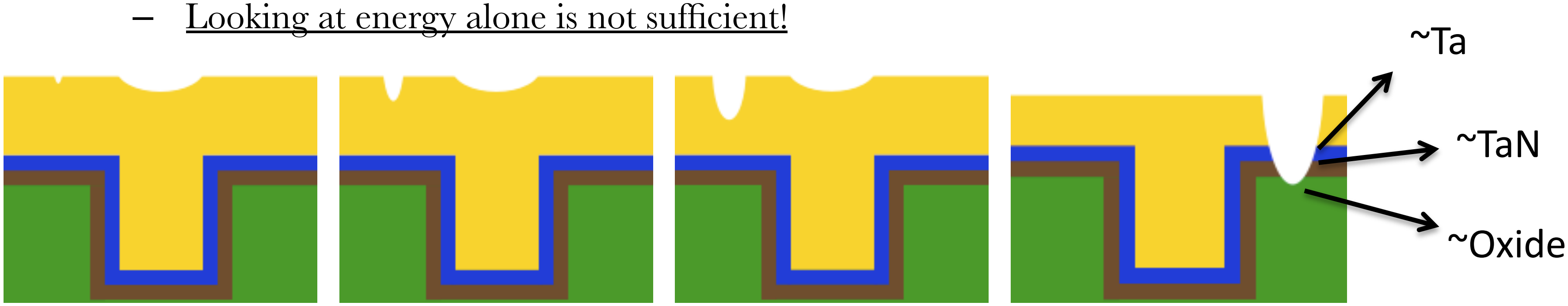




SDD – Signal Analysis

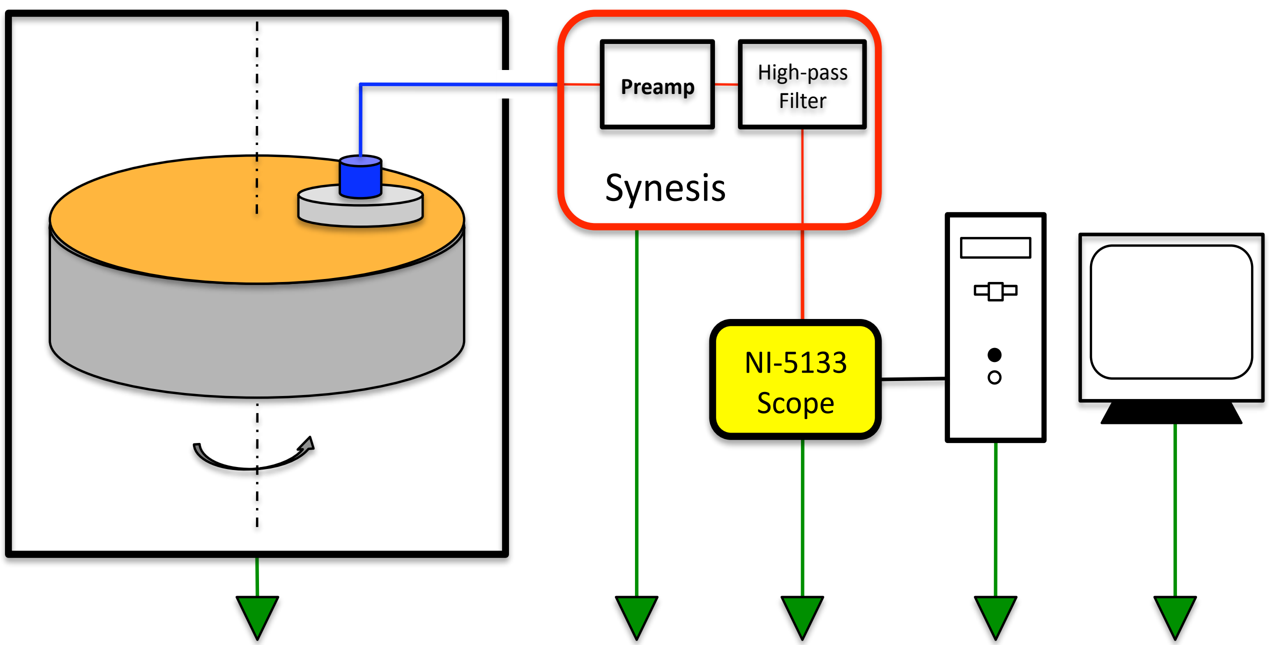
4

- How to extract Scratch component from the AE signal?
- Possible Solution #1: model AE Scratch signal
  - Ex. Green's Functions – transfer tensor (i.e. mapping) of a medium from an AE impulse at point x_1 and time t_1 to the sensor at point x_0 and time t_0.
  - <u>However, difficult to successfully model!</u> → ideally need 3-D model, account for multi-component impulses and reverberated (i.e. echoed) signals
- Possible Solution #2: empirically characterize AE signal
  - Characterize for different film combinations: ex. Cu+Ta/TaN+Ox+Si, Ta/TaN+Ox+Si, Ox+Si, Si → use <u>superposition</u>
  - Signal processing: energy-time-frequency (STFT, Wavelet, HHT)
  - <u>Looking at energy alone is not sufficient!</u>



SDD – Test Setup

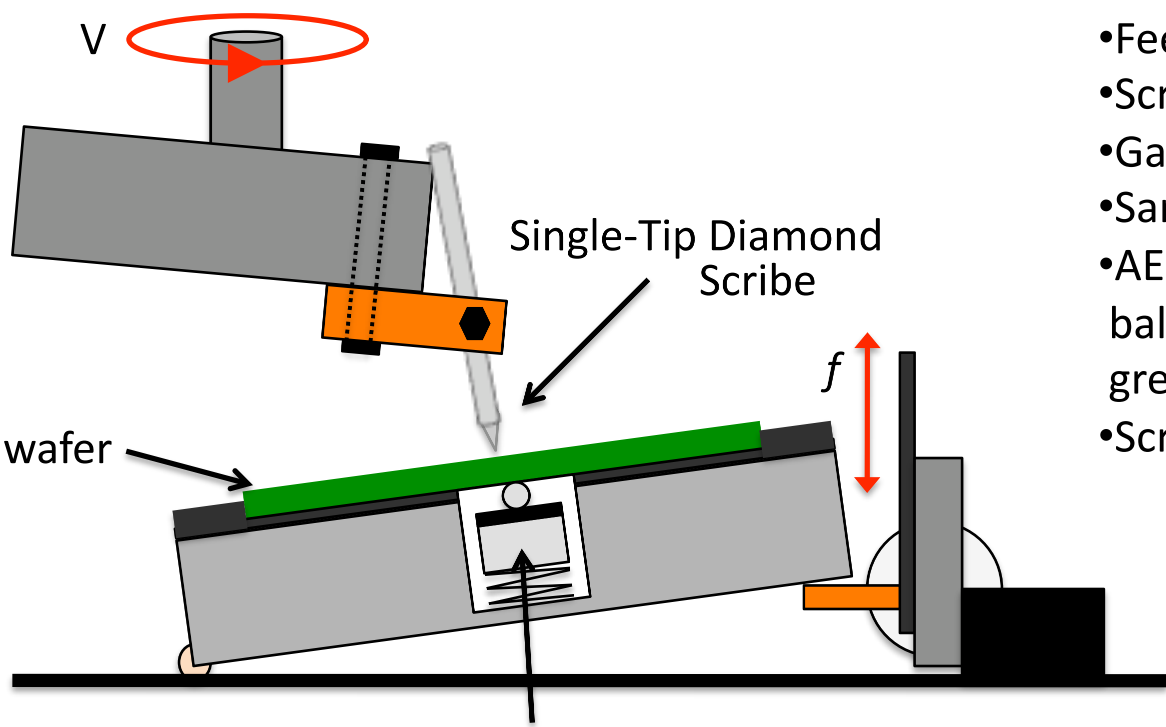
In-Situ Polishing Setup



- G&P Polishing Machine
- Pad: IC1010
- Abrasives (Alumina):
  - 50nm, 300nm
  - 1µm, 3µm
  - 15µm SiC
- Carrier head: 0 RPM

SDD – Test Setup

Single Scratch & Indentation

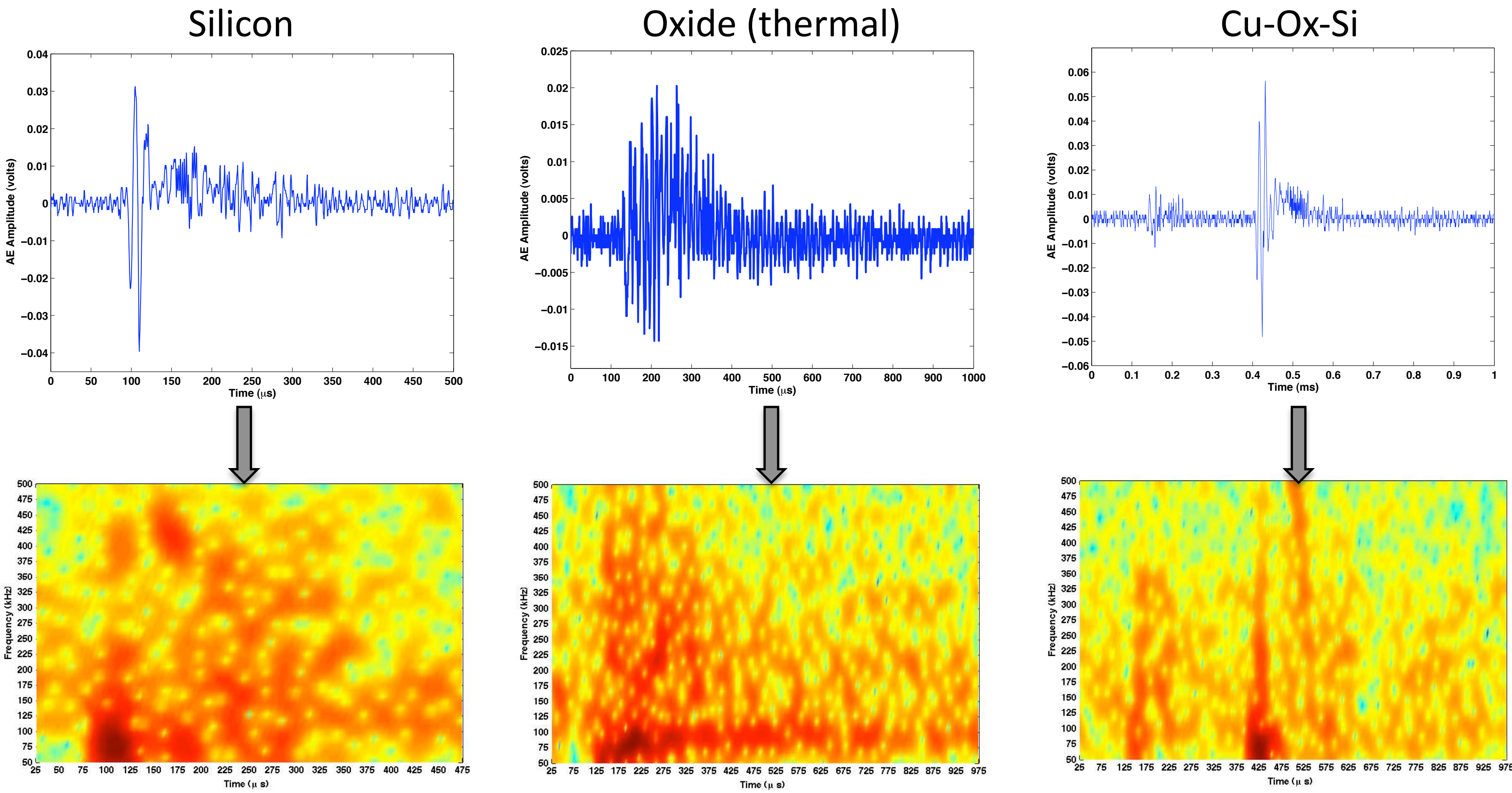


- Linear Velocity V ≈ 1.1m/s
- Feed Rate f ≈ 50µm/s
- Scribe: 15µm Diamond tip radius
- Gain: 99dB, 50kHz HP-filter
- Sampling: 2.5Ms/s
- AE Sensor spring loaded with ball-bearing point contact; industrial grease for improved contact
- Scratch along <100> plane

Test samples (4”):

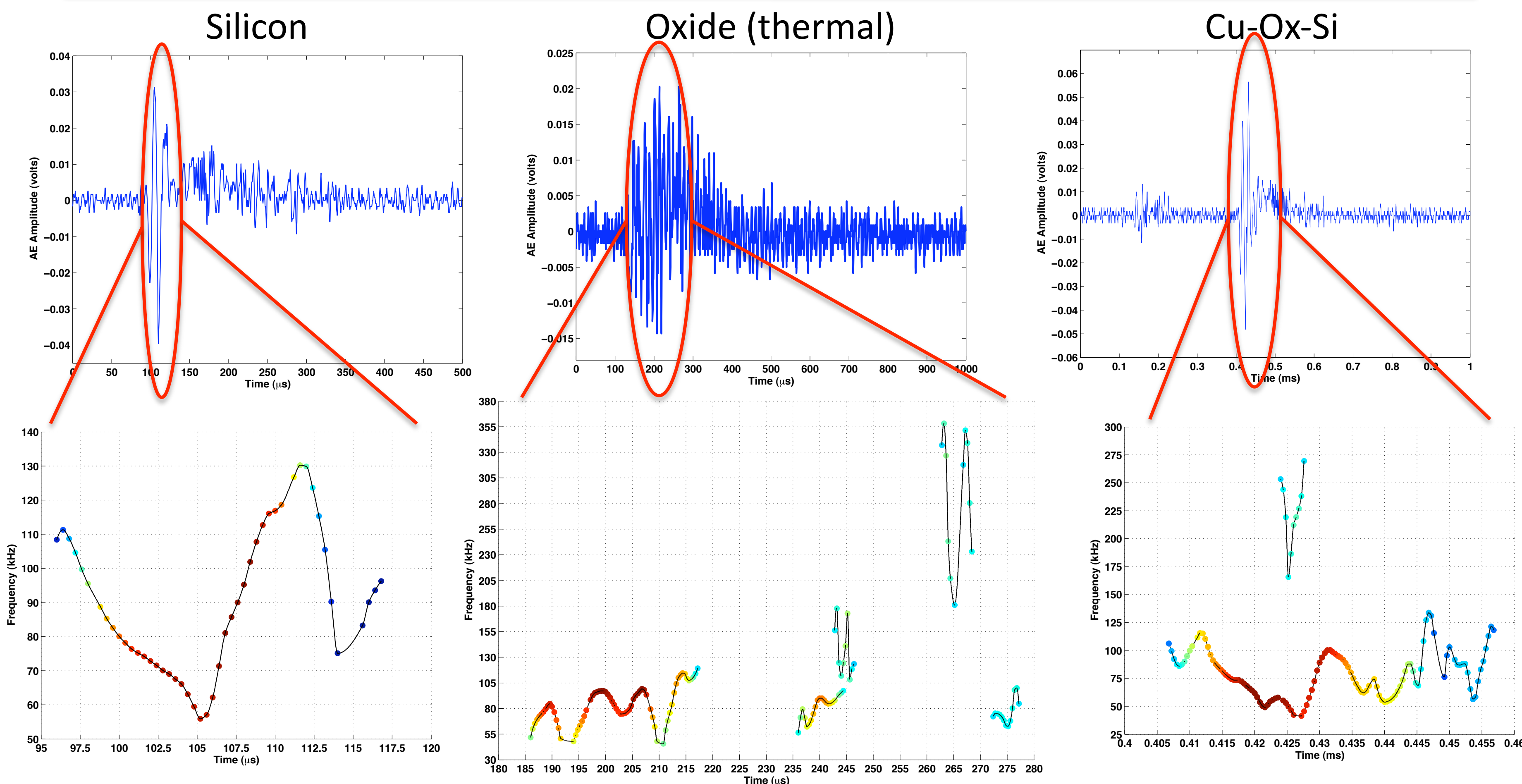
1. Bare Si wafer
2. Oxide wafer
3. Cu on Ox wafer

SDD – Indentation Results



Short Time Fourier Transform (STFT) Spectrum

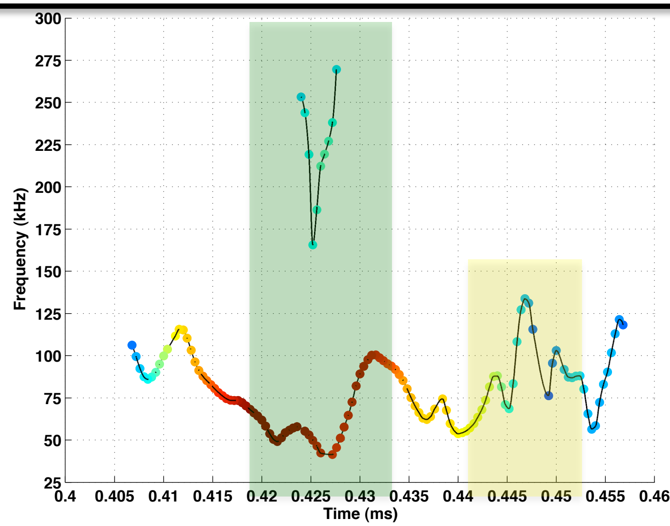
SDD – Indentation Results



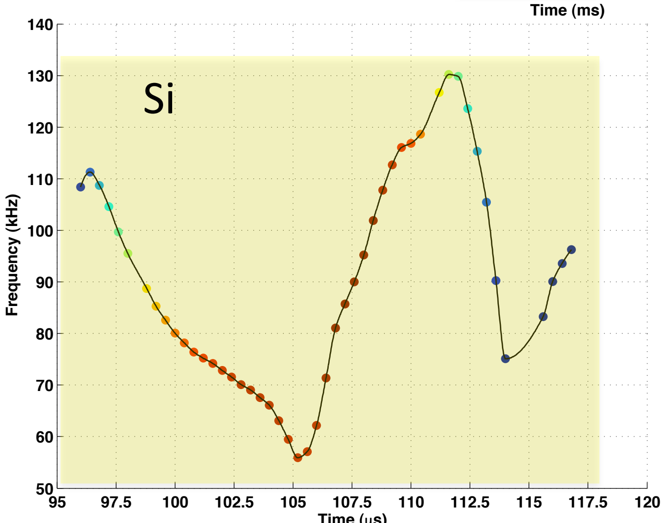
Hilbert-Huang Transform – Instantaneous Frequency

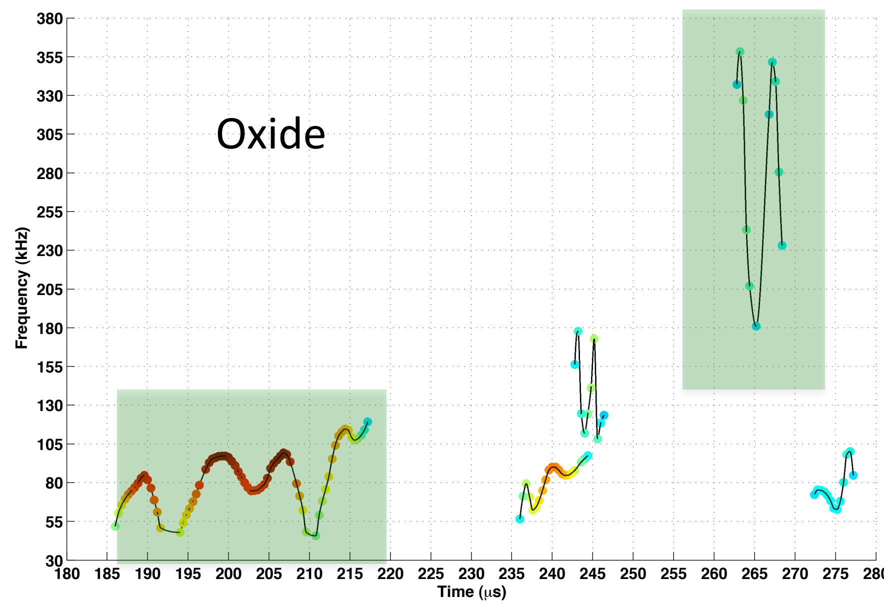
SDD – Indentation Results

Cu-Ox

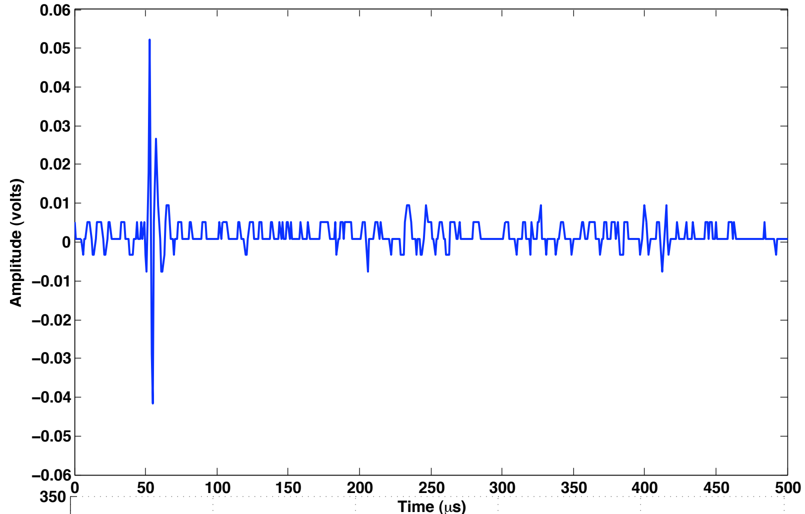


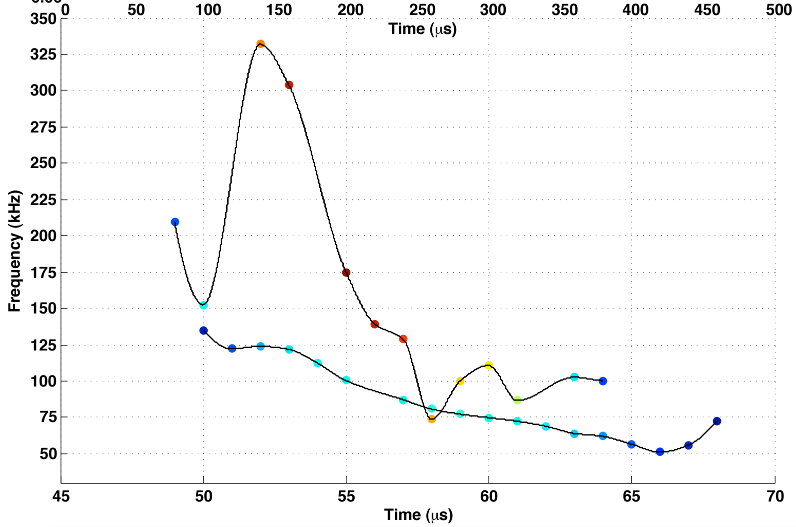
- **Empirical Mode Decomposition (EMD)**
  - Extract individual mono-component signals from multi-component signal
- First two **Intrinsic Mode Functions (IMF)**
  - First two contain highest detail – high frequency data



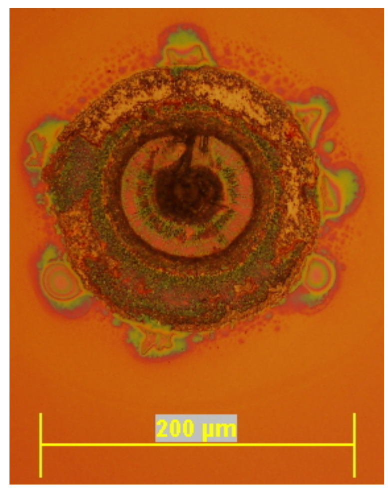


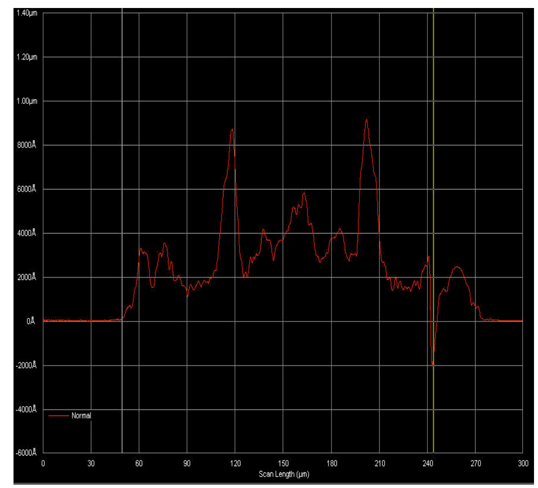
SDD – Polish Results





- Polish 1µm LPCVD wafer – 50nm Alumina, 1.5% Wt
- DF = 320N (~5.8psi), V_{platen} = 60RPM
- High-pass Filter: 75kHz
- Sample Rate: 1Ms/s
- Signal trigger @ 20mV





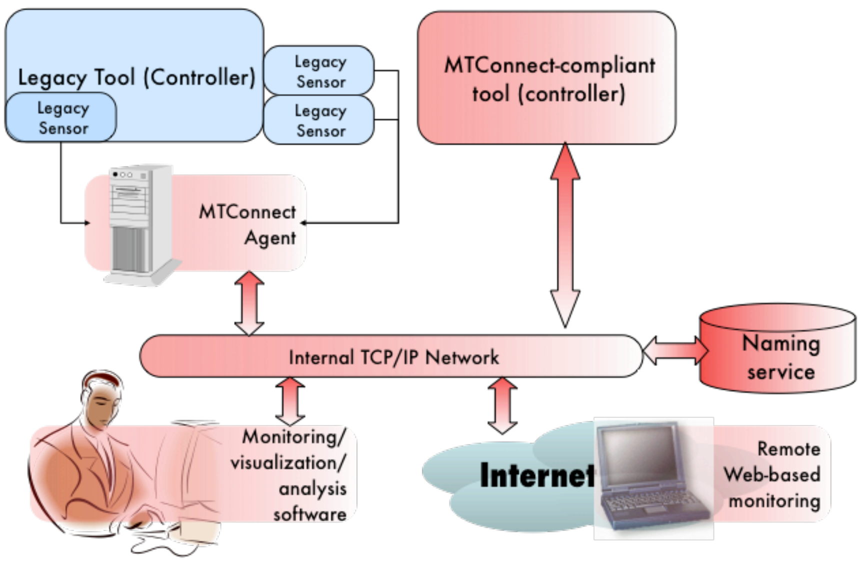
Foreign particle embedded in oxide!

Real-Time Implementation

- Integration of EPD and SDD
  - Same signal can be used for Endpoint and SDD
- Maximum computing delay time dictated by sampling rate, f_s, → $t_{delay} = 1/f_s$
  - EPD: f_s typically 50-100Hz → $t_{delay} = 10 - 20$ms
  - SDD: f_s, ranges 1-3MHz → $t_{delay} = 0.33 - 1$ μs
- Hard wire system not practical
  - Need wireless setup
  - "smooth" and shielded track setup
- Ideally computations done within sensor housing, "smart sensor"
  - Amplification, filtering, energy/time/frequency analysis performed locally
  - Output data simply a trigger → scratch yes/no

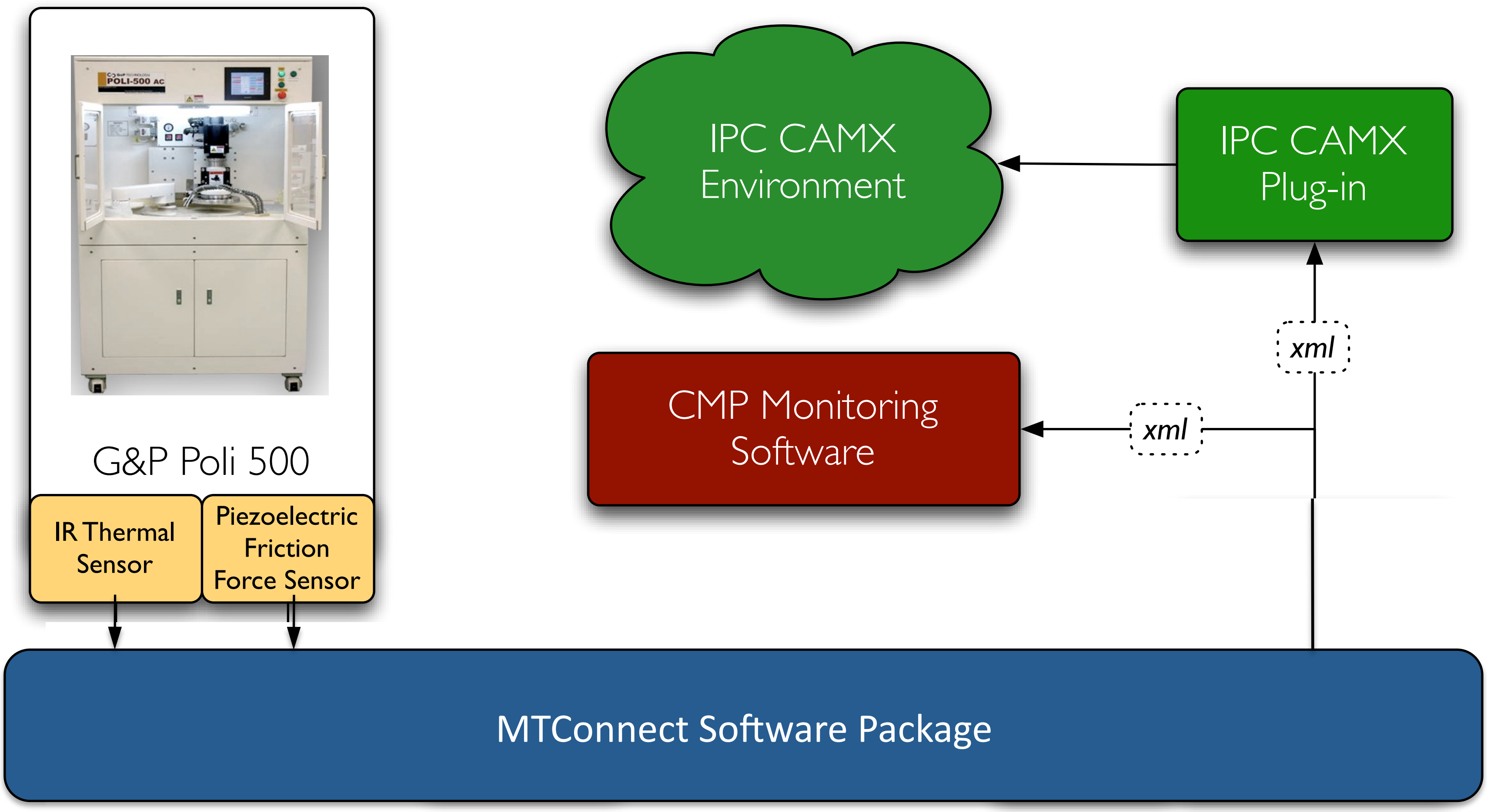
System Interoperability

- Process monitoring is vital to cut cost and increase quality
  - Expensive
  - Time consuming
- Standardization needed to decrease costs
  - Open standards required
- Example ➔ MTConnect
  - Open standard for mfg
  - Rapidly adopted in machining-based mechanical manufacturing sector



MTConnect architecture
(courtesy of Armando Fox and William Sorbel)

MTConnect Integration in CMP



Summary of AE Research

- AE has been shown as viable technique for CMP Process Monitoring
  - EPD, Slurry/Pad Condition Monitoring, Scratch & Defect Detection
- EPD via AE shows improvement over traditional friction based methods
  - Lower COO, higher throughput
- Potential for reliable and consistent Scratch & Defect Detection
  - Use energy-time-frequency characteristics to capture the non-linear behavior
  - Help improve yield
  - Addition testing still needed to determine consistency of results
- MTConnect enables process monitoring by easily integrating various disparate elements to allow for an effective means to gather relevant information bit-by-bit from sampled data

Thank You

Questions?

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Please visit our lab website: http://lmas.berkeley.edu/