Instantaneous Removal Rate in Copper CMP

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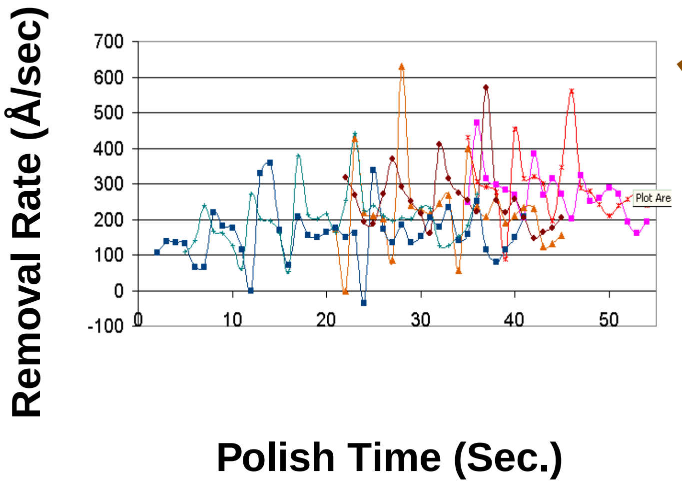
http://www-mtl.mit.edu/Metrology/

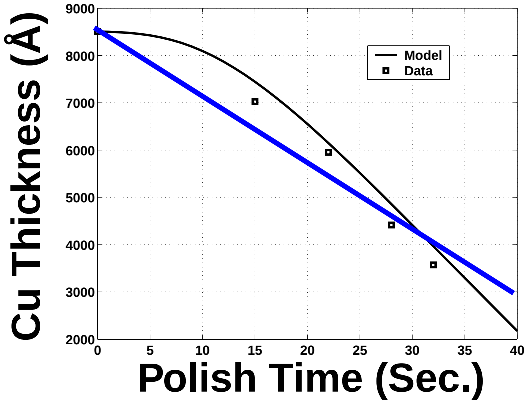
Motivation

CMP Process Development



Constant Removal Rate?
Non-Constant Removal Rate?

Modeling Result:
Thickness Profile Predictions



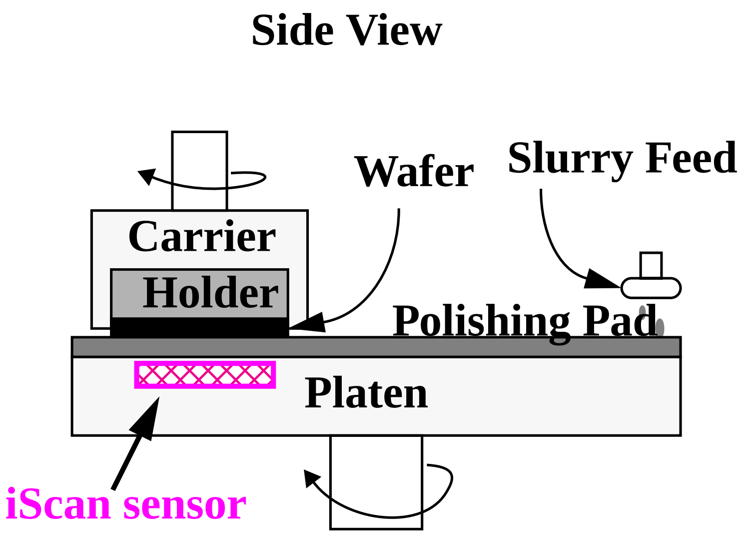
- Copper removal rate: typically assumed constant across time
- What if NOT?
  - Difficulties with control and stability of process
  - Copper CMP model extraction and simulation concerns

Outline

- Motivation
- Experimental Setup
    - Equipment and Consumable Setup
    - Wafer Polishing Setup
- Observation and Data Analysis
    - Raw Data
    - Comparison of Fits
        - Approach 1: fitting to amount removed and getting removal rate
        - Approach 2: fitting to 1 second interval removal rate
- Implications
- Conclusion

Experiment Setup 1

- Equipment
  - Applied Materials Mirra CMP Tool with in-situ iScan sensor: uses magnetic sensor with eddy current approach



- Process
  - 5 psi Down Force
  - 63 rpm of Table Speed
  - Matched Carrier Head Rotation
  - No Carrier Head Movement from Center to Edge of Table: try to measure the same location on the wafer but the wafer is not fixed by vacuum allowing wafer position to change
- Consumables
  - Slurry: Cabot 5001
  - Pad: Rodel IC1010

Experiment Setup 2

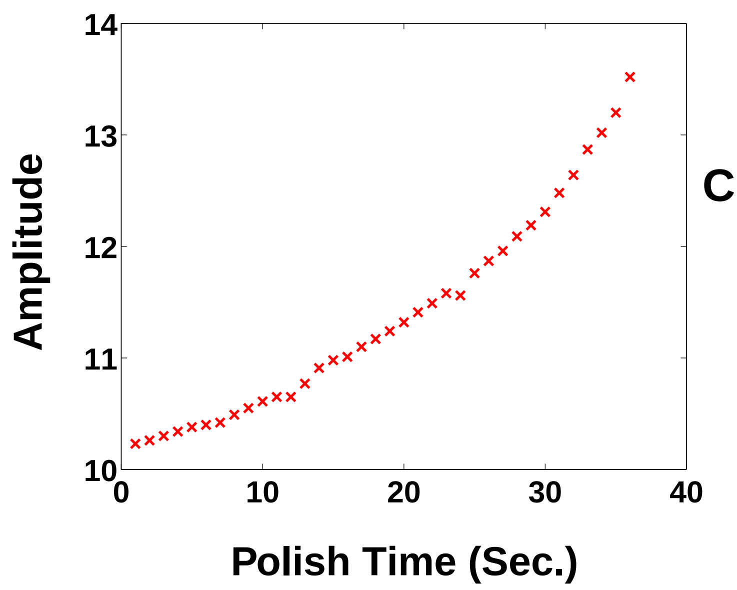
- Design of Experiment
  - Three different thicknesses and two replicates each are polished

Blanket Wafers	**Starting Thickness (Å)**
A1 and A2	8000
B1 and B2	9500
C1 and C2	13000

- Measurement and Data Filtering
  - Data is collected for each second from continuous iScan trace: average value across the sweeping arc on the wafer
  - iScan (in amplitude mode) is not capable of measuring copper thickness 8KÅ and above; thus, data only below 8KÅ is used
  - Calibration curve is used to convert iScan amplitudes to copper thickness
  - Converted copper thickness is filtered to exclude the last 5-10 seconds of each scan

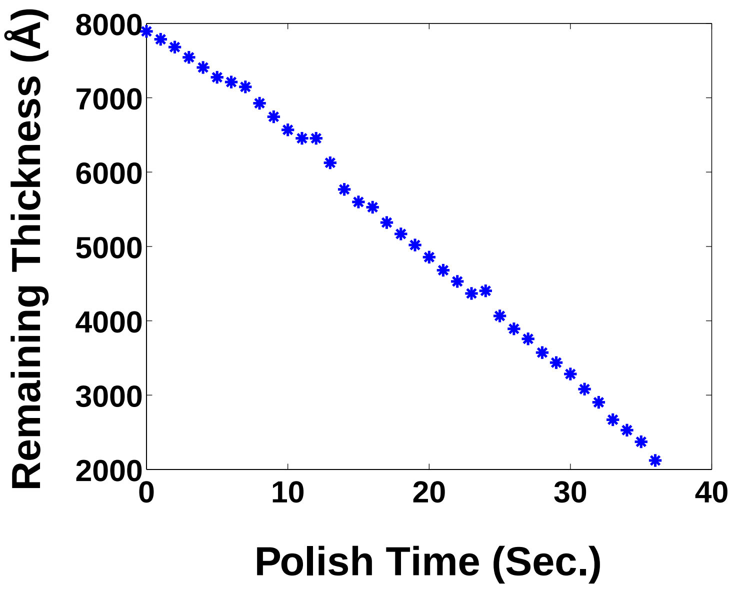
iScan Data and Conversion to Copper Thickness

iScan Amplitude



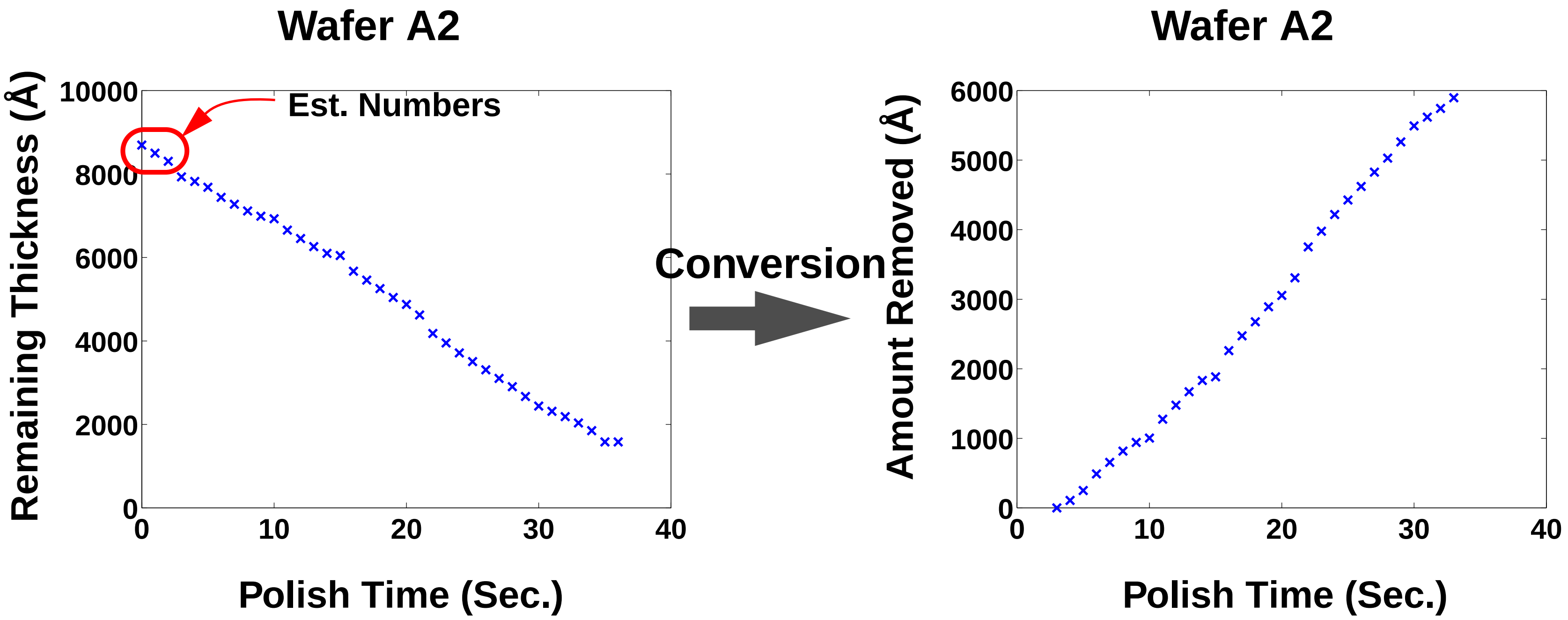
Conversion →

Copper Thickness (A1)



- iScan amplitudes are converted to copper thicknesses using a calibration curve

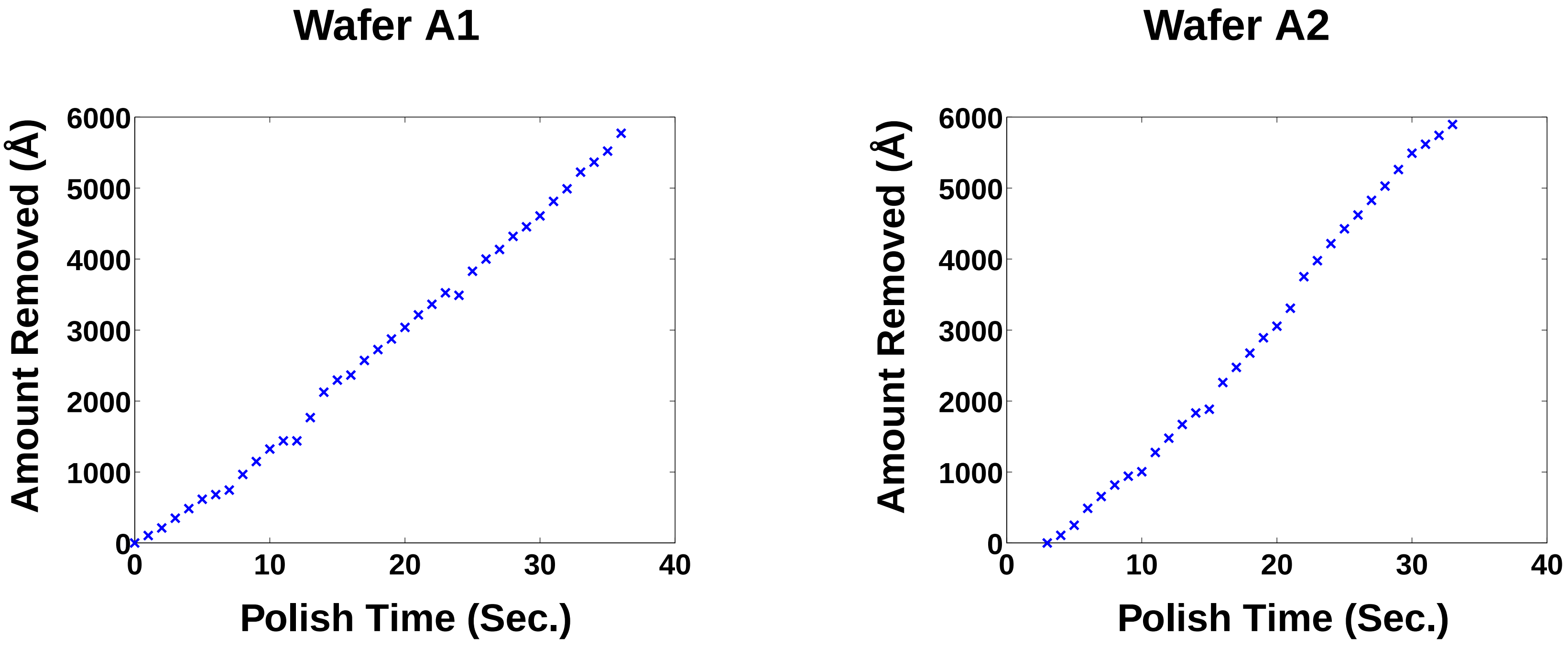
Conversion From Remaining Thickness to Amount Removed



Amount Removed = Orig. Thickness - Remaining Thickness

- Original thickness estimated from iScan data
  - When remaining thickness is greater than 8KÅ, first few seconds of data is not used in computing amount removed

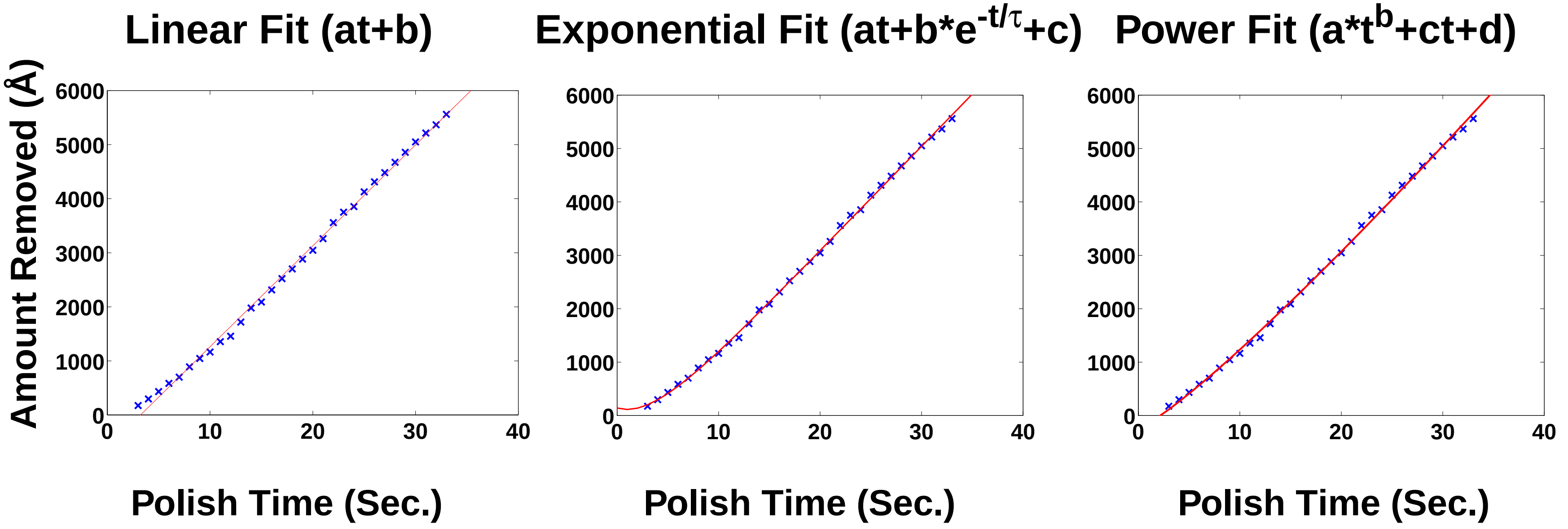
Copper Thickness Raw Data



- Difficult to “see” the non-linearity in the data
  - Roughly linear trend, which would correspond to a constant copper removal rate
- Goal: more careful analysis of removal rate trends

Approach 1: Different Model Fits on Amount Removed

Wafers A1 and A2 Averaged


Linear Fit (at+b)

Exponential Fit ($at+b*e^{-t/\tau}+c$)

Power Fit ($a*t^b+ct+d$)

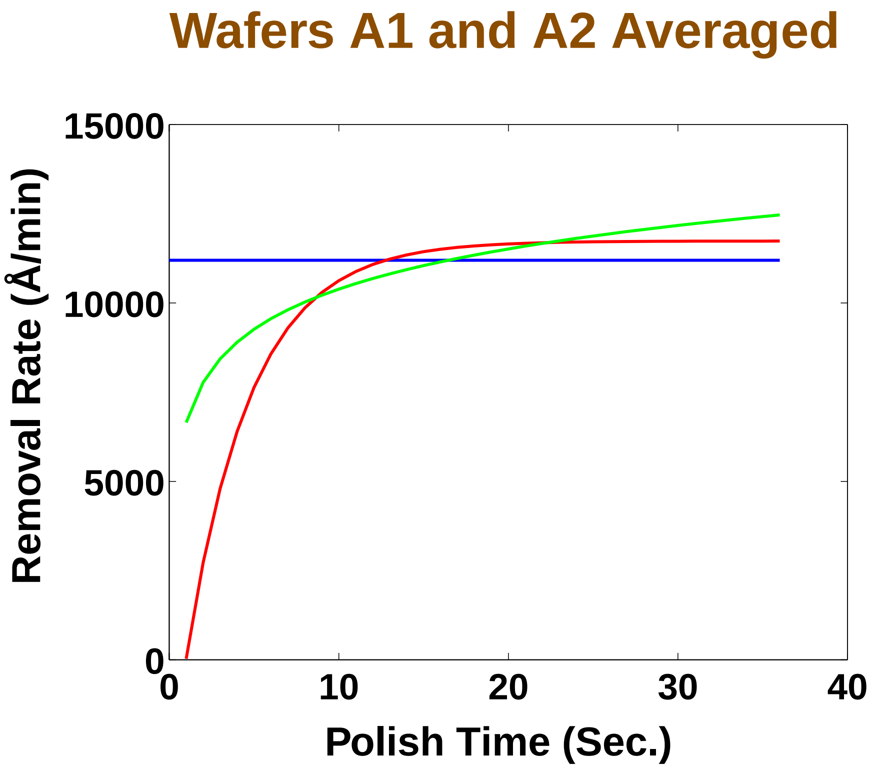
RMSE = 85.5Å

RMSE = 44.6Å

RMSE = 56.8Å

- Different forms of model fits are tried
- Exponential and power functions indicate better fit and track the data better

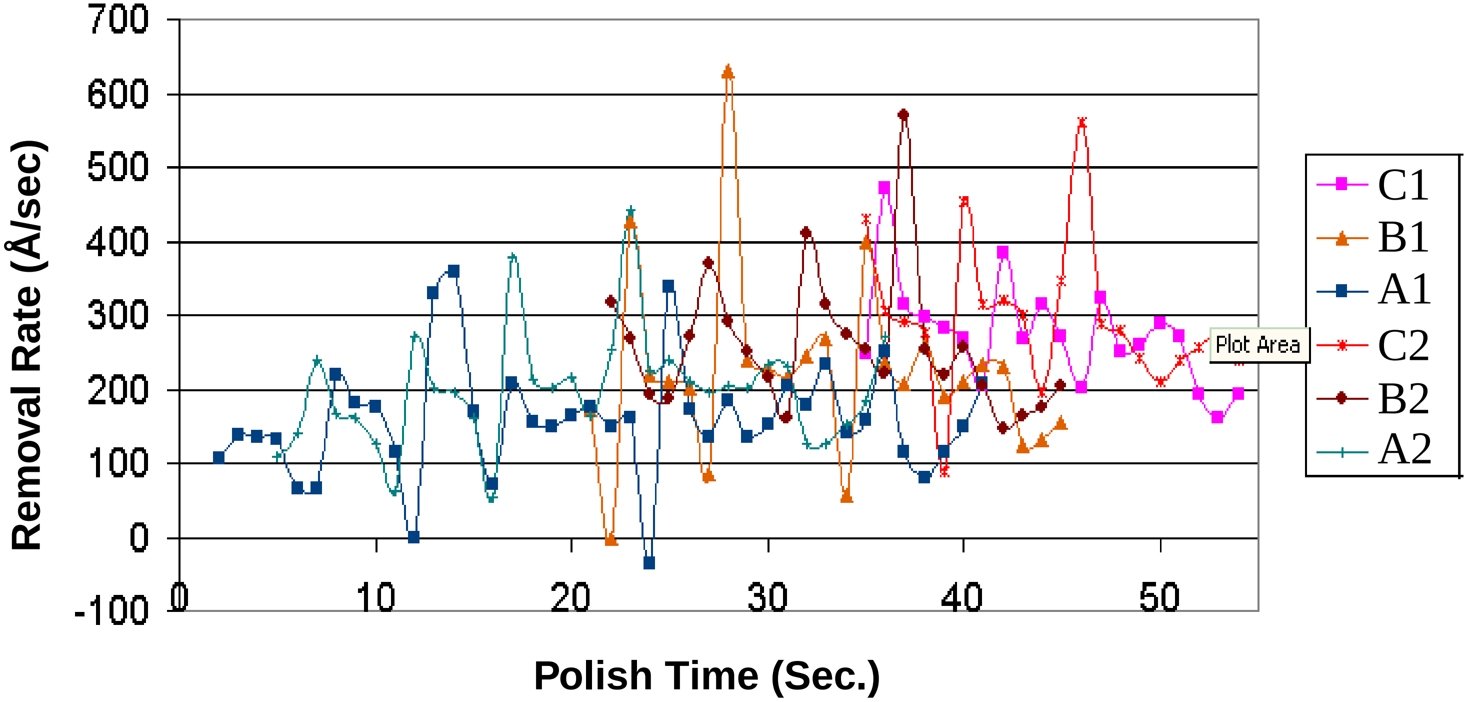
Approach 1: Removal Rates Determined from Amount Removed



--- **Blue**: Constant
--- **Red**: Exponential
--- **Green**: Power

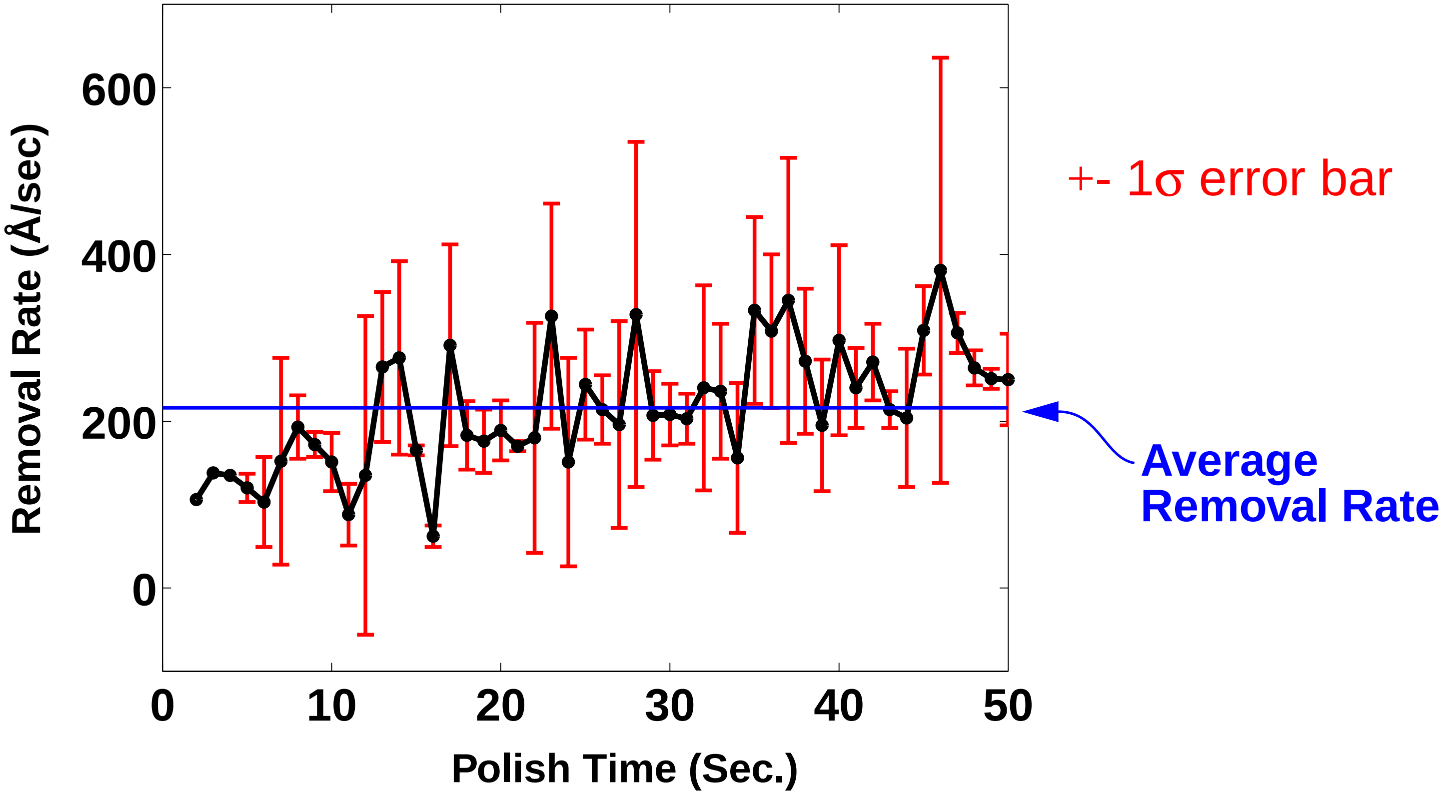
- Model fits for the amount removed are differentiated to give removal rate: significant difference in removal rates in first 10-15 seconds.

Approach 2: One Second Removal Rate



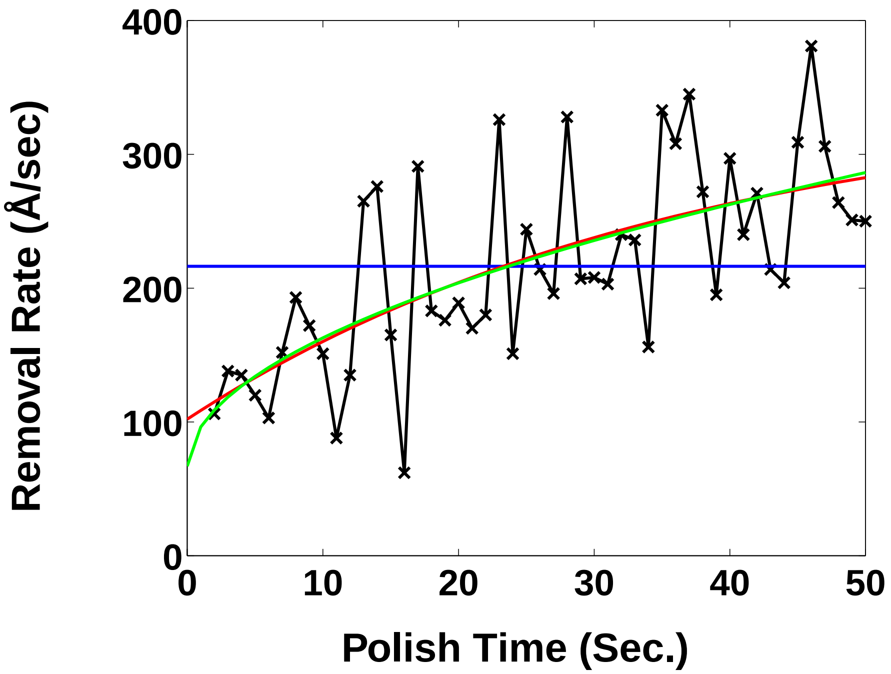
- Amount removed per each second is recorded for all six wafers in each relevant polish time domain
- Periodicity of removal rate is shown in the data

One Second Removal Rate: Point by Point Average



- Data points at each polish time are averaged
- Upward trend of the rate is observed

Approach 2: Averaged One Second Rate: Exponential and Power Function Fit



--- Blue: Constant
--- Red: Exponential
--- Green: Power

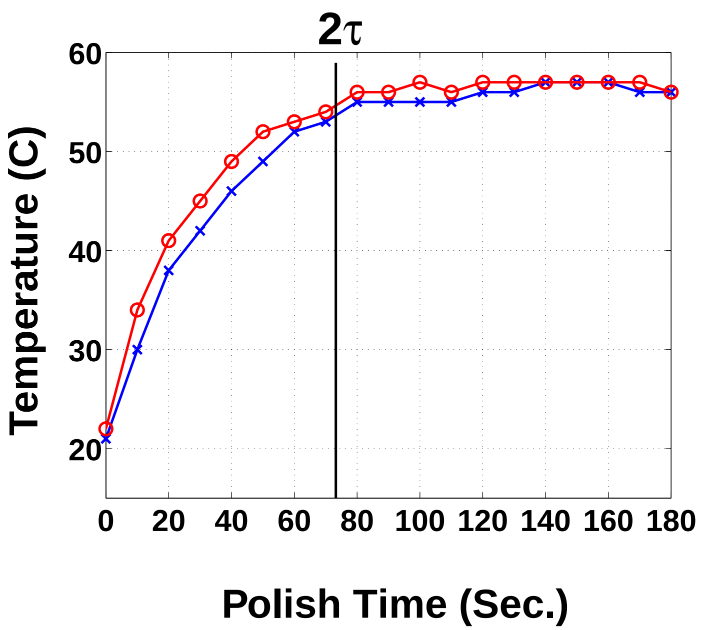
RMSE = 73.8Å/sec.
RMSE = 56.1Å/sec.
RMSE = 56.1Å/sec.

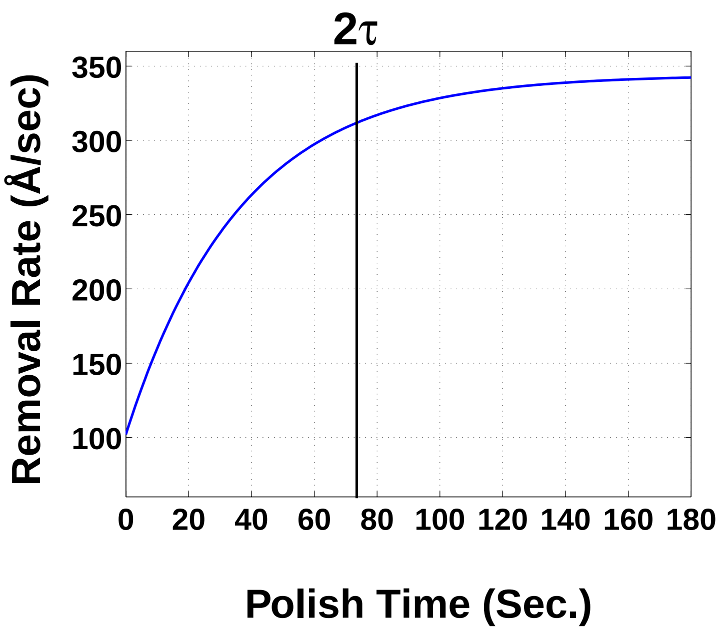
- Both exponential and power function fits follow the upward trend with similar errors that are less than the constant rate fit error

Summary of Model Fits

Model Fits	Approach 1: Amount Removed (A1 and A2 Averaged)	Approach 2: 1 sec. Removal Rate (All Data)
Linear	**$AR = at + b$**	**$RR = a$**
	a = 186.60	a = 216.31
	b = -603.32	
RMSE	85.5 Å	73.8 Å/sec.
Exponential	**$AR = at + be^{-t/\tau} + c$**	**$RR = a - (b/\tau)e^{-t/\tau}$**
	a = 195.62	a = 344.05
	b = 968.43	b= 8825.38
	τ = 3.82 sec.	τ = 36.47 sec.
	c = -827.39	
RMSE	44.6 Å	56.1 Å/sec.
Power	**$AR = at^{b} + ct + d$**	**$RR = abt^{(b-1)} + c$**
	a = 541249.23	a = 19.36
	b = 1.00005	b = 1.51448
	c = -541165.46	c = 66.97
	d = -226.43	
RMSE	56.8 Å	56.1 Å/sec.

Temperature: a Possible Relationship

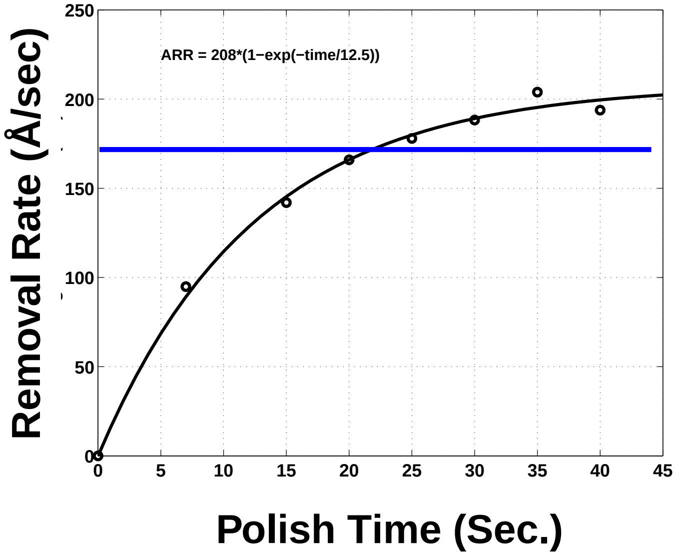

Tool Temperature


Exponential Removal Rate

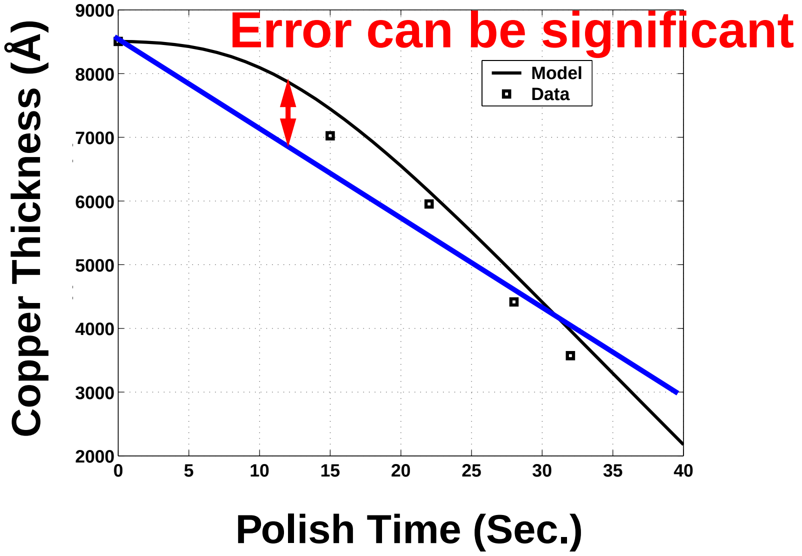
- Copper removal rate and the temperature rate change have similar initial upward trend
- Temperature change may also be related to chemical reaction during polishing

Implications on Modeling

Average Removal Rate (Blanket Wafer: Ex-Situ Data)

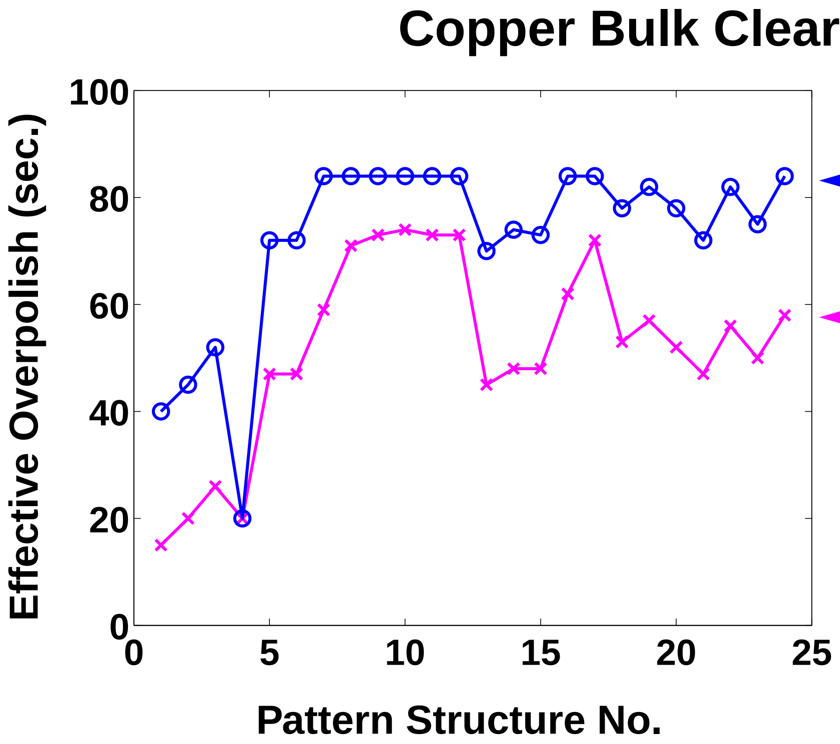


Copper Thickness in Field Area (Å) (Patterned Wafer)



- Data gathered using ex-situ sheet resistance measurement indicate similar increase of removal rate of copper
- Difficulty of model parameter extraction
- Stability and control problem in process development

Implications on Model Simulation



Blue: Using Constant RR

Magenta: Using Exponential RR

Mean Time Difference = 20 sec.

Nominal overpolish time = 15 sec.

- Cu CMP model simulation for clearing of copper is performed using the constant rate and exponential rate
  - ❑ min. feature of 0.25µm and 10% to 90% copper densities
- Constant removal rate leads to longer overpolish, and the difference could lead to false dishing and erosion predictions

Conclusion

- Non-linearity of copper removal rate is observed and shown
- Different model fits are examined
  - Approach 1: total amount removed fit and differentiated to get removal rate: exponential and power functions give best result
  - Approach 2: one second removal rate: exponential and power functions fit the best
  - ✔ **Approach 2 is better at observing and modeling the non-linear trend of copper removal rate**
- Initial temperature ramp up is similar to copper removal rate increase
  - Possible interactions: abrasive friction and chemical reaction
- Implications
  - Process development: stability and control problems
  - Cu CMP model: difficulty of model parameter extraction and possible simulation prediction errors

Future Work

- Longer polish times to cover the full ramp up and saturation
- Relate to thermal transient model*
- Effects on the removal rate due to multi-step process
- Possible ways of reducing the non-linear behavior of copper removal rate

*D. White, Ph.D. Thesis, MIT, Aug. 2001.