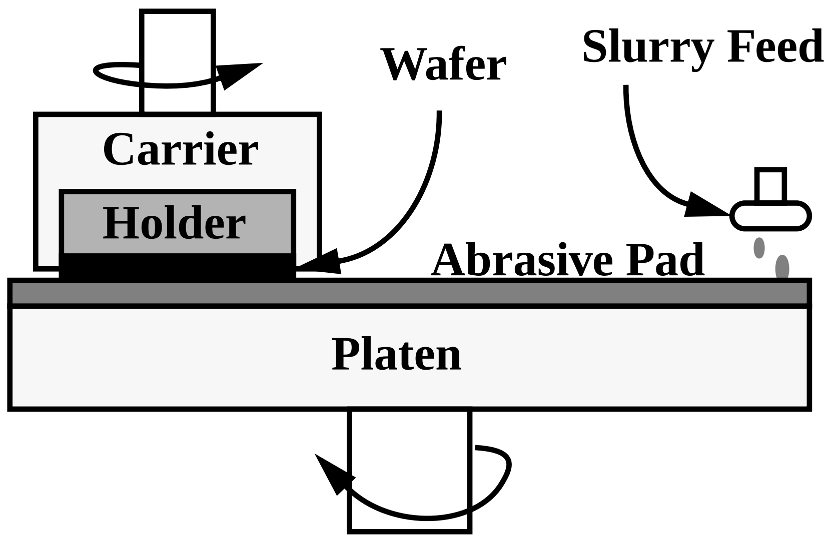
Integration of a Layout-Dependent CMP Model with Run by Run Methods for Improved CMP Control

Taber H. Smith, Simon J. Fang*, Jerry A. Stefani*, Greg B. Shinn*, Stephanie W. Butler*, and Duane S. Boning

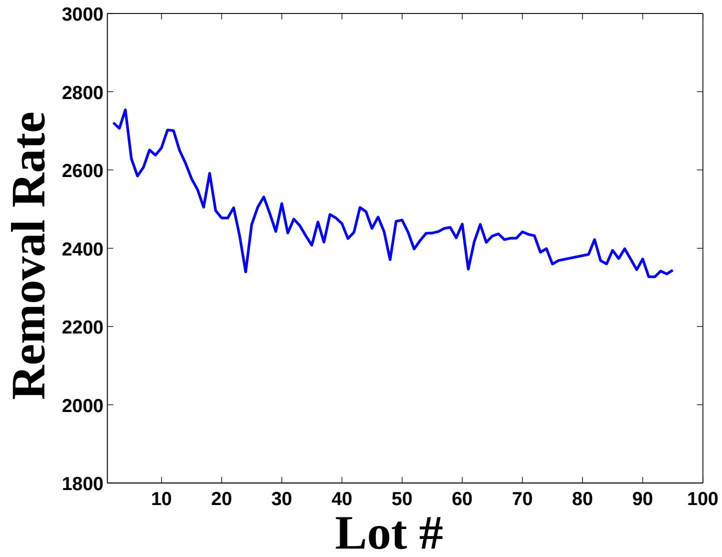
MIT Microsystems Technology Laboratories
Phone: (617) 253-7357, Email: taber@mit.edu

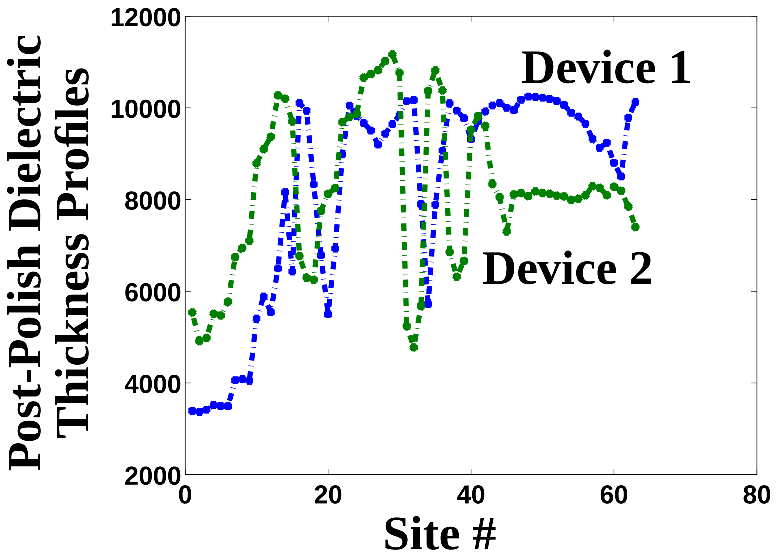
* Silicon Technology Development, Texas Instruments Inc.

Motivation



- Chemical-Mechanical Polishing (CMP) is important for dielectric and metal planarization.
- Pad wears, causing drop in removal rate
- Different devices (products) polish very differently

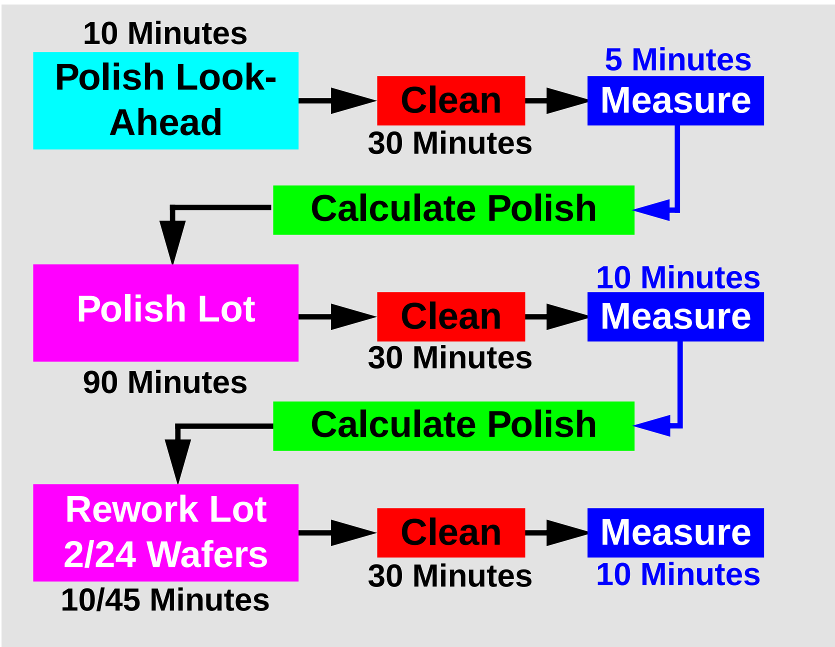




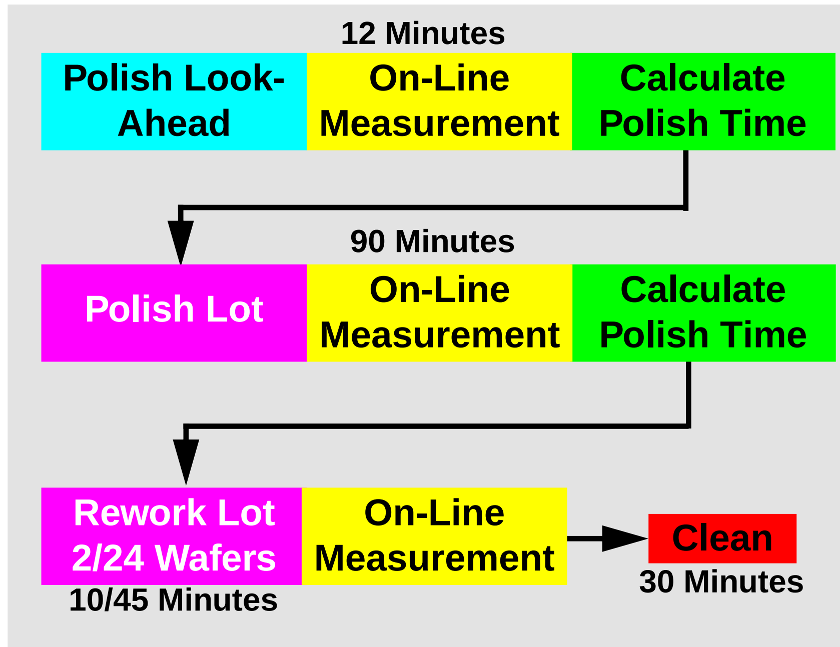
T. H. Smith, S. J. Fang, J. A. Stefani, G. B. Shinn, S. W. Butler, and D. S. Boning

Previous Work: Reduced Consumption by On-Line Process Measurements and Control

CMP Processing Without Sensors and Control



CMP Processing With Sensors and Control



Without Sensors and Control		With Sensors and Control
4 Hours 15 Minutes	80% Higher Throughput	2 Hours 22 Minutes
3 Cleans	66% Fewer Cleans	1 Clean

T. H. Smith, S. J. Fang, J. A. Stefani, G. B. Shinn, S. W. Butler, and D. S. Boning

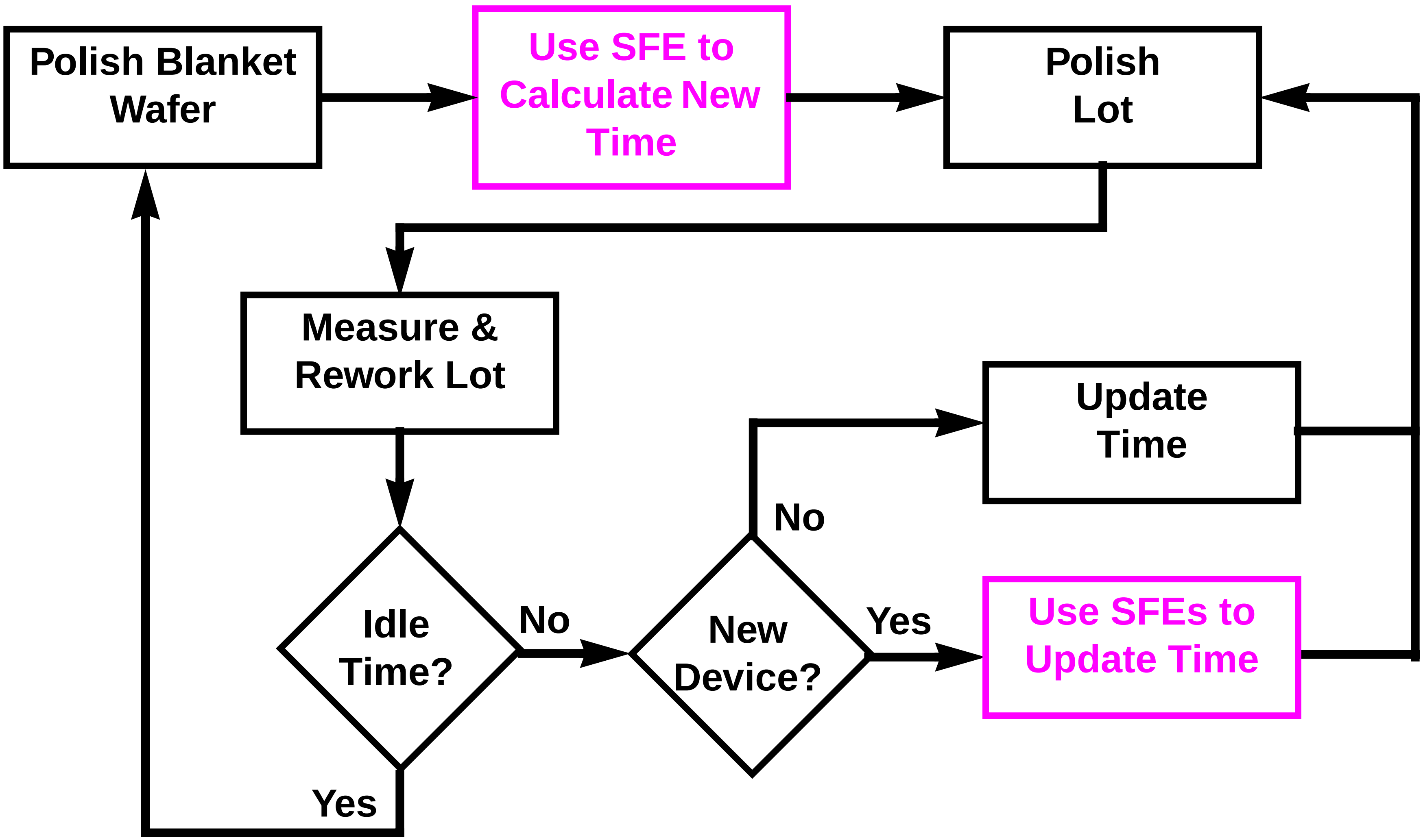
Motivation

- **Run by Run (RbR) process control is being used to compensate for equipment variations, improve uptime, reduce waste**
- **On-line metrology tools are making RbR methods more practical**
  - **Increase Automation**
  - **Improve Throughput**
  - **Reduce Look-Ahead and Monitor Waste**
- **However: Processing multiple devices (product types, layers) on a single tool still presents a barrier to the full utilization of RbR control in CMP**
  - **Different devices have different removal rates and uniformities**
  - **Starting lots after idle time or changing devices on a polisher generally requires using test wafers or inaccurate device dependent removal rate adjustments**
- **We need a device independent model-based RbR control strategy that can account for layout/device specific aspects of each product being polished**

Outline

- Review current practice
- Review MIT CMP model
- Discuss Device Independent RbR controller
- Control experiments
- Conclusions and future work

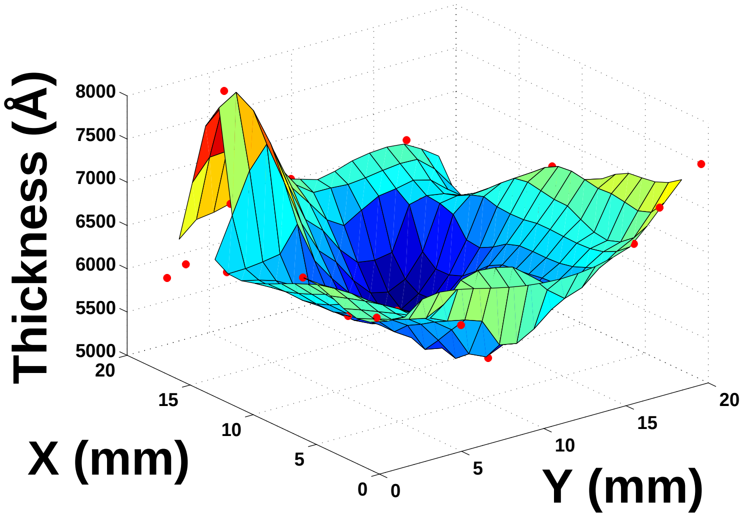
Current Practice



Problems With Current Practice

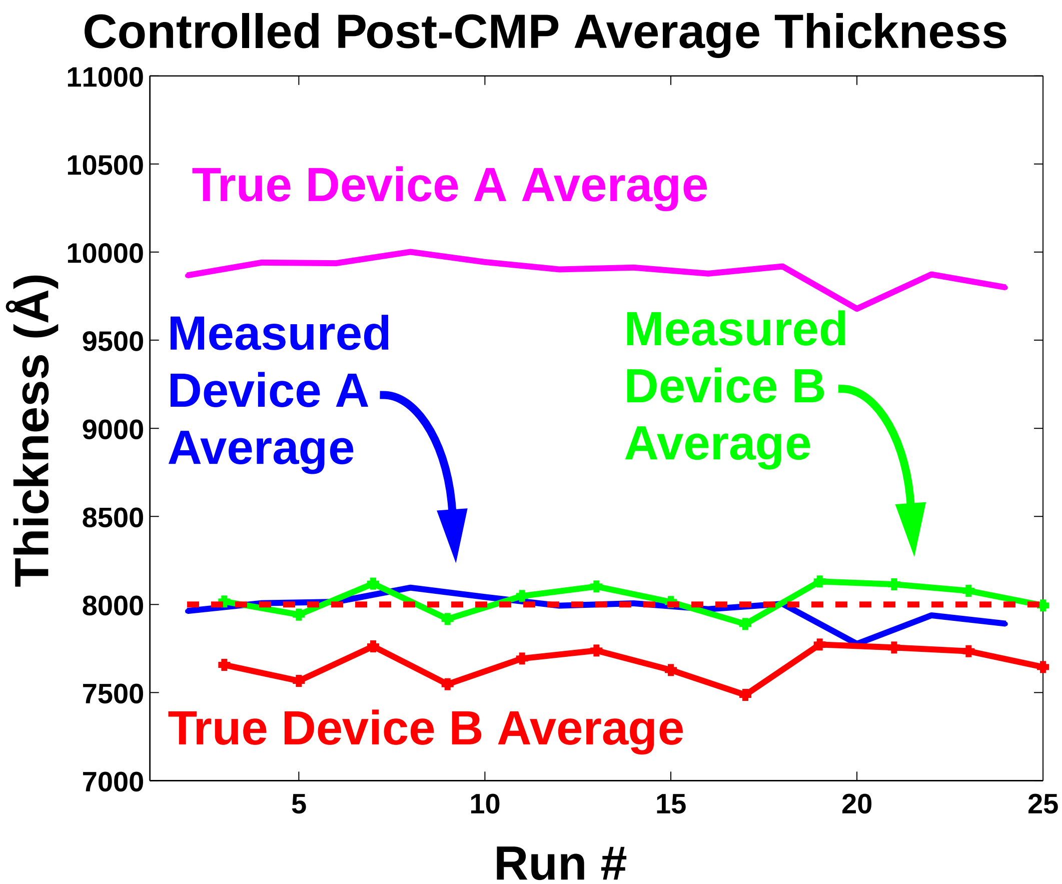
- Sheet Film Equivalents (SFEs) are inaccurate
- The controlled thickness depends on the measurement location(s)
- Controlling with one location within the die requires knowledge of the die-level polishing profile
- Process engineers generally don't realize this, and pick a location based on measurement reliability
- Traditional control with one location does not give sense of global non-uniformity!

Die-Level Oxide Thickness Variation

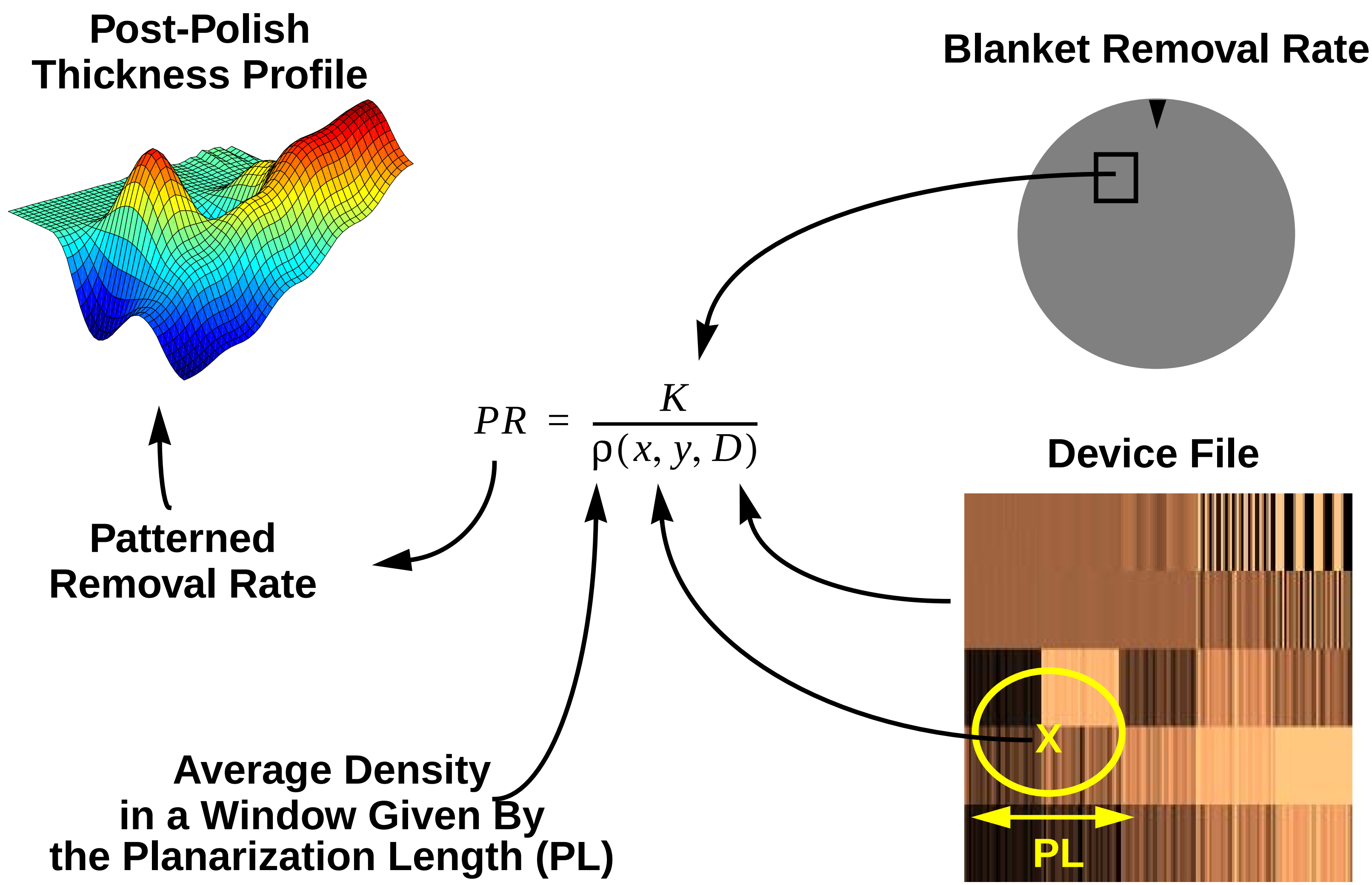


What Happens To the Controlled Thicknesses?

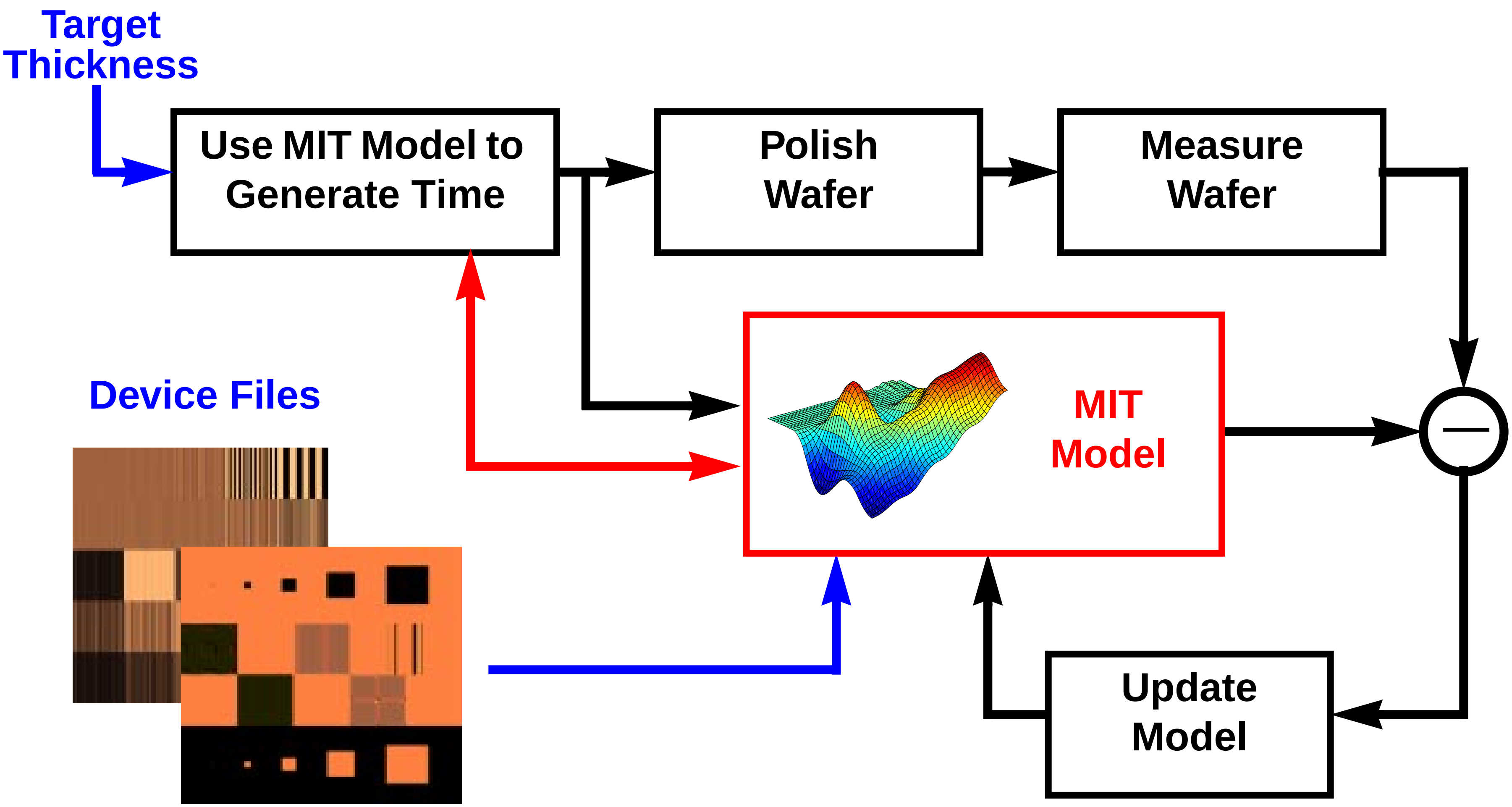
- Results are misleading
- Measured thicknesses (based on small number of on-line measurements) indicate control of both devices is on target
- True average (based on large number of ex-situ measurements) for each device does not equal the desired thickness



The MIT CMP Model



A Device Independent CMP Controller



T. H. Smith, S. J. Fang, J. A. Stefani, G. B. Shinn, S. W. Butler, and D. S. Boning

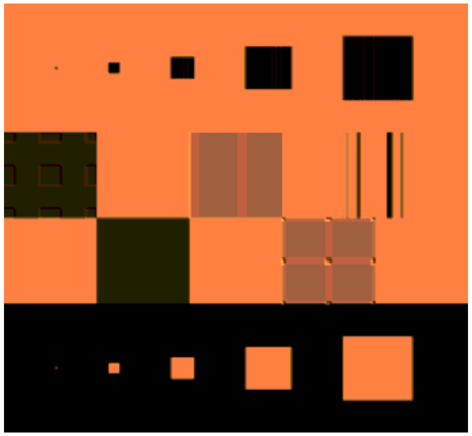
First Control Experiment

- Polishing done on an IPEC 472
- Measurements performed on ex-situ KLA/Tencor UV1280, on-line monitoring done using Nova
- Blanket wafer polished and fed into controller for initial blanket rate

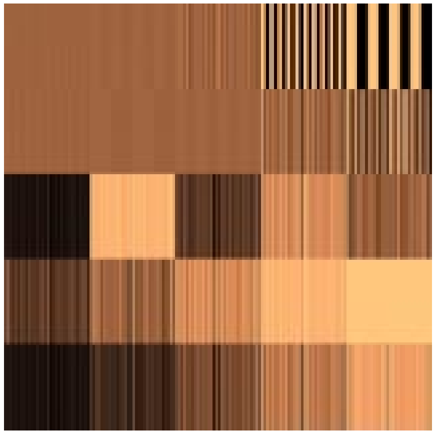
✔ Updating of planarization length (PL) and blanket rate (BR)

- Two devices were alternately polished

Mask 1

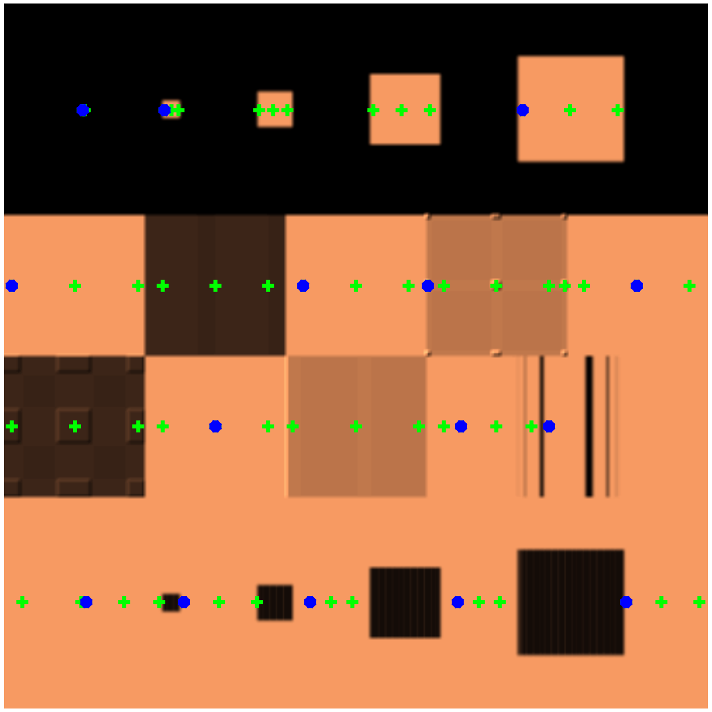


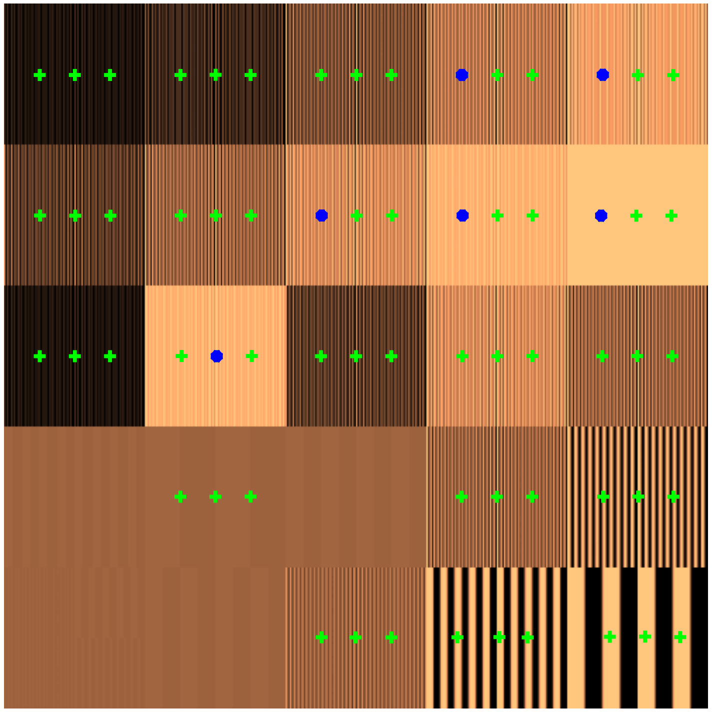
Mask 2



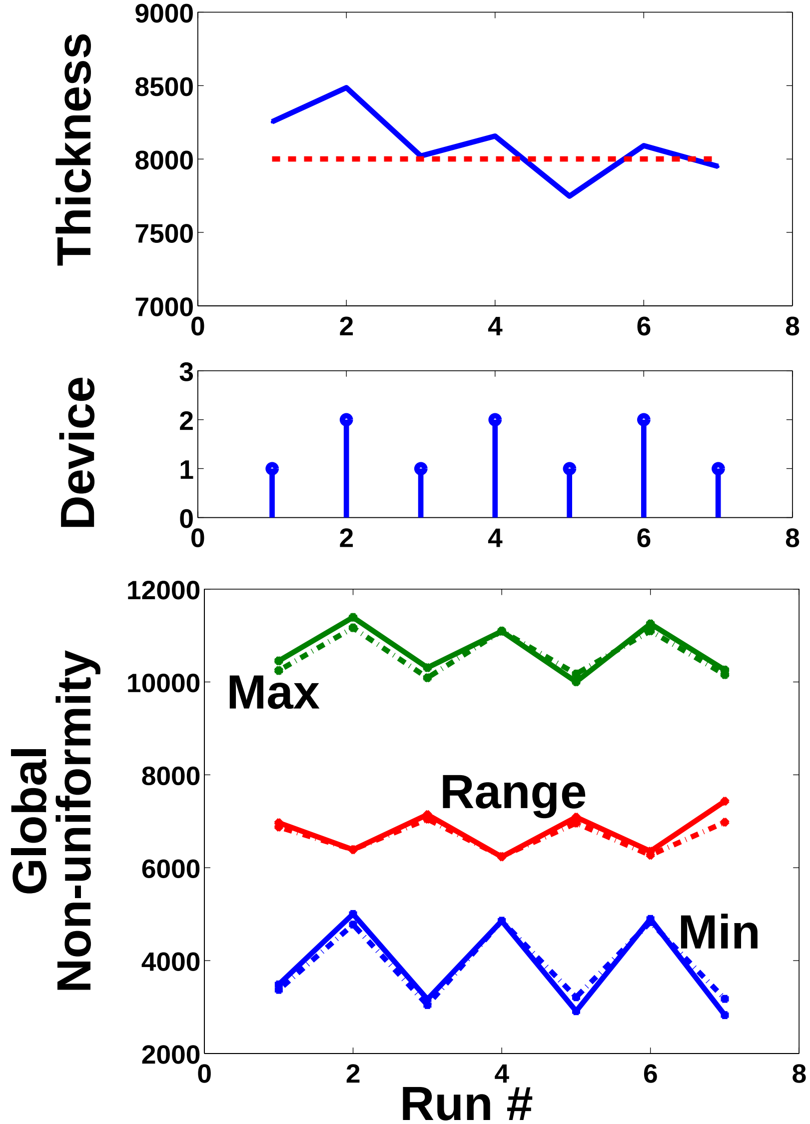
Experiment Measurement Plan

- **Mask 1 Measurement Plan**
  - 63 ex-situ measurement sites for verification (green crosses)
  - 15 on-line measurement sites for control (blue dots)
- **Mask 2 Measurement Plan**
  - 63 ex-situ measurement sites for verification (green crosses)
  - 6 on-line measurement sites for control (blue dots)



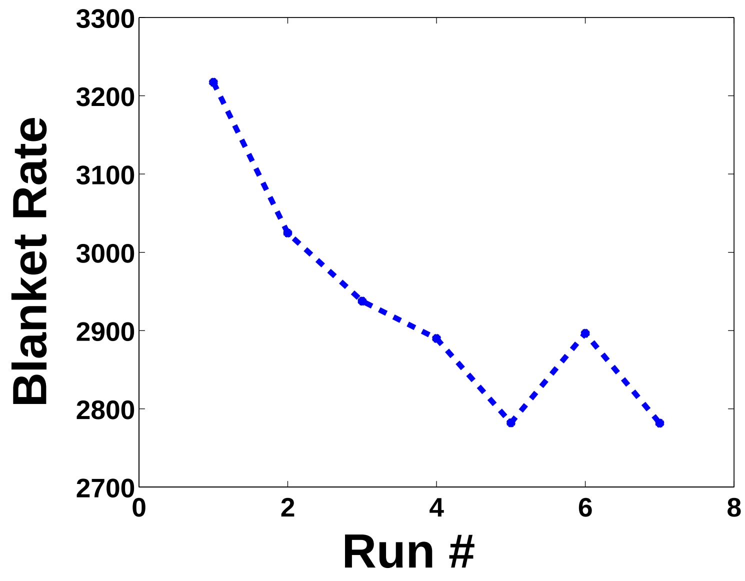


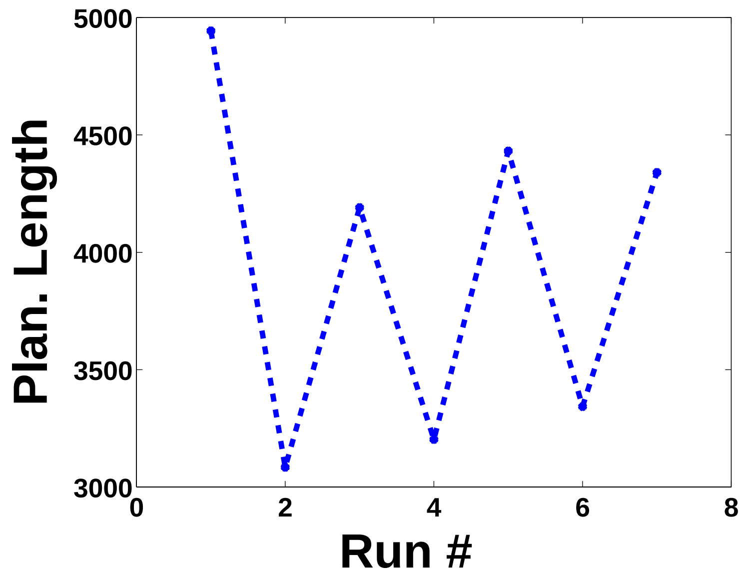
First Experiment Results



- Control to within +/- 400Å
- Good prediction of global minimum, maximum, and range due to
  - die pattern
  - within wafer nonuniformity
- Difficult to implement with ex-situ metrology
- Error in the controlled output seems large
- Is this dependent on the device?

Optimal Planarization Lengths and Blanket Rates



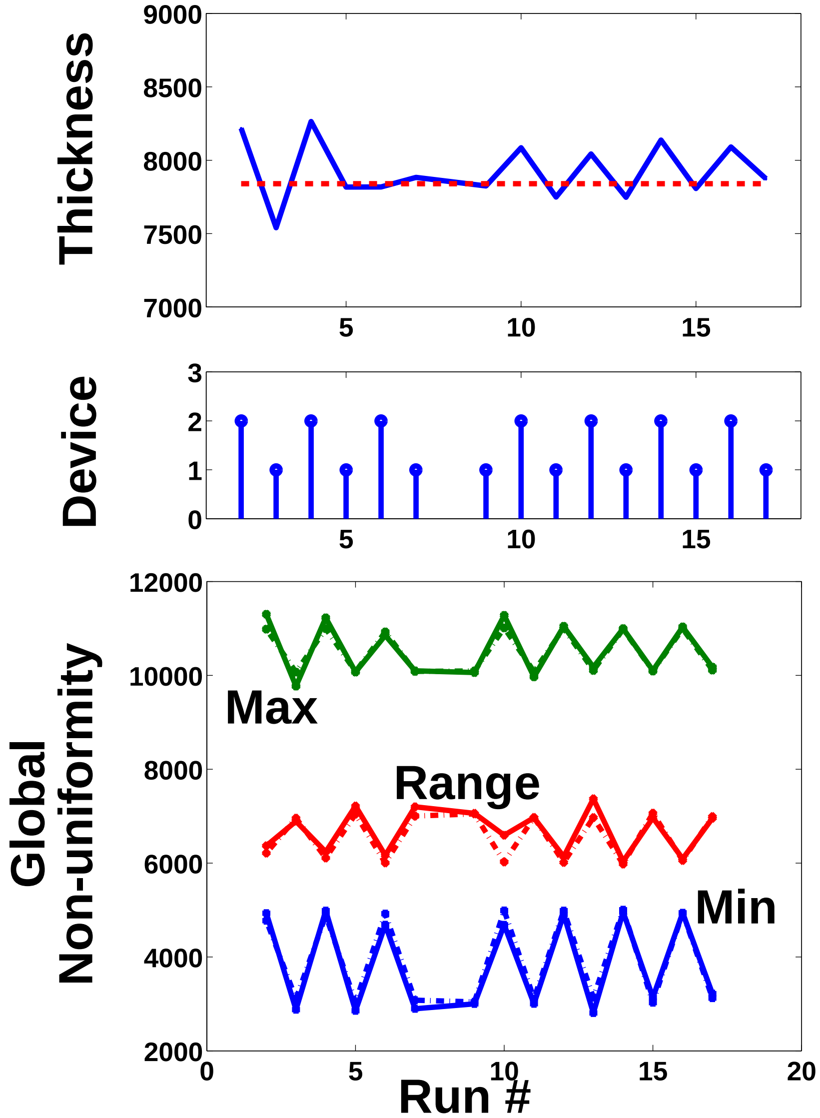


- Blanket rate estimated by the MIT model is fairly stable, with a slight drop-off at beginning of pad life
- Planarization length appears to be correlated with the device type

Second Control Experiment

- ✔ Planarization length (PL) fixed for each device
- ✔ Updating of just blanket rate (BR)
- Mask1 and Mask2 wafers alternately polished
- Measurements performed on-line using Nova
- Updated blanket rate, fixed device-dependent planarization lengths, and device files used in MIT model to generate the polish times

Second Control Results

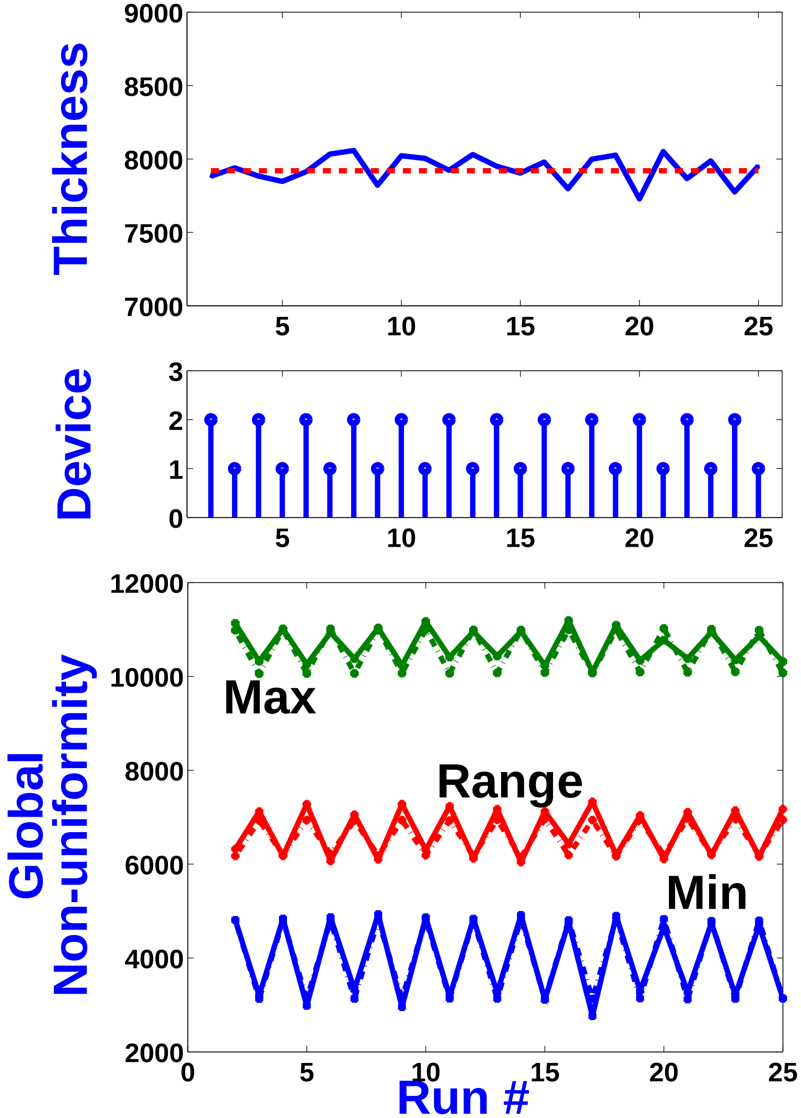


- Control to within +/- 200Å !
- Excellent prediction of global minimum, maximum, and range
- Error in the controlled output oscillates -- Device dependency very noticeable
- Is blanket rate a function of the device?

Third Control Experiment

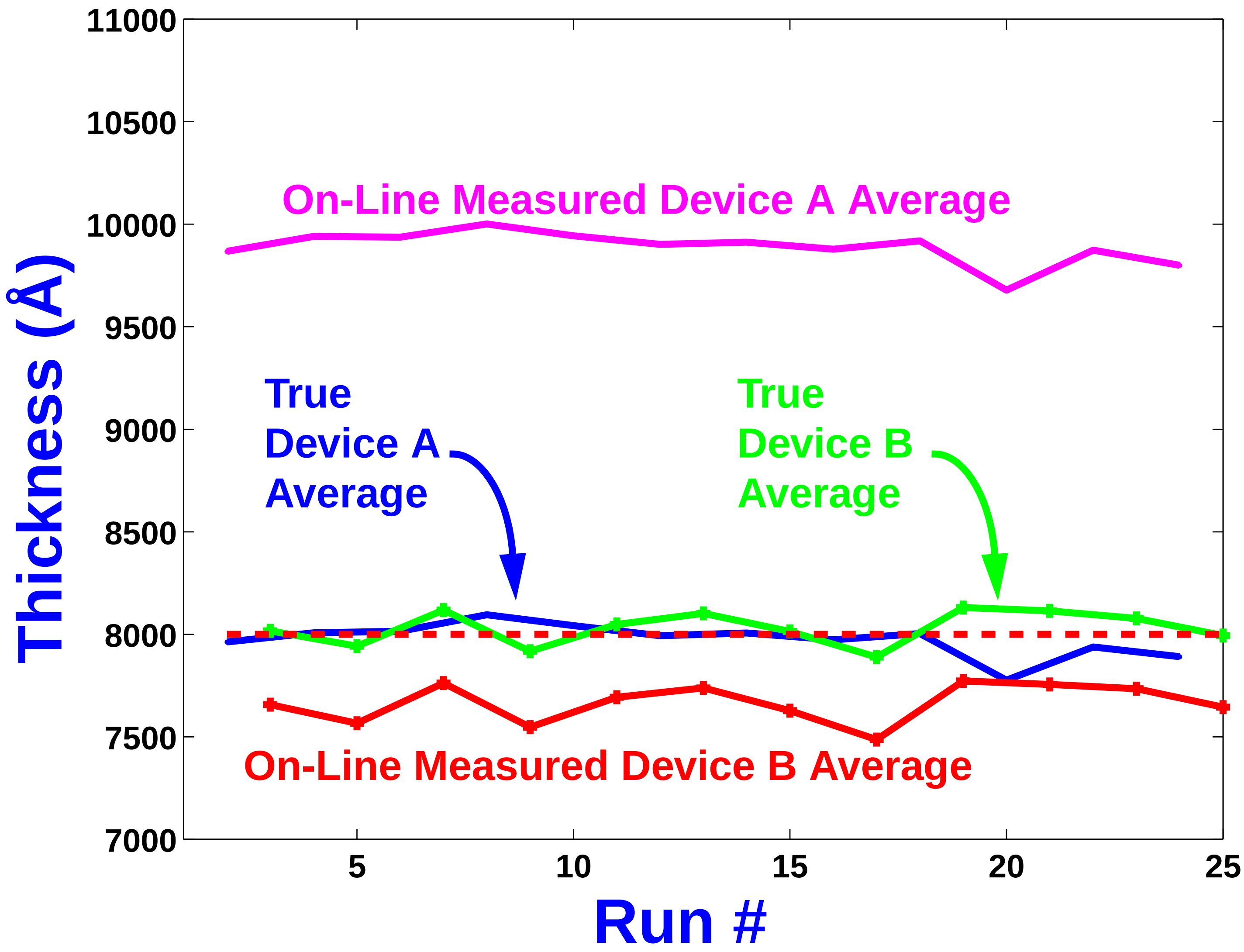
- ✔ Planarization length (PL) fixed for each device
- ✔ Assumes that the errors in the model can be corrected using a device dependent adjustment to the blanket rate
- BR(n) = BR_Constant + BR_Device(D) + Delta(n)
  - BR_Device(D) gives a constant offset which is different for each device
  - Delta(n) gives a run by run update to track pad wear or rate drift in the process
- Mask1 and Mask2 wafers alternately polished
- Measurements performed on-line using Nova
- Updated blanket rate, fixed device-dependent planarization lengths, and device files used in MIT model to generate the polish times

Third Experiment Results



- Control to within +/- 100Å !
- Average error of 82Å
- Device dependency is removed
- Excellent prediction of global minimum, maximum, and range for both devices!
- Drift in wafer-level and die-level uniformity can be monitored

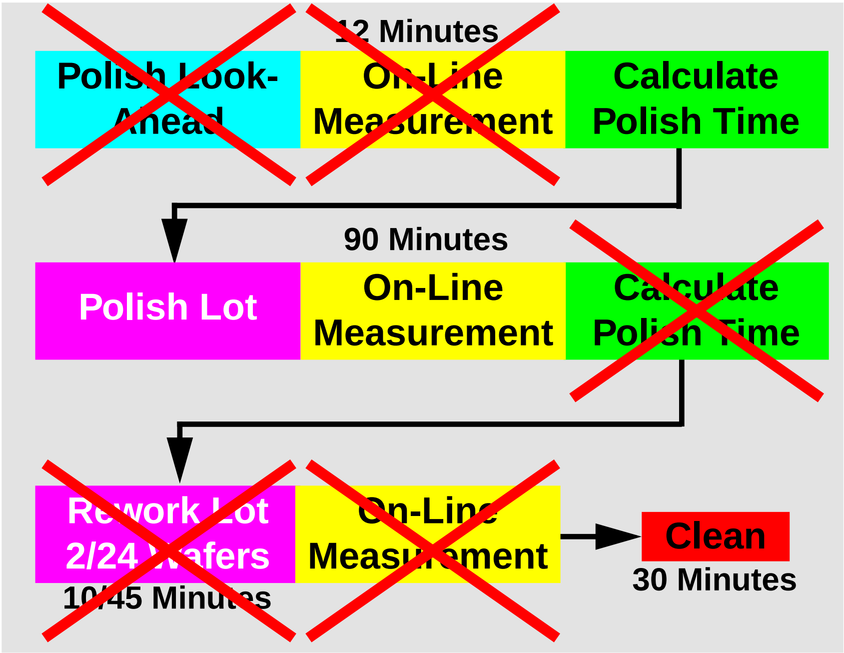
What About Those Measured Averages?



Result: Further Improvements by Integration of CMP Model with RbR Control

- Eliminate need to polish look-ahead wafer for each swap in device type coming to tool
- Accurate control: Eliminate need for rework

CMP Processing With Sensors and Control



Steps Eliminated by Model/RbR Control

Conclusions

- **Using a model-based CMP controller simplifies processing, improves quality, monitors global non-uniformity**
  - Model accounts for most device dependencies
  - Allows control of the true mean with only a few measurements placed anywhere on devices
  - Allows monitoring of the global polish non-uniformity -- both die-level and wafer-level
- **Improvements in the MIT CMP model can improve the device-independence**
  - E.g. improved model accuracy by modeling both density and step-height dependencies (CMP-MIC ’99)
- **Future control opportunities:**
  - Improve end-point detection and prediction -- reduce overpolish which wastes slurry and time, and degrades wafer quality (particularly in metal polish)