Spectral Transmission Measurements of Thin Films

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Outline

- Description of Transmission Measurement
- System Design Considerations
- Applications
  - Ultra-thin Metal Films
  - Multi-layer Optical Coatings and Films
- Summary

Transmission Measurement System

- **CCD-based spectral measurement**
  - **Visible light (380-780 nm) typical**
  - **Can extend into near IR (~1000-1100 nm) or into UV (down to 200 nm)**
- **QTH or alternate broad spectrum lamp**
- **Software and hardware system enhancements for increased dynamic range of instrument**

Transmission Measurement Method

- Measure known reference for calibration
- Measure sample
- Adjust signals
  - subtraction of CCD dark current effects
  - parameters to increase dynamic range
- Calculate percent transmission
- Apply result to current application

In situ Transmission Measurement System Considerations

- **Sensor alignment**
  - **Repeatable normal incident alignment using fixtures common across multiple chamber configurations**
  - **Fixtures that retain alignment inside the vacuum, during pumpdown and opening of chamber (externally-mounted)**
  - **Fiber feed-throughs and vacuum compatible fiber optics for in-chamber fixtures**

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In situ Transmission Measurement System Considerations

- **Hardware repeatability**
  - **CCD/Spectrometer stability**
  - **Lamp Stability**
  - **Alignment repeatability/stability**
- **Integration Issues**
  - **Interaction with process control software**
  - **Ability to re-calibrate as necessary**

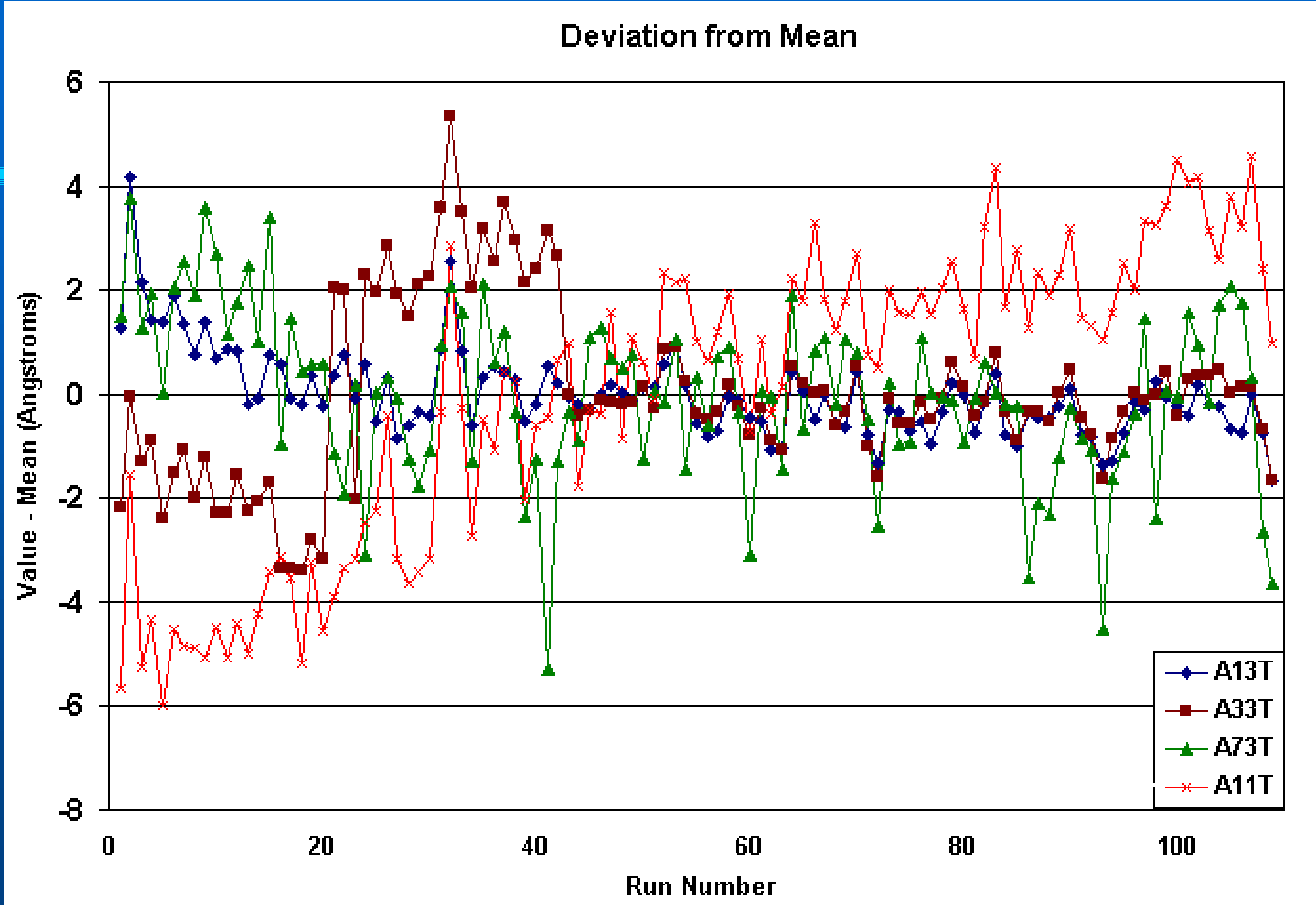
Metal Film Thickness Measurements

- **Goal: Measure ultra-thin metal films for process control (SPC & in situ feedback)**
- **Requirements:**
  - **Measure variety of metals**
  - **Demonstrate repeatability of measurement (sample-to-sample and unit-to-unit)**
  - **Measure optically thin and thick metals on same instrument (large dynamic range)**

Metal Film Thickness Measurements

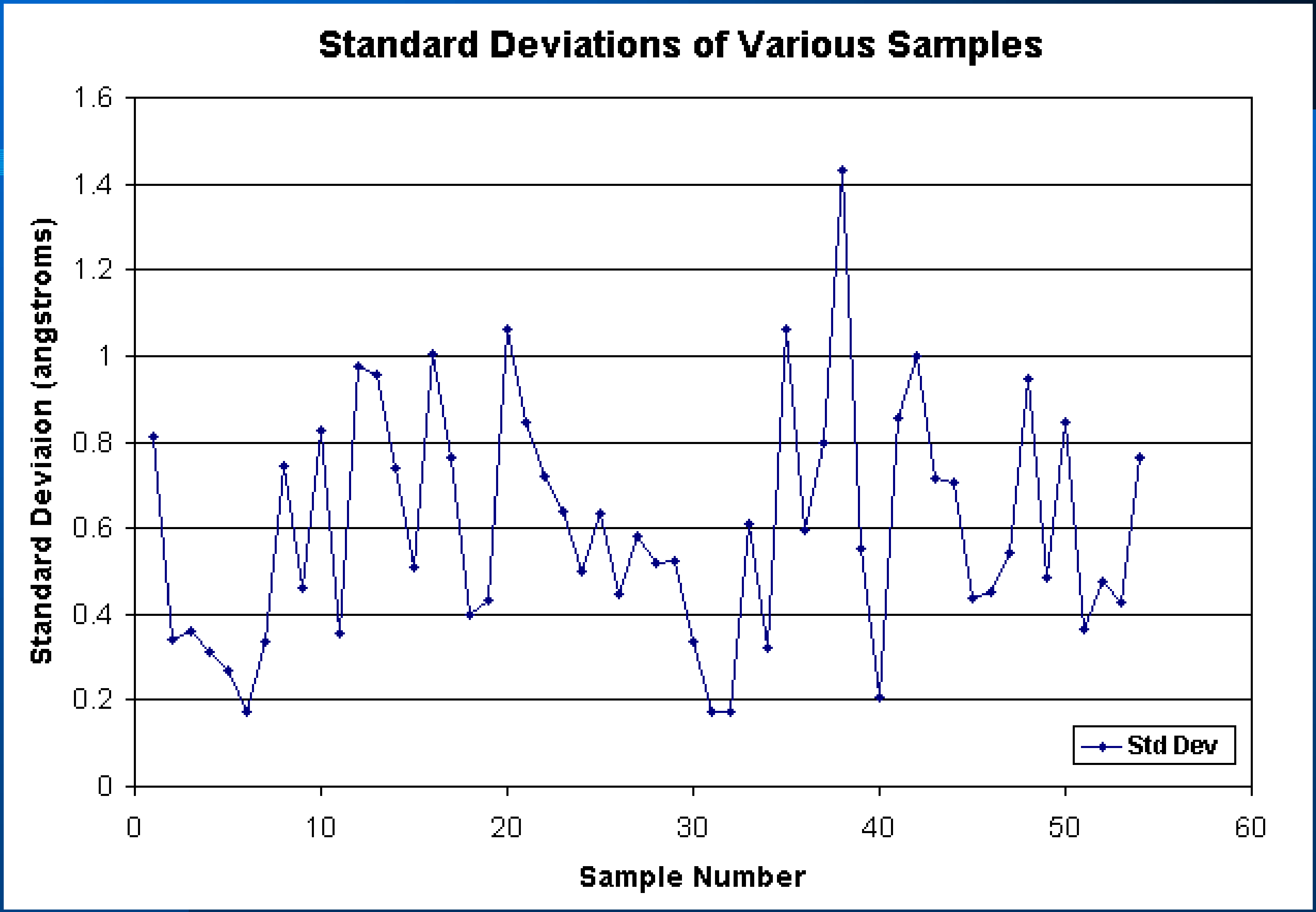
- **Instrument Configuration Procedure:**
  - **Measure Transmission / Optical Density (O.D. = log [100/%T]) of set of Metal samples of varying thickness**
  - **Measure sample thicknesses using alternate technique (XRR and XRF used here)**
  - **Create correlation equation(s) between O.D. data and thickness from alternate method**

Results



Deviation from Mean
Value - Mean (Angstroms)
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
Run Number
A13T
A33T
A73T
A11T

Results


Standard Deviations of Various Samples
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Standard Deviaion (angstroms)
0
10
20
30
40
50
60
Sample Number
Std Dev

Summary of Metal Thickness Monitor

- **Typical measurement repeatability 3σ < 6Å**
  - **Elemental metal lattice constants ~ 3 - 4 Å**
  - **Actual thickness variation not accounted for (absolutely uniform sample thickness assumed)**
- **Over 3.5 orders of magnitude dynamic range**
  - **Measure metals from nominally 0 O.D. (100%T) to over 5 O.D. (0.001%) with manual instrument adjustment (may be automated)**

Limitations of Metal Thickness Monitor

- **Single layer metal only**
  - **Method could be extended to extract thicknesses of multi-layer stack with additional modeling**
- **Accuracy dependent on quality of:**
  - **Independent thickness measurement (XRR/XRF/...)**
  - **Correlation Model**
  - **Process control (quality/repeatability)**

Multi-Layer Thin Film Monitor

- **Goal: Monitor and control multi-layer thin films during deposition.**
- **Requirements:**
  - **Target application: optical coatings (SiO_2, TiO_2)**
  - **Separately control each of 30-40+ layers**
  - **Control overall final optical properties of stack**

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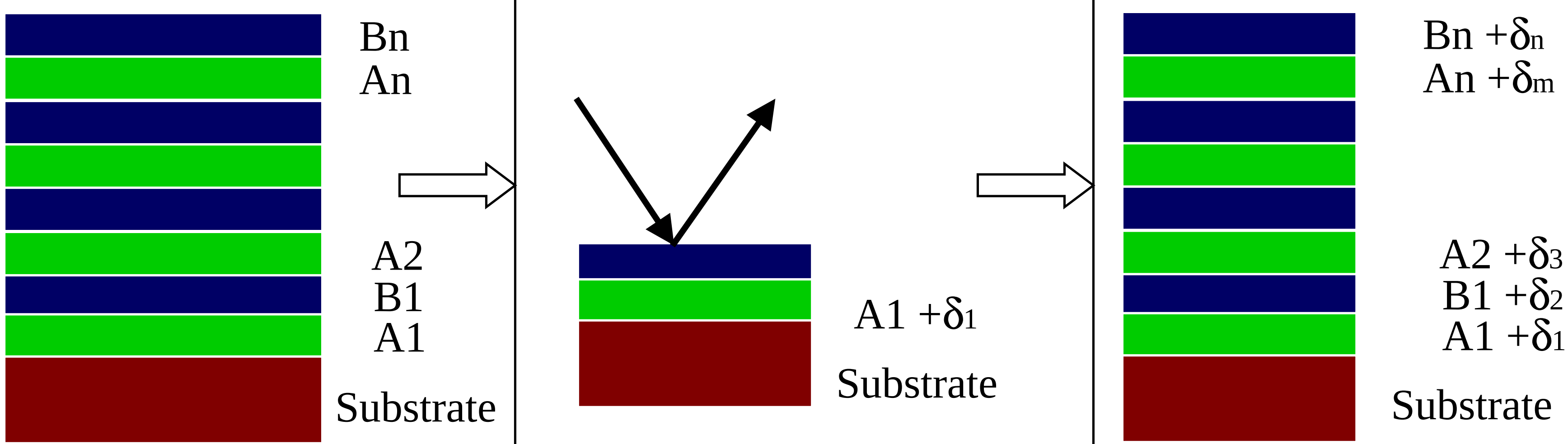
Multi-Layer Optical Coating Monitor - System Considerations

- **Systemic deviation from model**
- **Difficulties in monitoring new layers as more layers are added to the stack**

Systemic Variation From Model

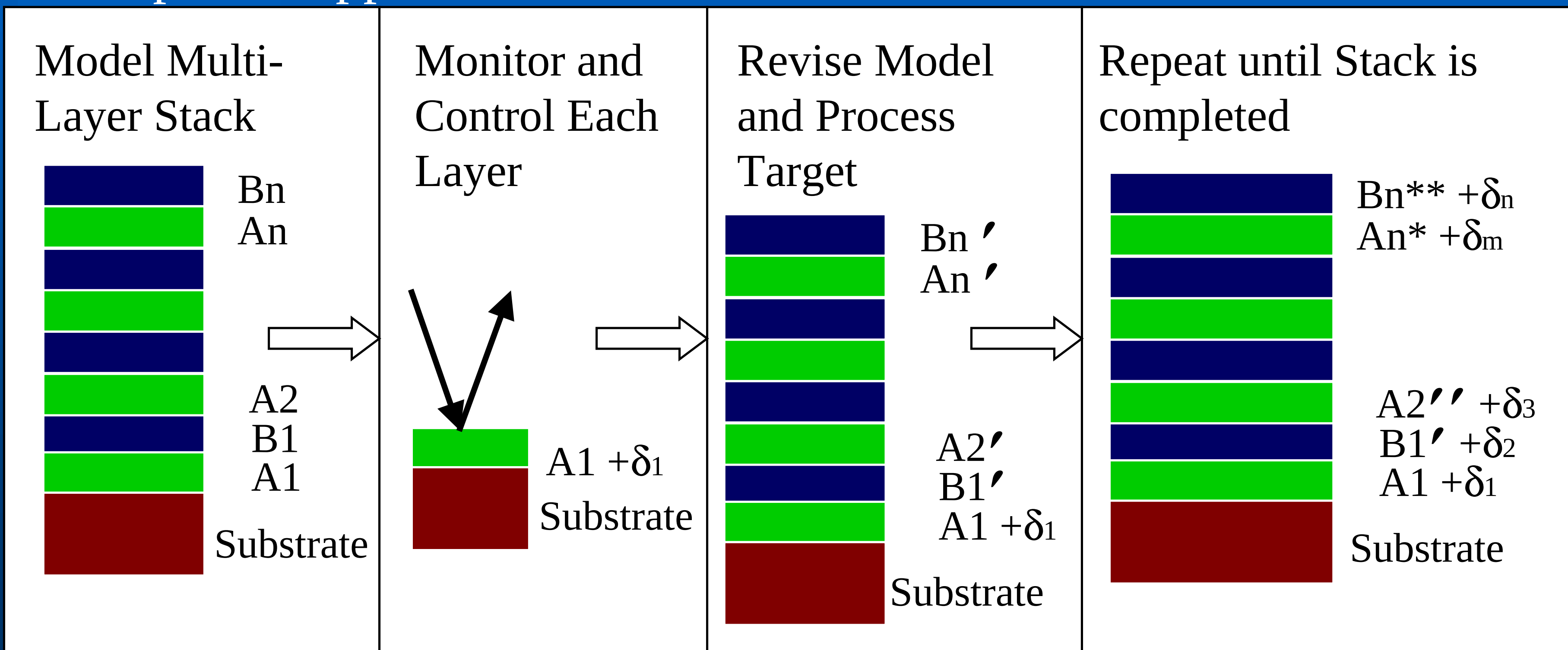
Traditional Process Model:

Model Multi-Layer Stack	Monitor and Control Growth of Each Process Layer	Go to Next Layer until Stack is completed



Systemic Variation from Model:

Proposed Approach:



Concept: Vidal and Pelletier, *Applied Optics* 18 (22), 15 Nov 1979, 3857

Techniques for Distinguishing Between Layers

- **Do complete modeling of sub-layers and current layer**
- **Use changes in signal (Virtual Interface)**
- **Compare signal to model or prior measurements (e.g. Neural Net)**
- **Measure separate substrate/sample**
  - **Optical coaters often have built in chip-changers for this purpose**

Optical Coating Monitor

- **Reflection on bare glass substrate for each layer (use chip-changer to introduce new substrate)**
  - **Use signals from this for endpoint of each layer**
- **Transmission through product for revising model at end of each layer**
  - **Modify remaining layer thicknesses**

Optical Coating Monitor - Limitations

- **Need to be able to revise model based on previous layer(s)**
  - **Optical, electrical, thermal, mechanical (stresses) effects must be taken into account**
  - **Must be fast enough to be useful in real time**
    - **Process tool may be able to suspend process through target shutters or gas flow valves**
  - **Previous layer measurements must be accurate to avoid introduction of error**

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Optical Coating Monitor - Limitations

- **Need method of monitoring growth of current layer with complex underlayers**
  - **Modeling becomes difficult or impossible to independently determine parameters of current layer**
  - **Optical coating chambers typically design around this through use of chip-changers**

Summary and Conclusions

- **Spectral transmission measurements can be used in situ to monitor and control processes**
- **Ultra-thin metal films can be measured with repeatability of 1-2 monolayers**
- **Multi-layer thin film growth can be monitored, and growth targets revised during process**