Lecture 55
Lithography: Linewidth Control

Chris A. Mack
Adjunct Associate Professor

Why is linewidth (or critical dimension, CD) control important?
- The answer depends on the process layer
- For all layers, CD control couples with overlay capability to determine the maximum packing density (i.e., design rules)

Classic Example: gate CD control
- Physical Result: gate switching time is proportional to gate length (for standard CMOS logic)
- How does gate across chip linewidth variation (ACLV) affect device performance?

Poly Gate CD Control
- Smallest transistor limits reliability due to leakage current
- Largest transistor in critical path limits speed
- Range of transistors limits clock speed due to timing variation (skew)

Exposure Latitude
- Not all linewidth errors are linear!

Linewidth Control Factors
- For small, uncoupled errors, CD variation can be expressed as
\[ \Delta CD = \frac{\partial CD}{\partial v} \Delta v \]

Factors which determine linewidth control:
- Magnitude of a process error (\(\Delta v\))
- Response of the process to that error, called the process latitude (\(\partial CD/\partial v\))
Analyzing CD Errors

- Temporal Variations
  - Trend charts, SPC analysis
- Spatial Variations
  - Wafer-to-wafer, lot-to-lot
  - Across wafer
  - Across field
  - Slit direction
  - Scan direction
- Random Variations
- Two types of analysis
  - Sources of variations (bottoms up)
  - Statistical analysis of data (top down)

Analyzing Spatial Signatures

- Measure N wafers at many spatial (x,y) locations

\[ M_i(x,y) = CD_0 + S_i(x,y) + R_i(x,y) \]

- By determining the standard deviation of the residual for each wafer (the random errors), an estimate of the uncertainty in the systematic spatial signature can be made

\[ S(x,y) = CCDE(x,y) \] with an uncertainty of \( \sigma_{CCDE(x,y)} / \sqrt{N} \)

- Similar analysis can give a composite field and composite slit

Linewidth Control Review

- Linewidth control is governed by two factors: the magnitude of a process error and the response of the process to that error
- Not all process errors are linear (e.g., swing curves, focus) nor independent (e.g., focus and dose)
- CD control has concrete impacts on device performance and yield
- CD errors are best characterized using bottom up (sources of variations) and top down (statistical spatial signatures) analysis

Lecture 55: What have we Learned?

- How does transistor gate CD variation affect the device?
- What two generic factors determine the resulting variation in CD?
- Name two process variables that result in quadratic rather than linear CD response
- Explain the difference between bottom-up and top-down CD error analysis