Within-field correlation vs. horizontal/vertical distance,

Dense ELM base case test structure:

Across-wafer variation:

For accurate, useful predictions, Monte Carlo analysis of canonical circuits

Two approaches to address this concern:

• Manufacturing-induced variation in device parameters leads to variability in circuit performance
• Two approaches to address this concern:
  – Tailor IC design to minimize sensitivity to parameter variation
  – Use process control to reduce manufacturing variation
• Both approaches can be investigated through Monte Carlo analysis of canonical circuits
  – Various design styles can be tested for susceptibility to variation
  – Hypothetical control scenarios can be mapped directly into circuit performance space to determine robustness
• For accurate, useful predictions, Monte Carlo framework must model reality very well
  – Specific focus of this work: spatial variation effects (correlation)

Motivation

• Systematic Variation
  – Hypothetical control scenarios can be mapped directly into circuit performance space to determine robustness
  – Tailor IC design to minimize sensitivity to parameter variation
  – For accurate, useful predictions, Monte Carlo framework must model reality very well

• Manufacturing-induced variation in device parameters

• Dense ELM base case test structure:

• Design new test structures to explore mid-range (10-1000 micron) spatial variability

• Submit new test structures for manufacture; gather measurements from fabricated test structures

2005 Main Objectives

• Exhaustive ELM poly-CD measurements (280/field):
  – Standardize each CD measurement, using wafer-wide distribution:
  \[ z_i = \left( \frac{x_i - \mu}{\sigma} \right) \]
  – For each spatial separation considered, calculate correlation \( r \) among all within-field pairs of points using:

\[
 r_{jk} = \frac{\sum z_j z_k}{n}
\]

Departure Point: Spatial Correlation Calculation

EML data provided by Jason Cain, UC Berkeley

Spatial Correlation Results

• Within-field correlation vs. horizontal/vertical distance, evaluated for entire wafer:

• Shape of correlation curve is confounded by non-stationary (systematic) components of variation

Decomposition of Non-stationary Variation Components

• CD variation can be thought of as nested systematic variations about a true mean:

\[
 CD_i = \mu + f_i + w_i + \sigma
\]

Within Field Systematic Variation Component

Within-field variation:

\[
 \text{Scant-}
\]

Field

Polyynomial model of across-field systematic variation

Removing this component of variation will simulate WIF process control

Across Wafer Systematic Variation Component

Across-wafer variation:

One more round of control: die-to-die (D2D) dose control

Eliminating D2D) dose control

Removing WIF, AW, and D2D variation components:

Simulated Full Process Control

• Large(mm-scale spatial correlation is largely accounted for by systematic variation; smallest(jan-scale correlation may still have structure, to be investigated in future work

Test Structure for Mid-Range CD Variation

• 2x10 Probe frame: 100um x 100um pads, 150um pitch

• Dense ELM base case test structure:

• Dummy lines used to extend measurable range, explore effects of pattern density and regularity

Variant ELM submodules

Future Goals

• Milestone M30: Spat. CD Correlation in IC Design

• November 21, 2005: Receive fabricated test structures; begin measurements

• Jan 26, 2005: Perform spatial variation analysis and incorporate results into Monte Carlo framework

• Jan 26, 2006: Evaluate impact of updated variation/correlation models on circuit performance variability using Monte Carlo Framework

Acknowledgments