Statistical Shape Analysis Applied to Microlithography

Alessandra Micheletti 1, Filippo Terragni 2

1 Dipartimento di Matematica - Università degli Studi di Milano, Italy, alessandra.micheletti@unimi.it
2 Dpto. Fundamentos Matemáticos, E.T.S.I. Aeronáuticos, Univ. Politécnica de Madrid, Spain, ficho81@gmail.com

Main Goals

To look for:
• A statistical-geometrical technique (and related software) for random shapes analysis and classification.
• A method to recognize in a robust and automatic way structures on a silicon wafer showing or not well-impressed shapes, thus improving the quality control process of integrated devices.

Mathematical Instrument: Size Functions

Let us consider a pair \((M, \varphi)\) where
• \(M\) is a topological space (sufficiently regular)
• \(\varphi : M \to \mathbb{R}\) is a continuous function, called measuring function.

Definition. We shall call Size Function associated with \((M, \varphi)\) the function
\[
\mathcal{L}(M, \varphi) : \mathbb{R} \to \mathbb{N} \cup \{+\infty\}
\]
defined by setting \(\mathcal{L}(M, \varphi)(x, y)\) equal to the number of equivalence classes into which the set \(M(\varphi \leq x) = \{ P \in M : \varphi(P) \leq x \}\) is divided by the relation of \((\varphi \leq y)\) - homotopy,
where two points \(P, Q \in M\) are \((\varphi \leq y)\)-homotopic if and only if either \(P = Q\) or a continuous path \(\gamma : [0,1] \to M\), joining \(P\) and \(Q\), exists in \(M\) such that \(\varphi(\gamma(t)) \leq y\) for every \(t \in [0,1]\).

Size Functions: Example and geometric interpretation

For \(x < y\), \(\mathcal{L}(M, \varphi)(x, y)\) is equal to the number of arcwise connected components of \(M, \varphi \leq y\) containing at least one point of \(M, \varphi \leq x\).

Size Functions: Main Properties

• For \(x < y\), cornerpoints and cornerlines uniquely determine the value of \(\mathcal{L}(M, \varphi)\) almost everywhere.

Matching distance is robust to shape perturbations

Effects of noise:
• Small displacements of cornerpoints and cornerlines
• Small triangles along the diagonal \(y = x\)

The matching distance compares two size functions by measuring the "cost" of overlapping their sets of cornerpoints and cornerlines, by minimizing the longest movement.

Analysis of “critical” shapes impressed on a silicon wafer

Goal

• “Global” description of a sample of shapes impressed with standard process conditions

Procedure

Sample of images
Clusters of cornerpoints

By computing the size functions related to different images of the same kind of pattern, we obtain clusters of cornerpoints because of the randomness of its shape. Each cluster is formed by one cornerpoint for each image.

Confidence Regions for a “well-impressed” shape

Matching distance
Cluster analysis
and research of outliers

Results and Conclusions: experiments on wafers

• Results consistent with expectations.
• Results have evidenced a higher sensitivity of the shapes to the focus offset variation than to the laser energy.
• Global and objective description of the interpreted shapes, which can improve the quality control process of devices.
• Automatic procedure to recognize structures not showing “well-impressed” shapes.
• Method which can be extended to other structures or applications.

References