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Quality control of silicon wafers by spatial analysis of wafer maps

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1 Background

A wafer map is a pattern of smaller units called cells organized in a two dimensional matrix, or coordinate system. Usually these cells, or chips, represent the final products manufactured from those wafers, such as integrated circuits or sensors. Typically, a wafer map is used for presenting a failure pattern consisting of defected and functional cells of a silicon wafer in a two-dimensional matrix consisting of binary values. Some typical examples of simple failure patterns on wafer maps, based on the examples shown in [1], [2], [3], and [4], are presented in Figure 1.

Yield improvement is a critical issue in the development of electronics manufacturing technology, and facilitating the diagnosis of occurred defects is an important part of this process. Spatial failure patterns presented on wafer maps provide a possible way of searching for the causes of unexpected process variation. In ideal conditions, wafer maps may provide vital guidance in defect diagnosis, making it possible to rapidly determine the potential root causes of defects by identifying patterns [1]. There are a few approaches that are typical in the analysis of spatially clustered wafer maps. Different neural network and clustering algorithms form the foundation of these.

Independent component analysis (ICA) is a statistical method that has been successfully applied to a variety of problems in signal processing [5]. ICA is a method for extracting underlying, fundamental factors or components from multivariate statistical data. It is designed so that it searches for components that are both statistically independent and non-Gaussian [5], which makes it a special method.

2 Aims

The purpose of this study is to find out if it is possible to group wafer maps associated with cell-specific data to enable further actions such as the search for the root causes of bad quality.

3 Materials and methods

3.1. Data

Following the guidelines for typical failure patterns shown in [6], [7], data for this study were artificially generated by creating both systematically occurring defect patterns and random defects and adding these data to a spatial arrangement of cells that is typical for sensor manufacturing. To study the effect of random errors on the extraction of systematically occurring failure patterns, two separate data sets containing 700 samples were constructed, the latter of which was contaminated by random failures (0.5% of cells).

3.2. Independent component analysis

It is assumed here that there are n observed signals (i.e., failure types), FS_1, FS_2, . . ., FS_n in the data, which are linear combinations of m independent components, IC_1, IC_2, . . ., IC_m. The equation for IC_i can be written as:

$$FS_i = a_{i1}IC_1 + a_{i2}IC_2 + \cdots + a_{im}IC_m = \sum_{j=1}^{m} a_{ij}IC_j$$

where i = 1, 2, . . ., n and the a_{ij} are real coefficients (contributions of ICs). The independent components, IC_j, and also the corresponding coefficients, a_{ij}, are unknown.

The statistical model in Eq. (1) is called the independent component analysis model [5]. The ICA model is a generative model that describes how the observed data are generated by a process of mixing the components IC_j. Both IC_j and a_{ij} need to be estimated using the observed data. The starting point for ICA is the assumption that the components IC_j are statistically independent, which can be concluded from non-gaussianity [5].

4 Results

Here, a fixed-point algorithm (Fast-ICA) was used as an implementation of ICA [5]. The analysis was performed using the Fast-ICA toolbox under the Matlab software platform (Mathworks, Natick, MA, USA). The independent components using the data contaminated by 0.5% of random failures can be seen in Figure 2. It can be seen that the set of extracted components follows quite nicely the set of patterns created artificially.

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5 Conclusions

Based on the results it can be concluded that the data analysis by ICA method allows for decomposition of independent, systematically occurring failure patterns from wafer map data. This new information can be used for guiding further study and may lead to more efficient extraction of root causes for quality problems.

References

[1] Hsu C.Y., Clustering Ensemble for Identifying Defective Wafer Bin Map in Semiconductor Manufacturing, Mathematical Problems in Engineering, 2015, Article ID 707358.

[2] Hsu S.C. and Chien C.F., Hybrid data mining approach for pattern extraction from wafer bin map to improve yield in semiconductor manufacturing, International Journal of Production Economics, 2007, 107, 88-103.

[3] Wang C.H., Recognition of semiconductor defect patterns using spatial filtering and spectral clustering, Expert Systems with Applications, 2008, 34, 1914-1923.

[4] Liu C.W. and Chien C.F., An intelligent system for wafer bin map defect diagnosis: An empirical study for semiconductor manufacturing, Engineering Applications of Artificial Intelligence, 2013, 26, 1479-1486.

[5] Hyvärinen A., Karhunen J., and Oja E., Independent Component Analysis, New York, John Wiley & Sons, 2001.

[6] Stapper C.H., LSI yield modeling and process monitoring, IBM Journal of Research and Development, 1976, 20, 228-234.

[7] Taam W. and Hamada M., Detecting spatial effects from factorial experiments: an application from integrated-circuit manufacturing, Technometrics, 1993, 35, 149-160.

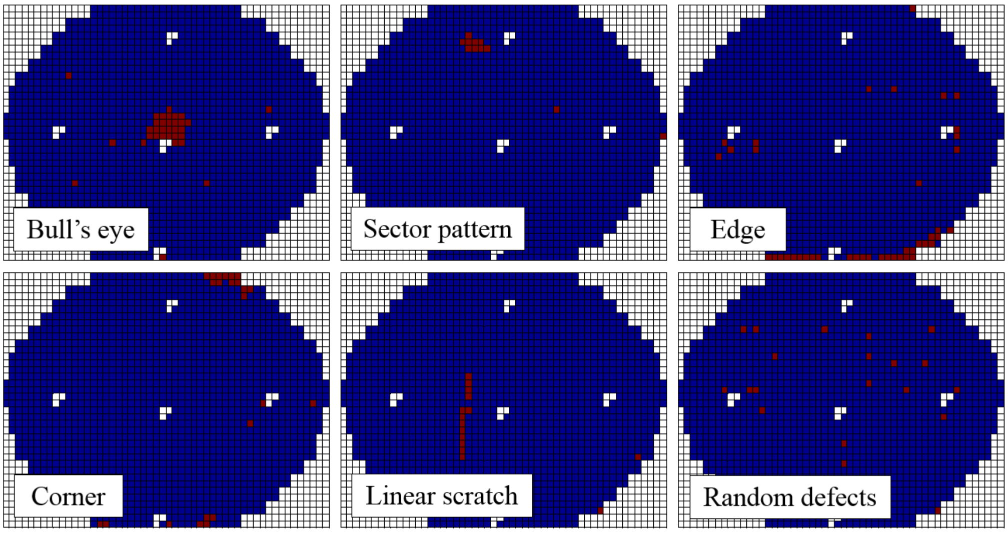

Figure 1: Examples of some typical failure patterns on wafer maps according to literature.

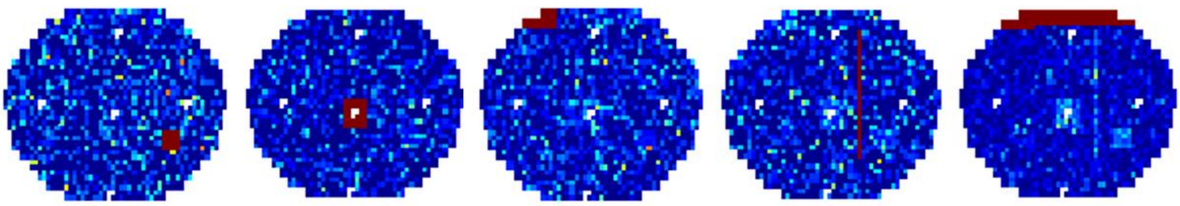

Figure 2: Independent components using the data contaminated by 0.5% of random failures.