Signal Processing 89 (2009) 1511–1520

Contents lists available at ScienceDirect

Signal Processing

journal homepage: www.elsevier.com/locate/sigpro

Defect detection in patterned wafers using multichannel Scanning Electron Microscope

Maria Zontak, Israel Cohen *

The Department of Electrical Engineering, Technion – Israel Institute of Technology, Technion City, Haifa 32000, Israel

ARTICLE INFO

Article history:
Received 16 April 2008
Received in revised form
9 February 2009
Accepted 10 February 2009
Available online 27 February 2009

Keywords:
Semiconductor defect detection
Anomaly detection
Anisotropic kernels
Image reconstruction
Similarity measure

ABSTRACT

Recent computational methods of wafer defect detection often inspect Scanning Electron Microscope (SEM) images of the wafer. In this paper, we propose a kernel-based approach to multichannel defect detection, which relies on simultaneous acquisition of three different images for each sample in a SEM tool. The reconstruction of a source patch from reference patches in the three channels is constrained by a similarity criterion across the three SEM images. The improved performance of the proposed algorithm is demonstrated, compared to a single-channel kernel-based defect detection method.

1. Introduction

Defect detection in wafers is a critical component of wafer manufacturing process. Various image processing techniques have been introduced for automatic defect detection in wafers [1–5]. Here we consider the problem of defect detection in patterned wafers using Scanning Electron Microscope (SEM) images. A wafer is irradiated with a focused beam of electrons directed to scan its surface. The analysis is carried out by moving the focused beam of electrons in a sweeping (raster) scan over the surface of the wafer. The energy exchange between the electron beam and the sample generates the emission of electrons and electromagnetic radiation which can be detected to produce an image. A SEM tool that is manufactured by Applied Materials can simultaneously produce three different images for a given sample, namely $External_1$, $External_2$ and *Internal* images. The external images are acquired by detecting low energy secondary electrons using external detectors placed by the two sides of the electrons beam, and the internal image is acquired by detecting high-energy backscattered electrons with a detector placed above the sample. The external images indicate the topography of the sample by light and shadows as if a "light source" is directed to a sample from top-left ($External_1$) or top-right ($External_2$). The internal image provides information about edges and material of the sample. Fig. 1 shows a SEM tool and examples of $External_1$, $External_2$ and *Internal* images of a patterned wafer. Arrows in the images point to faults in the pattern associated with imperfect connections.

A semiconductor wafer typically contains many copies of the same electrical component (denoted as "dies") laid out in a matrix pattern. A reference set of SEM images for one die is obtained by acquiring images of a random neighboring die, which is verified to be clear of defects. A common approach for defect detection utilizes the reference images for comparison with the inspected (source) images [6–10]. This method does not require a defect learning process, and identifies the defects according to the differences between the source images and their reference images. However, the reference images need to be aligned with the source images, and even if the

* Corresponding author. Tel.: +972 4 8294731; fax: +972 4 8295757.
E-mail addresses: zontakm@tx.technion.ac.il (M. Zontak), icohen@ee.technion.ac.il (I. Cohen).

0165-1684/$ - see front matter
doi:10.1016/j.sigpro.2009.02.010

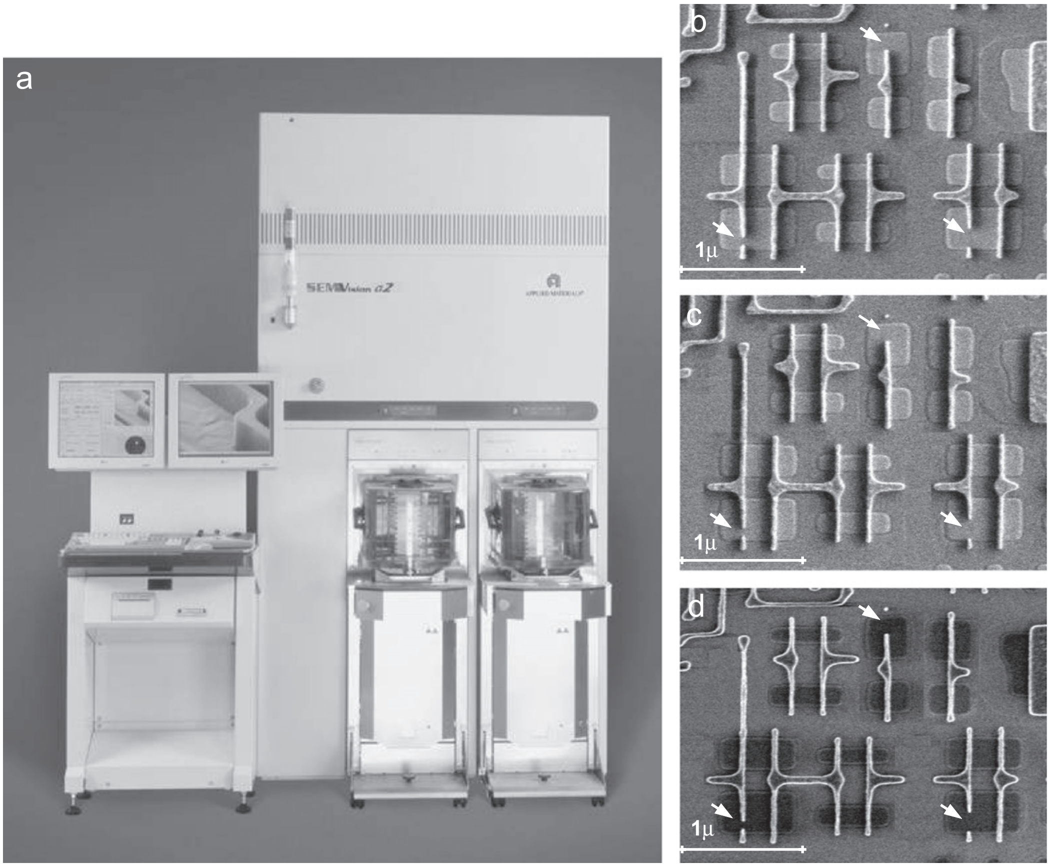

Fig. 1. (a) Scanning Electron Microscope; (b) *External*$_1$ image of a wafer, acquired by a SEM tool from top-right direction; (c) *External*$_2$ image of the same wafer, acquired from top-left direction; and (d) *Internal* image of the same wafer, acquired from top direction. Arrows in the images point to defects.

registration technique (e.g., [11–13]) is perfect, pattern variations between source and reference images may yield large differences that obscure the differences associated with defects.

Recently, we introduced a defect detection procedure, which avoids image registration and is robust to pattern variations [14]. The method is based on anisotropic kernel reconstruction of the source image using its reference image. The source and reference images are mapped into a feature space, where every feature from the source image is estimated by a weighted sum of neighboring features from the reference image. We used patches around pixels as features and showed that patches originating from defect regions are not reconstructible from the reference image, and hence can be identified.

In this paper, we extend the kernel-based approach to multichannel defect detection, which relies on the simultaneous acquisition of three different images for each sample in the SEM tool. The proposed method assumes that if a pattern-originated region in the source wafer is similar to certain regions in the reference wafer, then this similarity is maintained across the three SEM images. Accordingly, the reconstruction of a source patch from reference patches in the three channels is constrained by a consistency criterion that the locations of reference patches, which are most similar to the source patch, are identical in the three channels. We show that the proposed defect detection under constrained multichannel reconstruction is more advantageous than the single-channel defect detection method.

This paper is organized as follows. In Section 2, we briefly review the single-channel kernel-based defect detection method and discuss the motivation for a multichannel defect detection approach. In Section 3, we introduce an algorithm for multichannel defect detection and demonstrate its performance. In Section 4, we address some open issues and future research, and conclude in Section 5.

2. Background and problem formulation

In this section, we review the single-channel kernel-based defect detection algorithm [14], and discuss some of its drawbacks in the case of non-periodically patterned wafers.

Pattern to pattern comparison is the most suitable technique for a SEM-based inspection system. This comparison could be performed by using a reference image that is obtained from another random die of the