# QUALITY ESTIMATION OF SEM WAFER IMAGES

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## ABSTRACT

This paper describes a practical method for image quality estimation. In particular, this method applies to SEM images of VLSI wafers. Wafers are extremely sensitive to electron charging, since they may contain non-conducting materials. This forces utilization of low energy, low-current electron beams and short viewing times. The images generated under these SEM settings are noisy. An automatic inspection machine must use these noisy images as input to a machine vision algorithm in order to navigate on the wafer, locate the line to be measured, and measure it's width. During algorithm development, we encountered the need for an objective measure which can be used to evaluate SEM images.

The development and application such a measure for SEM image quality is described herein. This measure is simple, and facilitates the objective estimation of SEM image quality. It is utilized for evaluation of SEM operating parameters, in order to establish optimal conditions to produce sufficient image quality without damaging the specimen. Experimental results presented show that this measure reflects the same changes SNR (signal to noise ratio) is expected to show following a change in SEM operational parameters.

## INTRODUCTION

Inspection of VLSI wafers during integrated circuit fabrication is becoming increasingly dependent upon utilization of the Scanning Electron Microscope (SEM) as device dimensions are scaled down [4,5]. Presently, since integrated circuits are being fabricated with feature geometries measuring a micron or less, high resolution measurements of device features must be made in-process [4].

The SEM is a major means for non-destructive inspection beyond optical limits for critical pattern dimensions and defect inspection. Previous work with E-beams has shown that sample charging may dramatically distort line width measurement of non-conducting materials. Therefore, it is necessary to use below-critical electron dose and electron energy, which leads to weak signals with low S/N ratio [1,3].

The employment of an inspection system in-process imposes the following system requirements: ability to sense and navigate on the wafer, high precision location of the target to be measured, high speed and ease of operation. Automatic and accurate measurement systems need a pattern recognition technique in order to meet these requirements. SEM image pattern recognition introduces new challenges, due to the difficulties posed by contrast, edge properties, and the higher amount of noise, relative to optical images.

A major obstacle in developing a pattern recognition algorithm for SEM images is low image quality due to low electron energy and dose. The term signal to noise ratio (SNR) is often used in this context as a measure of image noise. However this measure is not applicable in the current case. To compute SNR two images are required: one with, and the other without noise [2]. In the current case, the signal and the noise are intermingled within a given single image, and it is difficult to separate each component.

Images obtained from a SEM are generated by the interaction of the scanning electron beam with the surface of the specimen, and the stimulated emission which is received by the detectors. The contrast in a SEM image is normally due to specimen topography, chemical composition, detector geometry and vacuum conditions. Nevertheless, in most SEM images the information consists mainly of edges. Changing one or more of the above mentioned factors will change edge image (adding noise, lowering contrast). The need to develop a reliable measure of SEM image quality became apparent to us while examining various electron beam energy levels for sufficient signal to noise ratio in the resulting images to allow adequate pattern recognition techniques.

## METHODS AND RESULTS

The method compares edge pixels data to data for pixels in a flat area. In order to accomplish this, local area statistics are used. There are two components of deviation in each local area: a 'signal' deviation due to edge, and a 'noise' deviation. The division of the corresponding standard deviations is the measure we use to compare SEM images under different electron emission parameters.

This measure was tested empirically by adjusting the SEM's operational parameters as follows: 1. increasing probe current 2. increasing electron collection (viewing) time. These two parameters of the SEM affect the number of electrons (events) collected from the specimen, thus affecting the signal to noise ratio proportional to the square root of the ratio of the number of events. Because there was no way to know the absolute SNR, we compared the square root of the ratio between these two SEM settings parameters to our image quality measure ratio (IQM).

Each SEM image was tested three times: The first test utilized a 30x30 pixels window (marked as size 1 in the tables), at a site marked as zone 1 in the tables. The second test utilized a 30x30 window (marked as size 1 in the tables) at another location in the image (marked as zone 2 in the tables). The third test used a 60x60 window (marked as size 2 in the tables), which included both zones 1 and 2. Figures 1-3 show the images and the zones. The three tests ware made in order to observe the effect of different placements of the window, and different window sizes. The results are summarized in tables 1-3.

Linear regression analysis in which the independent variable was SNR ratio and the dependent variable was image quality measure ratio gave $p<0.009$ in all cases. However, the slope, which was expected to be 1.0, deviated slightly from this ideal value. For experiment number 1, the slope was found to be 0.775, for experiment number 2 it was 0.914 and for experiment number 3 it was 0.947. Linear regression in which the dependent variable was IQM1 and the independent variable was IQM2 gave a slope of 0.788 ($p<0.0001$).

## DISCUSSION

The rationale behind our measure is the SEM property which generates an image describing specimen topography.

We show that our measure responds to changes of electron dose and electron energy as signal to noise ratio would, and therefore can be used as a measure of the SEM image quality of silicon wafers. By facilitating maintenance of the minimal image quality necessary, this measure enhances pattern recognition operations.

The results are highly correlated to the expected SNR ratio. This makes this method useful for comparing the quality of images taken under different conditions. The moderate correlation between IQM1 and IQM2, taken from different areas in the image, implies that the window placement should be selected carefully, and suggests that several measures in different locations on the image should be performed. The mean of these would be used as the final measure. Different window sizes (30x30 and 60x60) did not seem to affect the measure, but it is also advisable to keep this size fixed for all measures.

The measure presented in this report is very simple and the implementation and operation of such a program is easy. While simple, it compares information which is very important for machine vision algorithms: the edge information. Noise and edge quality in SEM images greatly influence the performance of pattern recognition techniques [6], therefore a measure of SEM image quality is essential in order to compare results obtained using different algorithms for pattern recognition of wafers SEM images.

Figure 1: SEM image used for the experiments. This image was produced using probe current of 31 pA and 4 seconds collection time. The window size was 30x30 pixels, and was placed in zone 1 on the image. The width of the lines seen in the picture is 1 micron.

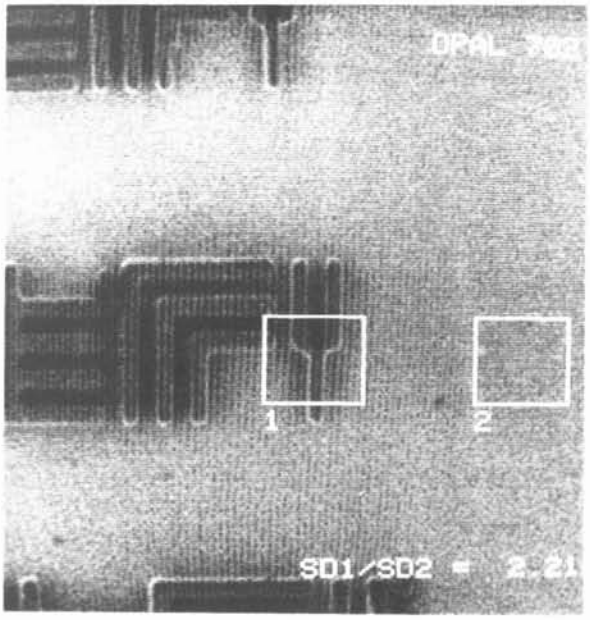


Figure 2: This SEM image was produced using probe current of 9 pA and 4 seconds collection time. The window size was 30x30 pixels, but was placed in different place (zone 2) on the image.

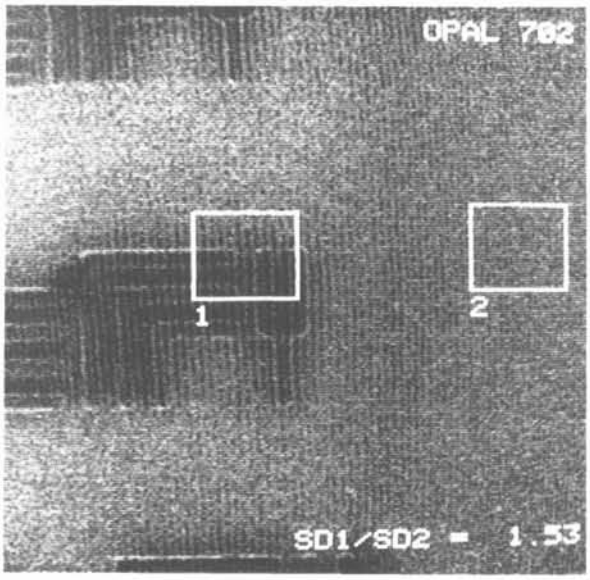


Figure 3: This SEM image was produced using probe current of 31 pA and 4 seconds collection time. The window size was 60x60 pixels.

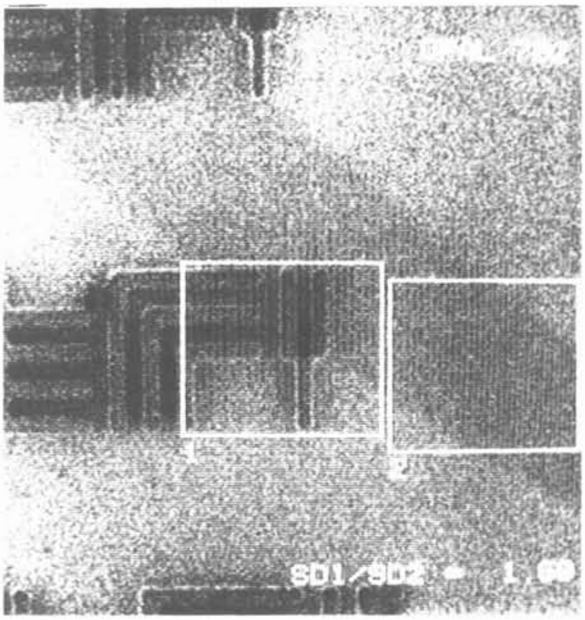


Table 1: results for 4 seconds collection time, varying probe current. Three combinations of window sizes and placements were tested, and the corresponding results are presented as exp. 1-3. Expected SNR ratio was computed by root squaring the ratio between corresponding probe currents.

| probe curr. (pA) | IQM size 1 zone 1 | IQM size 1 zone 2 | IQM size 2 zone 1 | expect SNR ratio | found ratio exp. 1 | found ratio exp. 2 | found ratio exp 3 |
|---|---|---|---|---|---|---|---|
| 9 | 1.31 | 1.53 | 1.46 | | | | |
| | | | | 1.15 | 1.20 | 1.19 | 1.20 |
| 12 | 1.58 | 1.82 | 1.76 | | | | |
| | | | | 1.22 | 1.12 | 1.05 | 1.11 |
| 18 | 1.78 | 1.91 | 1.96 | | | | |
| | | | | 1.10 | 1.13 | 1.18 | 1.14 |
| 22 | 2.01 | 2.26 | 2.23 | | | | |
| | | | | 1.04 | 1.02 | 1.04 | 1.02 |
| 24 | 2.04 | 2.34 | 2.29 | | | | |
| | | | | 1.12 | 1.16 | 1.08 | 1.12 |
| 30 | 2.37 | 2.52 | 2.57 | | | | |
| | | | | 1.02 | 0.93 | 0.98 | 1.00 |
| 31 | 2.21 | 2.48 | 2.56 | | | | |

table 2: Results for 5 seconds collection time, varying probe current. For explenation see legend of table 1.

| probe curr. (pA) | IQM size 1 zone 1 | IQM size 1 zone 2 | IQM size 2 zone 1 | expect SNR ratio | found ratio exp. 1 | found ratio exp. 2 | found ratio exp 3 |
|---|---|---|---|---|---|---|---|
| 9 | 1.53 | 1.53 | 1.60 | | | | |
| | | | | 1.41 | 1.37 | 1.48 | 1.46 |
| 18 | 2.09 | 2.26 | 2.34 | | | | |
| | | | | 1.25 | 1.18 | 1.21 | 1.21 |
| 24 | 2.46 | 2.74 | 2.84 | | | | |
| | | | | 1.14 | 1.16 | 1.19 | 1.18 |
| 31 | 2.85 | 3.26 | 3.35 | | | | |

Table 3: fixed probe current of 31 pA, varying collection time. Three combinations of window sizes and placements were tested, and the corresponding results are presented as exp. 1-3. Expected SNR ratio was computed by root squaring the ratio between corresponding collection times.

| coll. time (pA) | IQM size 1 zone 1 | IQM size 1 zone 2 | IQM size 2 zone 1 | expect SNR ratio | found ratio exp. 1 | found ratio exp. 2 | found ratio exp 3 |
|---|---|---|---|---|---|---|---|
| 2 | 1.67 | 1.81 | 1.82 | | | | |
| | | | | 1.41 | 1.32 | 1.37 | 1.40 |
| 4 | 2.21 | 2.48 | 2.56 | | | | |
| | | | | 1.12 | 1.29 | 1.31 | 1.30 |
| 5 | 2.85 | 3.26 | 3.35 | | | | |

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