THROUGH FOCUS SIGNATURE ANALYSIS FOR NANO FEATURES

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Abstract: *Semiconductor device fabrication process is the most sophisticated and complex manufacturing process. Advances in the manufacturing processes has brought down the feature size of gate to as low as 22 nm. Hence there is a great demand for process control of feature dimension below the resolution limit of visible wavelength microscopy. Lot of research has been focused on increasing the resolution of the metrology tools. We have adopted a novel optical technique that shows nanoscale measurement sensitivity using conventional optical microscopes. Here through-focus images are acquired at different focus positions. These focused and defocused images are used to build an intensity map whose signature reflects the target pattern. This technique is used to identify relative nanoscale change in dimension between two targets by finding the change in the signature of the intensity map.*

Keywords: *Through Focus Imaging, Focus Metric, Through Focus Signature, CD Metrology, Nano Metrology, Diffraction Limit*

1. INTRODUCTION

With advanced patterning effort, various advanced metrology tools are evolving. Conventional optical microscope is generally considered to be not suitable for measurements less than half the wavelength of visible light. This paper presents an innovative 'Through Focus Imaging Technique' to analyse grating structures on silicon wafer. We demonstrate that this method captures the nanometric variation in line width and line height of the Si grating. Here images are acquired as the Si grating target is moved along the focus direction. This method is found to be relatively simple and inexpensive and provides nanoscale dimensional sensitivity. This technique is adopted in digital camera for auto focus. Also confocal microscopy adopts this technique to build the 3D shape.

Scanning Electron Microscope (SEM) is the primary method used for line width measurement in microelectronic manufacturing. However, CD SEMs are relatively slow and not suited for in-situ measurement. The sensitivity of ellipsometric measurements to the topography of diffraction gratings has been recently explored as a metrology tool due to the development of computer modelling tools for quantitative data analysis. However Specroscopic Elipsometry at near-normal incidence is reported to be advantageous for topographic analysis of periodic gratings [1]

2. CONCEPT OF THROUGH FOCUS IMAGING

Generally image based measurement system work with focussed image with well-defined edges. When measurement resolution goes below the resolvable limit of optical microscope, the edge based measurement will not yield meaningful results. The light that is scattered off the structure contains the information of pattern geometry (line width, line height, side wall angle and pitch). Hence it is more appropriate to collect the entire scattered light in and around the focus by an appropriate image sensor. By bundling the focussed image with set of de-focussed images we get an extended intensity map (signature) of the grating structure that truly reflects the dimensional details of the structure. It is claimed to increase lateral and vertical measurement resolutions over optical microscopy matching atomic force microscopy and scanning electron microscopy [2]. With this method conventional optical microscope could be transformed into a nano metrology tool. The rest of the paper focuses on the above concept and shows the dimensional sensitivity to nanoscale feature variation using line gratings with varying line width, line height on a silicon wafer

3. EXPERIMENTAL SETUP

The developed system consists of bright field microscope, a digital camera, piezo controlled focus stage for sample movement. Further instead of processing a single image at best focus, set of through focus images are captured as the sample is moved along the focus position at every equal interval of 0.1 µ.

Following the optical settings used for the experiment

- Halogen light source for homogeneous illumination of the sample (Kohler illumination)
- Magnification is set at 1000X
- Collection numerical aperture is set at 0.9 and illumination numerical aperture at its minimum.

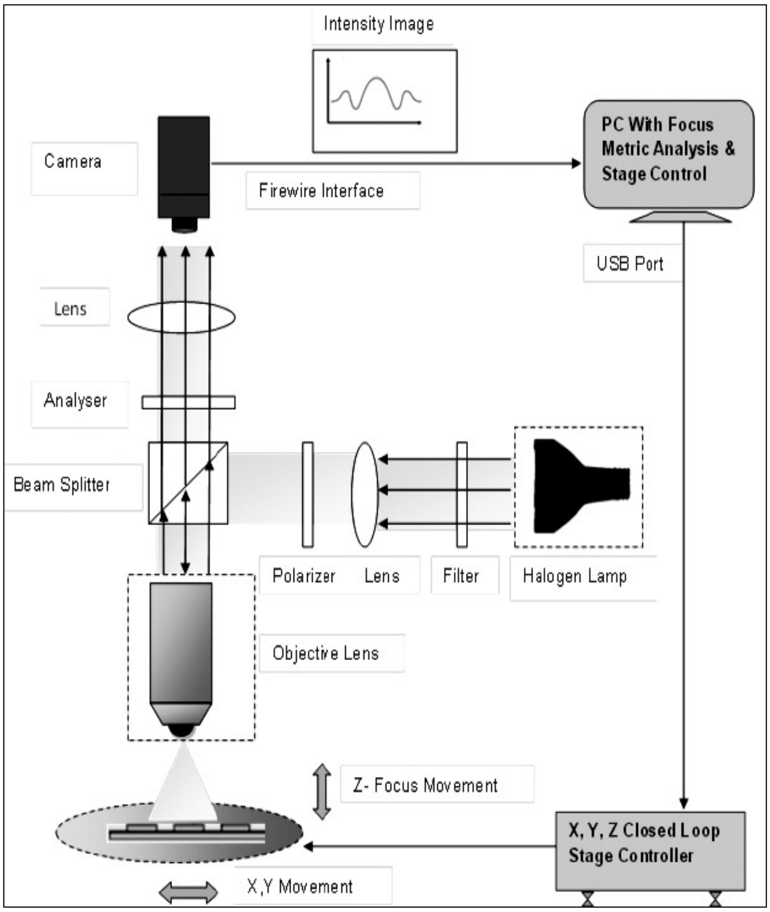

Fig 1. Experimental Setup for TSOM

Sensitivity to change in a feature is a critical issue. Hence to simplify the sensitivity analysis the parameter not of measurement interest is kept constant while the quantity to be measured is varied. A single line grating is created on silicon wafer using 'Focus Ion Beam'. Two set of samples are taken for analysis, one with varying line width keeping the line height constant and the other with varying line height keeping the line width constant.

4. SENSITIVITY OF THE FOCUS METRIC TO FOCUS POSITION

As the sample is moved through the focus, images are acquired at different focus position. The intensity profile captured at each focus position. Focus position is the distance from the objective lens to the substrate or the feature top. Focus metric is measure of intensity parameter like Contrast, Total Intensity Standard Deviation, Laplace and Gradient Energy [3]. The focus metric algorithm calculates a focus metric value for an image at every focus position. Now in this process the image intensity is reduced to a numerical value called focus metric. The developed algorithm computes various focus metric. However the results reported in this paper are restricted to only standard deviation.

The standard deviation is defined as the standard deviation of the image pixel values from the mean of all included pixels. It is computed by the following equation.

$$s = \sqrt{\frac{\sum \left| I_{xy} - \bar{I} \right|^2}{n-1}}$$

Focus metric algorithm is applied to a selected ROI. Fig 2 shows the variation of different focus metric values with respect to focus positions for single line grating on Si. It is clear from the plot that at best focus the most of the focus metric values reach the peak. Hence the focus metric can be used as a measure to get the best focus position during auto focus. Also it is found that the through focus response shows a strong sensitivity to change in line width.

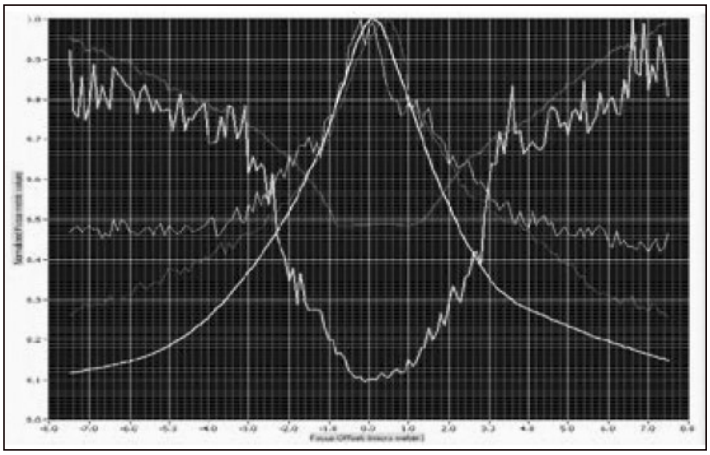

Fig 2. Focus Metric Plot for Single Line Grating

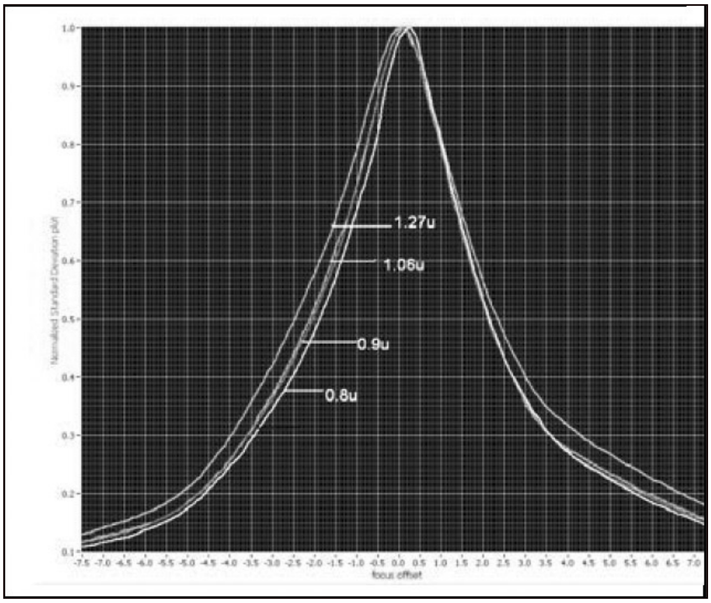

Fig 3. Focus Plot for a Single Line Grating Structure

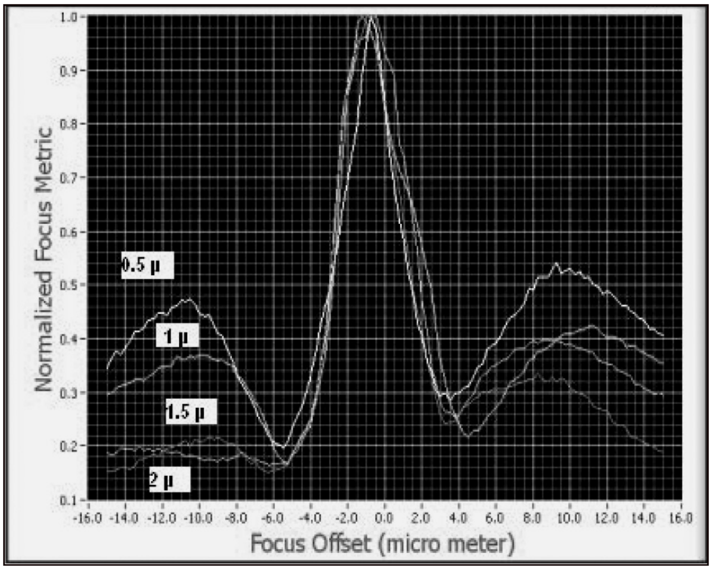

Fig 4. Focus Plot for Multi-Line Grating Structure

Fig. 3 shows focus metric plot for a single line grating for varying line width. Fig. 4 shows the same for multi-line grating structure for varying line width. In both the cases the line height is kept constant as 500nm.

It is clear from the plot that the single line grating has a single peak whereas the multi-line grating structure gives rise to multiple peaks [4]. Also it is found that at focussed position focus metric value reaches the peak and it is the case even if the line width is changed. The variation in line width is showing up the deviation in the side lobes or on both positive and negative de-focussed position.

5. THROUGH FOCUS SCANNING OPTICAL IMAGE (TSOM)

In the case of focus metric analysis every image detail is converted into a numerical value called focus metric and its response to focus position is recorded that reveals sensitivity to nano scale dimensional variation. In an alternative method optical images are acquired as the sample is moved through the focus of the microscope at very 100nm (along the Z axis). The intensity profile along a line of interest is extracted from each image at different focus position. These intensity profiles are stacked at the respective focus position to form a 2 dimensional intensity map where x represents the spatial position of the sample in x direction and z represents the corresponding focus position. This intensity map (the XZ plane) contains the entire scattered light information in and around the focus position along the selected line ROI. This could be extended to create a 3D intensity map. The signature of this intensity map depends on the sample features and the optical parameters like wavelength, illumination numerical aperture. By keeping all the optical parameters constant the variation in the signature is directly related to nano scale variation in the sample feature.

Fig. 5 a and b show TSOM image for single line grating with 100nm variation in line width

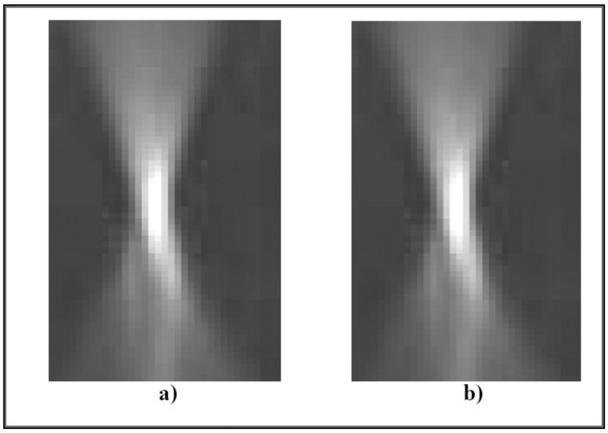

Fig 5. TSOM Image; LD=0.5µ a)LW=0.8µ, b) LW=0.9µ

Fig. 6 a and b show TSOM image for single line grating with 160 nm variation in line width.

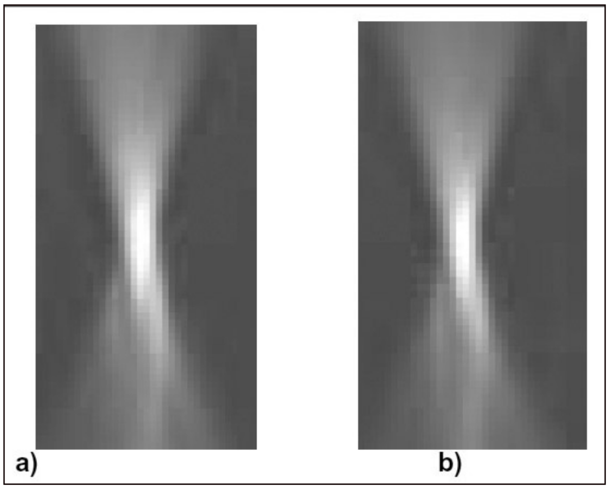

Fig 6. TSOM Image; LD=0.5 µ a)LW=1.06 µ, b)LW=0.9 µ

Fig. 7 a and b show TSOM image for single line grating with 50nm variation in line depth.

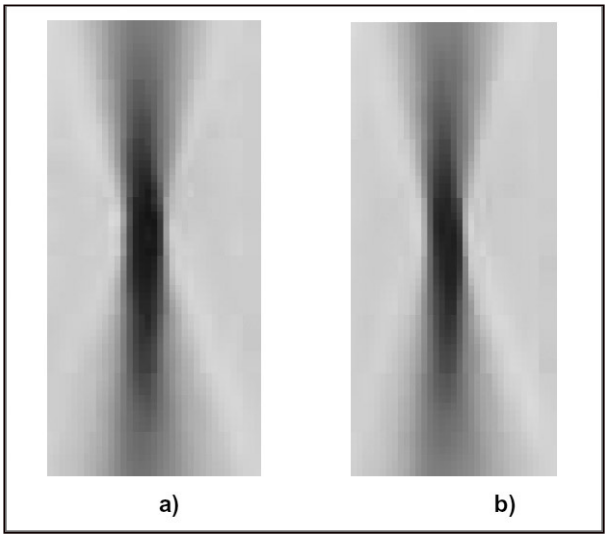

Fig 7. TSOM Image; LW=0.82 µ a)LD=0.5 µ b)LD=0.55 µ

Fig. 8 a and b show TSOM image for single line grating with 100nm variation in line depth.

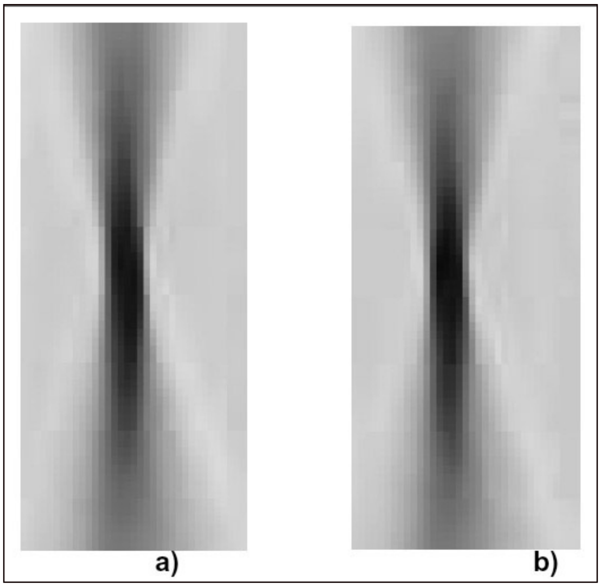

Fig 8. TSOM Image; LW=0.82 µ
a) LD=0.55 µ b) LD=0.65 µ

6. ANALYSIS OF TSOM IMAGE

In TSOM image the entire optical information is retained unlike focus metric computation method where the image intensity is converted to a single numerical parameter called focus metric. Hence it is expected that TSOM image analysis will yield results more closer to the actual scenario. Change in dimension results in corresponding change in TSOM image signature. When the change in dimension is in nanometer scale, it is difficult to identify the difference in signature of the TSOM image. However the differential TSOM image reveals the change in signature distinctly.

7. ANALYSIS OF FEATURE VARIATION THROUGH DIFFERENTIAL TSOM IMAGE

The differential TSOM image is computed by first correlating the two TSOM image and then finding the difference between the two TSOM images. This differential TSOM image truly represents the dimensional difference between the two samples. The differential image is quantified by finding the mean difference between the two corresponding TSOM images. It is given by

$$MD = \frac{1}{N}\sum_{i=0}^{n}(A_i - B_i)$$

Where N is the total number of pixels in the

Table 1: Mean Difference for Samples with Varying Line Width

LW Sample 1	LW Sample 2	Difference	MD
0.9 µ	0.8 µ	0.1 µ	1.839
1.06 µ	0.9 µ	0.16 µ	2.279
1.27 µ	1.06 µ	0.21 µ	2.929
2.11 µ	1.90 µ	0.21 µ	2.930
1.27 µ	0.9 µ	0.37 µ	3.322
1.69 µ	1.27 µ	0.42 µ	5.168
2.11 µ	1.69 µ	0.42 µ	5.300

Table 2: Mean Difference for samples with varying Line Depth

Line Depth	Line Depth	Difference	MD
550 nm	500 nm	50	2.389
650 nm	550 nm	100	2.502
650 nm	500 nm	150	3.265

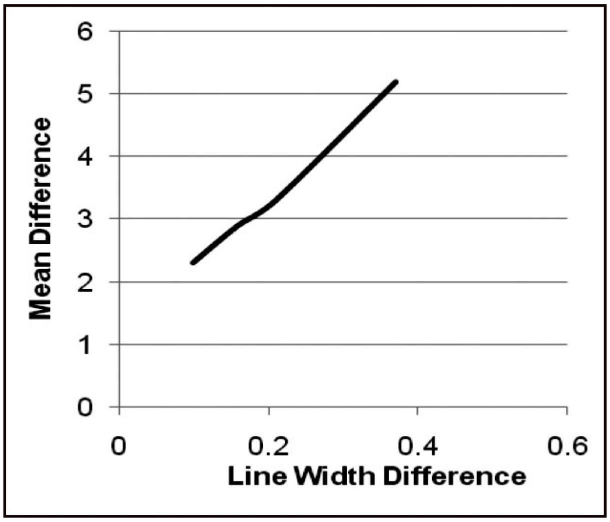

Fig 9. Change in Line Width Vs. Mean Differences

TSOM image, A and B are the two TSOM images. Table 1 and Table 2 give the mean difference computed for varying line width and line depth. Fig. 10 a and b show the differential TSOM image for 100nm change in line width and line depth

All the above experiments were conducted with wavelength λ = 546nm, numerical aperture at 0.9 and illumination numerical aperture at its minimum. The software is developed in Labview

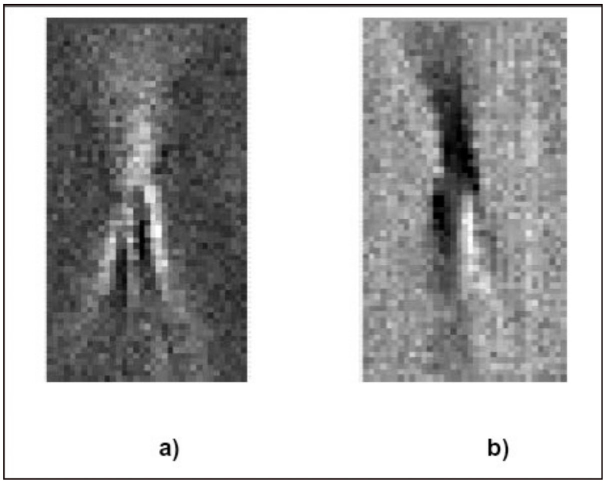

Fig 10. DTSOM Image a) 100nm Change in Line width 100nm Change in Line Depth

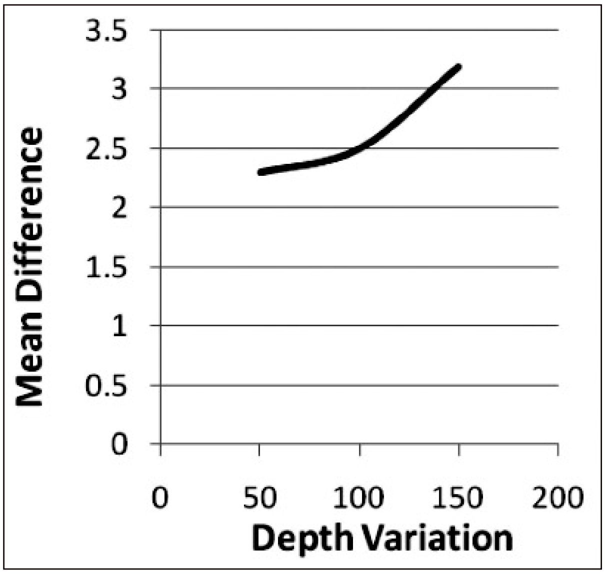

Fig 11. Change in Line Depth Vs. Mean Difference

that includes the following features

- X, Y, Z and Rotary Stage ControlImage acquisition & Automatic Focusing
- Auto Sequencing (Move, Acquire,& Extract data)
- Development of various focus metric algorithms
- Analysis of dimensional sensitivity using focus metric
- Development Through focus intensity map(TSOM Image)
- Computation of differential TSOM and mean difference to quantify the dimensional variation

7. CONCLUSION

TSOM is relatively a simple and inexpensive method to analyse nano features. This technique facilitates identification of the dimensional difference between two nano-sized targets and the ability to derive the actual target dimension using a library matching method [6]. It is observed through experimentation that the intensity image of a structured target contains certain significant information called 'focus metric' that varies as the target is moved through focus. These focus metrics are sensitive to the dimension of the target. Its response to nano level dimensional variation in the line grating structures are evaluated and reported in this paper. Also by an alternative method of generating complete 3D intensity map, the nano level sensitivity is demonstrated. The TSOM setup requires a controlled atmosphere (temperature, humidity and vibration) and properly set optical conditions in order to ensure accurate measurement result. All the experimental results reveal nano level sensitivity with this simple, inexpensive and innovative through focus imaging technique.

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