Inspection of Directed Self-Assembly Defects

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ABSTRACT

Directed Self-Assembly (DSA) is considered as a potential patterning solution for future generation devices. One of the most critical challenges for translating DSA into high volume manufacturing is to achieve low defect density in the DSA patterning process. The defect inspection capability is fundamental to defect reduction in any process, particularly the DSA process, as it provides engineers with information on the numbers and types of defects. While the challenges of other candidates of new generation lithography are well known (for example, smaller size, noise level due to LER etc.), the DSA process causes certain defects that are unique. These defects are nearly planar and in a material which produces very little defect scattering signal. These defects, termed as “dislocation” and “disclination” have unique shapes and have very little material contrast. While large clusters of these unique defects are easy to detect, single dislocation and disclination defects offer considerable challenge during inspection. In this investigation, etching the DSA pattern into a silicon (Si) substrate structure to enhance defect signal and Signal-to-Noise Ratio (SNR) is studied. We used a Rigorous Coupled-Wave Analysis (RCWA) method for solving Maxwell’s equations to simulate the DSA unique defects and calculate inspection parameters. Controllable inspection parameters include various illumination and collection apertures, wavelength band, polarization, noise filtering, focus, pixel size, and signal processing. From the RCWA simulation, we compared SNR between “Post-SiN etch” and “Post-SiN+Si-substrate etch” steps. The study is also extended to investigate wafer-level data at post etch inspection. Both the simulations and inspection tool results showed dramatic signal and SNR improvements when the pattern was etched into the SiN+Si substrate allowing capture of DSA unique defect types.

Keywords: Directed self-assembly, DSA defects, Defect simulation, Inspection signal simulation

1. INTRODUCTION

Detection of DSA unique defects is a key to improving defect density for eventual production use. Because DSA specific defects such a single dislocations are very small, and the layer is very thin, composed of a material which does not scatter much, they are difficult to detect with conventional inspection methods.

The concept of pattern transfer of a low signal producing layer into a more high scattering material was first explored by young-Yong Cho et al [1] for EUV lithography. In this work, a method to enhance DSA defect signal and SNR by etching into a Si substrate is studied. The main purpose of this investigation is to develop the best inspection parameters for which we used an internally developed electro-magnetic (EM) simulator to determine the best optical inspection parameters for the KLA-Tencor 2915 broadband plasma inspector. We also compared the simulated SNR to the inspection results on single dislocation type defects.

2. SIMULATION

The top view of the DSA pattern is a simple line and space array as shown on the top right of Figure 2. The critical dimension (CD) of the line is 14nm and the pitch is 28nm, with a line/space ratio of 1:1. This clip represents the typical
2.1 Simulation Flow

Prior to starting the EM simulation for solving Maxwell equations, we prepared models of the nominal pattern, layer thicknesses, a line edge roughness (LER) wafer noise model, and defect shapes. Each of them has parameters of material n/k across the wavelengths used with the 2915 wafer inspection tool. The RCWA code first solves the electro-magnetic fields in the wafer and outputs the amplitude and phase in the farfield. Then we apply the 2915 tool properties for inspection, such as wavelength band, light budget, numerical aperture (NA), apertures, polarization, pixel size, inspection speed, tool noise, and so on, to calculate optical images of nominal pattern, wafer noise, and defects by applying these optics and inspection tool conditions. After processing the images, we can calculate the expected signal and SNR for possible inspection tool parameters.

![Simulation Flow Diagram](http://proceedings.spiedigitallibrary.org/)

2.2 Stack Model

The bottom of Figure 2 shows the film stack model after the DSA pattern transfer into a 14nm thick SiN layer which is etched. Then the next process step is to use the SiN pattern and etch into the Si substrate to a depth of 25nm. In this etch process, the SiN is partially consumed and we assumed the remaining depth as 5nm.
2.3 Wafer Noise Model

The top left of Figure 2 shows wafer noise model which we based on SEM observation of the etched wafer. The model we use generates a random LER pattern with statistics of a 0.5nm line-edge roughness and a 50nm correlation length. We used the same LER model for the SiN etch and the SiN/Si etch simulations even though the etch process may smooth out the roughness to some extent. For the SiN/Si etch simulation, the same LER profile is applied for both SiN and Si layer as we did not have enough data on LER for these layers.

![Wafer Noise model](image)

Figure 2. Stack and wafer noise model

2.4 Defect Models

Figure 3 shows the defect models for the single dislocation and the island defect after the Si substrate etch. These models are developed from SEM images which are not shown in this figure. On our wafers we noticed a defect which is neither dislocation nor disclination and hitherto not discussed in the DSA literature. We named it an ‘island defect’ which is shown in the right hand side of Figure 3. The detection of island defect is as challenging as single dislocation.

We attempted to duplicate the full nature of the DSA defects that spread to adjacent lines well beyond the center of the defect by bending these lines. While these simulations are specific to these exact shapes, we expect that the results will identify inspection parameters that are useful for other shaped defects as generally the layer materials and thickness are most important for the inspection parameters. We used the same shapes for the etched SiN and the etched into Si substrate.

![Defect models](image)

Figure 3. Defect model
3. SIMULATION RESULTS

3.1 Signal to Noise Ratio (SNR) comparison between after SiN etch versus SiN+Si substrate etch

SNR is one of major parameters to evaluate defect detectability. A comparison of SNR between “Post SiN etch” and “Post SiN +Si substrate etch” indicates how much improved detectability can be expected between the two processes. Our simulation results, shown in Figure 4, indicate that the SNR (as a function of wavelength) is dramatically improved by >10 times for the “etched Si substrate” compared to the “SiN only etch”. The SNR reached the detectable level which is SNR > 1.3 for the 2915 wafer inspection tool operating in the brightfield optical mode. Defect signal intensity is also shows improvement >10 times as shown in Figure 5. This means we can separate defect signal and noise easily. The simulator predicts that the shorter wavelength bands on the 2915 should be the most effective.

Figure 4. Defect SNR comparison between post SiN etch and SiN+Si etch on each defect type

Figure 5. Defect Signal intensity comparison between post SiN etch and SiN+Si etch on each defect type

3.2 Apertures and pixel size evaluation

Aperture and pixel size are key factors to define inspection sensitivity. The 2915 inspector has a range of available apertures and pixel sizes to optimize inspection sensitivity. Figure 6 compares simulation of apertures and pixel sizes for the single dislocation and island defects. The simulation predicts that “aperture 6” with a 50nm pixel size has the best SNR on both of defect types. Inspection results using this mode are reported later in this paper.
4. WAFER INSPECTION

The post-etch wafer inspection was performed with the 2915, a new broadband plasma patterned wafer defect inspector. Second-generation laser pumped plasma technology on this inspector produces higher light intensity which can help with detection of subtle defects on low contrast materials. On small DSA-dislocation defects, under equivalent optical conditions, the 2915 demonstrated high capture rate because of the improved SNR (4.8 on 2915 vs. 2.1 on the previous-generation 2835 inspector). The new apertures and inspection modes, together with flexible apertures enable detection of very small defects and their unique wafer signatures.

The typical methodology used in inspection recipe setup on defect inspection tools is to identify “candidate defects” using a sensitive pre-inspection built from knowledge base. A higher percentage of false defects is acceptable at this stage since the purpose is to find candidate defects. Using defect review SEM the wafer is analyzed thoroughly and candidate defects are selected and identified through their unique defect coordinates. On this initial inspection, we identified two single dislocation-type defects which are shown in figure 7. The single dislocation we would like to detect is very close in appearance to these defects and therefore we performed detailed “optics characterization” on these two defects. It is our belief that if we identify optical parameters that will enhance detection of these two candidate defects, the probability of detection of single dislocation and disclination is very high, considering the fact that our post-etch signal strength and SNR are 10X greater. The signal strength and SNR were extensively studied using multiple wavelength bands, apertures, polarization, pixel size, focus and scan speed and the optimum settings were determined.

Figure 7. Defect sample SEM image for optics characterization
4.1 Signal to Noise Ratio (SNR) comparison between simulation and tool

Our simulation tool has the capability of predicting SNR for the tool’s various wavelength bands (as shown in the left-hand side of Figure 8). The optimum settings determined from experiment shown in the right-hand side of Figure 8 matches quite well simulation results. It appears that SNR is better in DUV band compared to UV band in simulation and experiment.

![Simulation Result vs Defect Signal on Wafer](image)

Figure 8. Simulation result for single dislocation and wafer-level tool data comparison

4.2 Wafer inspection result with best mode from the simulation

A recipe was generated with the best optical mode obtained from simulation and the full “SiN + Si etch wafer” was inspected. Review was performed using KLA-Tencor’s eDR-7000 review SEM. Due to high defectivity, we reviewed a single row where 939 defects were classified. We were able to successfully find single dislocation defects (Defect ID 6285 and 6459). The patch images from the 2915 for these two defects show clear defect signals, as seen in Figure 9.

![SEM image and 2915 image](image)

Figure 9. Wafer inspection result with best mode on simulation

The reviewed defects were also classified and a defect Pareto was generated (Figure 10). In addition to dislocation defects and clusters, this mode also detected “single open” defects that are very small and of unknown origin. As shown in the Pareto, only two single dislocations were captured. The patch image on 2915 showed very strong signal as shown in the right-hand side of the Figure 9. From this we conclude that our recipe has enough sensitivity and would have
5. SUMMARY

Etching the DSA pattern into a Si substrate improves the defect SNR of small dislocation defects >10 times compared to the DSA pattern just etched into SiN. The simulations we ran predicted this dramatic improvement using the 2915 wafer inspection tool parameters. The simulation SNR prediction shows good correlation to the KLA-Tencor 2915 inspection results for the single dislocation type defect. Also by using the best combination of aperture and pixel size from the simulation, i.e. Aperture6 and 50nm pixel size, the 2915 could detect small dislocation defects. In this experiment, the inspected area (single row) is equal to 3.66 sq cm. We found 939 defects and reviewed 100% of the defects. We found only 223 defects are DSA-specific. Hence our conclusion is that the defect density of dislocation-type DSA defects in the current process = [223/ 3.66] = 61 defects per sq cm.

6. CONCLUSION

Etching the DSA pattern into the Si substrate to a depth of 25nm is very effective to improve defect SNR to facilitate wafer inspection for DSA unique defects that are small, on a thin, low scattering material. This decoration effect boosts the inspection signal strength and SNR which helps us to understand defectiveness of the DSA process, helping to accelerate the path to reduce defectivity.

KLA-Tencor 2915 platform has the capability to detect these unique DSA defects and in our estimate DSA unique defect density in their process is approximately 61 defects / sq cm.
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REFERENCES

[1] Kyoung-Yong Cho; Joo-On Park; Changmin Park; Young-Mi Lee; In-Yong Kang; Jeong-Ho Yeo; Seong-Woon Choi; Chan-Hoon Park; Steven R. Lange; SungChan Cho; Robert M. Danen; Gregory L. Kirk; Yeon-Ho Pae “The analysis of EUV mask defects using a wafer defect inspection system” Proc. SPIE 7636 (2010)