Metrology of micro-step height structures using 3D scatterometry in 4xnm advanced DRAM

Mason Duan*[a], Clark Chen[b] .Calvin Hsu[b]
[a]INOTERA MEMORIES. INC. Hwa-Ya Technology Park 667, Fuhsing 3 Rd.,Kueishan, Taoyuan, Taiwan,R.O.C
Elvis Wang[a], ZhiQing Xu[a], Elsie Yu[b], Qiongyan Yuan[b], Sungchul Yoo[b], Zhengquan Tan[b]
[b]KLA-Tencor Corporation, One Technology Drive, Milpitas, CA, USA 95035

ABSTRACT

As DRAM design rules scale below 4Xnm, controlling the micro-step height caused by the etching process after patterning becomes more critical because it affects the post Chemical Mechanical Planarization (CMP) process window and furthermore affects yield. In this study, the latest Multi-Azimuth angle capability of Scatterometry Critical Dimension (SCD) was used to analyze the model of the micro-step height of nitride. SCD results were verified with Atomic Force Microscope (AFM) measurements.

Keywords: scatterometry, azimuth angle, metrology, step height, CD, etch, process control, memory

1. INTRODUCTION

SCD technology is widely used in metrology measurements for in-line process control of CMOS and DRAM devices. It measures complex features and structures at poly gate, shallow trench isolation, and other advanced processing layers at the 130nm node and beyond [1-6, 11]. In general, SCD has three main advantages: (1) It provides a fast time to result compared to cross-section Scanning Electron Microscopy (X-SEM), Transmission Electron Microscope (X-TEM) or AFM measurement; (2) It is nondestructive; (3) It is precise and has a small total measurement uncertainty (TMU) [6-8]. Recently, 3D SCD monitoring of contact and via holes, based on measurements of cell areas or proximity structures in the grating pad, is maturing [9, 10]. The reason for migrating measurements to 3D cell areas or proximity structures is to reduce the loading effect caused by critical dimension (CD) differential from grating area to cell area. This phenomenon is especially severe for micro-CD measurements like the micro-step height measurement in this study.

As structure complexity increases, metrology to characterize and control such structures becomes more challenging. Scatterometry has consistently been improved since its introduction. However, SCD is susceptible to correlation (convolution) among critical measurement parameters, thus reducing its applicability [11]. In this study, the latest Multiple Azimuth angle (Multi-AZ) methods of SCD were utilized. The results show that using Multi-AZ (0, +90) improved measurement precision, increased tool sensitivity and ultimately reduced the undesirable correlation among measurement parameters.

As DRAM design rule scaling continues below 4Xnm, micro-step height control is becoming more critical. Micro-step height is determined by the etching process after patterning, and improper control of this feature will affect the post-CMP process thus impacting yield. Figure 1a shows a simplified DRAM structure that was formed at Inter-Layer Dielectric (ILD) after photo patterning. Etching and wet cleaning followed, to form contact hole. The micro-step height of nitride was determined after photo exposure, oxide After Clean Inspection (ACI) and wet clean. Figure 1b shows the structure formed by poly deposition. It shows how micro-step height affects poly CMP process control. If the micro-step height of nitride is too high, it will cause poly CMP under-polish and lead to poly shorts in the following process. In contrast, if the micro-step height of nitride is too low, it will cause poly CMP over-polish and will lead to via opens in the following process. It is therefore very critical to control the micro-step height of nitride, especially in the pilot run stage of a new process or design rule.

Metrology, Inspection, and Process Control for Microlithography XXV, edited by Christopher J. Raymond,
Proc. of SPIE Vol. 7971, 79712J · © 2011 SPIE · CCC code: 0277-786X/11/$18 · doi: 10.1117/12.881322

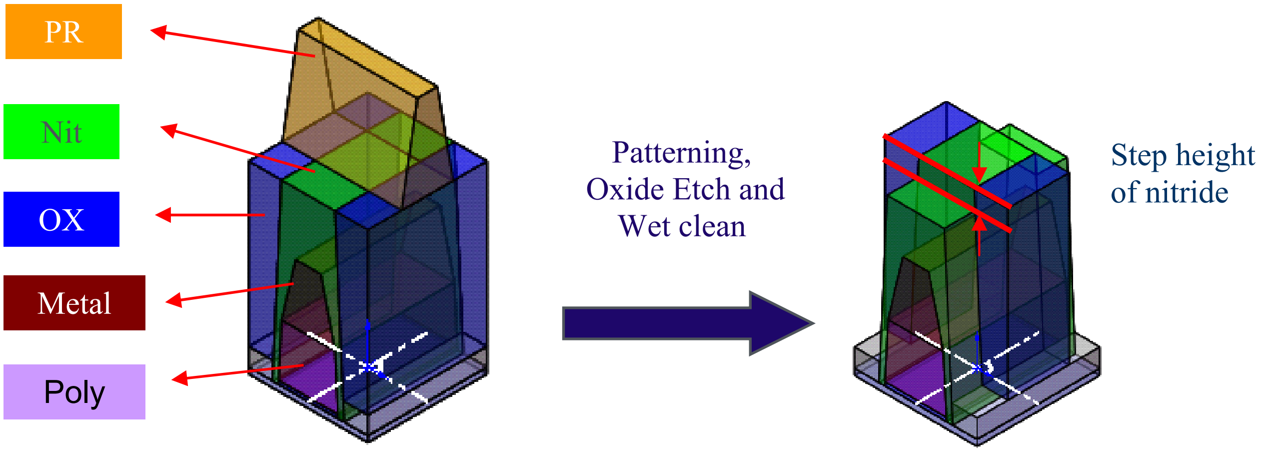

Figure 1a. A simplified DRAM structure, formed at ILD. The micro-step height of nitride is revealed after patterning, oxide etch and wet clean.

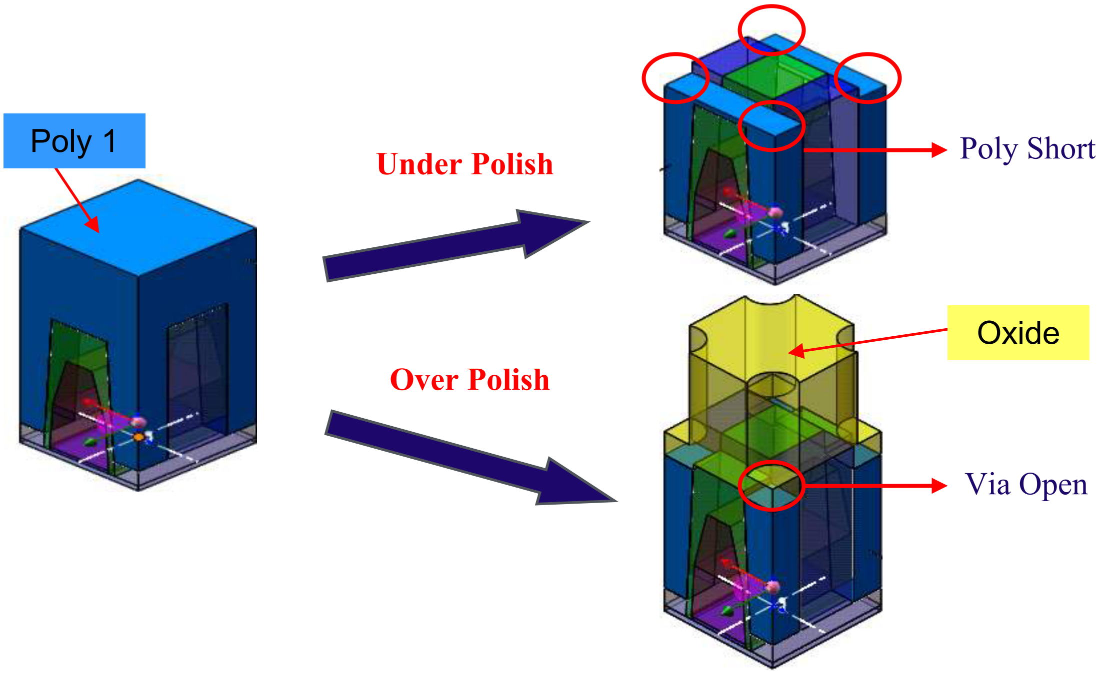

Figure 1b. Structure formed by poly deposition, and the effect of micro-step height on poly CMP process control.

2. DESCRIPTION OF METROLOGIES

2.1 Scatterometry

Scatterometry is a valuable metrology measurement technique because of its high throughput, low relative cost and small TMU. Scatterometry is an optical method in which the 0th order reflected light from a regular array is collected and analyzed. The KLA-Tencor SpectraCD™ metrology system with the latest SCD modeling software, AcuShape™, was used in this experiment. Figure 2 shows an overview of the scatterometry measurement process. Basically, a grating is illuminated with broad-spectrum polarized light and the spectrum is measured through a second polarizer. Ellipsometric values α and β are extracted as a function of wavelength. These are called the measured spectra, which are then compared to an existing group of theoretical spectra (referred to as the library). The theoretical spectra are typically generated prior to measurement using known information about the sample. Such information includes: film optical constants, the period of the features and the profile characteristics. Parameters describing the sample are varied, and a theoretical spectrum is generated for each set of parameter values. The measured spectrum is then compared to the set of theoretical spectra to determine best-fit parameter values.

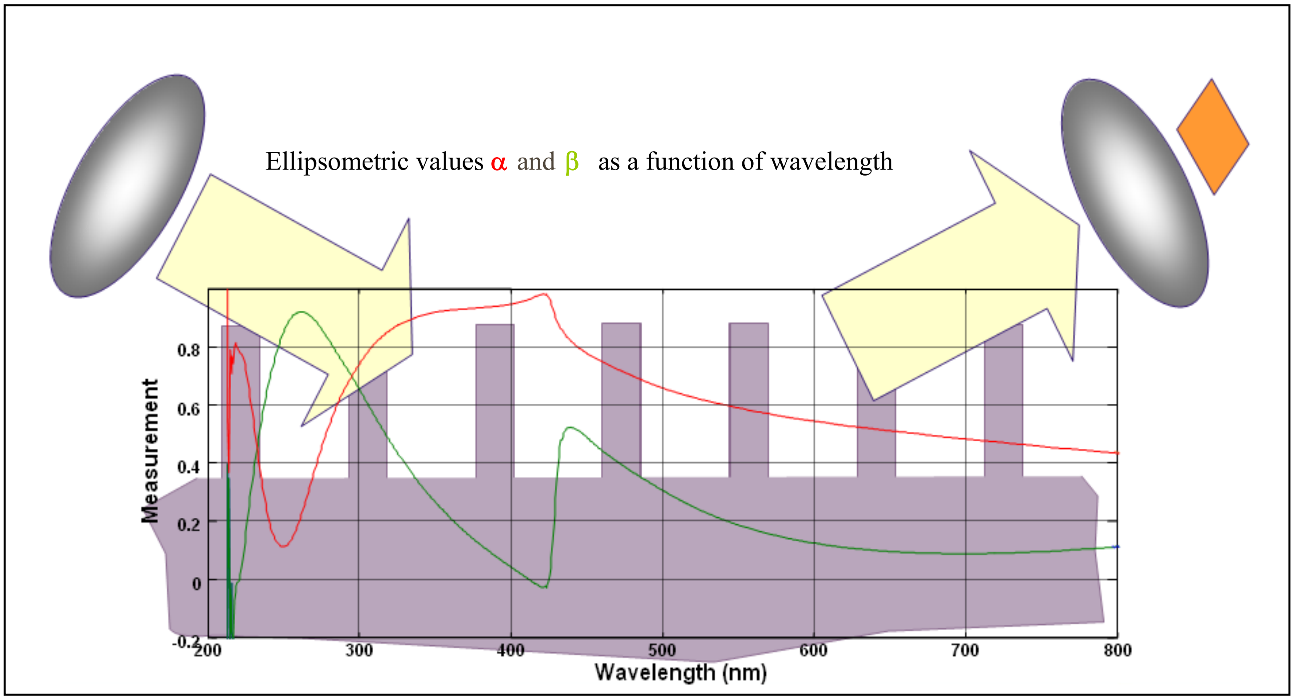

Figure 2. Overview of the scatterometry measurement process. KLA-Tencor's SpectraCD 200 was the scatterometer used in this experiment..

2.2 Multi-AZ analysis of the model

Figure 3 illustrates the use of variable-AZ angle scatterometry [11]. The plots in this figure demonstrate how sensitive different spectral regimes can be to changes in AZ angles. In multiple-AZ angle scatterometry, spectra from two or more different AZ angles are collected sequentially from the same structure and analyzed simultaneously. The same physical model of the structure is used to analyze both spectra; a single set of results is the output. Because this approach can be significantly increase the amount of information collected from the sample, it can result in significant gains in sensitivity and reduced correlation among measurement parameters; thereby producing a better result.

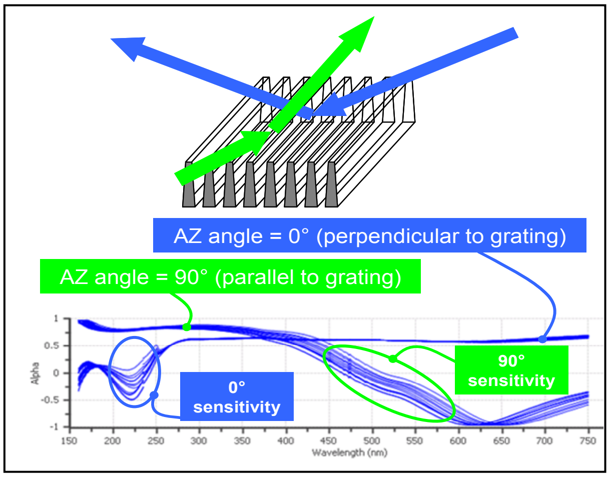

Figure 3. Schematic showing the alpha spectra difference between azimuth (AZ) angles of 0 and 90 degrees. The spectral plots are not from wafers in this study; however, they demonstrate how spectral sensitivity as a function of wavelength can vary from one AZ angle to another.

2.3 Atomic force microscopy

An atomic force microscope (AFM) is considered an established Reference Measurement System (RMS) as it is very sensitive to changes in height and depth. However, the AFM's susceptibility to under-measuring high aspect ratio structures and the cost of periodic tip changes make it a less valuable candidate for micro-step height applications. The DT mode of Veeco's Dimension X1D AFM was used in this study. The AFM works by scanning a sharp semiconductor tip over the sample surface. The tip is positioned at the end of a cantilever, which deflects as the tip is attracted or repelled by the surface. A laser beam is reflected off the cantilever and onto a photodetector that measures the amount of deflection. A plot of the laser signal as a function of the tip position yields an AFM image.

3. MEASUREMENT MODEL

A schematic presentation of isometric and top views of the model used for the oxide contact etch ACI process step is shown in Figure 4. There are seven degrees of freedom (DOFs) in this model: the step height of nitride; the height, width and sidewall angle of nitride spacer; the middle CD of poly; the height of epi; and the top CD of the oxide. For SCD 3D applications, it is very important to build the model as close as possible to the X-TEM image.

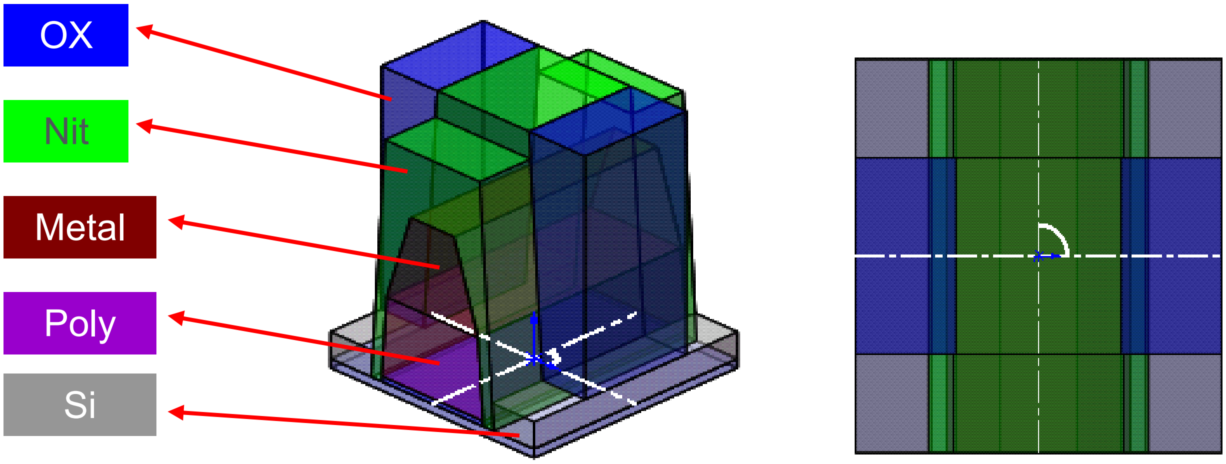

Figure 4. Isometric (left) and top view (right) of the simplified model used for the oxide contact etch ACI process step.

4. RESULTS AND DISCUSSION

4.1 Multi-AZ analysis in the model

Figure 5 compares precision and correlation of the critical model parameters at 0 degrees only, 90 degrees only and multi-AZ angle (combination of both 0 and 90 degrees). In figure 5a, the multi-AZ angle approach shows significantly better precision for all major parameters than 0 degrees only and 90 degrees only approaches. Multi-AZ results in a 1.5x improvement in precision of step height of nitride compared to 0 degrees only, and a 4x improvement compared to 90 degrees only.

In figure 5b, Multi-AZ lowered the correlation among key parameters. Three parameters (nitride_ Ht, nitride_ SWA and Ox_ TCD) have a higher correlation – greater than 0.9 – when using an azimuthal angle of 0 degrees. With multi-AZ , the correlations for these three parameters are reduced to less than 0.9. Most importantly, multi-AZ has the lowest correlation among key parameters on the micro-step height of nitride. The benefit of this analysis can help SCD application users decide on which azimuthal angle will be used in the library. For better precision, 0 degrees only or multi-AZ would be good candidates. For correlation reduction, multi-AZ would be the best choice. In this study, due to current tool limitations, an azimuthal angle of 0 degrees only was selected to create the library.

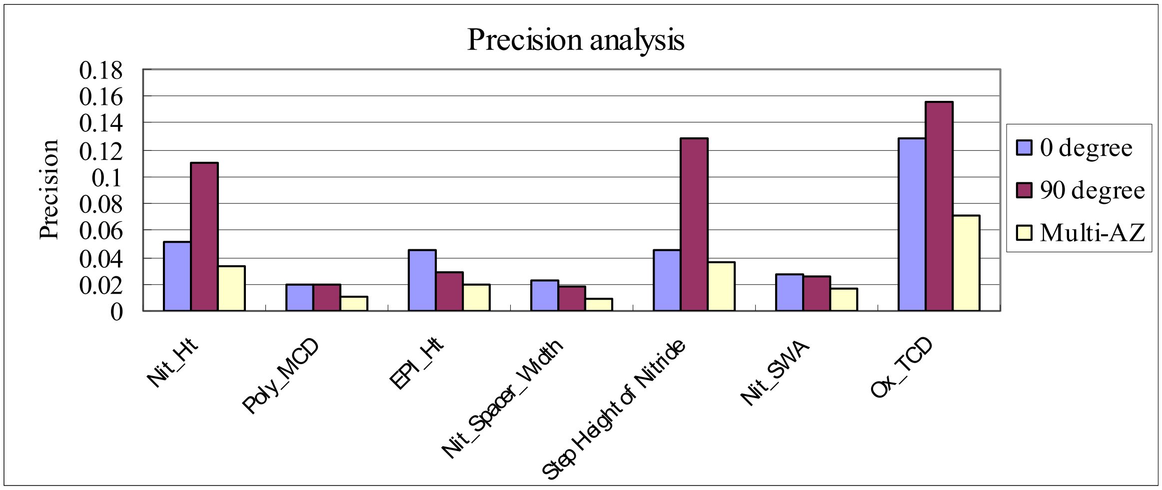

Figure 5a. Precision analysis in the model.

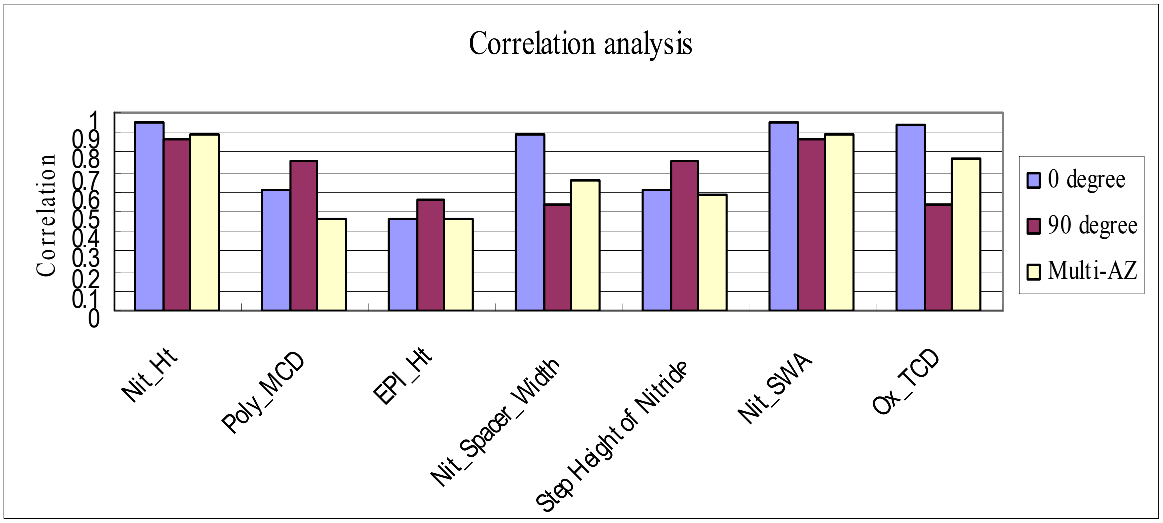

Figure 5b. Correlation analysis in the model.

4.2 Agreement between SCD and AFM Results

As mentioned in section 2.3, AFM has the advantage of being a well established RMS and is very sensitive to changes in height and depth. But the AFM's susceptibility to under-measuring high aspect ratio structures and the cost of periodic tip changes make it undesirable for production applications. Figure 6 shows the results from a ten-run precision test of the micro-step height measurement. The AFM measurement became unstable after run four due to tip failure. Poor tip life is a big concern in adopting AFM for this application. Figure 7 shows the agreement between AFM and SCD results. SCD measured results correlated well with AFM results. Additionally, both SCD and AFM show the step height of nitride within wafer is around 2nm.

4.3 Precision testing on SCD

A static precision test consists of repeated measurements of the same structure without changing the relative positions of the wafer and optical beam. For this study, data from five repeats of SCD measurements of the micro-step height were collected. The results are displayed in figure 8. The standard deviation of the mean value of the step height of nitride is less than 0.2 nm. This result shows 3D SCD is suitable for production monitoring of this step height.

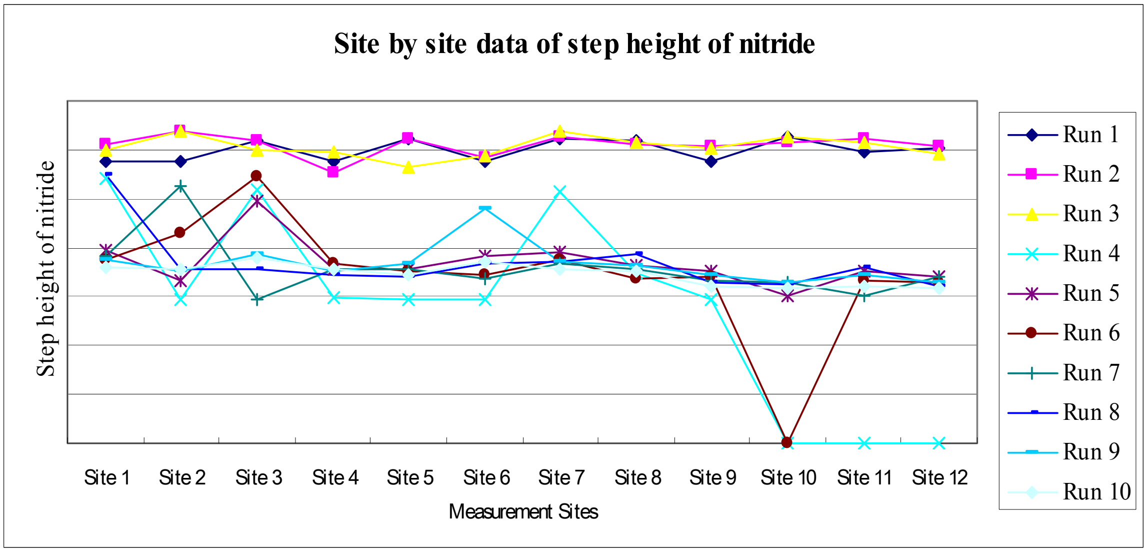

Figure 6.Results of precision test using AFM for micro-step height measurements.

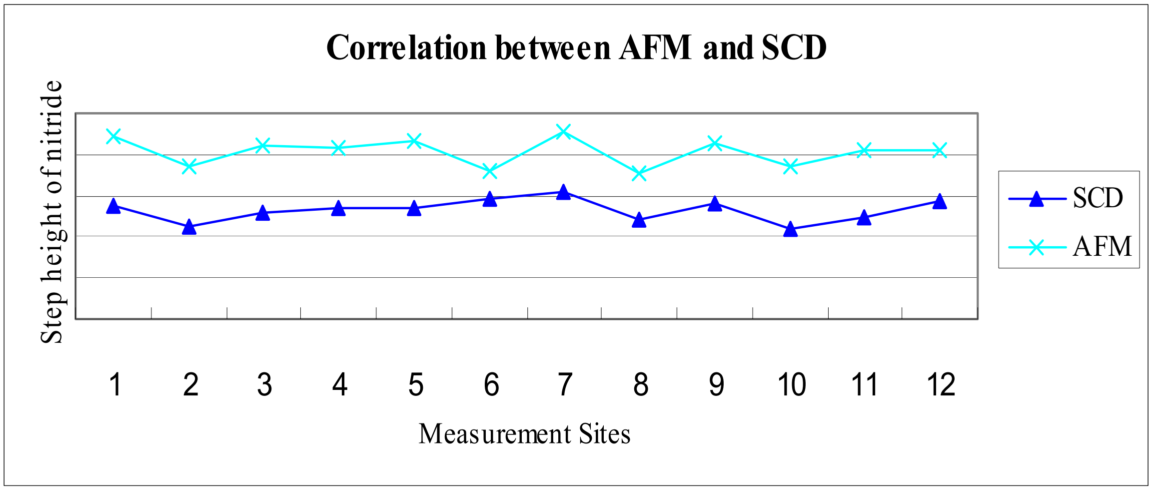

Figure 7. Agreement between AFM and SCD results for micro-step height measurements.

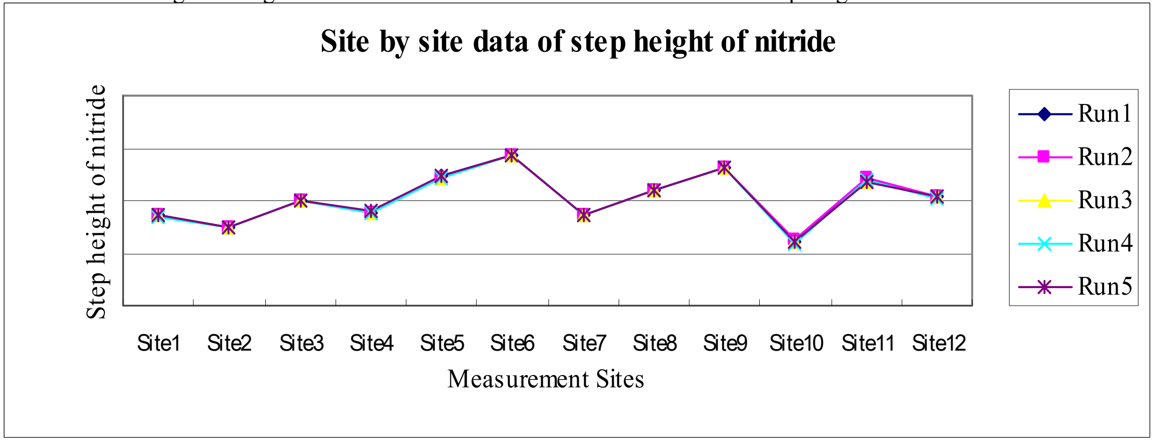

Figure 8. Within-wafer precision measurement results using SCD for micro-step height measurements.

5. CONCLUSIONS

As DRAM design rule scaling continues below 4Xnm, micro-step height control has become more critical. Improper micro-step height control will affect the post-CMP process window and subsequently impact yield. A SCD 3D application showed good correlation to AFM, the Reference Measurement System, and thus can be used to monitor step height difference in production. SCD also has the advantage over other available metrology technologies of being a non-destructive method, and was shown to provide more repeatable measurements.

As structure complexity increases, metrology to characterize and control such structures becomes more challenging. The Multiple Azimuth angle method of SCD application, by acquiring more information from the sample, can provide better precision and lower correlation among the model's key parameters.

ACKNOWLEDGEMENTS

The authors would like to thank the Shin Chieh Kao who contributed their resources to this project. We also thank Hunter Chen of Inotera, who performed all of the Veeco X1D measurement used in this project.

REFERENCES

[1] J. S. Hodges et al., “Improved Gate Process Control at the 130nm Node Using Spectroscopic Ellipsometry Based Profile Metrology”, Proc. of SPIE Vol. 5038, p. 2 15-223, 2003
[2] T. Hingst et al., “Spectroscopic Ellipsometry based Scatterometry enabling 193nm Litho and Etch process control for the 110nm technology node and beyond”, Proc. of SPIE Vol. 5038, p. 274-285, 2003
[3] D. Herisson et al., “Spectroscopic Ellipsometry for lithography front-end level CD control: a complete analysis for production integration”, Proc. of SPIE Vol.5038, p. 264-273, 2003
[4] M. Yeh et al., “Capability of spectroscopic ellipsometry-based profile metrology for detecting the profile excursion of poly silicon”, Proc. of SPIE Vol. 5375, p.1135-1143, 2004
[5] T.G Dziura et al., “Measurement of high-k and metal film thickness on FinFET sidewalls using scatterometry”Proc. of SPIE, Vol.6922, 2008
[6] R. Liou et al, “Feasibility of measuring Four Profile Parameters for Metal-0 Trench of DRAM by Spectroscopic Ellipsometry Based Profile Technology”, Semiconductor Manufacturing Technology Workshop Proceedings, p.156~159, 2004
[7] M..K. Lee et al, “Applications of AFM in semiconductor R&D and manufacturing at 45nm technology node and beyond”, Proc. of SPIE Vol. 7272, 2009
[8] M. Sendelbach et al, “Comparison of scatterometry, atomic force microscope, dual beam system, and XSEM to measure etched via depths”, Proc. of SPIE Vol. 5752, p.272-287, 2005
[9] J. Huang et al, “Application of 3D scatterometry to contacts and vias at 90nm and beyond”, Proc. of SPIE, Vol.5752,p.1266-1270, 2005
[10] K. Barry, A. Viswanathan, X. Niu, J. Bischoff, “Scatterometry for contact hole lithography” Proc. of SPIE , Vol. 5375,p. 1081 – 1086, 2004
[11] M. Sendelbach et al, “Use of multiple azimuthal angles to enable advanced scatterometry applications”Proc. of SPIE, Vol.7638, 2010