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Extreme Ultraviolet Scatterometry for Characterizing Nanometer Scale Features in a Damascene Sample

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Abstract: We characterize nanoscale out-of-plane features on an industrially relevant semiconductor sample using a coherent extreme ultraviolet high harmonic generation source at 29nm. The advantages of using 13.5nm light are also shown.

1. Introduction

As integrated circuits are fabricated with increasingly smaller features on the order of single nanometers, the development of new non-destructive, elemental-specific metrology techniques to measure these features is of critical importance. Extreme ultraviolet (EUV) light is especially well-suited for this task due to its high sensitivity to nanoscale geometric structures and its high contrast elemental specificity in this wavelength range. Several characterization techniques have benefited from the use of EUV light over the past decade including reflectometry, scatterometry, imaging methods such as ptychography, and recently imaging reflectometry for a full characterization of the three-dimensional geometric structure and elemental composition [1-5]. While each technique has its use cases, scatterometry, where a forward diffraction model is fit to experimentally measured diffraction efficiency data, is particularly well suited for the measurement of periodic structures in a highly accurate, fast, and convenient manner.

In addition to the development of characterization techniques, EUV metrology has also benefited greatly from advances in high harmonic generation (HHG), where an intense ultrafast laser pulse is focused into a gas in a phase matched geometry to generate coherent laser-like high harmonic beams [6,7]. Using EUV HHG, it is now possible to have a full characterization of scientifically and industrially relevant samples with EUV light in a tabletop set up [1-5]. While 20nm has been the dominant wavelength for tabletop EUV metrology, 13.5nm light is also of interest since it enables higher resolution ptychographic imaging [4].

2. Results

We present here the use of a tabletop HHG 29nm EUV light source to extract single nanometer scale out of plane features on a periodic damascene-like sample via EUV scatterometry. Furthermore, simulations are presented that show how 13.5nm light can provide up to an order of magnitude increase in the diffracted signal for the same incident flux. The geometry of the sample measured is shown schematically in Fig. 1(a). A periodic array of copper pads is arranged on top of a SiO_2 substrate and separated by a thin ~100nm layer of SiCN. The copper pads are depressed into the sample by a small amount on the order of single nanometers from differences in the polishing rate of each material,

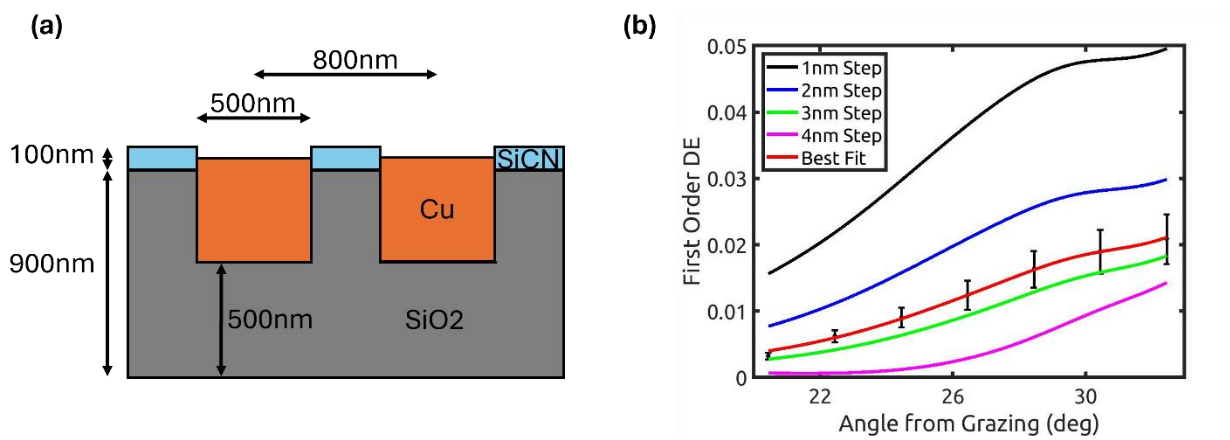

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Fig. 1. (a) Schematic cross-section of the sample (not to scale). We wish to measure the average height difference between the copper and SiCN surfaces (b) Experimental data (black error bars) and modeled diffraction efficiency data showing sub-nanometer accuracy in determining the average step height.

and we want to measure the exact value of this step height. Fig. 1(b) shows the experimentally measured diffraction efficiency and a series of predicted fitting curves, each of which corresponds to a single nanometer change in the step height. The model parameters were fit to the experimental data using a genetic algorithm to obtain a quantitative measurement of the step height between the copper pads and the surrounding SiCN. Small offsets in the measured density of materials and wavelength of illumination were also refined by keeping them as free parameters during the optimization. Based on the error bars on our data and the separation between each of the curves, we observe an accuracy of better than a single nanometer in determining the average step height.

We also compare the diffraction efficiency as a function of step height for 13.5nm illumination and compare it to 29nm for the sample geometry shown in Fig. 1. As shown in Fig. 2, the peak of the total power diffracted into the first order is significantly higher for 13.5nm illumination as compared to 29nm. Consequently, performing these measurements with 13.5nm illumination will provide a much stronger signal and reduce the errors bars on our measurements significantly, thus improving the accuracy of our measurements. Moreover, as shown in Fig. 2(b), the diffraction efficiency curves are well separated and therefore are conducive to a simple optimization routine to fit the experimental data to the model parameters. Simulations also show that the second order diffracted power is high enough to be measurable, thus providing more data to fit the model to and increasing accuracy.

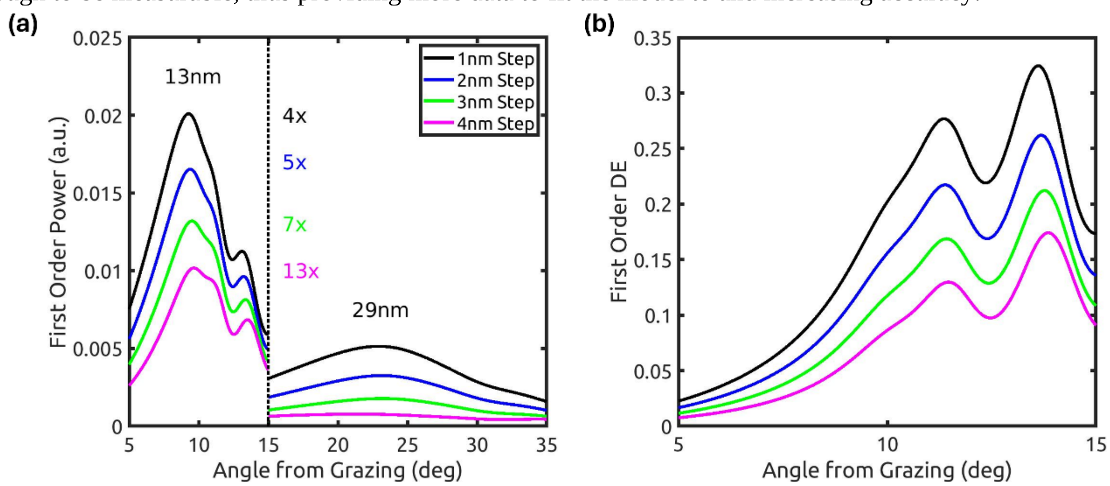

Fig. 2. (a) The total power diffracted into the first order diffraction spot at 13.5nm and 29nm for the same incident flux. A significant improvement of up to an order of magnitude is expected in the measured signal. (b) Simulated diffraction efficiency curves for 13.5nm illumination.

3. Conclusion

In summary, we have used a 29nm tabletop HHG light source to measure dishing in a periodic damascene-like sample using EUV scatterometry. Depth features on the sample on the order of single nanometers were measured with sub-nanometer accuracy. Simulations were performed to show how 13.5nm illumination can provide up to an order of magnitude increase in the diffracted signal for the same incident flux. This result motivates further investigations into the use of 13.5nm illumination for scatterometry, and we expect that it will play a vital role in the characterization of industrially and scientifically relevant samples.

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