Ultra large pitch and depth structures metrology using spectral reflectometry in combination with RCWA based model and TLM Algorithm

AM: Advanced Metrology

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Abstract - The mainstream of dimensional metrology development is focused towards continuous shrinking of the devices (Moore scaling). Current cutting-edge technologies are in few nanometer range (3-7nm). There is also a growing demand to characterize structures with large dimensions in microns range (pitch, CD or depth). New technology megatrends such as internet of things (IOT) additionally require More than Moore scaling and heterogeneous integration [1-3]. Due to recent developments ultra large pitch scatterometry applications growth is observed in high power, sensors and packaging areas. Here we present novel approach that is focused on ultra large pitch scatterometry and its challenges. We demonstrate how to extend usage of conventional scatterometry for micro size devices.

Keywords: large pitch, OCD, scatterometry, RCWA limits, metrology, deep trench

I. INTRODUCTION

The mainstream optical scatterometry tools and algorithms are tuned towards shrinking device size. Larger dimensions (micron range) are challenging for conventional optical scatterometry measurements, because of multiple reasons, including less periods within measurement spot, surface scattering, etc. For ultra large pitch applications the enhanced algorithmic solutions need to be implemented to tackle these challenges [1-3]. This need to be done preferably without changing hardware settings of modern scatterometers to allow measurements of both nano-structures (Moore scaling) and micro-structures (More than Moore scaling). For some applications in ultra large pitch area, it was considered that extended IR (infra red) is required to obtain solution (i.e. WL till 20 microns)[4]. Such solutions, however, require additional hardware that increases manufacturing cost and inline metrology configuration complexity. Furthermore, throughput of IR- reflectometers is typically lower than standard UV(ultraviolet) -VIS(visible spectrum) tools. In this paper we demonstrate a method which utilize a more cost-effective visible hardware only with unique algorithmic approach. We utilize combination of Nova's thick layer measurement (TLM) algorithm, which is based on analyzing reflectivity from multiple surfaces and rigorous coupled-wave analysis (RCWA). This solution works with conventional spectral range typical for cleanroom ellipsometers and reflectometers (deep ultra-violet to near IR). In this paper we focus on application for BCD (BIPOLAR-CMOS-DMOS) technology that combines advantages of bipolar, CMOS (Complementary Metal Oxide Semiconductor) and DMOS transistors (Double Diffused Metal Oxide

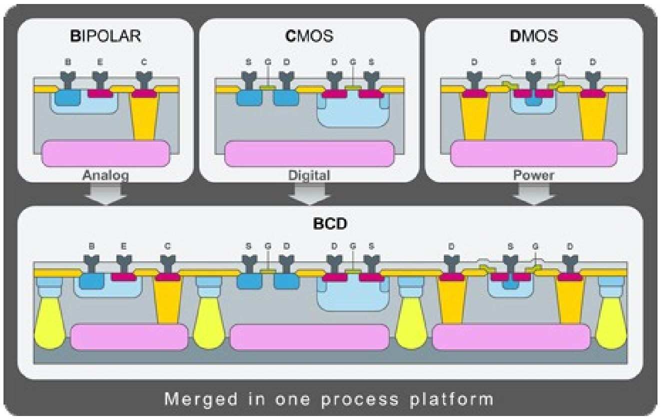


Fig. 1. BCD (BIPOLAR-CMOS-DMOS) is a key technology for power ICsSemiconductor) [5]

As described in Fig.1. Multipower BCD technology is using two or more power MOS devices on the same chip, isolated from each other, with both high-voltage and high-current capabilities, together with low-level signal and memory components. Using BCD technology, the pixels' structure is based on growing an epitaxial silicon layer, on which we can have any analog/digital CMOS circuit completely surrounded by N-doped zone which isolate the internal epitaxial layer from substrate. In addition to BCD technology our work is relevant for various trench depth, high pitch applications across various IoT devices.

II. RESULTS AND DISCUSSION

The modeled structure is shown in Fig. 2. Si trench depth for isolation structures can reach 30 µm with pitch as large as 8 µm and trench CD of 2 µm. These dimensions are orders of magnitude larger than most OCD [6] (optical critical dimension) applications in advanced logic and memory. A set of wafers with structures described in Fig. 2 were prepared with design of experiment (DOE) that included etch split conditions representing process window (+/- 10% of process of record). The trench depth was varied. The modeled results are compared to SEM x-section metrology.

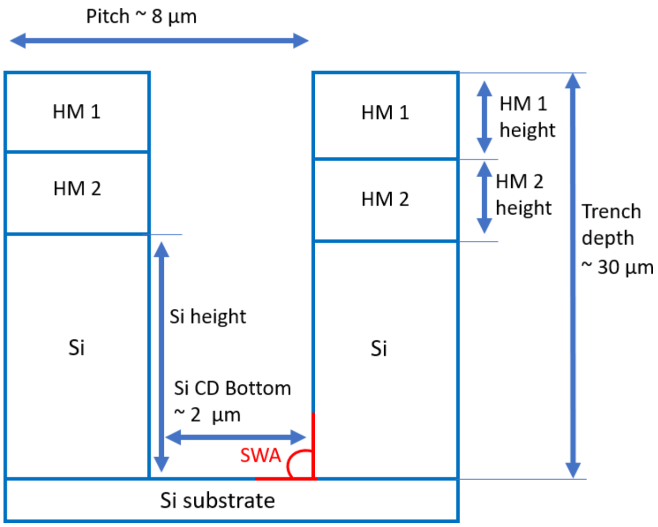


Fig. 2. Deep trench structure details.

OCD is based on spectral measurement of reflectivity from a sample at different polarizations, angles of incidence and azimuths and fitting the measurement to a theoretical model to reconstruct the parameters of the structure under test.

One of the most common ways to calculate the reflected spectrum of a theoretical model is to use RCWA (rigorous coupled wave analysis). It is a semi-analytical method in computational electromagnetics that is most typically applied to solve scattering from periodic dielectric structures. As rule of thumb the pitch of the measured structure needs to be approximately an order of magnitude smaller than the measurement spot size. The pitch of the structure in Fig. 2 is 8 µm and thus RCWA assumption is on its application limit. Therefore, RCWA based modeling of theoretical spectra is not fully applicable in a standard way due to the very large pitch of the measured structure.

Fig. 3 shows representative spectral measurement of the deep trench structure described in Fig 2. Normal S polarization shows fast oscillations modulated on top of slower oscillations signal. The slow frequency mainly represents the top layers while the fast frequency is associated with Si depth. Normal P polarization only has low frequency oscillations thus it is not sensitive to Si depth. Despite dimensional limitations related to RCWA the materials in the stack also play a role [7,8]. The layers with that have relatively high index of refraction contributes stronger to scattering. This is the case for the Si layer. Other challenge is related to the fact that time of calculation of theoretical spectra increases nearly exponentially with the number or retained diffraction orders, which in turn is inversely proportional to the optical wavelengths [9]. There are also other approaches than classical RCWA for scatterometry calculations such as finite element modeling (FEM) [10]. However, FEM methods in general are more computing power intensive than RCWA. The solution in this work is to use combination [6] between existing RCWA and new TLM methods.

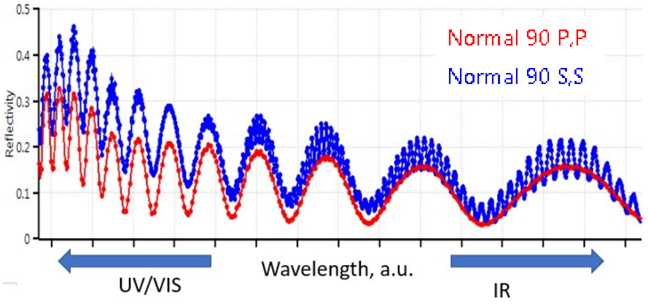


Fig 3. Representative spectral reflectivity of structure in Fig 2.

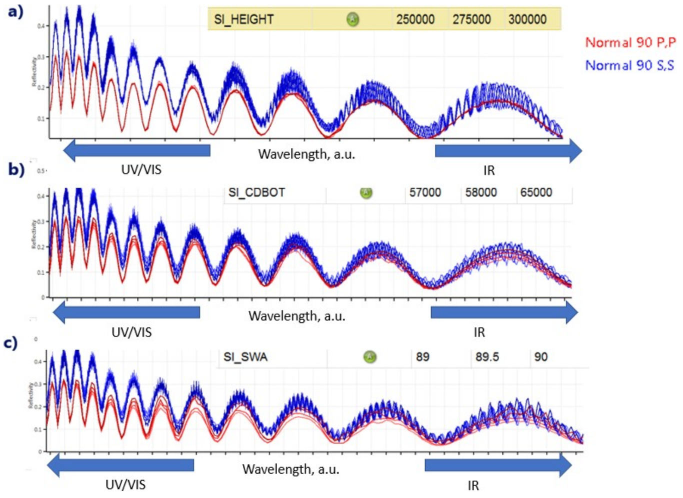
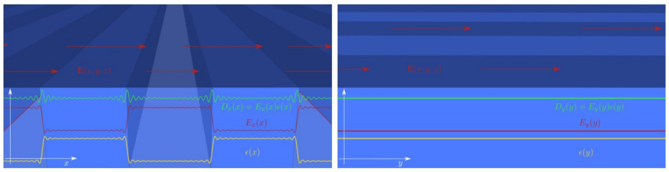


Fig. 4. Simulated reflectivity for three different initial points using RCWA calculations: a) Si height, b) CD-Bottom, c) Si SWA. The legend shows thickness in Angstroms and SWA in degrees.



(a) TM polarization

(b) TE polarization

Fig, 5. TM (-s) and TE (-p) polarization at a one-dimensional grating (modulation along x): a) TM (-s) polarization causes unphysical oscillations at the grating slopes resulting in bad convergence behavior b) TE polarization without jump discontinuities. The schematic is shown only for illustrative purpose (the wave propagation is more complex in the studied application).

To show challenges of ultra-high pitch and depth structures we performed RCWA simulations as shown in Fig. 4. We generated theoretical reflectivity for angle of incidence of 90 degree. The s- polarization (perpendicular or transverse magnetic (TM)) is marked in blue color. The p-polarization (parallel or transverse electric (TE). Typically, TM component is more problematic for RCWA convergence [11]. The TE and TM are shown in Fig. 5 for clarity. The grating pitch variation, interface effects and surface scattering can strongly influence TM wave propagation. Furthermore, due to air- trench components with various dielectric functions and respective interfaces propagated wave is always a discontinuous function and subject to Gibbs phenomenon [12]. In our case we could extract valuable RCWA information only from TE component. It is also clear from Fig. 4a that there is almost no difference in TE polarization (red curves) for varied height of the Si. Therefore, there is no Si height sensitivity using TE component. On the other hand, we observe clear differences in simulated reflectance for Si CD bottom (Fig.4b) and Si SWA (Fig. 4c) and TE (-p) component can be used for those dimensions. In summary TE component and RCWA give the two dimensions of interest but cannot be used for trench depth. The fast frequency oscillations presented in TM channel can be modeled with TLM approach to extract trench depth. To measure the depth of the Si from the TM spectra we may use the fact that the frequency of the fast frequency oscillations is proportional to the depth and can be used to extract trench depth with TLM algorithm, that is fast and does not require RCWA calculations. We could obtain all geometrical parameters of the structure described in Fig. 2. by combining the RCWA and TLM methods. Trench depth results are in a good agreement with the designed split conditions and with x-SEM reference depth as shown in Fig. 6. We were able to achieve very good Si depth correlation to x-SEM data (R^2 = 0.98). Additional target parameters, including HM1 and HM2 height, show good correlation to thickness of the solid sites, as shown in Fig. 7. The combination of RCWA and TLM is shown to be optimal algorithmic approach. Our methodology can be used for in line process monitoring and control of etch process by attaching an integrated normal only reflectometer to an etcher or by using stand-alone (SA) tool. The growing need of micron-size device evaluation can be addressed by applying novel methods of analysis of existing scatterometry hardware signals.

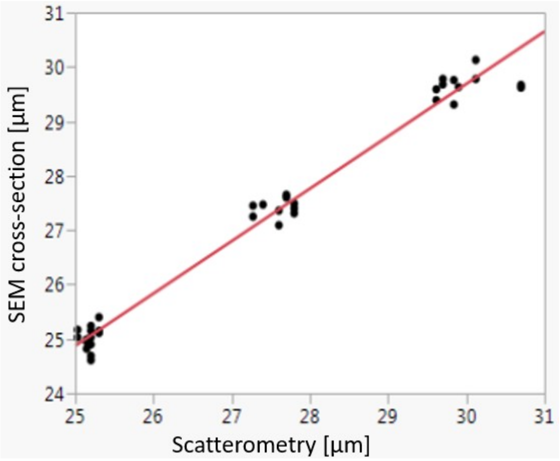


Fig. 6. Trench depth correlation to x-SEM

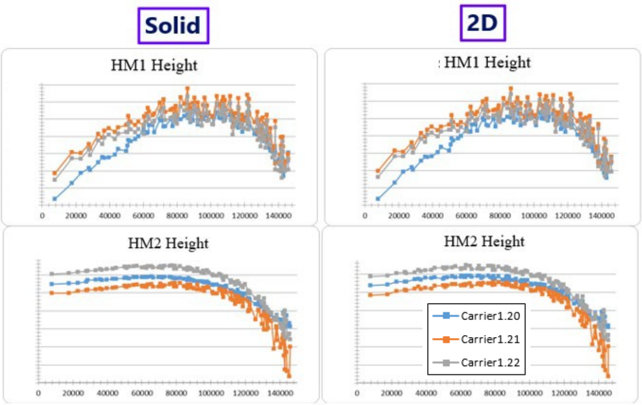


Fig. 7. HM1 and HM2 height radial plots obtained using RCWA model interpretation. Data for solid measurement pad (left hand side) and two-dimensional structure (right hand side).

III. CONCLUSIONS

In summary, this paper proposes a new approach to address optical modeling challenges of micron range devices. We discuss current scatterometry hardware that is tuned to nanometer range dimensions and algorithms that can extend usage of modern scatterometry hardware for micron size dimensions (extension of maximal measurable thickness/height limit). Presented methodology can be used for optical characterization of various device concepts in More than Moore scaling approach. As future work RCWA limitations and potential modifications and combined algorithmic approaches need to be explored. This can extend usage conventional cleanroom scatterometery hardware beyond commonly accepted specifications.

ACKNOWELEGMENTS

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REFERENCES

[1] Graef, M. (2011). "Positioning More Than Moore Characterization Needs and Methods within the 2011 ITRS." AIP Conference Proceedings 1395: 345-350.

[2] Smart Metrology for Continuing Moore's Law Scaling, M. Kuhn and Z. Ma. SPIE Adv. Litho. (2016)

[3] Continuing Moor’s law, M. Bohr, Intel Technology manufacturing day in China (2017)

[4] M. Gostein, P. A. Rosenthal, A. Maznev, A. Kasic, P. Weidner, and P.-Y. Guittet, "Measuring deep-trench structures with model- based IR," Solid State Technology, vol. 49, pp. 38-41, (2006).

[5] A. Andreini, C. Contiero, P. Galbiati, “A New Integrated Silicon Gate Technology Combining Bipolar Linear, CMOS Logic, and DMOS Power Parts,” IEEE Transactions on Electron Devices, vol. 33 (1986)

[6] P. Reinig, R. Dost, M. Moert, T. Hingst, U. Mantz, J. Moffitt, et al., Metrology of deep trench etched memory structures using 3D scatterometry vol. 5752: SPIE, (2005).

[7] R. Antos, J. Pistora, J. Mistrik, T. Yamaguchi, S. Yamaguchi, M. Horie, et al., "Convergence properties of critical dimension measurements by spectroscopic ellipsometry on gratings made of various materials," Journal of Applied Physics, vol. 100, pp. -, 2006.

[8] N. Xinhui, N. Jakatdar, B. Junwei, and C. J. Spanos, "Specular spectroscopic scatterometry," IEEE Transactions on Semiconductor Manufacturing, vol. 14, pp. 97-111, 2001.

[9] S. O’Mullane, N. Keller, and A. Diebold, "Modeling ellipsometric measurement of three-dimensional structures with rigorous coupled wave analysis and finite element method simulations," Journal of Micro/Nanolithography, MEMS, and MOEMS, vol. 15, p. 044003, 2016,

[10] P. Lalanne and G. M. Morris, "Highly improved convergence of the coupled-wave method for TM polarization," Journal of the Optical Society of America A, vol. 13, pp. 779-784, 1996/04/01 1996.

[11] Wilbraham, Henry (1848) "On a certain periodic function," The Cambridge and Dublin Mathematical Journal, 3 : 198–201