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# Optical Critical Dimension Metrology for the SiC Trench MOSFET Process

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**Abstract.** Silicon carbide (SiC) MOSFETs are widely utilized in power device applications for their numerous advantages, and the device's properties can be further optimized through the implementation of trench structures. The formation of the trench structure is a multi-step process, in which it is important to monitor the result of each step and ensure that the structure meets the desired requirements. OCD (optical critical dimension) metrology can provide a fast, non-destructive solution for this purpose. In this article, an OCD analysis of structures at two different process steps is presented and compared with the results from the electron microscopy images. OCD results show high sensitivity to the geometrical dimensions of the structure and produce a good correlation with the electron microscopy images. This metrology can provide a means to detect subtle structural differences without causing any damage to the sample.

## 1 Introduction

Silicon Carbide (SiC) MOSFETs are extensively researched and widespread in power device applications owing to their many advantages, and trench structures can further improve their properties. The vertical channel in trench MOSFETs increases integration density, heat dissipation and channel mobility, simultaneously reducing on-resistance, enabling the production of more efficient devices with lower power consumption [1, 2].

Trench structures are fabricated in a multi-step process, involving different etching steps [3]. Trench formation in SiC is usually carried out using dry etching processes. During the process, $SiO_2$ serves as a masking material, and the shape of the hard mask (HM) has a significant influence on the shape of the final SiC trench [1]. A certain sidewall angle (~90°) is required for trenches to obtain high charge carrier mobility, to minimize the interface states between the SiC sidewall and the gate oxide, and to avoid cavities during the subsequent polysilicon filling. In addition to the shape, the depth of the trenches is also a critical parameter for obtaining the length of the channel that allows the desired properties to be achieved [1, 2]. There are many process steps in which it is important to monitor whether the structure meets the requirements for an optimal trench MOSFET device.

Optical critical dimension metrology (OCD) offers a fast, non-destructive, non-contact method for investigating the geometrical parameters of the structure (sidewall angle (SWA), depth, critical dimension (CD) parameters, etc.). We present the advantages and results of OCD evaluation of two types of structures (hard mask trench on SiC substrate and SiC trench with a hard mask on top). The investigated structures are analyzed by scanning electron microscopy (SEM) as well, which allows us to compare the parameter values obtained by the two methods and to validate the OCD analysis results. It is important to highlight that OCD measures average results within the measurement spot (50 µm), and therefore, local variation in trench geometry can make direct SEM comparison challenging.

## 2 Methods

### 2.1 Evaluation method

OCD metrology, also known as Model-Based Dimension (MBD) metrology or scatterometry, allows the geometric parameters and shape of the investigated structure to be characterized rapidly and non-destructively [4]. Measurements used by OCD, such as reflectometry and ellipsometry, can be sensitive to buried structures as well, which are traditionally not measurable by non-destructive techniques. This is an indirect, model-based method; thus, an accurate theoretical model of the trench structure has to be built for accurate evaluation. This requires some prior knowledge of the structure, including the shape and nominal dimensions of the trench structure and the optical constants of constituent materials. Furthermore, a successful OCD evaluation requires the measurement spot to cover a periodically repeating structure with a sufficient number of periods [5]. Evaluation is done by modelling the light-matter interaction of the measurement beam with the sample structure. Most commonly, the Rigorous Coupled-Wave Analysis (RCWA) [6] method is applied for this purpose, and it was also used in this study. The geometrical parameters are extracted by an algorithm which finds the trench parameters that produce the best match between simulated and measured spectra. With an optimized evaluation algorithm, this allows fast full-wafer mapping and tight process control in many steps of the process. To accurately model SiC, the optical anisotropy of the material has to be considered in RCWA [7]. To further increase accuracy, the instrumentation properties (like detector resolution and focusing optics properties) were taken into account [8].

In this study, Spectroscopic Polarized Reflectometry measurements were performed on the wafers to characterize the trenches. The sample under investigation is illuminated with light of two polarizations: parallel to the plane of incidence (p-polarization) and perpendicular to it (s-polarization) and reflectance is measured independently for both polarizations. Extraction of the geometrical dimensions of the trenches is then done with a dedicated software which performs the simulation of the measurement and parameter fitting. With an optimized evaluation recipe, the evaluation can be done in seconds, allowing the characterization of the trench dimensions to be performed on each die on the wafer, or even at multiple sites within a single device.

### 2.2 Investigated structures and SEM measurements

Several samples were fabricated according to the process described in Rusch et al. [1]. In the first example (Fig. 1.), the wafer has already gone through the HM etching process and the characterization of the dimensions of the oxide mask is performed. The HM defines the shape and width of the final trench; therefore, this process step is critical to monitor.

The second example (Fig. 2.) is a case of SiC trench etch monitoring right before hard mask removal. The presented optical method allows the monitoring of both the SiC trench etch depth and the remaining HM thickness; therefore, in this step, it is possible to contain the etch process.

The samples were prepared for SEM measurements by FIB milling to reveal the cross-section of the trenches. SEM images were taken at 10k, 50k and 100k magnifications, aligned at a 52° angle to the surface normal. This angle was accounted for in the measurements and the SEM images shown are scaled accordingly for visual comparison with OCD evaluation.

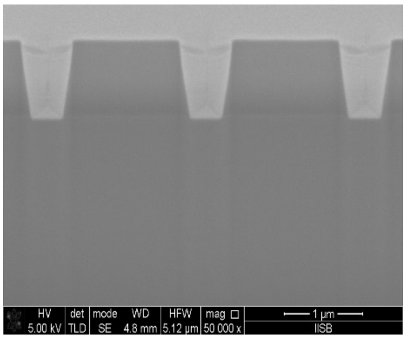

**Fig. 1.** SEM image of SiO2 hard mask trench on SiC.

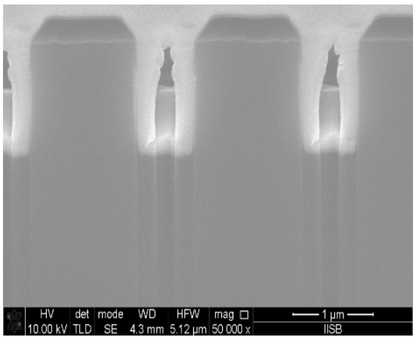

**Fig. 2.** SEM image of SiC trench with a $SiO_2$ mask on top.

## 3 Results and Discussion

### 3.1 OCD analysis of hard mask etched SiC samples

The comparison of the SEM and OCD analysis results was performed at three different points on the wafer. For one of the sites, Fig. 3. shows the measured and fitted reflectance spectra derived from RCWA simulation based on the modelled structure. For the same site, the SEM image and the OCD model for the $SiO_2$ hard mask trench are shown in Fig. 4. The trench is modelled with a trapezoidal shape in the OCD model. The results show very good agreement with the structure observed in the electron microscopy image. The agreement of the results, and the good match between the measured and modelled spectra for both polarizations show the accuracy of the theoretical model and reliability of the evaluation algorithm. It is important to note here as well that the OCD evaluation represents an average over the entire measurement spot, rather than the parameters of a single trench as in the SEM measurement. Therefore, the comparison should be interpreted accordingly.

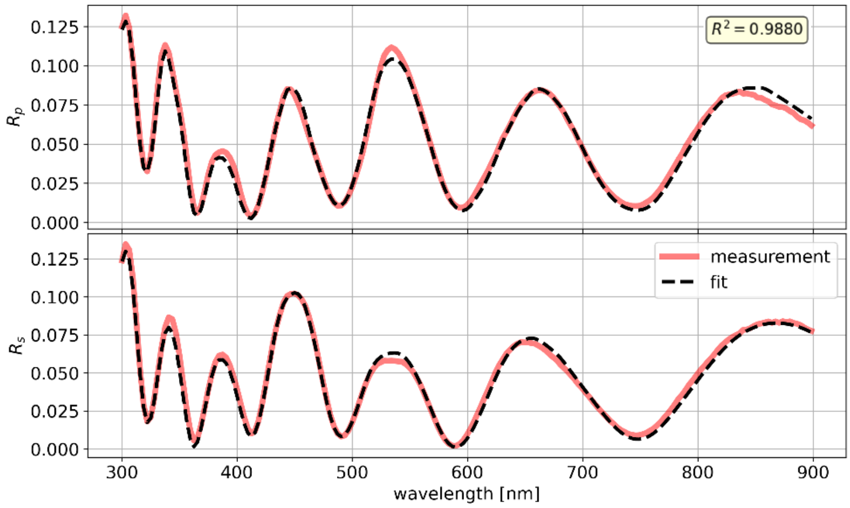

**Fig. 3.** Measured and fitted reflectance spectra of HM trench.

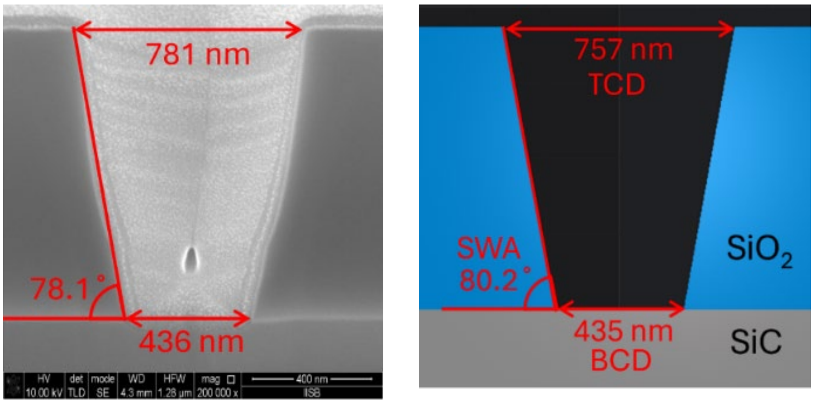

**Fig. 4.** SEM image and trench structure resulting from the OCD evaluation – $SiO_2$ hard mask trench on SiC.

Considering the results of the three sites on the wafer, a strong correlation can be observed between the extracted and SEM parameter values. Fig. 5. shows the relation between these values for the trench bottom CD (BCD), top CD (TCD), and $SiO_2$ wall sidewall angle (SWA) parameters. The diagrams confirm that accurate structural modelling allows the extraction of reliable structural parameters by OCD analysis, in a fast and non-destructive way.

The HM sidewall angle, for example, is a key parameter, as it significantly influences the shape of the final SiC trench. Knowing this value allows us to be aware of whether the desired structure has been achieved and whether it is worthwhile to proceed with the SiC trench formation process.

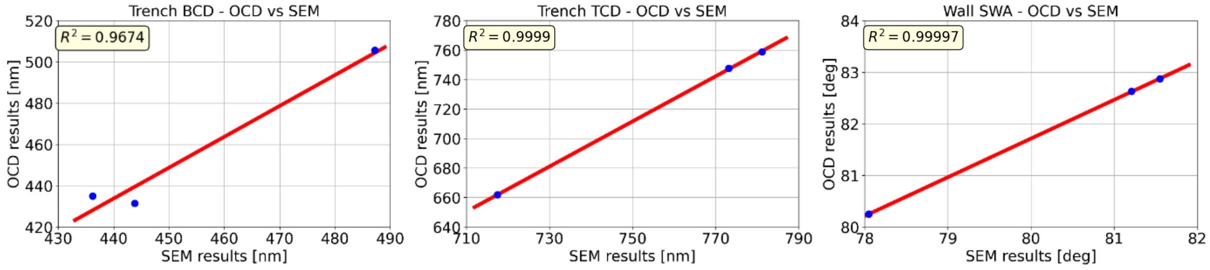

**Fig. 5.** Trench BCD, TCD, and Wall SWA – relationship between SEM and OCD analysis results.

### 3.2 OCD analysis of SiC trench samples with an oxide mask on top

In this case as well, the comparison was performed at three different points on the wafer. The measured and simulated spectra at one measurement points are shown in Fig. 6. This OCD model is built from a total of 6 trapezoids to describe the shape of the SiC trench wall and that of the remaining HM oxide on top and redeposited on the wall. Similar to the HM trench, very good agreement was observed between the structure obtained from the OCD analysis and that derived from the SEM images (Fig. 8.). The shape of the trench also closely follows the form observed in the electron microscopy image (Fig. 7.).

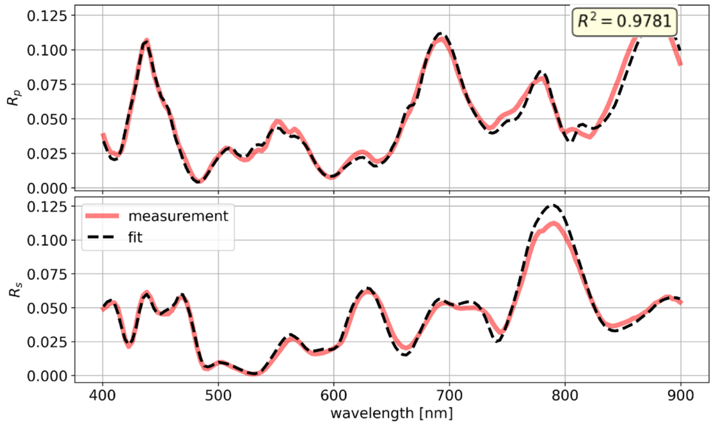

**Fig. 6.** Measured and fitted reflectance spectra of SiC trench with an oxide mask on top.

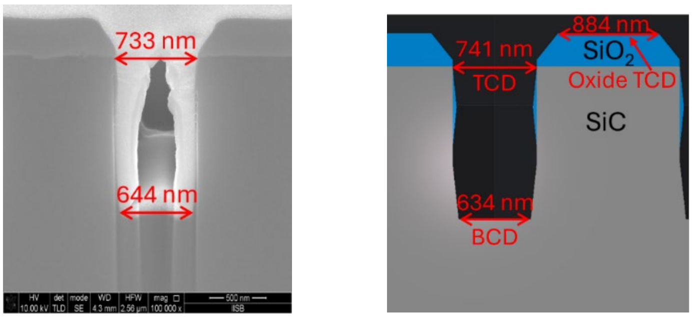

**Fig. 7.** SEM image and trench structure resulting from the OCD evaluation – SiC trench with an oxide mask on top.

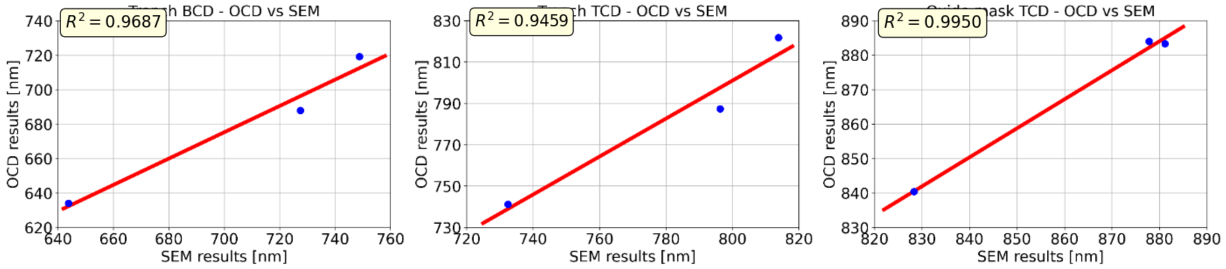

**Fig. 8.** Trench BCD, TCD, and oxide mask TCD – relationship between SEM and OCD analysis results.

### 3.3 Full wafer and micro-mapping of trench dimensions

OCD analysis enables fast evaluation of the structural parameters across the wafer at multiple measurement points. Fig. 9 shows the measured SWA, trench TCD, and height maps of the HM trench across the entire wafer. These maps provide insight into how the structure changes and where the desired trench shape has been successfully achieved.

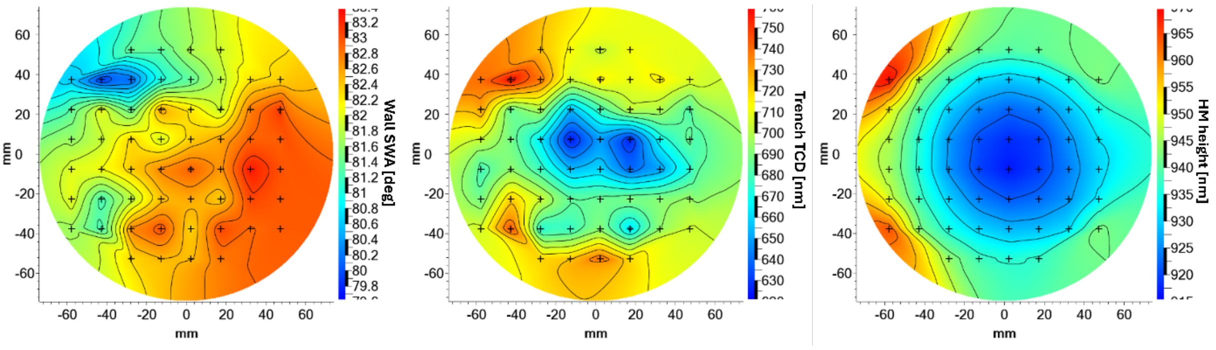

**Fig. 9.** Wall SWA, trench TCD, and HM height maps across the wafer – $SiO_2$ hard mask trench on SiC.

In addition to the wafer-scale maps, it is also possible to scan specific regions of the wafer at a smaller scale, providing insight into structural variations at the microscale. Fig. 10. presents maps of the parameters shown in the wafer-scale maps but measured over a selected 3.4 × 2.4 mm region of the wafer using a 200 µm step size. This represents the active area of a single trench MOSFET device. Even within such a small region, the distribution of the parameters can be characterized, providing feedback for process control and verification.

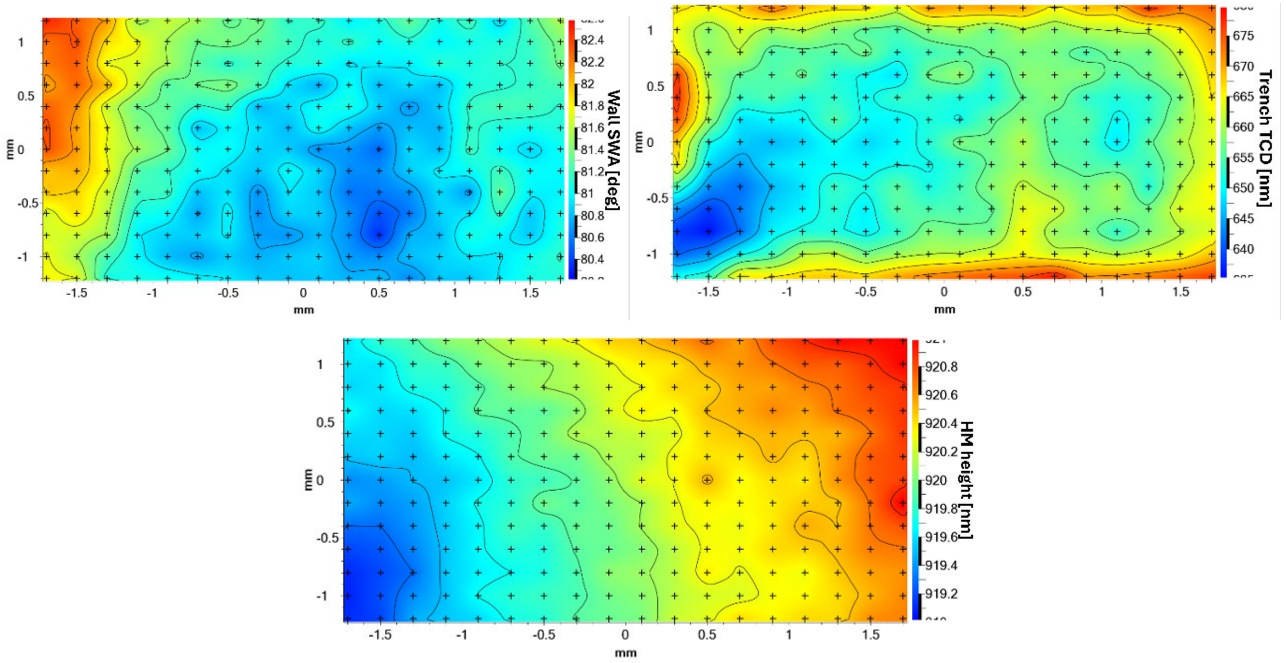

**Fig. 10.** Wall SWA, trench TCD, HM height maps with a 200 µm step – $SiO_2$ hard mask trench on SiC.

In a similar manner, the SiC trench wafer was also characterized using these approaches. The parameter distributions of trench TCD and height are shown at macro (Fig. 11) and micro (Fig. 12) scales in the following figures. The thickness of the residual oxide mask was roughly uniform on a millimeter scale, so only the full wafer map is presented for this parameter.

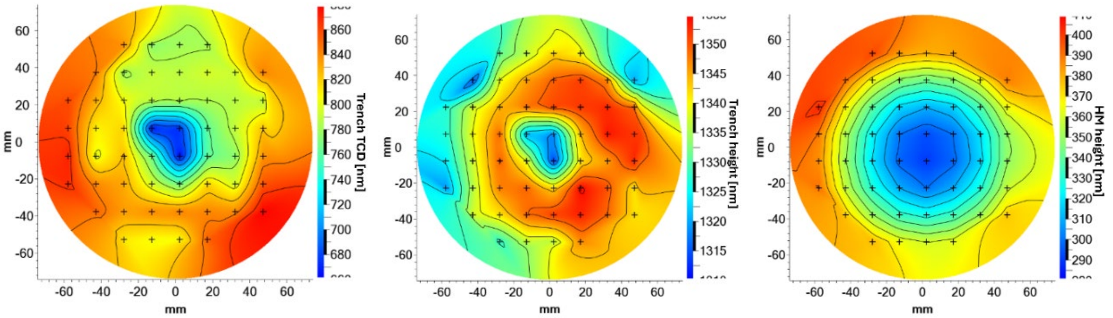

**Fig. 11.** Trench TCD, trench height, and HM height maps across the wafer – $SiO_2$ hard mask trench on SiC.

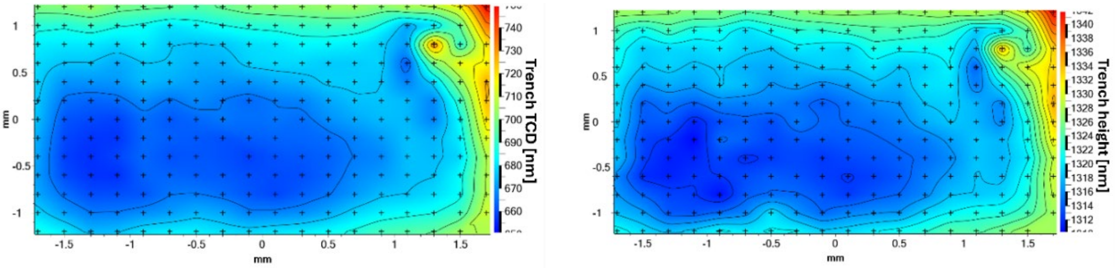

**Fig. 12.** Trench TCD and trench height maps with a 200 µm step – $SiO_2$ hard mask trench on SiC.

## 4 Conclusion

Silicon carbide trench devices are fabricated in a multi-step process during which it is essential to monitor whether the structure is indeed forming according to the requirements.

We presented the evaluation of the structural parameters of two types of structures (hard mask trench on SiC substrate and SiC trench with a hard mask on top) using a non-contact, non-destructive and fast method. The results obtained from the OCD analysis for three sites were compared with electron microscope images taken at the same sites on the wafer.

OCD shows high sensitivity to structure details and the results show good correlation with the SEM parameter values proving the reliability of the OCD measurement. We presented wafer maps evaluated by OCD analysis to show the variation of parameters across the wafer, and we also investigated the parameter changes on the scale of a single device.

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