Effective In-Line Monitoring Structures for Critical Dimension Measurement in Photolithography

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Abstract

In-line monitoring structures for critical dimension (CD) measurement in HBT photolithography have been designed and implemented to reduce the measurement deviation between the standard CD artifact and the product die. The novel structure was designed to match the product device topography and features as closely as possible. This minimized the dimension deviation as a function of structure and made the measurements more accurate. By using the new structure, the accuracy of measurement was improved from 0.03µm to 0.01µm.

INTRODUCTION

Final measurements of dimension are critical to impose process control over the photolithography module, so that a product meets final specifications. The precise photo tolerance is a must for HBT's parameters, and the device's electrical and circuit performance. Control of each photolithography layer plays a very important role in creating a reliable and high yielding manufacturing process. In semiconductor industries, controlling and measuring feature dimensions are one of the key steps for successful production. They are irreplaceable requirements for precision and measurement accuracy. However, measuring the feature size with the standard artifact which is widely used currently becomes less and less meaningful because the in-line dimension data from the standard artifact features is not the actual measurement of the device. This means the feature size of the standard artifact and the real device dimension may not be well correlated or have non-linear deviations.

In this paper, the problems of the standard artifact features were analyzed. A new critical dimension measurement structure was designed and implemented. The results showed it was an effective way to replace the standard artifact features in manufacturing.

BACKGROUND

The standard CD artifact used for in-line critical dimension measurements is a pair of chevrons (two L Bars, see Figure 1). The layer label 32 and a pair of chevrons are built on the flat surface. The topography from upstream layers has no impact on the two L Bars artifact. Regardless whether the real device feature sizes are 0.7µm, 1.0µm, 3.0µm, 5.0µm, etc., the drawn dimension of the standard artifact features is 2.0µm for most of photolithography layers. In practice, we found that the device's electrical performance didn't achieve the expectation even if the SPC chart of the critical photo dimensions was in control.

Figure 1. The standard artifact used to measure in-line critical dimensions, here shown for layer 32.

The investigation revealed that the standard artifact and the real device dimension were not well correlated or perfectly linear, especially when the measured feature width and the real device dimension had a big difference. Non-linear CD measurement resulted in a difference between the real device and the measured artifact feature. In order to fix it, the features with the same width as the device with submicron dimension were added in some layers. However those features were landing on the flat substrate and still didn't eliminate the deviation caused by the topography. As a consequence, the measurement deviation affected the device performance.

To eliminate this measurement deviation, it is necessary to measure the device in the circuit die, which provides the true value. However, the charging effects of CD Scanning Electron Microscopes (CD SEM) on the photoresist may damage the device which could affect the quality of that die and lead to reliability issues. Moreover, measuring the actual device requires engineers to create a special SEM recipe for every mask at each layer and for a specific measurement requirement set. This is inefficient and time consuming.

DESCRIPTION OF NEW CD STRUCTURE

To get rid of the disadvantages of the standard dimension artifact, we designed a new CD structure which is shown on the right side in Figure 2. This measurement structure matches the product device topography and feature size and consists of identical upstream layers as the real device. Here, layer 32 is the measured layer label, and layer 30 is the reference layer label. Layer 32 is aligned to the marks created at layer 30. Besides the critical dimension, the alignment accuracy of one layer to another is also a critical parameter that determines the device's performance. The CD mark is located at the right side of the label 30 and used to measure the width of the resist pattern in the measured layer. It is built on the same topography as the real device instead of on the flat surface to improve the measurement accuracy.

Figure 2. The new CD structure is shown in the far right. The new structure closely matches the product device topography and feature size.

Besides the dimension of the resist patterns, we are also interested in the uniformity across the wafer and across a printfield. Tight control of resist pattern uniformity is necessary for achieving yield targets. The standard artifact features are only placed in the Process Control Monitors (PCM) area, which means it cannot be used for checking feature size uniformity across the printfield. The new measurement structure has the capability to make up this deficiency. It is located in the scribe streets in the center and all four corners, Upper-Left (UL), Upper-Right (UR), Lower-Left (LL) and Lower-Right (LR) of the tile in a printfield (see Figure 3). It makes the all sites measurement across the wafer possible when the wafer layout doesn't have a PCM in every printfield. It is also a more effective approach of CD in-line monitoring in HBT photolithography without changing PCM and circuit die layouts.

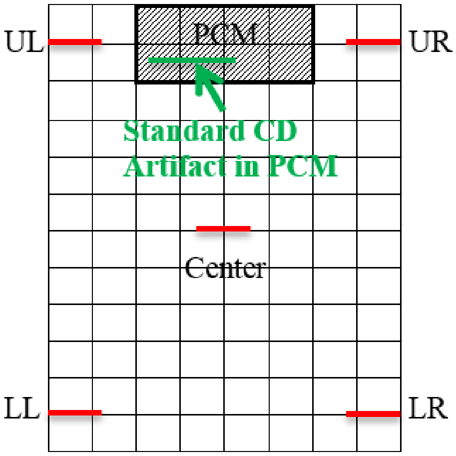


Figure3. The standard artifact is placed in the PCM area. The new CD structures are placed in the center and 4 corners (Upper-left, Upper-Right, Lower-Left and Lower-Right) of a printfield.

The new structure also helps to detect CD uniformity issues, and provide the opportunity to monitor the stepper performance such as focus and tilt issues etc. at the same time. As device dimensions decrease and field sizes increase, photolithography operations become increasingly sensitive to changes in focus-tilt conditions [1]. Focus and tilt are interrelated parameters and have huge impact on photo critical dimensions. They must both be carefully controlled. The collection of critical dimension data from across the wafer or across a printfield allows us to quickly find and fix focus-tilt issue, therefore improving resist pattern uniformity.

RESULTS AND DISCUSSIONS

The novel dimension structure was designed and implemented to eliminate the deviation from the standard measurement artifact. The differences between the drawn and the measured features, which include the device (Device CD), the new structure (New CD) and the standard structure (Std CD), is shown in Figure 4. All the measurements were done on a Hitachi 9220 SEM tool. Considering that the measurement locations may affect the measurement value, we selected the sites of the measured features in the same printfield as closely as possible. As mentioned above, the new layer 32 structure had identical upstream layers as the real device, the deviation between the new critical dimension structure and the real device was minimized. As a result, this improved the accuracy of measurement from 0.03μm to 0.01μm. The measurements from the new structure can be used to control the process directly with accuracy.

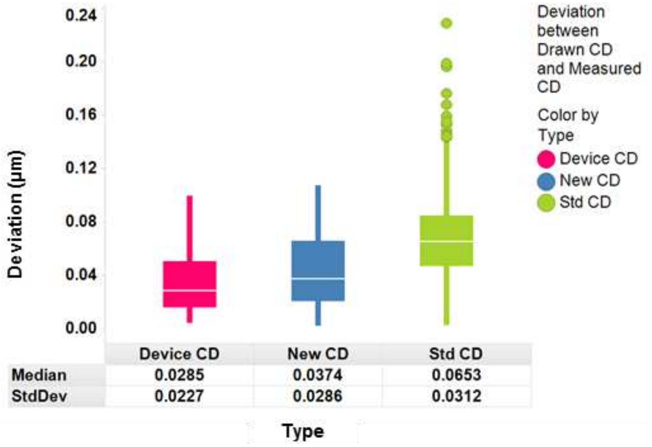


Figure 4. A boxplot showing the population differences between the Device CD, the New CD Structure and the Standard CD Structure.

The new measurement structures were also used to check the uniformity across the wafer and across the printfield. Figure 5 shows a wafermap of measurements as a function of tile position, the dimension (in microns) is indicated by gray scale. The feature was measured on 13 printfields and 5 sites in each printfield. Problem CD values were seen at one complete and two partial printfields at the edge of the wafer, which are highlighted in rectangles. The gradual CD increment in the three edge fields indicated that there were focus and tilt issues. To investigate, we checked the resist patterns in the SEM and indeed there were focus and tilt issues in all three printfields, see Figure 6a for an example. The poor focus made the resist profile sloped with a larger CD and loss of control. An example of a well-defined resist pattern is shown in Figure 6b where near-vertical sidewall profiles are observed.

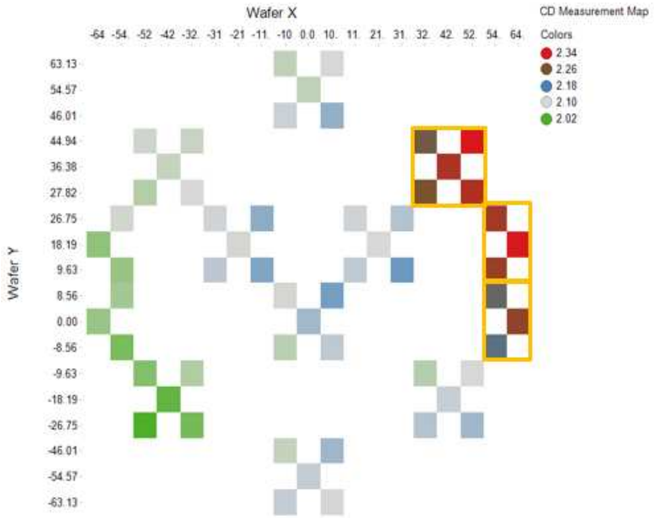
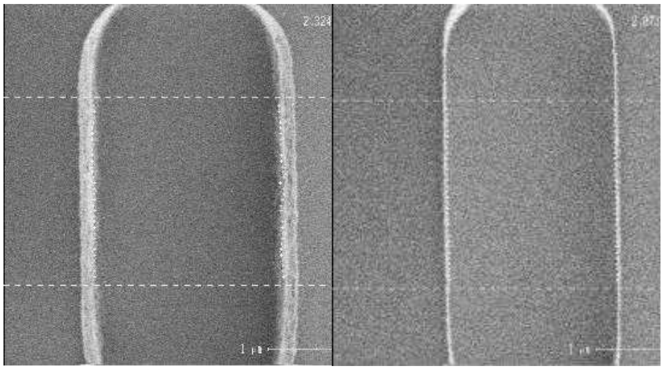


Figure 5. A wafermap showing feature critical dimensions as a function of position. The CDs are indicated by gray scale (in microns) and problem sites are boxed in yellow.

Focus and tilt are interrelated parameters. Most steppers provide the capability to precisely control the focus and tilt conditions, such as, field-by-field focus leveling system. However, focus control at the edge of the wafer is very difficult, especially when the wafer has extreme topography and high-stress thin-films which can cause the wafers to warp. The field-by-field focus leveling system requires information to determine the local focal plane of the field. Correction to nominal focus is made by adjusting the X and Y axes, determining the image field tilt, and the third z axis for height separation of the lens and wafer field. At the edge of the wafer, the focus leveling algorithms usually do not have enough data to calculate stepper field planarity and must extrapolate the focal plane by averaging focus leveling measurement data from adjacent fields. The variation in focus at the edge of the wafer produces a poor CD uniformity which can be increased when the wafer is not flat. This is the reason why the wafer shown in Figure 5 had abnormal CDs at the edge printfields and poor uniformity across the wafer and printfield.

In order to improve the dimension uniformity, first, a Focus-Exposure Matrix (FEM) was performed on the stepper to re-center the process window by optimizing the focus offset and the exposure dose. Second, an optimization of the exclusion zone setting to get the optimum stepper focus leveling strategy was completed. These actions insured proper imaging of the resist patterns across the entire wafer. The CD measurement wafermap post process optimization is shown in Figure 7, and compared to the wafermap in Figure 5, the CD uniformity improved by 4.5%.



(a) (b)

Figure 6a. SEM images of the resist patterns found to be out of focus at the edge of the wafer. Figure 6b. Shows a well-defined resist pattern.

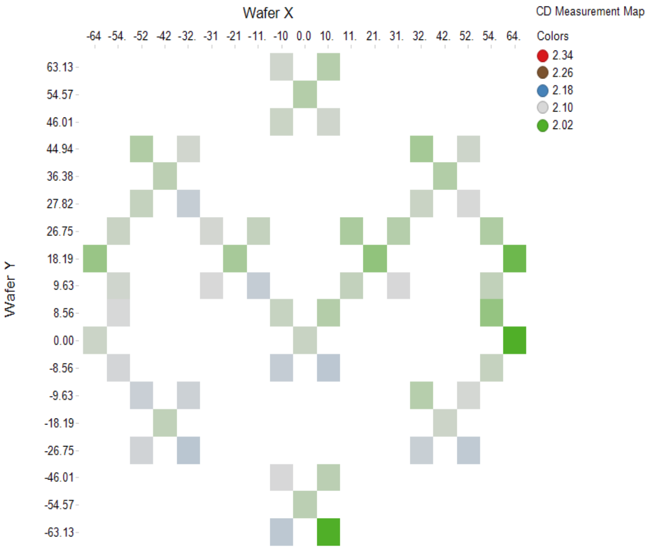


Figure 7. A CD measurement wafermap post process optimization. Compare to the wafermap in Figure 5.

CONCLUSIONS

The standard dimension artifact has been replaced by a new CD structure. By using the new structure, the measurement deviation has been minimized and the measurement accuracy improved from 0.03µm to 0.01µm. We have demonstrated the new dimension structure can be used to check and fix the CD uniformity across the wafer and across the printfield. It provides the opportunity to monitor the stepper performance such as focus and tilt. These structures can be refined to further optimize the artifacts for greater fidelity to the actual device.

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REFERENCE

[1] Edited by John N. Helbert, "Handbook of VLSI Microlithography", 2nd Edition, 369, (2001).

ACRONYMS

HBT: Hetero-junction Bipolar Transistor
CD: Critical Dimension
SEM: Scanning Electron Microscope
PCM: Process Control Module
SPC: Statistical Process Control
FEM: Focus-Expose Matrix