65 nm Photolithography Process Window Qualification Study with Advanced e-beam Metrology and Inspection Systems

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ABSTRACT

Focus exposure matrix (FEM) using contact mask is applied to two 65-nm production wafers. One wafer is dropped at after etch inspection (AEI) while another one is stopped after tungsten chemical mechanical polishing (WCMP). Gray level value (GLV) and critical dimension (CD) are measured using eProfile® at different hole patterns, such as dense, isolate, and static random access memory (SRAM) array of the contact AEI wafer. All results show very reasonable CD variation trends in focus exposure PWQ chart. Defect inspections using eScan®300 is performed on WCMP wafer at SRAM array area. The major defects detected are missing, bridging and dark voltage contrast (DVC) which is caused by open or partial open of the contact hole. We found that open defect is mainly sensitive to exposure energy. The higher the exposure energy, the fewer the DVC defects. The GLV map of oval tungsten plug (W-plug) correlates with GLV map of oval contact and DVC defect map very well.

Keywords: critical dimension (CD), focus exposure matrix (FEM), process window qualification (PWQ), dark voltage contrast (DVC), and gray level value (GLV).

1. INTRODUCTION

While integrated circuit (IC) feature size farther shrinking into the sub-wavelength regime, resolution enhancements techniques (RET) such as phase shifting mask (PSM), optical proximity correction (OPC), and scatter bar (SB) are commonly applied in the photo mask to reduce k_1 and improve photolithography resolution. Photolithography with low k_1 and high mask error factor (MEF) increases the printability, however, it also increases frequency of yield impacting repeating defects from mask defects and RET layout defects. Therefore, process window qualification (PWQ) that qualifies a mask needs to include both mask inspection before wafer printing and wafer inspection after wafer printing using the proprietary patterns with mask of interest. Wafer inspection provides information on the regions of marginality within the reticle field or features within the die that have smaller process window than expected. Wafer inspection part of

the PWQ usually is performed on a photoresist wafer with focus exposure matrix (FEM) after photoresist development. Scanning electron microscope (SEM) is commonly used to measure CD variation on the FEM wafer to determine process window. [1], [2] As the feature size continues shrinking, contact mask PQW needs to involve defect inspection not only at after development inspection (ADI) and after etch inspection (AEI) levels, but also at WCMP layer to determine whether the reticle is robust enough to allow etch process fully open the contact hole and achieve good electrical contact between tungsten plugs and silicon within the photolithography process window. Both eScan®300 that inspect defects and eProfile® that measures GLV and CD of contact holes and W-plugs of interest are very power tools for this application.

2. PROCEDURE

We used two full flow wafers after pre-metal dielectric (PMD) CMP. A 193-nm scanner was used to expose the FEM on photoresist with a contact mask. FEM pattern is illustrated in Figure 1. After photoresist development and UV bake, wafers were processed to contact AEI. One of the two wafers was held while another one continued processing until WCMP, then both wafers were send to eScan®300 for defect inspection and eProfile® to measure CD and GLV. Results were feedback to the system. The procedure is illustrated in Figure 2.

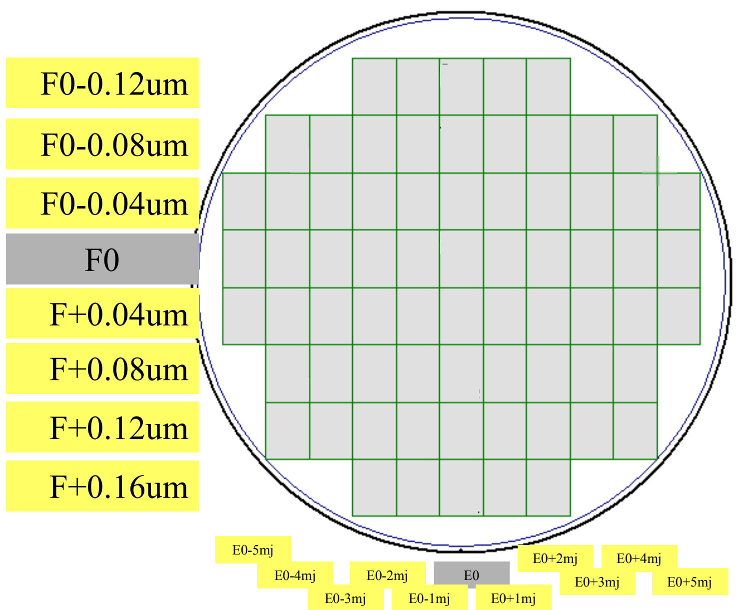


Figure 1. FEM pattern

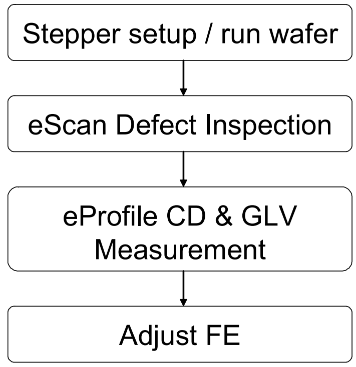


Figure 2. Procedure flow of this study

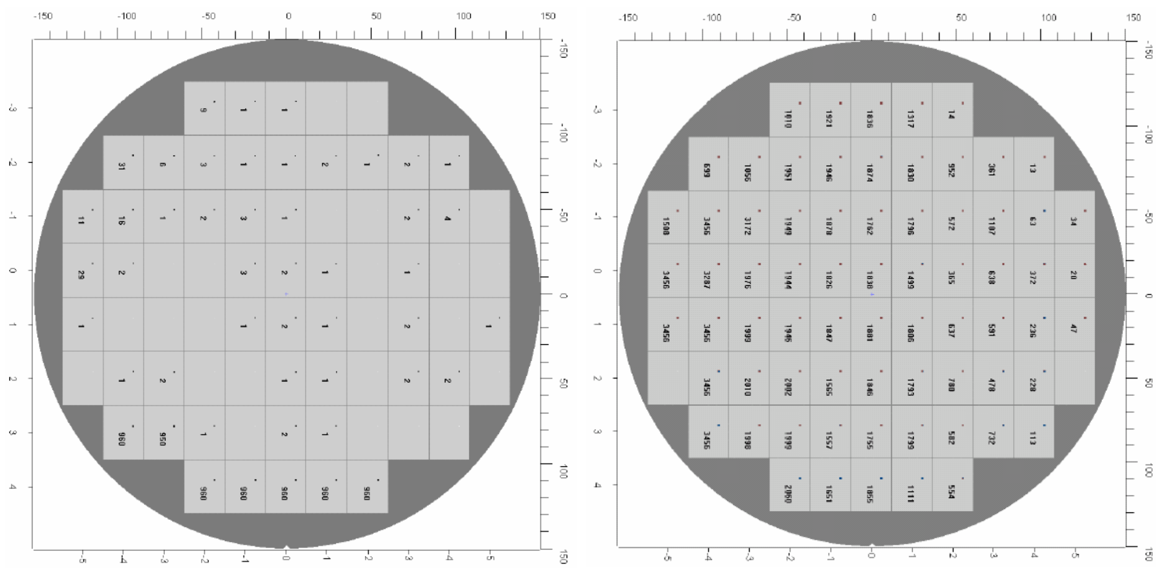
3. DEFECT INSPECTION

Both contact ACI wafer and WCMP wafers are inspected by eScan®300, a high-resolution electron beam (e-beam) inspection system. [3] At contact AEI level, contact hole with bottom remain usually has higher GLV than the normal holes, which is called bight voltage contrast (BVC) defect. The thicker of the remain, the higher the GLV. At WCMP level, we inspect the wafer with 500 eV landing energy, which is at positive mode. [4] For plugs with good contact to P+/N-well, their images in SEM are bright with high GLV. In case there are open contacts or partially open contacts, the GLV of these W-plugs will be lower than normal, which is commonly called DVC defect. The higher of the contact resistance, the lower the GLV. [5]

We sampled part of SRAM array as the care area and the defect count maps in the care area of contact ACI and WCMP wafer are shown in Figure 3a and 3b, respectively.

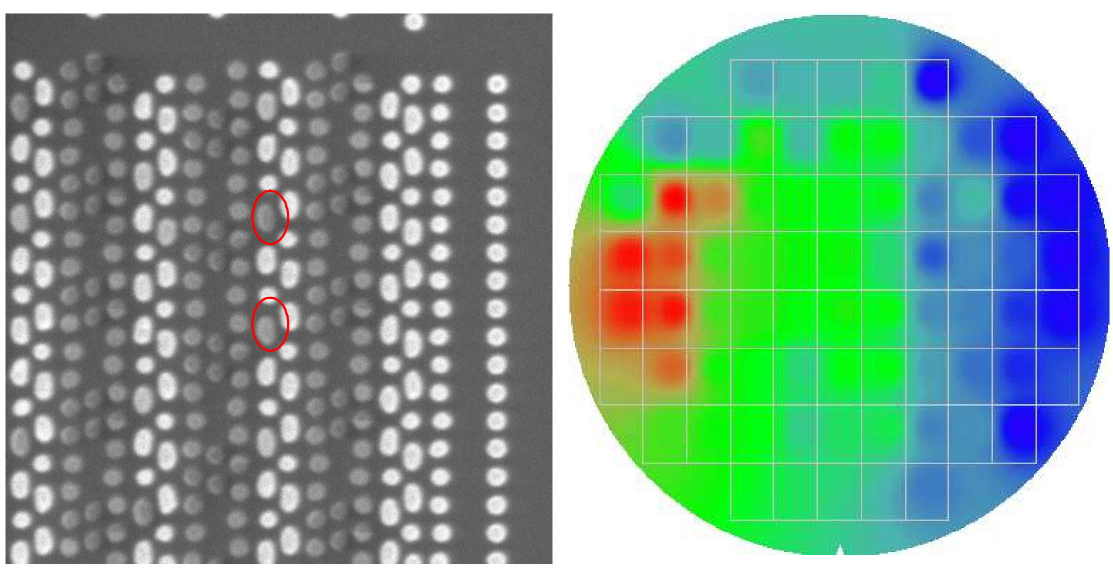
We find that the main defects are contact hole missing, open contact and bridging. Because significantly higher secondary electron (SE) emission of W-Plug than that from bottom of contact hole, the sensitive of defect detection at WCMP wafer is much higher then that at AEI wafer.

The DVC defect image and defect map of the WCMP wafer are shown in Figure 4a and 4b, respectively. We find that dies with higher exposure energy have less DVC defects while dies with lower exposure energy have more DVC defects. It is because higher dose exposure helps to open the holes on photoresist with larger CD, which helps to completely clear the dielectric on the bottom of the holes during the contact etch. With lower exposure energy, photoresist hole CD is small and some holes maybe have some photoresist remain at the bottom, which causes incomplete contact hole etch, BVC defect at contact AEI and DVC defect at WCMP.



(a) (b)

Figure 3. Total defects in SRAM array of AEI wafer (a) and WCMP wafer (b).



(a) (b)

Figure 4. SRAM array of WCMP wafer: DVC defect (in red circle) image (a) and DVC defect map (red represents high defect count and blue represents low defect count (b).

4. CD AND GLV MEASUREMENT

Figure 5 is a schematic of eProfile®, a high-throughput (up to 20 wafer per hour) e-beam GLV measurement and monitoring system developed form eScan®300 of Hermes Microvision Inc. [6]. One of its major applications is monitoring via or contact etch process by measuring GLV at the bottom of via or contact holes. With high resolution, it can accurately measure GLV of hole without effect of the hole CD. The higher GLV indicates thicker remain at bottom of a hole, and lower GLV indicates thinner remain.

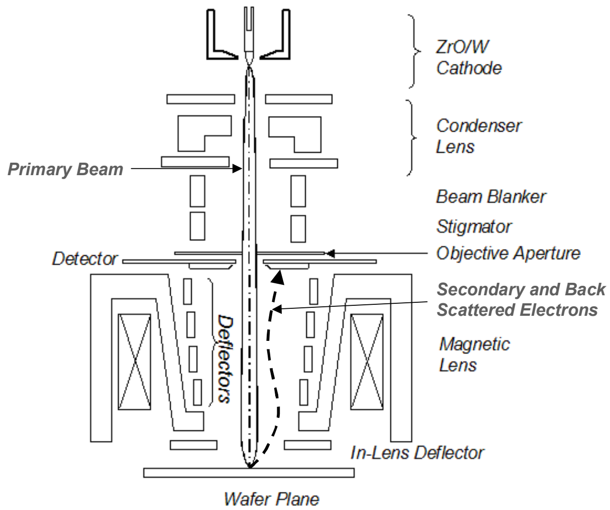
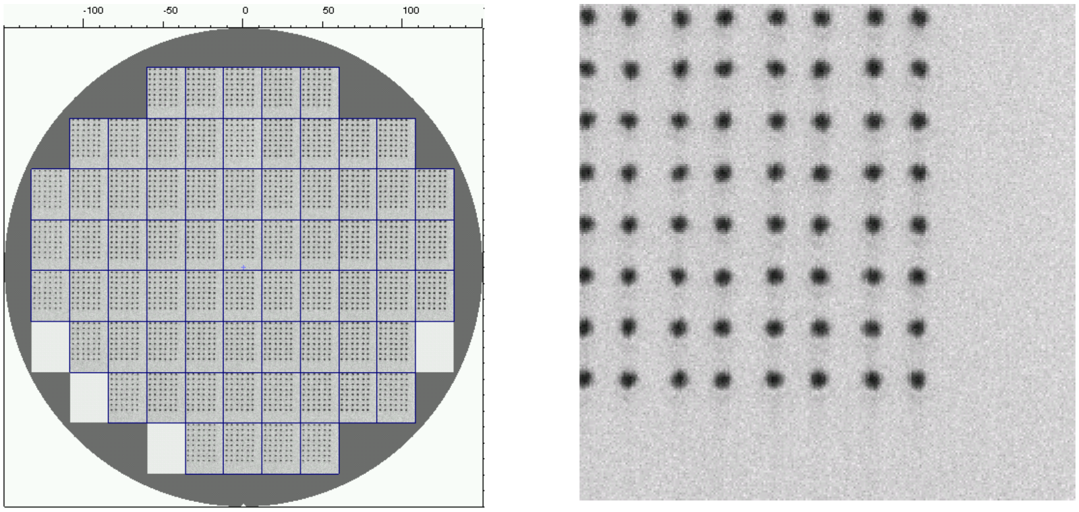


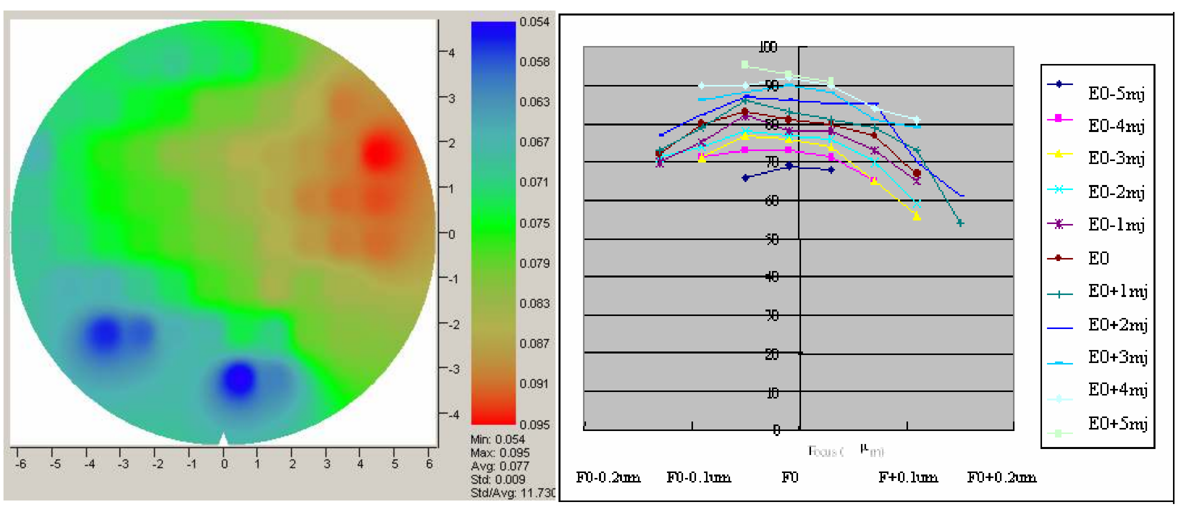
Figure 5. Schematic of eProfile®

By taking SEM images at the same location of each die or sampled dies, GLV signature of structure of interest can be measured to help process monitoring. For via or contact holes, CD can be measured using the same SEM image of holes that measures GLV. Figure 6a shows the die sampling plan of semi dense hole pattern and Figure 6b shows one of the SEM images of the semi dense pattern of the AEI wafer. Measurement of the same location of the sampled dies achieved via accurate stage movement control and robust pattern match algorithm. Figure 7a is the average CD of the semi dense hole pattern of the Figure 6, and the Figure 7b is the PWQ chart of the measurement. Figure 8a shows the die sampling plan of isolated hole and Figure 8b shows one of the SEM images of the isolated hole of the AEI wafer. Figure 9a is the CD of the hole pattern of the Figure 8, and the Figure 9b is the PWQ chart of the measurement. From PWQ chart, we find that the optimized focus and energy should be at negative focus and high energy side, which is consistent with the defect inspection results, as shown in Figure 3.



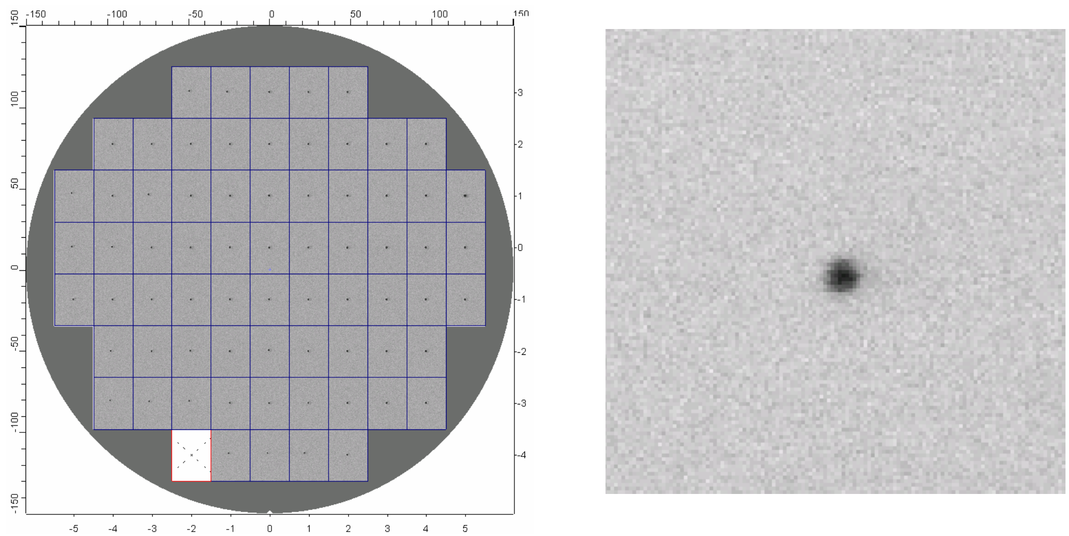
(a) (b)

Figure 6. Semi dense hole pattern sampling plan (a) and SEM image (b).



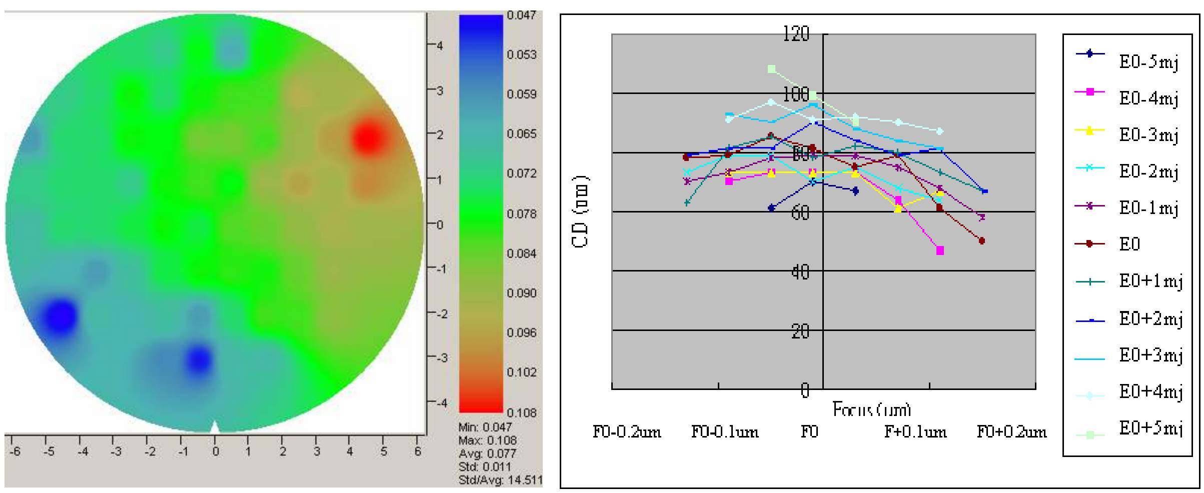
(a) (b)

Figure 7. Semi dense hole CD variation (a) and PWQ chart (b).



(a) (b)

Figure 8. Sampling plan of isolated hole pattern (a) and SEM image (b).

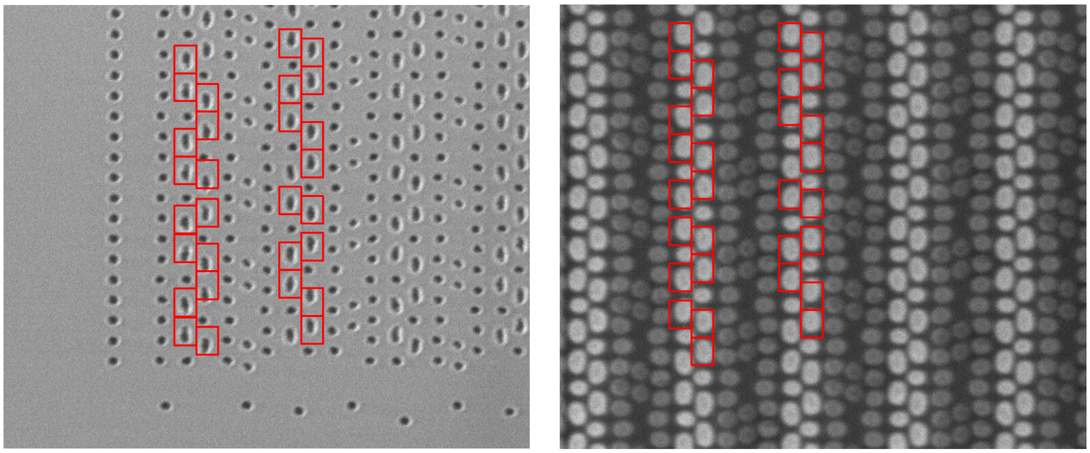


(a) (b)

Figure 9. Isolated hole CD variation (a) and PWQ chart (b).

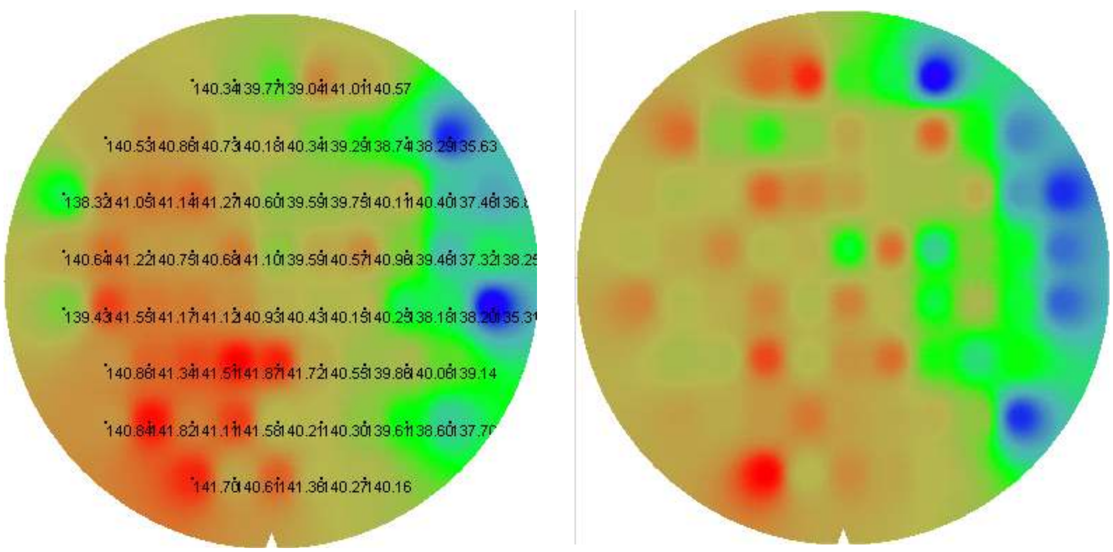
One of the most important defects of interest (DOI) of contact module is the open contact. Based on the inspection result, most open defects in SRAM array, BVC at AEI wafer and DVC at WCMP wafer, are the oval contacts, as shown in Figure 4b. Thus, we selected the oval contact holes on AEI wafer and oval W-plugs on WCMP wafer as the structure of interest to measure GLV, as show in Figure 10a and Figure 10b, respectively.

The GLV of oval contact hole and reversed GLV of W-plug are shown in Figure 11a and 11b, respectively. We can see significant correlation between them, as illustrated in Figure 12. We can also see the correlation between reversed GLV of oval W-plug in Figure 11b and WCMP DVC defect map in Figure 4b.



(a) (b)

Figure 10. Structure of interest for GLV measurement of contact AEI (a) and WCMP (b).



(a) (b)

Figure 11. GLV results of oval contact holes (a) and reversed GLV of oval W-plugs (b).

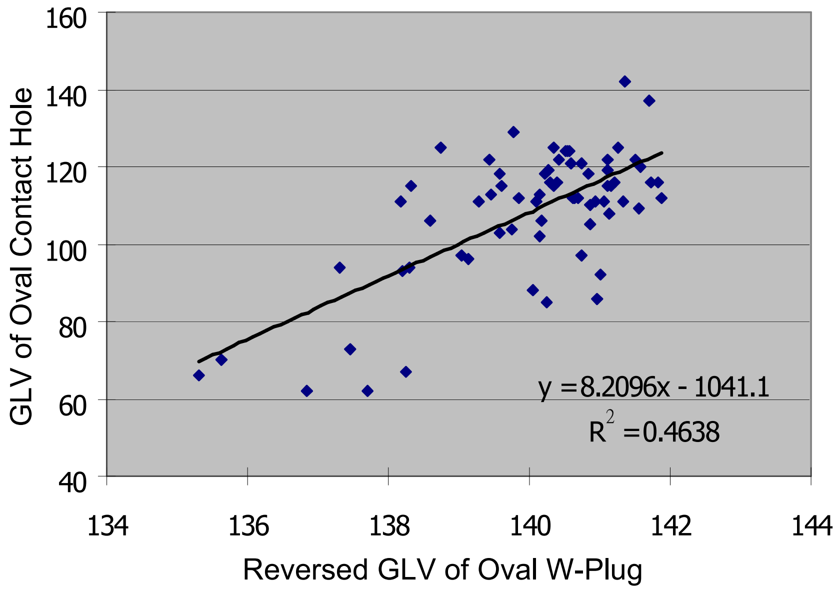


Figure 12. Correlation of GLV of oval contact holes and oval W-plugs.

5. SUMMARY

In this study, we did defect inspection a contact AEI wafer with FEM and a WCMP wafer with the same contact mask FEM. Inspection found that missing defects are mainly determined by focus, open defects are mainly determined by exposure dosage, and bridge defects are determined by exposure and focus. The structure of interest for open defects are the oval contact holes and oval W-plugs, which connect both PMOS poly gate and P+/N-well. GLV map of W-plug strongly correlates with oval contact hole, it also correlates with WCMP DVC defects map. We found that e-beam defect inspection and GLV and CD measurement can be very promising tools for contact reticle PWQ.

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