High-throughput contact critical dimension and gray level value measurement

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ABSTRACT

A high-throughput e-beam monitoring system, eProfile®, is designed to quickly measure gray level value (GLV) and critical dimension (CD) of the structures of interest on product wafers. Two wafers are used in this study, one wafer is at after etch inspection (AEI) with contact mask focus exposure matrix (FEM), and another is normal exposure contact AEI wafer. High-throughput CD measurement of AEI wafer at holes with different patterns, such as semi-dense and SRAM array were measured with results matched the FEM expectation very well. The system is also be used to measure GLV of the SEM images on contact holes of a normal production wafer to reflected the under etch (high GLV) problem in a semi-dense hole pattern.

1. INTRODUCTION

Because shrinking of the device dimension as well as the killer defect dimension, IC chip fabrication has increasingly used SEM systems for CD measurement, defect inspection, defect recapturing, review and identification. The unique capability for e-beam to detect electrical defects such as short or leak circuit and open or partially open circuit due to the charging effect of the e-beam makes it an equipment of choice for interconnect process inspection and monitoring.

Figure 1 is a schematic of eProfile®, an high-resolution e-beam GLV measurement and monitoring system newly developed form eScan®300 by Hermes Microvision Inc. [1] It consists an electron gun, an electron beam column with objective apertures, a semiconductor detector, and focus lenses assembly.

When primary beam electrons hit a tiny spot (a pixel as small as 5 nm by 5 nm) on the wafer surface, they will excite many secondary electron (SE) and back scattering electron (BSE) out of that surface.

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The ring shaped detector effectively collects SE and BSE from the wafer surface and the electrical signals are processed into digital format along with the scanning signal to form SEM image. The GLV of that pixel in the SEM image is determined by the total number of electrons from the pixel collected by the detector. High-resolution SEM image up to 1024×1024 pixels can be formed when e-beam scan across the sample surface at the rate of 4000 images per hour, allowing high-throughput (up to 20 wafers per hour) in-line process monitoring.

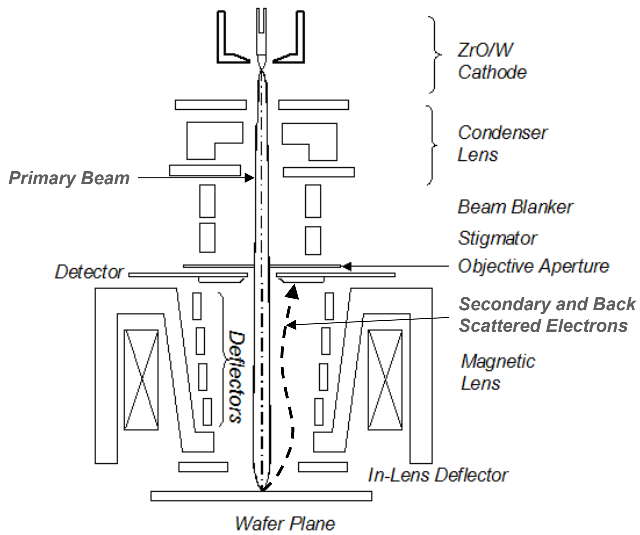


Figure 1. Schematics of eProfile®.

2. GLV METHODOLOGY

When using e-beam to scan a wafer with contact holes, SE in the holes usually are harder to come out and be collected by the detector, therefore, holes normally have lower GLV than the surface. In under-etch case, the bottom dielectric remain could be charged up by the electrons, especially for electrons with low LE that cannot penetrate the thin layer. Therefore, under etched holes usually have higher GLV than the holes that are etched through, which reach the substrate underneath the dielectric film and allows electrons to leak to the ground. [2] The holes with thicker remain will have higher GLV. Figure 2 illustrates these cases. Figure 2a, 2b and 2c are images of via holes and their GLV. Figure 2d, 2e and 2f are the cross-section SEM images of the 2a, 2b and 2c. We can see that different remain thickness correlates with the GLV. With small pixel, high-resolution e-beam system, we can draw a circle along the edge of hole and accurately measure GLV inside the circle. In this way we can monitor

the remain at the hole bottom without the effects of the CD variation. We can also measure bottom CD (diameter of the circle) with the same image that measures GLV.

By collecting images of each die or sampled dies at the same die location and measuring the GLV of contact, one can do in-line process monitoring for both hole CD and bottom remain.

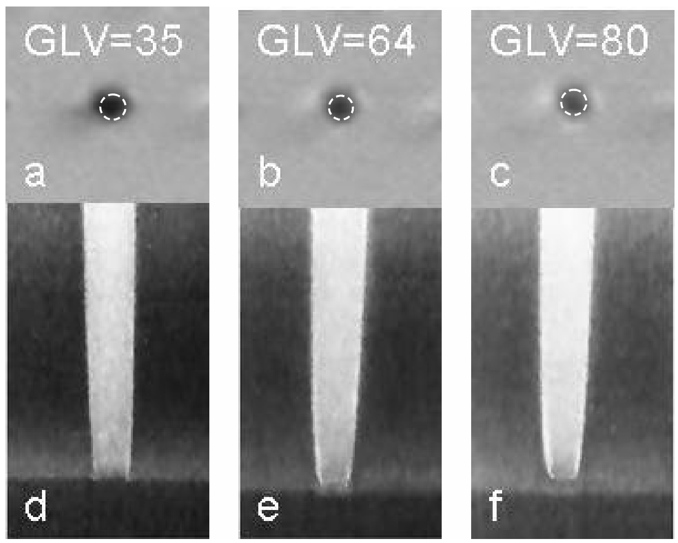
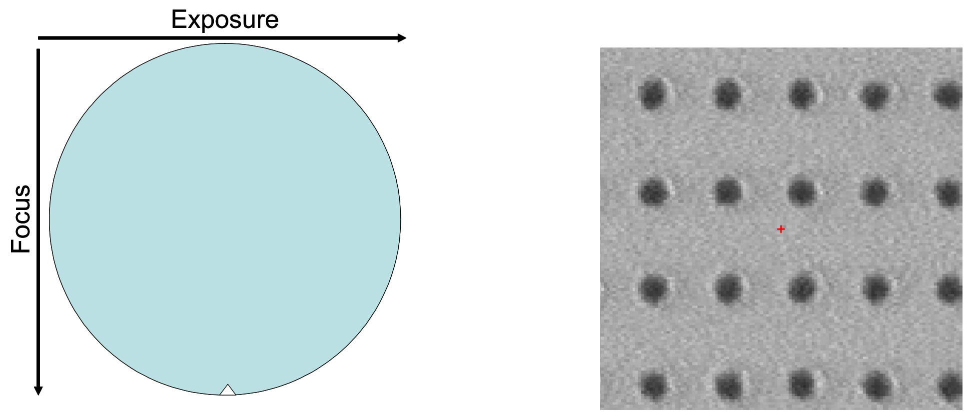


Figure 2. GLV of via holes (a, b and c) and cross-section SEM images (d, e and f) of contact hole with different remain thicknesses.

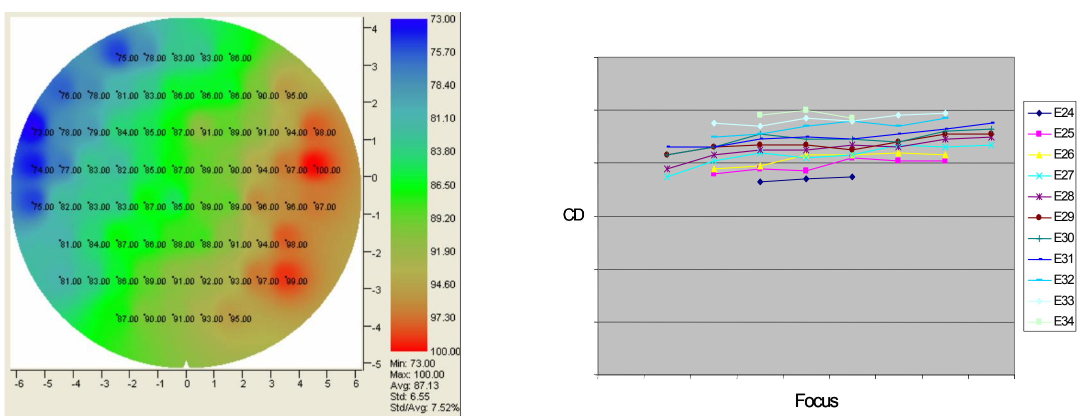
3. PROCEDURE AND MEASUREMENT RESULTS

We used a contact mask and exposed a produce wafer with FEM. After photoresist development and UV bake, wafer was processed to contact AEI. Then the wafer was sent to eProfile® to measure CD and GLV. The e-beam conditions were 500 eV landing energy, 10 nA beam current, and 10 nm pixel size. Figure 3a shows the direction of focus/exposure variations on the dies of the wafer and Figure 3b is one of SEM images of semi-dense hole pattern. We took one such image at the same location of each die across the wafer. Figure 4a is the CD map measured from these images. Figure 4b is the PWQ chart. The GLV measured from the same images is illustrated in Figure 5a. We found very little correlation between GLV and CD, as shown in Figure 5b. Thus the we are confident that GLV represents the remain at the hole bottom with little influences from hole CD. More results about FEM wafers are published in SPIE Microlithography 2006 by R. H. Hsu, etc. [3]



(a) (b)

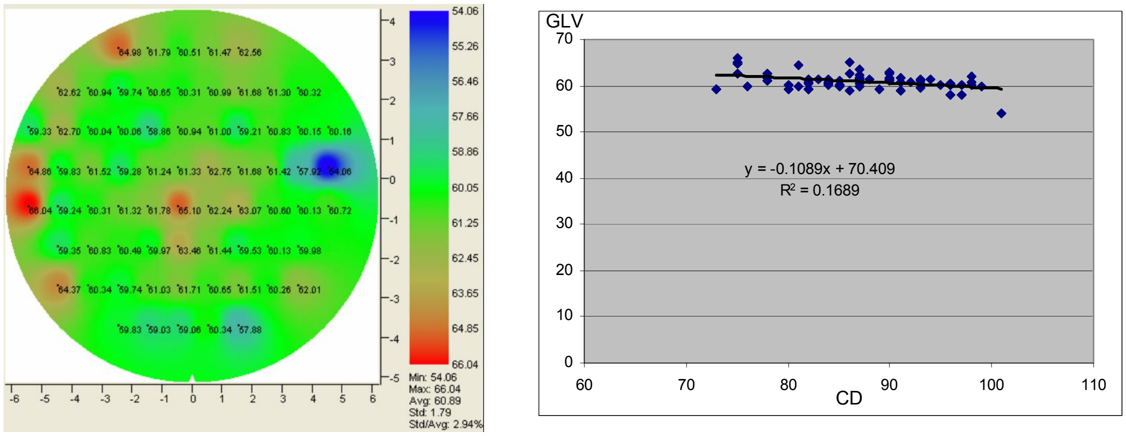
Figure 3. Focus/exposure direction (a) and SEM image of semi-dense hole



(a) (b)

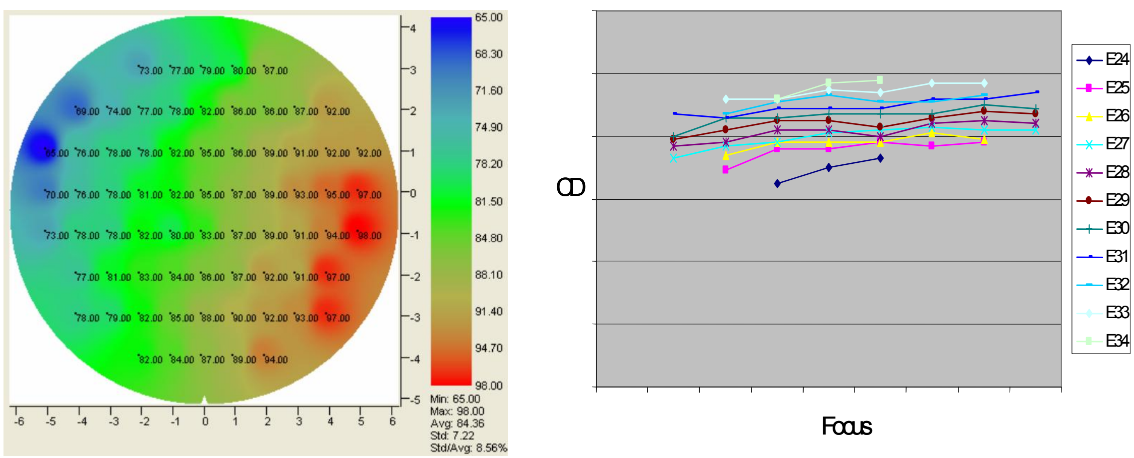
Figure 4. Semi-dense hole CD map of the EFM wafer (a) and the PWQ chart (b).

There are two contact hole shapes in SRAM array, oval shaped local interconnect holes that connect to both P+/N-well and PMOS polysilicon gate and round contact holes that only connect to P+/N-well, N+/P-well, or NMOS polysilicon gates. We also measured CD of the round holes in SRAM array, and the results are shown in Figure 6a, and PWQ chart is shown in Figure 6b. We found that CD maps and PWQ charts of round holes of SRAM array are very similar to these of semi dense holes.



(a) (b)

Figure 5. Semi-dense hole GLV map (a) and the correlation data of GLV and CD.

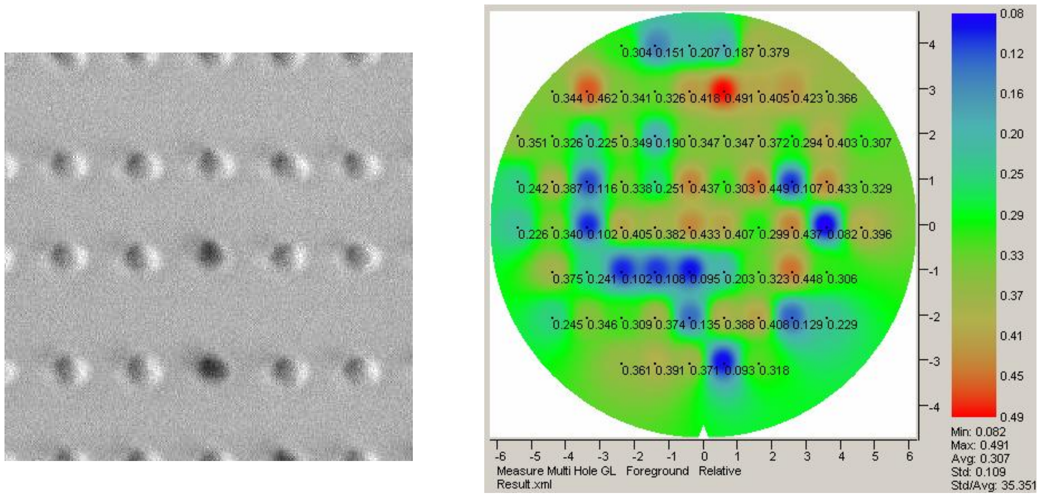


(a) (b)

Figure 6. CD map of the round holes in SRAM array (a) and the PWQ chart (b).

Another contact AEI wafer with standard exposure is also measured. Figure 7a shows one of the measurement images of semi-dense pattern. From this image, we knew the GLV of the holes within the field of view (FOV) of the SEM is not uniform. We can quantify the GLV variation within FOV with multiple holes by calculating the ratio of the difference between maximum GLV and minimum GLV and 2 times of average GLV, or $(GLV_{max} - GLV_{min})/(2* GLV_{ave})$. The GLV variation of semi-dense hole pattern across wafer is illustrated in Figure 7b. We can see that it varies a lot across wafer, indicates

some process issues. The large GLV variation within FOV of SEM is likely caused by insufficient over etch after endpoint detection, causing some holes still have dielectric remains at the bottom while others are completely etched through. Therefore, GLV measurement could be a very powerful tool to allow engineers to quickly check the uniformity within a dense or semi-dense hole pattern and across wafer for in-line process monitoring.



(a) (b)

Figure 7. SEM images of semi-dense hole (a) and within FOV GLV variation map (b).

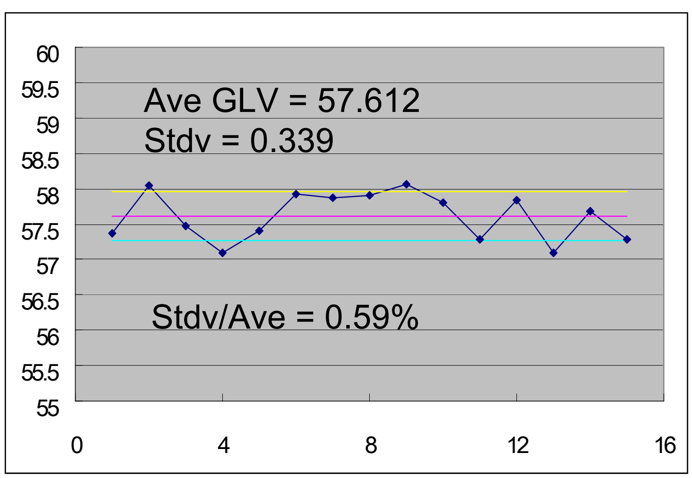


Figure 8. 15-time repeatability of the semi-dense hole GLV.

4. SUMMARY

We used eProfile®, a high-throughput e-beam monitoring system, to measure CD and GLV of different contact holes on contact AEI wafers. CD PWQ chart can be quickly generated for FEM wafer and the results match expectation well. GLV measurement can be used to quickly check the sanity of the contact etch process. With reasonable repeatability, eProfile can be used in-line process control by using to monitor hole GLV and CD on hole patterns of interest.

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