Use of Automated EBR Metrology Inspection to Optimize the Edge Bead Process

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ABSTRACT

Accurate placement of the edge exclusion region is critical to maintaining edge die yield. Variation in film overlay in the edge exclusion region can lead to yield-limiting defects. Edge Bead Removal (EBR) metrology or Edge Exclusion Width (EEW) metrology describes a topside surface measurement of the wafer edge exclusion region relative to the wafer center and the wafer edge. This measurement is typically made at several points along the wafer's edge and often ranges between 0 mm and 6 mm in width. In photolithography, EBR metrology data can be used to determine the repeatability of wafer alignment and the accuracy of EBR dispensing nozzles on the coat track.

In addition to EBR/EEW metrology, wafer edge inspection provides an indirect method to control the EBR process by detecting jaggedness of the EBR profile, scalloping, splashing, and other EBR line defects. Improper EBR can also create residuals on other edge surfaces that can lead to cross-contamination of wafers and handling equipment.

This paper describes a combined EBR/EEW metrology and wafer edge inspection method that can quickly detect EBR-related defects and characterize the quality of the EBR process. This data reveals the relationship between EBR-related defects and the quality of the EBR process, and can be used to make necessary adjustments to the coat track – and as a basis for wafer rework decisions. Proper tuning and monitoring of the EBR/EEW process allows for the eventual elimination of an entire class of EBR-related defects, thus significantly increasing edge die yield.

INTRODUCTION

The EBR process is used directly after resist coating to remove excess photo resist around the perimeter of the wafer at a fixed distance from the wafer edge. The edge exclusion region can be created in two ways. In a chemical EBR process, a solvent is dispensed in this area as the wafer rotates to create an edge exclusion region. An optical EBR is created during wafer exposure by also exposing the photo resist around the perimeter of the wafer.

The EBR process is often overlooked as a mechanism that can cause front side damage. This is because EBR metrology (the ability to determine if the EBR is too big, too small, off-center, etc.) is still a manually intensive step in modern fabs. The most common method to measure EBR dimensions is to place the wafer onto an optical microscope and measure the distance from the EBR line to the wafer edge at three or more positions around the wafer.

At National Semiconductor in South Portland, Maine, EBR has been measured on monitor wafers by using a manual profiler which is also used to measure trench depths. The tool works by dragging a stylus across the wafer from the center outward. To measure EBR, the distance (measurement #1) is recorded from some reference point to the point where the stylus drops down from the resist height to the bare wafer where the EBR begins. The distance from the same reference point to the point where the stylus falls off the edge of the wafer (measurement #2) is also recorded. EBR width is calculated by subtracting measurement #1 from measurement #2. These measurements are taken at three points around the wafer, 120 degrees apart.

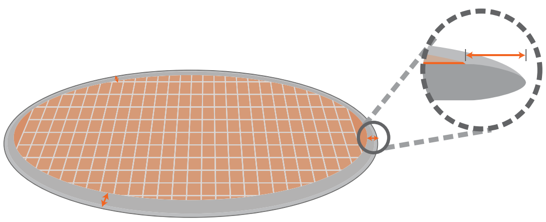

Figure 1 - National Semiconductor measures EBR manually at three points around the wafer, 120 degrees apart

EBR measurements taken on the profiler can be susceptible to error. The tool is very sensitive to vibration, which can often result in false readings. The stylus can also give inaccurate readings on non-uniform wafer topography, requiring additional measurements. This process is time consuming, as it can take up to 10 minutes to measure two wafers using this method.

This approach can also be problematic for several other reasons. First, the wafer bevel transition can easily be mistaken for the wafer edge apex, leading to a smaller Edge Exclusion Width (EEW) measurement, thus compromising the integrity of the data. Secondly, the EBR line can be difficult to distinguish on patterned wafers, especially when some layers are patterned all the way to the edge. Additionally, the EBR line may be discontinuous around the wafer leading to erroneous measurement; and finally, three measurement points per wafer is insufficient to statistically represent the EBR characteristics of a wafer.

Manual EBR metrology is generally reserved for preventive maintenance using test wafers. As a result, infrequent sampling allows out-of-spec EBR to go unnoticed. Out of spec or off-center EBR can result in several different process-related issues. If the EBR width is too narrow, edge grippers on process tools can touch the hardened, brittle photoresist and cause it to crack and flake off, causing contamination. If the edge exclusion is too wide, there will be less surface area available for product die. The ITRS roadmap currently calls for an edge exclusion of 2 mm. In 2007, this value will change to 1.5 mm to tie in with the 65 nm node.[1]

Poor control of the Edge Bead Removal process leads to poor edge die yield. EBR control and accuracy are important with multiple stacked layers. If EBR is off-center, undercutting of films can lead to popping at the edge. Additionally, there is a correlation between out-of-spec EBR metrology and edge film adhesion. For example, an off-center EBR indicates that part of the wafer edge is under-cleaned. A larger-than-usual EBR may indicate an edge “overhang” problem in a film stack. Unwanted film geometry along the wafer edge can cause unexpected film stress and reduce film adhesion to the substrate, resulting in delamination and flaking. These defects can then be transferred to the frontside of the wafer. This is particularly crucial in metal CMP where the delaminated metal flakes can move from the wafer edge and lodge between the polishing pad and the front surface of the wafer, causing severe frontside scratches during the polishing step. If an EBR excursion is not detected in a timely manner, product may need to be reworked or scrapped.

INSPECTION METHODOLOGY

National Semiconductor uses Rudolph Technologies' AXi™ Series macro inspection system with integrated backside (B20™) and edge (E20™) inspection at several inspection steps. The E20 System scans the wafer edge, acquires a set of images and uses proprietary algorithms to detect a wide range of process-related or mechanically-induced edge defects.

In addition to performing edge top and edge bevel inspection, the E20 System can perform automatic high-resolution Edge Bead Removal (EBR) metrology on both unpatterned and patterned wafers by using a patent-pending algorithm on brightfield images acquired by the edge top camera. During edge top inspection, the edge top sensor collects 360º of overlapping images. The system stitches these images together and compresses them to form an "EBR fingerprint" map. From the EBR fingerprint, the locations of the wafer edge and EBR edge are calculated, along with their relationship to the wafer center. This compression erases non-vertical features from the images and allows the EBR algorithm to measure the EBR feature even when patterning extends to the wafer edge. Circular EBR features appear as vertical lines in the "EBR fingerprint" map while oblong or off-centered EBR features appear as sinusoidal lines.

The E20 System provides a more comprehensive EBR metrology data set than the manual measurements taken on the profiler. From this inspection, the E20 System calculates the EBR width around the perimeter of the wafer using up to 360 points; the standard deviation, which gives some indication of EBR line roughness; and the X and Y center and radial offset of the EBR relative to the wafer center.

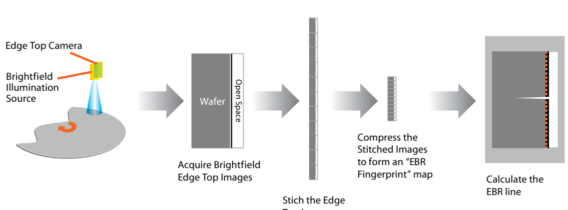

Figure 2 - The E20 System uses brightfield or darkfield illumination and a color camera to collect images as the wafer rotates. These images are then stitched together, and compressed to form an "EBR fingerprint".

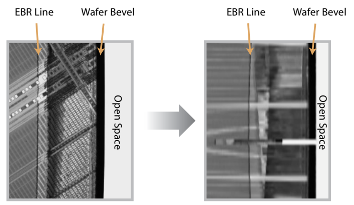

Figure 3 - An example of an edge top image (left) and a graphical representation of an EBR fingerprint map (right).

EXPERIMENTAL PROCEDURE

EBR metrology data was collected on a set of 14 monitor wafers, which included wafers coated on two different coat tracks, using three different resists, both chemical EBR and optical EBR, and nominal EBR widths of 2.0 mm and 1.5 mm. The outer and inner EBR tolerances are +/- 0.5 mm. All wafers were measured twice on the profiler and five times on the E20 System to compare mean EBR width, within-wafer sigma, and measurement repeatability.

During this testing, the same profiler was used to collect all manual measurements. Two coat tracks which had historically exhibited the most variation in EBR were selected for testing. Two wafers were run through each of the following seven combinations, as listed in Table 1.

Wafer	EBR Processing	Nominal EBR
1,2	Track 2, Resist 3 – Chemical EBR	2.0 mm
3,4	Track 1, Resist 2 – Optical EBR	2.0 mm
5,6	Track 2, Resist 2 – Chemical EBR	2.0 mm
7,8	Track 2, Resist 1 – Chemical EBR	2.0 mm
9,10	Track 1, Resist 1 – Optical EBR	2.0 mm
11,12	Track 1, Resist 2 – Chemical EBR	1.5 mm
13,14	Track 1, Resist 1 – Chemical EBR	1.5 mm

Table 1. Wafers and EBR processing used for testing.

DATA

Automated EBR measurements were taken once per day on 14 wafers on the E20 System over a period of five days, collecting 360 data points around the perimeter of the wafer. All measurements are in millimeters.

Wafer	Nominal EBR (mm)	E20 Mean EBR	Within Wafer EBR Std. Dev.	Run to Run Std. Dev.	X Center	Y Center	Radius	Radial Offset
1	2.0 mm	2.265	0.049	0.00037	-0.066	-0.015	97.813	0.068
2	2.0 mm	1.925	0.041	0.00015	0.045	0.073	98.130	0.086
3	2.0 mm	2.086	0.023	0.01136	0.023	-0.016	97.989	0.030
4	2.0 mm	2.081	0.025	0.00044	0.030	-0.018	97.996	0.035
5	2.0 mm	2.225	0.067	0.00028	-0.090	0.022	97.851	0.093
6	2.0 mm	2.238	0.066	0.01608	-0.079	0.053	97.842	0.096
7	2.0 mm	2.263	0.189	0.00036	0.140	-0.255	97.829	0.291
8	2.0 mm	2.165	0.112	0.00049	0.107	-0.165	97.935	0.197
9	2.0 mm	2.135	0.013	0.00029	-0.011	0.008	97.940	0.014
10	2.0 mm	2.140	0.023	0.00016	0.017	0.023	97.937	0.029
11	1.5 mm	1.581	0.024	0.00027	0.029	0.012	97.497	0.031
12	1.5 mm	1.580	0.051	0.00024	0.083	0.085	97.534	0.119
13	1.5 mm	1.584	0.024	0.00029	0.032	-0.006	98.493	0.033
14	1.5 mm	1.567	0.048	0.00027	0.069	0.058	98.526	0.090

Table 2. Automated EBR measurements from E20 System.

The corresponding measurement data from the profiler is listed in Table 3. Each wafer was measured twice on this tool, collecting three data points, 120 degrees apart, on each wafer.

Wafer	Nominal EBR (mm)	Profiler Mean EBR	Range	Wafer Std. Dev.	Run to Run Std. Dev.
1	2.0 mm	2.07	0.10	0.05	0.0092
2	2.0 mm	1.74	0.14	0.08	0.0005
3	2.0 mm	1.89	0.05	0.03	0.0019
4	2.0 mm	1.89	0.06	0.03	0.0016
5	2.0 mm	2.03	0.17	0.08	0.0016
6	2.0 mm	2.03	0.17	0.08	0.0057
7	2.0 mm	2.05	0.46	0.26	0.0014
8	2.0 mm	1.94	0.29	0.17	0.0092
9	2.0 mm	1.94	0.04	0.02	0.0000
10	2.0 mm	1.94	0.05	0.02	0.0035
11	1.5 mm	1.37	0.06	0.03	0.0000
12	1.5 mm	1.33	0.19	0.09	0.0035
13	1.5 mm	1.37	0.06	0.03	0.0075
14	1.5 mm	1.36	0.14	0.07	0.0040

Table 3. Manual EBR measurements from profiler

The within-wafer standard deviation values and run to run standard deviation values can be indicative of the quality of the EBR. The data from Tables 2 and 3 shows that wafers 3, 4, 9, and 10 have the lowest within-wafer standard deviation values for EBR measurements. These four wafers were all processed on the same coat track with optical EBR, which results in a much cleaner EBR transition (see Figure 4a).

Wafer 7, which was processed on coat track #2 with chemical EBR has the highest standard deviation for within-wafer EBR measurements. Its EBR transition is more ragged looking (see Figure 4b). Wafer 6 had the highest standard deviation when measuring run-to-run repeatability on the E20 System. Figure 4c shows a very jagged and uneven EBR profile.

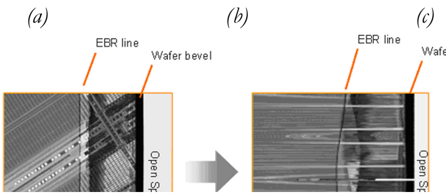

Figure 4 - (a) shows an optical EBR profile (Wafer 9). (b) shows the rougher looking chemical EBR profile (Wafer 7). (c) shows a very jagged and uneven EBR profile (Wafer 6).

The higher within-wafer standard deviation can also be indicative of an EBR that is off-center. Wafer 7 has very high X and Y center values (0.14 mm, -0.255 mm), and a radial offset of 0.291 mm (see Figure 5). Wafers 3, 4, 9, and 10 all have X Center, Y Center, and radial offset values that are comparatively much lower.

In addition to the data in the tables above, an additional set of measurements was taken on each of the tools to compare the profiler and E20 System measurements at the same three points on the wafer, 120 degrees apart. The summary of the point to point comparison is listed in Table 4.

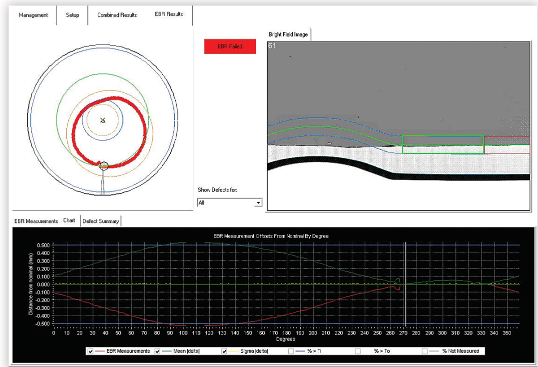

Figure 5 - Wafer map shows best-fit circle based on EBR measurements for wafer 7. The EBR is noticeably off-center.

Wafer	Nominal EBR (mm)	Profiler Mean EBR	Wafer Range	Wafer Std. Dev.	E20 Mean EBR	Wafer Range	Wafer Std. Dev.	Mean EBR Delta Between Tools
1	2.0 mm	2.06	0.10	0.06	2.26	0.10	0.06	0.20
2	2.0 mm	1.74	0.14	0.08	1.95	0.15	0.08	0.20
3	2.0 mm	1.89	0.06	0.03	2.08	0.05	0.02	0.19
4	2.0 mm	1.89	0.06	0.03	2.08	0.05	0.03	0.19
5	2.0 mm	2.03	0.17	0.08	2.23	0.16	0.08	0.20
6	2.0 mm	2.02	0.17	0.08	2.22	0.18	0.09	0.20
7	2.0 mm	2.05	0.46	0.26	2.25	0.43	0.24	0.20
8	2.0 mm	1.94	0.31	0.17	2.14	0.29	0.16	0.20
9	2.0 mm	1.94	0.013	0.02	2.14	0.04	0.02	0.19
10	2.0 mm	1.95	0.04	0.02	2.14	0.06	0.03	0.19
11	1.5 mm	1.37	0.08	0.04	1.58	0.06	0.03	0.21
12	1.5 mm	1.33	0.18	0.09	1.54	0.20	0.10	0.21
13	1.5 mm	1.38	0.05	0.03	1.58	0.05	0.03	0.21
14	1.5 mm	1.35	0.14	0.07	1.55	0.16	0.08	0.20

Table 4. Comparison of three point measurement between the E20 System and profiler.

During this experiment, it was noted that there was a consistent offset of ~0.2 mm between the profiler and the E20 System EBR measurements. In order to verify the accuracy of our EBR measurements, two of the wafers used in the experiment were also measured with a micro cleaving system, and with a hand-held micrometer at the same three locations that were measured on the profiler. It was found that there was an additional delta of ~0.14 mm between this new set of measurements and the profiler, as shown in Table 5.

Wafer	Profiler Mean EBR	Profiler Sigma	Cleaving Tool Mean EBR	Cleaving Tool Sigma	Mean EBR Value Delta
10	1.95	0.04	1.80	0.05	-0.15
11	1.37	0.07	1.24	0.07	-0.13

Table 5. Comparison of profiler measurement to cleaving tool.

This also means that there is a delta of ~0.34 mm between the measurements from the cleaving tool and micrometer and the EBR results from the E20 System. Subsequent investigation revealed that the systematic delta is the result of a less-than-optimal system calibration and can be corrected by fine-tuning a calibration value on the tool.

FUTURE WORK

As more data is collected, the goal is to implement the E20 System to monitor control of the EBR process on each coat track more than twice per week, while the profiler would be used as a backup tool. This will allow more frequent and consistent monitoring of the EBR process, and any excursions can be discovered before any product wafers are further processed.

CONCLUSION

One of the goals of implementing EBR metrology at National Semiconductor was to achieve better control of the EBR process. As shown in the data above, the run to run repeatability and within wafer sigma values of the E20 System and profiler measurements are comparable.

The E20 System's EBR inspection and EBR metrology provide a more comprehensive data set that can be used to control the EBR process. In addition to calculating the EBR width around the entire perimeter of the wafer, this data includes the X and Y offset values and radial offset of the EBR region, which provide information about the centricity of the EBR placement. The comprehensive nature of the E20 System's data collection provides the ability to track EBR variations over the entire wafer. These variations are almost completely missed by looking at only three points on the wafer.

The time required to measure two wafers using the profiler is generally between five and ten minutes. Using the automated EBR metrology tool requires only about one minute per wafer, which greatly enhances the efficiency of monitoring the EBR process with a much higher UPH in throughput.

As the industry transitions from a nominal 2.0 mm to a nominal 1.5 mm EBR in advanced technology nodes, changes will be required to the EBR measurement process and wafer handling techniques throughout the fab. This transition will require EBR/EEW measurements throughout the front-end process. More efficient methods of EBR metrology measurement and edge inspection can help with this transition.

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REFERENCES

1. The International Technology Roadmap for Semiconductors, 2005.