Reducing 300mm Wafer Coating Defects without Compromising Uniformity

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Bottom Anti-Reflective Coating (BARC) defects drop when applying design of experiments techniques.

Because defects are the major source of lower fab yields, manufacturers continually try to improve wafer processing methods. Increasingly, experimental-design protocol is being used within the wafer fabrication industry to investigate coating defects and uniformity issues. Design of experiments (DOE), a vibrant discovery and analysis methodology, allows engineers to study numerous complex factors with a minimum number of experimental runs.

Recently, applications engineers at our Rolla, Missouri, facility implemented a new process to reduce bottom anti-reflective coating (BARC) defects on 300mm wafers. Our indispensable discovery tool was DOE, a quality-control creation from the 1920s that continues to flourish as an important Six Sigma instrument. We knew from earlier work that dispense volume on smaller, 200mm wafers generally does not have a great influence on defects – whereas dispense speed does. Presuming dispense speed to similarly influence 300mm wafer processing, we became intrigued when this variable never showed up as a statistically significant factor for the larger wafers. In fact, neither dispense speed nor volume had any effect on defects.

INVESTIGATING THE FACTORS

To begin establishing critical 300mm BARC settings, we conducted a DOE to find a process for reducing those irksome coating defects – without compromising uniformity. With the help of Design-Expert® software, we varied the following factors within a two-level factorial design:

1. Dispense Speed (Factor A)
2. Exhaust (Factor B)
3. Dispense Volume (Factor C)
4. Relax Speed (Factor D)
5. Pump Reload Rate (Factor E).

The responses were:

1. Thickness
2. Uniformity
3. Number of Defects.

Darron Dipple, a field applications engineer with Brewer Science, Inc., coated the 300mm wafers using a TEL ACT12 track.

Flaws measuring 0.16µm and larger were noted via a KLA/Tencor SP1. The DOE software from Stat-Ease, Inc. revealed that Dispense Speed (Factor A), Dispense Volume (Factor C), and Relax Speed (Factor D) had no strong effect on defects. Two factors in this factorial DOE (shown in Figure 1), were problematic: Exhaust (Factor B) and Reload Rate (Factor E).

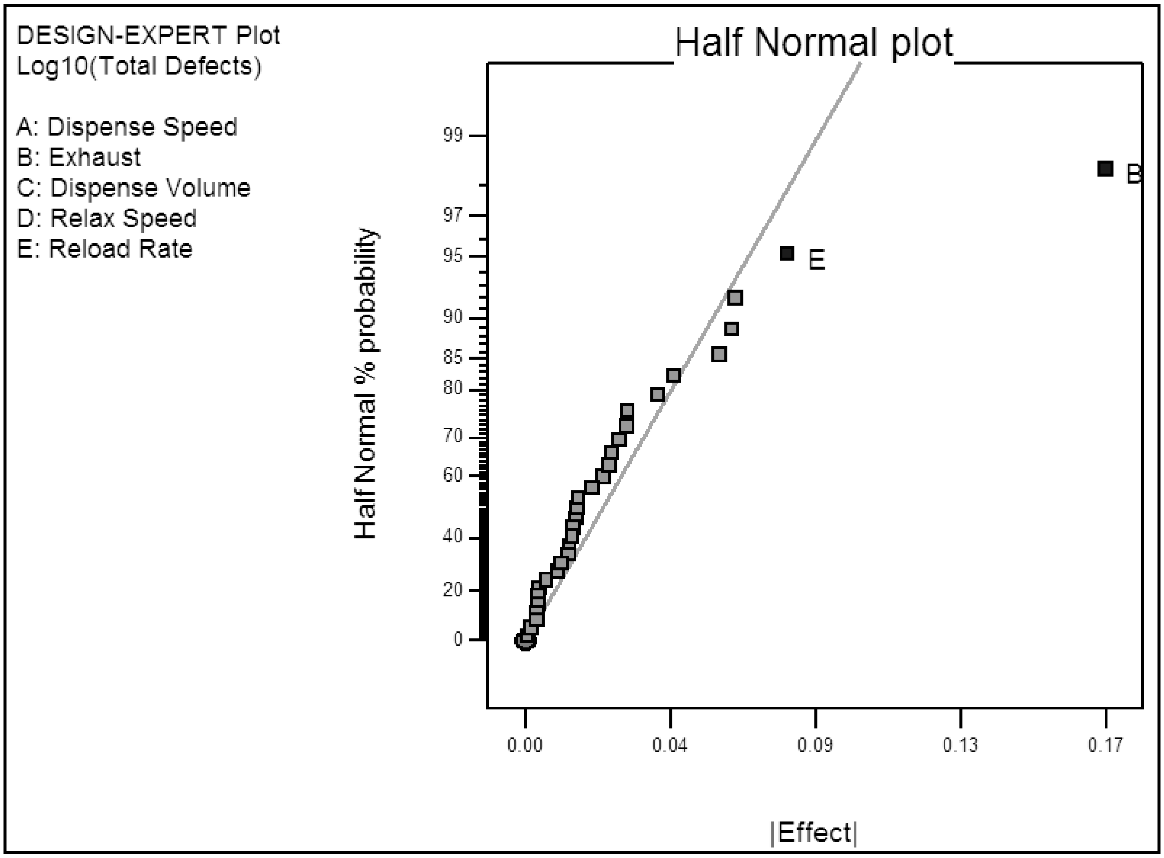

FIGURE 1 – HALF-NORMAL PLOT. DOE software screenshot displays the main effects of the five factors under study. Two factors stand out – Exhaust (Factor B) having the largest effect, and Reload Rate (Factor E) to a lesser degree. Both factors reveal themselves to be statistically significant at $p<0.01$. Not shown here are two additional, yet relatively weak factor effects – Dispense Volume (Factor C) and Dispense Speed (Factor A). *(Screenshot courtesy of Stat-Ease, Inc.)*

We now had strong statistical evidence naming not five, but instead two strong and two weak key factors involved in BARC coating defects (Table 1).

TABLE 1 – FACTOR PERCENTAGE CONTRIBUTIONS. These statistics, automatically generated by the DOE software, help explain why Relax Speed (Factor D) is dropped from subsequent analysis. As indicated via yellow highlighting, its 0.3% contribution is not deemed important. The 5-to-4 factor reduction from the initial factorial screening experiment is not only more cost-efficient, it is less time-consuming. *(Data courtesy of Brewer Science, Inc.)*

FACTOR	**EFFECT**	**% CONTRIBUTION**
Exhaust (Factor B)	0.17	52%
Reload Rate (Factor E)	0.079	11%
Dispense Volume (Factor C)	0.028	1%
Dispense Speed (Factor A)	0.045	3%
Relax Speed (Factor D)	0.013	0.3%

Because of these findings, we began another DOE, this time a response surface DOE addressing fewer factors. Response Surface Methodology (RSM) involves fitting polynomial models to actual data, then drawing contours of select predicted values to map the experimental region.

THE RESPONSE SURFACE METHODOLOGY RECIPE

Having defined the four heaviest-hitting factors through the factorial DOE, we set out to discover the lowest-defect coating recipe. To do so, another set of 300mm wafers were coated, again using the TEL ACT12 track. As with the factorial, before dispensing the bottom anti-reflective coating onto the wafers with an IWAKI FT 100-1 bellow pump, we pre-wet them with ethyl lactate. The wafers baked at 190°C for 60sec. Defects 0.16µm and larger were again measured using a KLA/Tencor SP1, and wafer thickness and uniformity were measured with a KLA/Tencor ASET F5. Data were again analyzed using Design-Expert® software.

Using the graphic capabilities of the DOE software's RSM analysis, we generated a contour map in order to better visualize the valuable operating region that has been revealed (Figure 2).

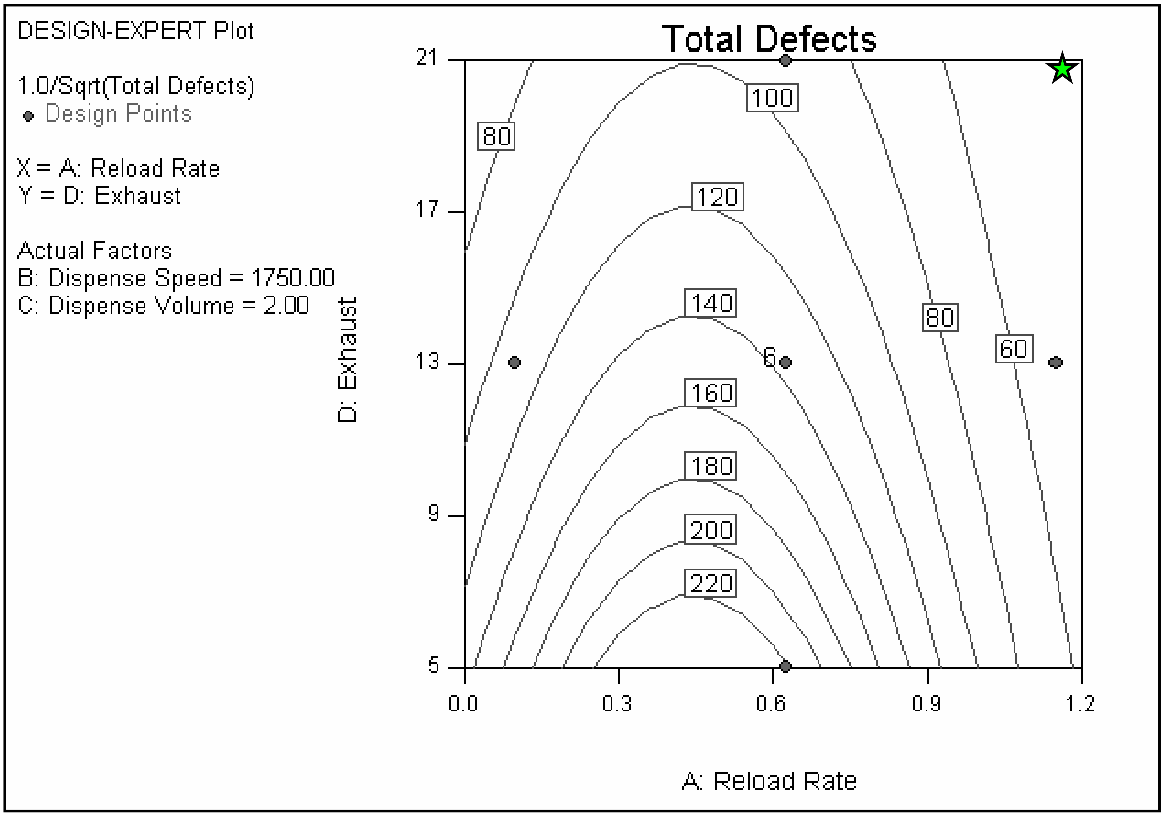

FIGURE 2 – RSM (RESPONSE SURFACE METHODOLOGY) CONTOUR MAP. Screenshot graphically displays that a specific factor combination produces lower defects. The star pinpoints a recipe defining high Exhaust (Factor D at 21 Kpa) and high Reload Rate (Factor A at 1.15 mL/sec) as a quantifiable solution. *(Screenshot courtesy of Stat-Ease, Inc.)*

RATIONALIZING THE FINDINGS

If fluid viscosity and cavitations are considered, defect generation via varied reload rates is easily rationalized – given the varied diameters and lengths of lines in a pump system. By varying exhaust levels on 300mm products, the solvent-rich environment inside the spin bowl changes, leading to modifications in evaporation rates and defects (Figure 3).

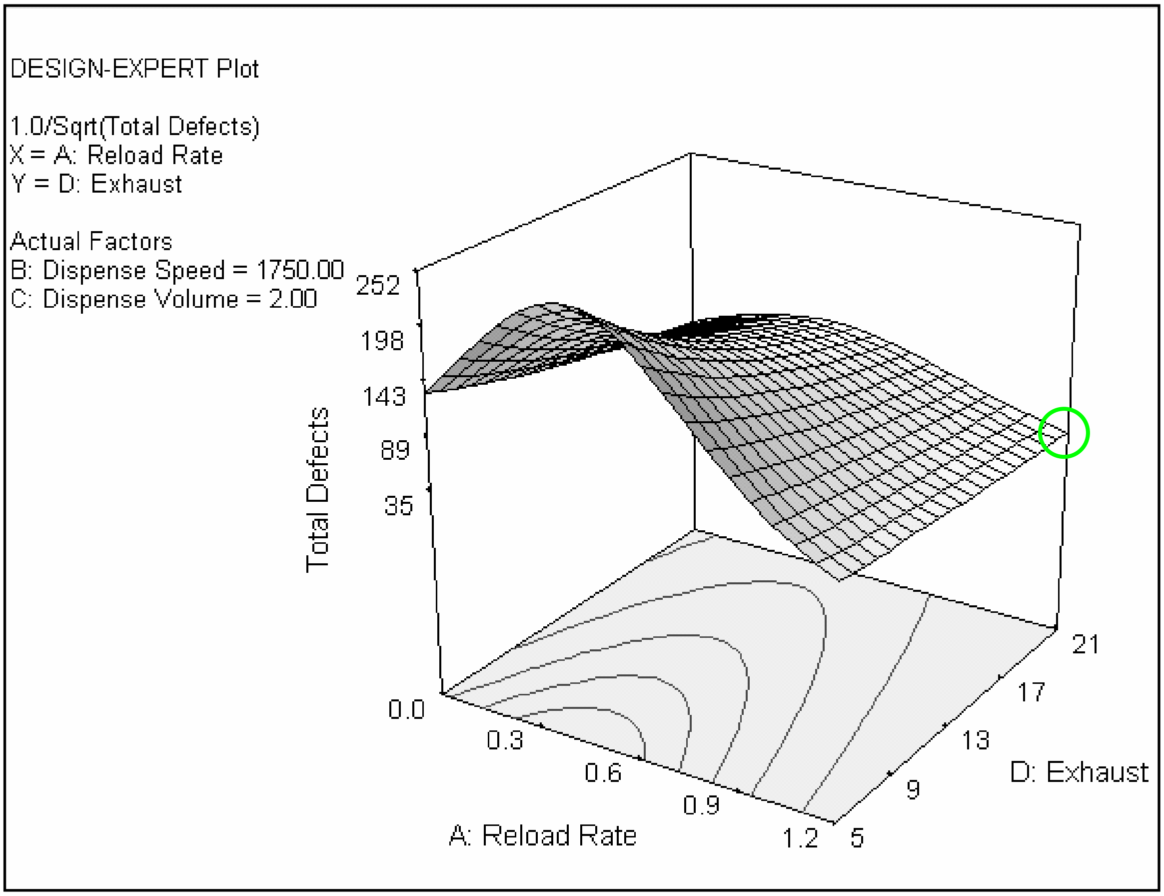

FIGURE 3 – RSM 3D VIEW. This is a 3D representation of the contour map shown in Figure 2. It reveals the actual surface of the "response surface." The lowest-defect location is circled in green. *(Screenshot courtesy of Stat-Ease, Inc.)*

The results from the changing exhaust levels were somewhat surprising when taken in tandem with our experiences with the smaller 200mm wafers. On those wafers, a 4000- to 5000-rpm dispense speed is usually desirable. That specific, high dispense speed range propels micro-bubbles and particles to the edge of, and subsequently off, the wafer during the deposition step. The wafer is then cast at a lower speed to set the thickness and finish the coating process.

The 300mm wafers cannot be safely cast at rotations higher than 2500 rpm. Because of our recent RSM DOE studies, we now know that defects on 300mm wafers are not removed by dispense speeds as with smaller wafer diameters. The DOEs and follow-up confirmation runs validate this in that dispense speed no longer emerges as a significant factor. The solution is instead a reload rate of 1.15mL/sec at 21 KPa exhaust. Although these levels are at their highest settings, they are the best, falling at the top of the tested range. Both points together generate an environment within the spin bowl that is low in solvent and low in initial defects. This provides a proper film-drying time that allows uniform evaporation, better coating qualities, and fewer defects (Figure 4).

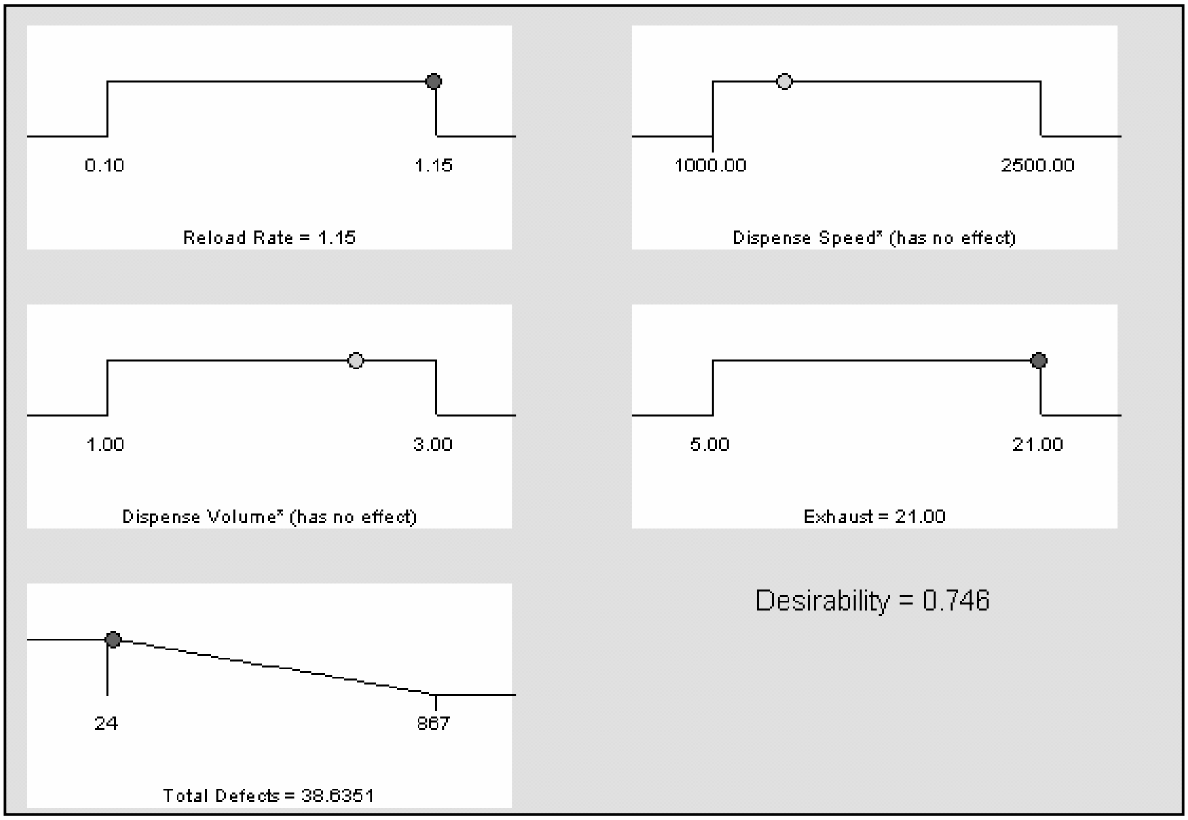

FIGURE 4 – LOWEST-DEFECT SUMMARY. Exact settings near change edges in this ramp chart produce the best results. The settings generate solvent-starved environments in the spin bowl that speed film-drying times. The result is fast and uniform evaporation that produces superior 300mm wafer BARC coatings. *(Figure courtesy of Stat-Ease, Inc.)*

Coating uniformity is now outstanding across all wafers, with a standard deviation in all cases of less then 7Å for 700Å film. Reload rate and exhaust changes via our DOE studies continue to control defects, once again settling the "BARCing dogs" into silence.

ABOUT THE AUTHOR:

Carlton Washburn is an Applications Engineer with Brewer Science's Applications Research and Development group. For two years he has characterized and supported recent semiconductor

BARC discoveries. Mr. Washburn wishes to thank Darron Dipple, Brewer Science Field Applications Engineer, whose polymer research, photolithography process engineering, and product support knowledge were instrumental. Mr. Washburn holds B.S. Degrees in Mechanical Engineering and Physics from the University of Missouri at Rolla and Illinois College, respectively. Mr. Dipple holds a B.S. Degree in Chemical Engineering from the University of Texas at Austin.

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