Deflection Mapping is Useful for its Ability to Identify Distortion-prone GaAs Wafers

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ABSTRACT

Deflection Mapping is a valuable technique in its ability to recognize distortion-prone SI-GaAs wafers. This method was entertained for the purpose of characterizing wafer distortion, after the number of stepper misalignments increased in photolithography, and the nature of the misalignments suggested the Rapid Thermal Anneal (RTA) process was the root cause. Not only did Deflection Mapping prove useful in addressing distortion at the unit process, it helped characterize distortion-prone boules. More importantly, it helped identify an unknowing supplier of distortion prone ingots. The metric that Deflection Mapping provides is now instrumental in qualifying tools and matching multiple RTA's to one another.

INTRODUCTION

In photolithography, the quality of layer to layer pattern registration is often measured in 2 axes. If global stepper misalignment occurs, the measured value of misalignment for a given axis is the same across the entire wafer. Global misalignment can usually be remedied by a rework of the photo process. However, there is no photo remedy for a wafer that exhibits severe misalignment at one location, and perfect alignment at another location along the same axis. Alignment gradients occur when I-Line steppers have trouble compensating for severe changes in wafer flatness. With a change in wafer flatness, stepper reference targets undergo 'continental drift' (they move away from each other).

Deflection Mapping was employed for the sake of characterizing wafer distortion through the Rapid Thermal Anneal (RTA), process. Layers that are printed after RTA were, at times, displaying absolute gradients as severe as .4 - .5 µm along one axis. Once it became evident that the problem was intermittent, it was concluded that the RTA degree of impact on wafer distortion was convoluted as a result of some other significant intervening factor. Consequently, distortion at the RTA process level could not be addressed until the impact of the unknown factor could be quantified, and subsequently compared to the impact of the RTA process itself. A screening DOE was conducted more to confirm, rather than to identify, the unknown factor, which was thought to be related to wafer vendor at that time. Deflection Mapping was incorporated into the DOE for the metric it provides, which was expected to correlate to the magnitude of the alignment gradient. If correlation could be proven, it would provide a production friendly means of monitoring and controlling process induced distortion in the future.

DEFLECTION MAPPING (The Technique Summarized)

The Deflection Mapping capability comes from the Tencor FLX-5400 Thin Film Stress Measurement Gauge. The primary function of this tool is to calculate dielectric stress from the change in the substrate radius of curvature as a result of a film deposition. However, it also calculates Bow (see figure 1), so that a similar comparison will allow the user to calculate the change in bow, ΔBow, through a process.

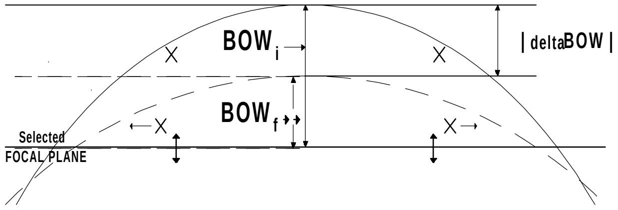


Fig. 1. Bow is the difference between the selected focal plane and the surface height of the unclamped wafer at the center. It can be a positive or negative value.

A deflection map is a mapping of the change in bow, Δbow, between two measurements. For maximum resolution, this tool can perform up to 12 unique scans (if each offset is user selected to be 15° from the next), of the wafer surface in a single measurement (see figure 2).

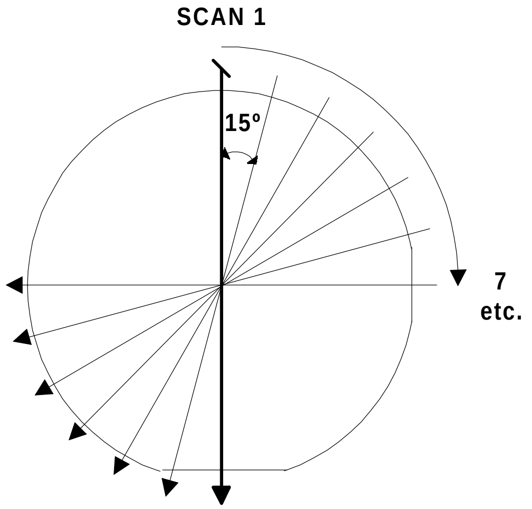
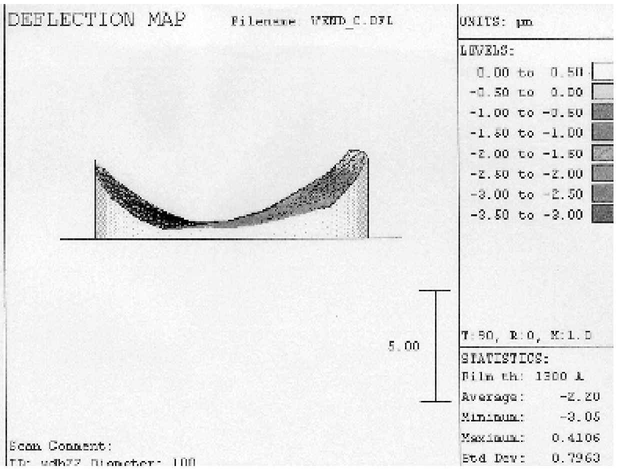


Fig. 2. 12 scans for one measurement on the FLX-5400, each separated by 15°.



STATISTICS:
Film th: 1300 Å
Average: -2.20
Minimum: -3.05
Maximum: 0.4106
Std Dev: 0.7963

Scan Comment:
ID: vdb22 Diameter: 100

Fig. 3. 3D Deflection Map

The FLX-5400 is capable of plotting a 3D portrayal of deflection, from a compilation of all the deflection scans, and a little interpolation (see figure 3). 2D deflection maps are also possible, should the need arise to compare bow on a scan by scan basis (see figure 4).

How Deflection Was Incorporated Into This Study

For the sake of this examination, each wafer measurement, before and after RTA, consisted of 12 scans on the FLX-5400. Subsequently, the average of the 12 absolute ΔBow (average |ΔBow|), measurements was calculated to simplify the analysis and the presentation of the data.

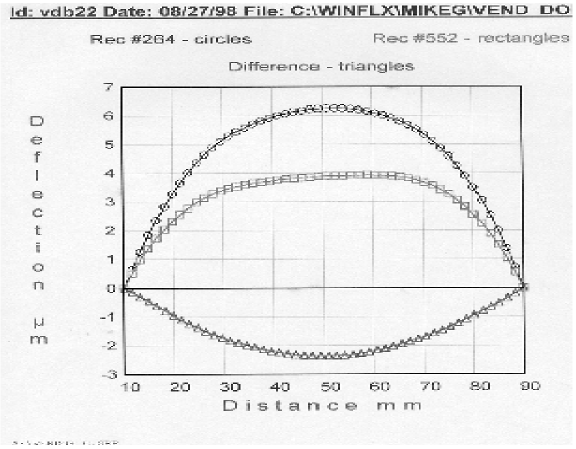


Fig. 4. 2D Deflection Map of the same scan before and after RTA.

EXPERIMENTAL DESIGN

Minitab was used to design an experiment aimed at comparing the impact of the RTA process on distortion, to that of the impact of wafer vendor on distortion (see Table 1). Specifically, its objective was to find out, i.) How much of the problem was the unit process contributing, ii.) How much was each wafer supplier contributing, and iii.) Whether or not one RTA was distorting wafers more than another. A full factorial (3 Vendor x 2 RTA), experiment was conducted with 1 replicate to test the statistical significance of these 2 factors on the distortion responses, which were selected to be average |ΔBow|, Range in X, and Range in Y.

TABLE 1

Minitab Set-up of a 2 RTA x 6 Boule (3 vendor) DOE

Run Order	**RTA**	**Vendor**		**mean |ΔBOW| (um) FLX-5400**	**Range in X (um)**	**Range in Y (um)**
15	1	1A		0.08141	0.564	0.480
18	2	1A		*	1.092	0.720
9	1	1A		0.21823	0.810	0.492
11	2	1A		0.65617	1.062	0.738
24	1	2A		0.42030	0.882	0.534
3	2	2A		0.81835	1.200	0.804
2	1	2A		0.51500	1.098	0.594
17	2	2A		0.77353	1.230	0.858
19	1	1B		0.09417	0.726	0.408
14	2	1B		0.68005	1.044	0.642
5	1	1B		0.07833	0.840	0.444
16	2	1B		0.60341	1.014	0.678
4	1	2B		0.06832	0.678	0.480
13	2	2B		0.59167	0.942	0.588
10	1	2B		0.13750	0.882	0.522
7	2	2B		0.53833	1.092	0.618
12	1	1C		0.70667	0.864	0.622
20	2	1C		2.05583	1.254	0.936
23	1	1C		0.82083	0.948	0.708
6	2	1C		2.06500	1.494	0.948
8	1	2C		1.73917	0.954	0.858
21	2	2C		2.71367	1.746	1.506
22	1	2C		1.84333	1.218	1.038
1	2	2C		2.72767	1.686	1.362

Range is the stepper calculated difference between the biggest positive drive distance to target, and the biggest negative drive distance, for a given axis. These values are taken before any stepper correction is made to the distorted array. The magnitude of the alignment gradient that is visible upon inspection is subjective, so that the stepper acquired value (Range), which is a multiple of the gradient value, was used as a more accurate substitute in the experiment. The FLX-5400 response would also have to be tested for correlation against the stepper responses owing to the fact that wafers are unclamped for the FLX-5400 measurement, and clamped while on the stepper (see section on Data Analysis and Results).

Wafer Selection and Initial Measurement

The wafers selected for this experiment were taken from 6 randomly selected boules of (100) GaAs. There were two boules selected to represent each vendor and 4 wafers chosen at random from each boule. Prior to any processing, each substrate was measured bare on the FLX-5400 to characterize initial wafer bow based on 12 scans per wafer.

Processing

Each wafer was printed with the same stepper array and the reference alignment marks were etched into each substrate. Before the anneal cycle, each wafer was stressed under a compressive dielectric that is similar to that of the production MESFET process.

Rapid Thermal Anneal (RTA)

Just prior to anneal, each wafer was measured on the FLX-5400, again using 12 scans/wafer. In order to control extraneous variables in the experiment, DOE ‘blocking’ was carried out by conducting the experiment over the course of a couple of days and in the random order defined in Table 1. Annealing was performed with the same two graphite susceptors for each machine. Consequently, a small susceptor dependence on distortion was evident in the results of the experiment.

Post-RTA FLX-5400 Measurements

Following anneal, 12 Bow scans/wafer were done on the FLX-5400 with the dielectric still on the wafers. The dielectric was subsequently stripped off and another FLX-5400 measurement performed with 12 scans/wafer. This made it possible to compare the deflection of the dielectric coated wafer through anneal to the deflection of just the bare substrate as a result of anneal (remember that the first FLX-5400 measurement was done prior to any processing). This comparison provided insight into the effect of a compressive dielectric on wafer distortion (see figure 7).

DATA ANALYSIS AND RESULTS

Regression analysis of average |Bow| and alignment range, shown in Figure 5, suggests that there is a good positive correlation between the stepper response to distortion and the deflection response, average |ΔBow|. Specifically, the average |ΔBow| is directly proportional to the Range in Alignment (or alignment gradient), for either axis. Therefore, Deflection Mapping is a useful tool for measuring process-induced distortion.

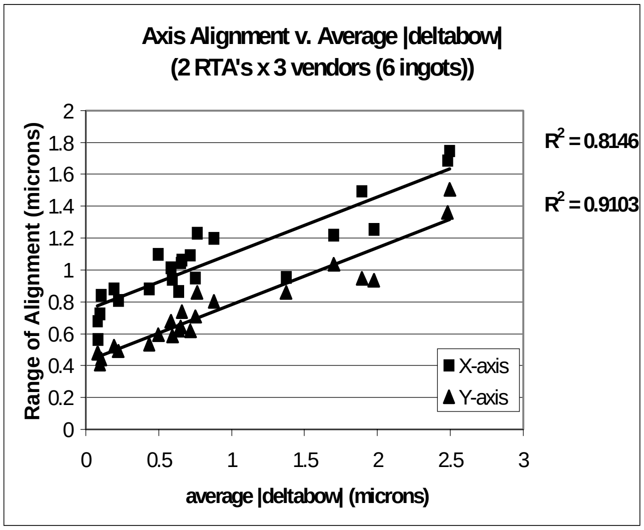


Fig. 5. Good positive correlation exists between the stepper response to distortion and the deflection response to distortion.

Minitab was used to analyze the experimental data. Minitab showed vendor to have a more statistically significant effect on distortion (average |Δbow|), than the RTA process. By order of rank, vendor had the biggest effect, followed by RTA 2. Specifically, vendor C wafers were distorting more than wafers supplied by other vendors (as shown in Figure 6). Vendor C was temporarily disqualified as a vendor.

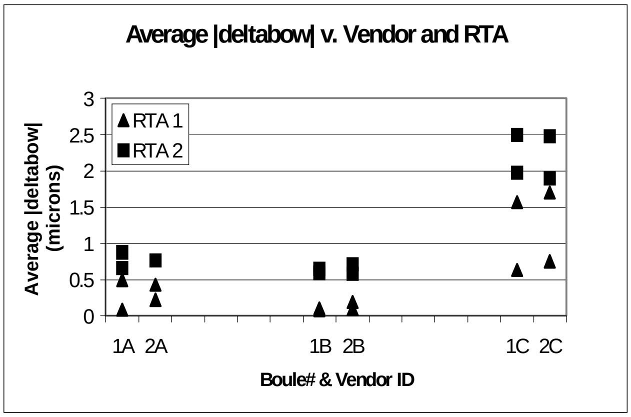


Fig. 6. – Effect of Vendor and RTA on Deflection.

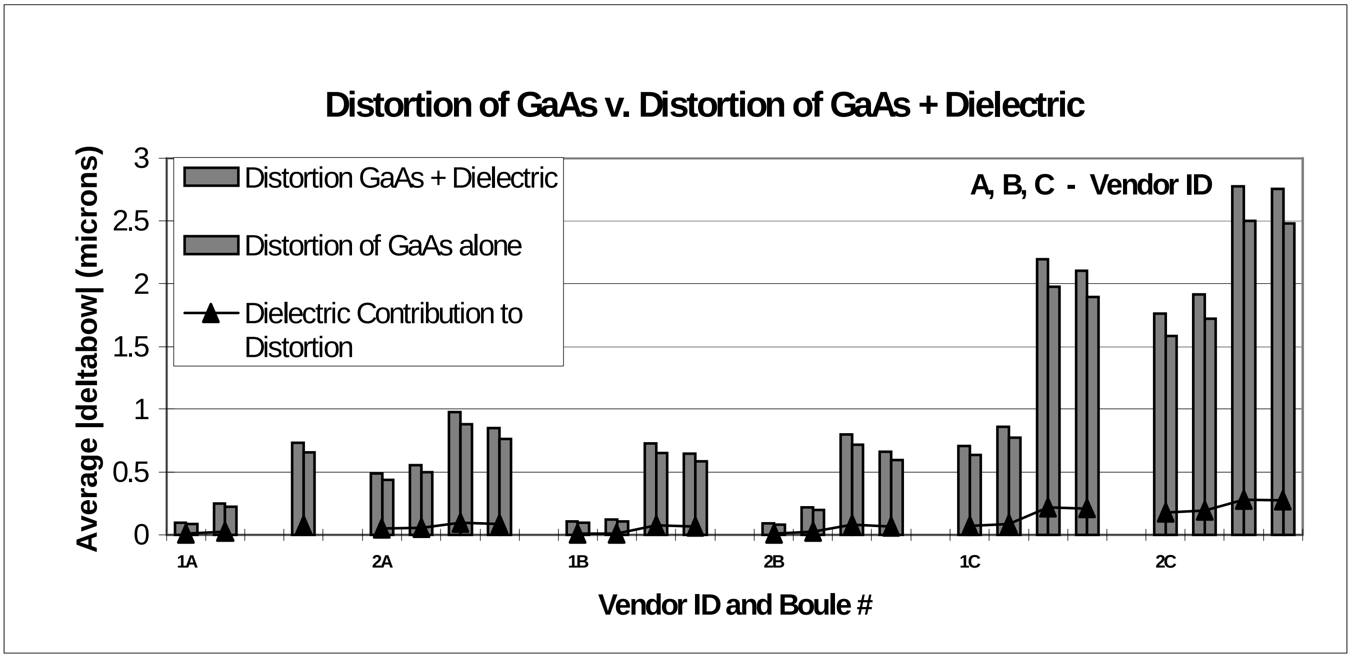


Fig. 7. Dielectric influence on wafer distortion

FOLLOW UP EXPERIMENTS

Experiments were conducted with the problem vendor, to study the effects of the sawing, polishing, and boule annealing techniques on wafer distortion. Change in bow was the sole response in these experiments. A remedy was discovered that eventually brought this vendor back in line with the others. They were reinstituted as a vendor for TriQuint Semiconductor.

One experiment, to study the effects of the RTA process on distortion, has been conducted. Of the factors that have been investigated to date, one factor has been identified as having a dramatic effect on distortion with respect to the others. This factor was optimized and a bigger improvement was made to the better RTA even though it helped both RTA's with this problem. Experiments are still being conducted to find out the fundamental difference between the two machines. Deflection Mapping is the tool being used for these experiments.

CONCLUSIONS

The FLX-5400 is not just a tool for measuring thin film stress. Its Deflection Mapping capability provides a viable technique for quantifying thermally induced wafer distortion. Using this technique, it was determined that alignment problems become significant when deflection values approach 2 um. Similarly, slip lines can be seen on wafers after the RTA process when deflection reaches approximately .5 um, even if lateral temperature uniformity across the wafer, is ideal during the high temperature anneal cycle. This technique can be easily incorporated into production. Its metric may be used for Statistical Process Control of wafer distortion, and for qualifying the tool after preventive maintenance is performed on the RTA. Finally, this tool can measure deflection through any process if the need arises.

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