Study of relationship between 300 mm Si wafer surface and annealing temperatures for advanced semiconductor-based applications

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Abstract **- Surface morphology dependence on annealing conditions is one of the most important parameters that is being monitored in current manufacturing environments. Understanding the science behind surface properties and anneal temperatures is of high interest. This paper explores this phenomenon in more detail and its practical applications for manufacturing environments.**

I. Introduction

Ultrafast Laser Anneal as a process has been adopted during the past years in semiconductor device manufacturing to further improve transistor performance.

As a monitoring vehicle for traditional anneal tools, the measurement of sheet resistivity of an implanted bare silicon wafer after anneal is widely used across the industry. While such a resistivity tool is known to be very robust and accurate, and therefore critical for product development, the tool's move and measure time (~1s.) make it unsuitable for production applications. Systems based on thermal and plasma waves (such as KLA-Tencor's Therma-Probe) have the ability to provide more data at higher throughput. However, with laser annealing processes in particular, manufacturing facilities (fabs) may now consider an additional tool.

Laser annealing tends to disturb the surface of the substrate in a manner that mimics the uniformity of the bulk substrate. Therefore a system that provides a full-wafer, high resolution map of surface quality can be valuable for monitoring laser annealing uniformity—and cost-effective if that system already exists in the fab.

SURFmonitor creates high resolution, full-wafer parametric maps in under a minute using a standard unpatterned wafer inspection system (KLA-Tencor's Surfscan $SP2^{XP}$) - while traditional defect information is collected simultaneously. On SURFmonitor the "haze" information is used as a basis for analysis.

In the semiconductor industry, the term *haze* is widely used to describe the micro-roughness of a wafer surface (See Fig. 1). It is an important parameter for both IC and wafer manufacturers. Background scatter caused by imperfections on the surface of the substrate, such as intrinsic substrate roughness and polishing damage, leads to haze, which can be evaluated by the Surfscan family of tools. Haze has been shown to correlate to a broad array of process parameters such as surface roughness, grain size, and process temperature.

SURFmonitor can automatically analyze haze data delivered from the Surfscan SP2 and send it to the fab's yield manage-

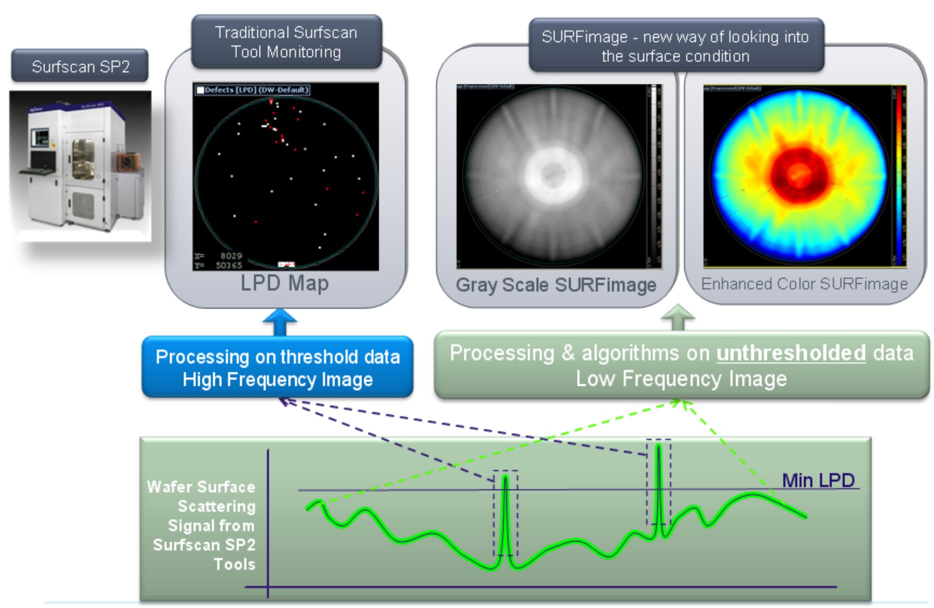

Figure 1: Explanation of wafer scattering surface signal also known as "haze"

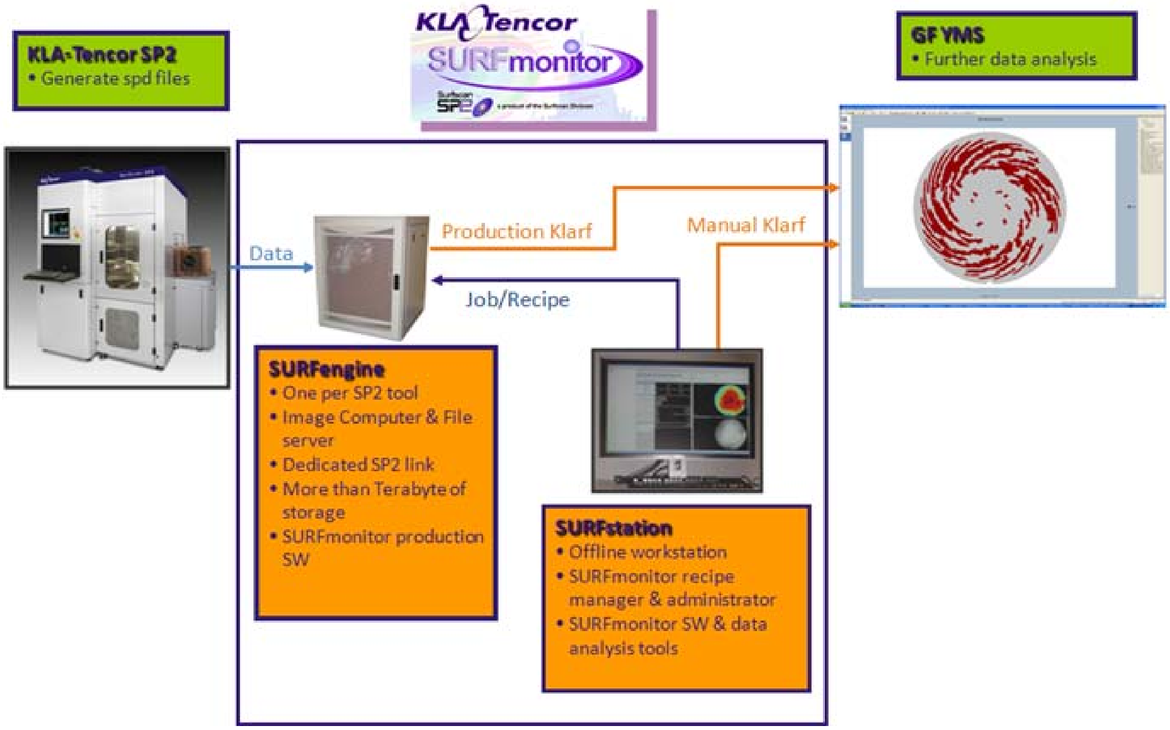

Figure 2. SURFmonitor architecture.

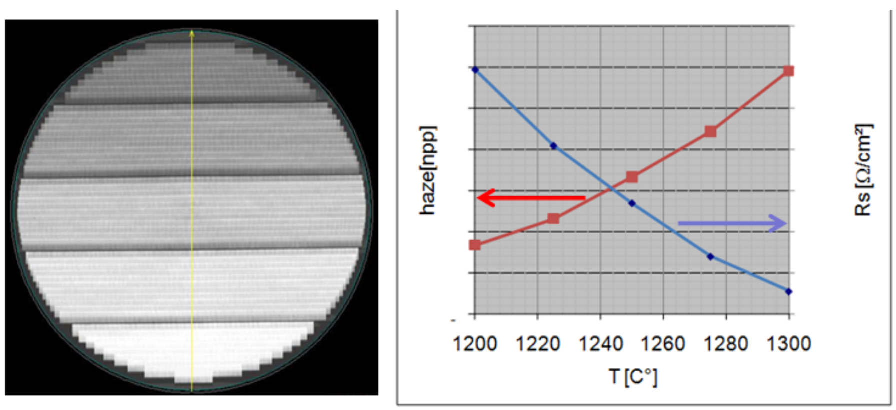

Figure 3. Relationship of haze and resistivity to annealing temperature.

ment system in order to track process tools using statistical process control (SPC) methodology. See Fig. 2.

This paper will report how haze is measured and the data acquired implemented into a laser anneal monitoring strategy as a complement to resistivity tools. By employing the haze measurement instrumentation described above, we were also able to draw a good relationship between surface morphology features and one of the process conditions, namely laser anneal. Our findings are significant from both a scientific and practical perspective and will be detailed in the following sections.

II. Experimental

SURFmonitor is a module that extends KLA-Tencor's Surfscan SP2 unpatterned surface inspection system beyond traditional defect inspection to also monitor process variation and drift. The SURFmonitor system is designed to quantify haze (as described in the previous section) and relate haze to the material and surface properties of bare, 300 mm Si wafers or blanket films. As a first approach the process temperature was tested to investigate the correlation between measured haze and resistivity. '

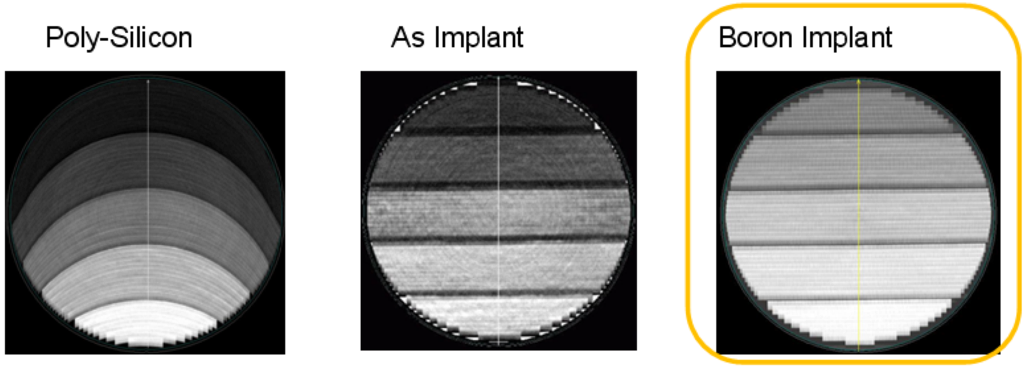

Figure 4: Comparison between different test layers - Boron Implant selected for additional investigation.

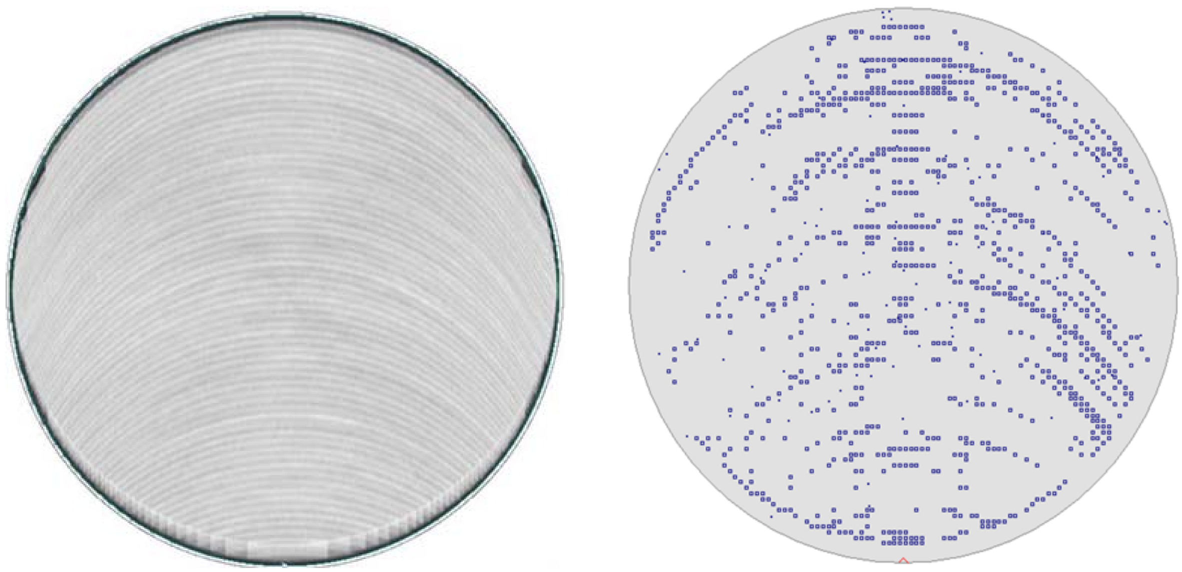

Figure 5: Plain haze map of a laser annealed wafer vs extracted defects from a bad processed wafer, sent to the yield management system.

As seen in Fig. 3, a 300mm Si wafer was exposed to different anneal process conditions on 5 separate locations on the wafer. The same figure shows a plot of resistivity and haze values measured across the wafer in a diagonal direction (yellow line). Good inverse correlation is noticed for these experimental data points, as outlined in the adjacent graphs. The higher the resistivity values of the respective sector, the lower the measured haze. Given the direct relationship between haze and surface topography, higher haze (higher surface roughness) appears to correlate with lower anneal process temperature. More investigation is in progress.

Continuing our experimental observations, different layers were studied for haze and resistivity . Fig. 4 shows that Poly Silicon, As Implant, and Boron Implant produced different results. The same fixed scale was used for comparison.

The Boron Implant layer showed the best signal-to-noise ratio for haze measurements, and was selected for additional investigation. Signal-to-noise ratio refers to the capability to clearly resolve haze features for the 5 different anneal temperatures used for the samples. The variation in haze (grey scale) would indicate a difference in Rs, as exemplified in Figure #3.

Standard SURFmonitor algorithms were used to analyze the haze maps further, not only globally but more in detail. Using algorithms later described, special and unique laser anneal features can be filtered out in order to analyze variability in the surface properties produced by the laser anneal.

Step 1: A pre-measurement using Surfscan SP2 was followed by the laser annealing step then a post scan using the Surfscan SP2 again.

Step 2: Both pre and post scan data were sent to SURFmonitor for Overlay Differential Analysis. This is a software function which can compare two maps and outline the signal differences between the two. The main goal here is to compensate haze signatures seen on both pre and post scans, i.e. to identify the changes due to laser annealing.

The next step was the application of a grid over the full wafer. A cell size of 3x3mm was defined on SURFmonitor and gave suitable results. After normalizing the grid cells to the mean (Step 4), cells with a high standard deviation were marked and exported to the yield management system in industry-standard "KLARF" file format. See Fig. 5.

This methodology opens the door to new monitoring techniques like SPC and troubleshooting methods, as former tool based data now will be available in a common database.

III. Conclusions

Determining the relationship between surface morphology and process conditions during IC manufacturing steps is of vital importance to making reliable IC devices. This paper explored the connection between surface morphology of 300 mm bare Si samples evaluated using haze measurements and laser anneal process steps. We found an inverse relationship between haze values (as measured by the KLA-Tencor's Surfscan $SP2^{XP}$toolset) and sheet resistivity data. In addition, a strong relationship between haze and elemental implant was found. Additional work is underway to explore these phenomena in more detail.

IV. Acknowledgements

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