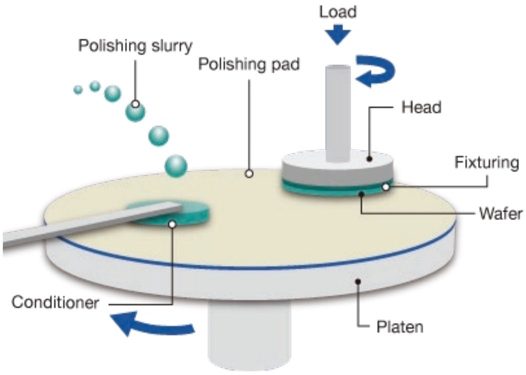
In-situ metrology for pad surface monitoring in CMP

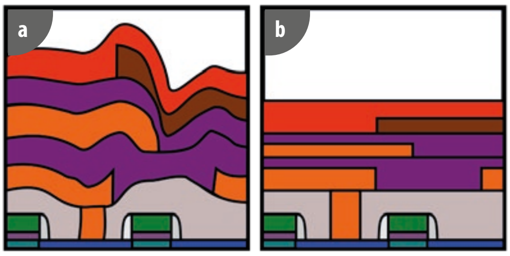
The CMP process

Chemical Mechanical Planarization (CMP) is one of the most critical processes in the semiconductor, hard disk and LED wafer manufacturing segments. The process is applied to assure the required planarity of the substrate wafer and for re-planarization at some intermediate points following deposition and lithographic processing for the structures built upon the wafer. In general, planarization is necessary to ensure functionality of the mutli-level interconnects within the structures, but the technique is also commonly used to reduce wafer thickness whilst maintaining uniformity.



CMP process schematic diagram

During the CMP process, the wafer is held on a rotating fixture and pressed against a rotating polishing pad while an abrasive chemical liquid (slurry) is distributed between the wafer and the pad. Pad rotation and concentric grooves engineered into the pad surface serve to transport the slurry across the interface between the pad and wafer. The chemical slurry weakens the surface of the wafer, thus enabling removal of material by asperities of the pad [1].

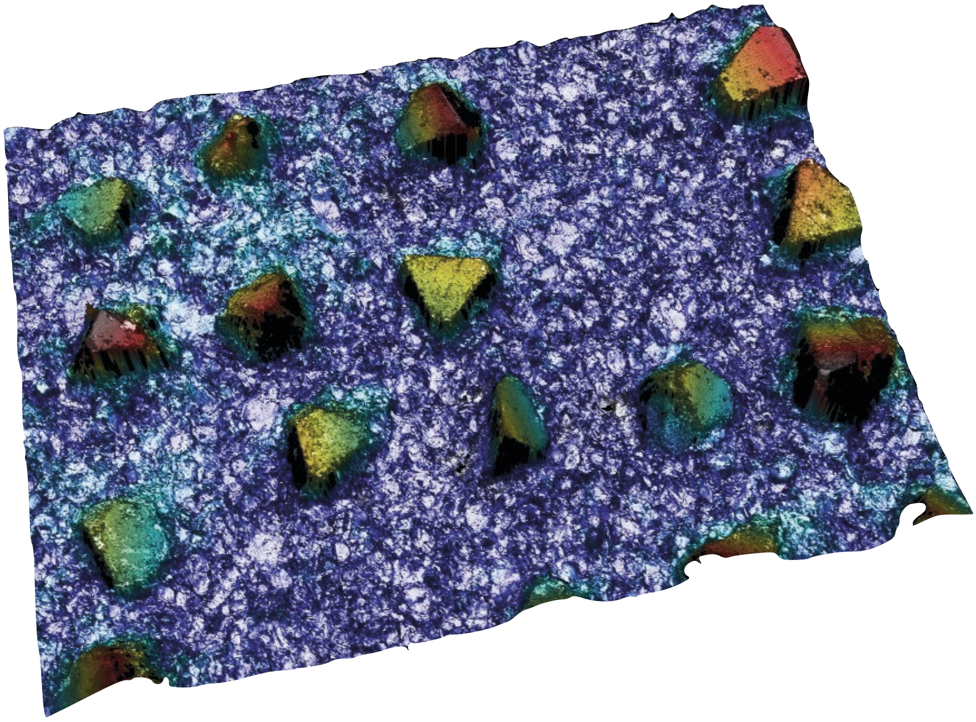


Wafer manufacturing without CMP (a) and with CMP (b)

The quantity of material removed from the wafer and the quality of the overall process is highly influenced by the surface properties of the polishing pad. The surface of the pad degrades as a result of the polishing action, so it needs to be constantly reconditioned. Conditioning involves an abrasive process on the pad surface, where a rotating abrasive or conditioning disk recovers the pad surface. These disks are usually made of stainless steel or electroplated diamond.

Surface Metrology for CMP

The need for surface metrology for the CMP process is evident given that mechanical interaction between the surfaces is a critical variable for all stages of the process. The surfaces that need to be periodically characterized throughout the process include the conditioning disk surface, the wafer surface and the pad surface. In high volume production environments, however, non-destructive in-situ pad characterization at natural pauses in the polishing process (for example, when changing wafers) is desired. This would permit detection of drifts in key pad parameters and assist in validation of process changes. The goal in all cases is to extend the lifetime of consumables and to improve the yield of the whole process.

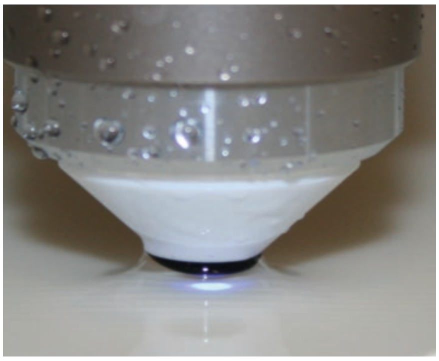


3D topography of conditioning disk surface

There are two main factors affecting pad surface degradation and lifecycle – pad groove occlusion and pad glazing.

Groove occlusion

During the polishing process the material removed from the wafer deposits in the pad grooves, thus occluding them. This prevents uniform slurry distribution across the water, thus causing non-uniform removal between the center and edge of the wafer. Monitoring of groove occlusion enables prediction of the need to clean the pad grooves and determining the best point in time to do it. This cleaning operation can extend pad lifetime by up to 20% [2].



Immersion objective

Pad glazing

Glazing is a more complex phenomenon where the polishing ability of the pad is reduced due to surface degradation. This phenomenon enhances wear between wafer and pad, thus increasing process temperature and that may result in material selectivity during polishing. The phenomenon cannot be predicted as easily as groove occlusion and requires constant monitoring in order to guarantee ideal performance of the CMP process.

In order to enable in-situ pad surface monitoring, the metrology approach used must be able to work under wet conditions. Only immersion metrology can meet these requirements. The main benefit of this approach is that the pad does not need to be removed from the polisher in order to be characterized. This makes it possible to monitor pad glazing and groove occlusion in-situ at various points in the pad's life-cycle. In-situ metrology has proven to extend pad lifetime, allowing operators to utilize the pads to the end of their useful life.

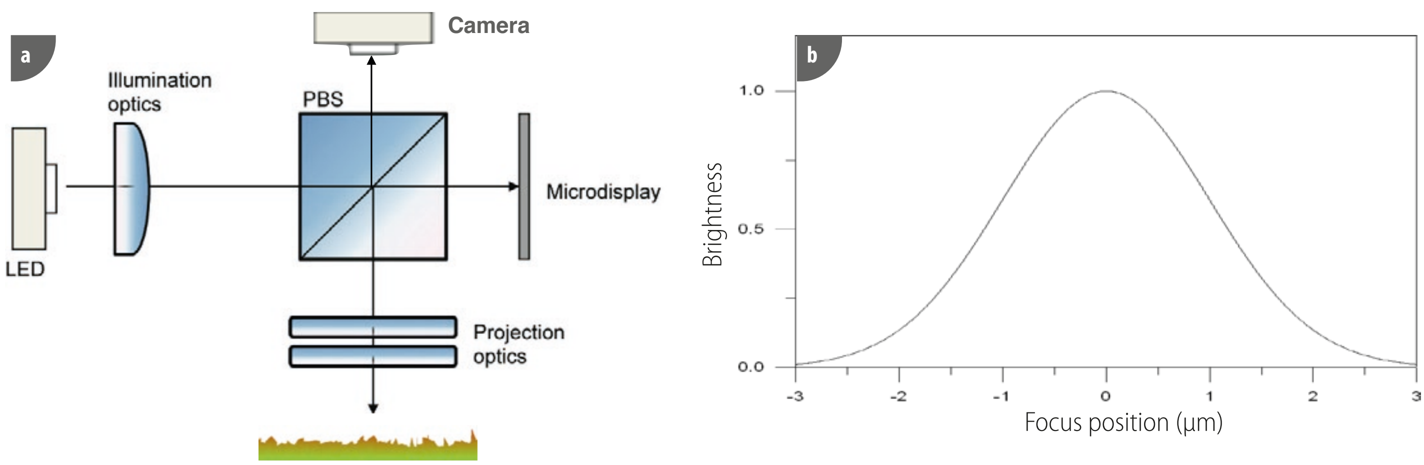
A new immersion metrology system

Working closely with experts in the field, Sensofar has developed the most suitable solution to solve this problem. The goal: change the polishing pads only when there is an absolute need, thus increasing yield per pad and minimizing downtime of the polishing systems.

The proposed solution is a non-destructive, in-situ metrology system, S mart CMP. Utilizing a portable stand, the sensor can be simply placed on the pad while the pad is still installed inside the polishing system and provides an immediate status on pad condition. S mart CMP is equipped with a laptop computer for enhanced portability and has been designed to work both as a stand-alone sensor and alternatively as a system that can be integrated into the production line as an automatic metrology solution. In both cases, S mart CMP is capable of rapidly acquiring and analyzing data in order to effectively monitor key pad characteristics.

S mart CMP, 3D optical sensor

This solution has already been proven to successfully monitor pad glazing and groove occlusion. Thanks to S mart CMP it has been clearly demonstrated that CMP pads are largely under-utilized and are often discarded with more than half of the useful lifetime still remaining.



(a) *Optical diagram of S mart sensor;* **(b)** *Pixel axial responser*

Basic operation of S mart CMP

S mart CMP is provided with Sensofar patented microdisplay technology and a high intensity blue LED, allowing combination of Confocal microscopy and Focus Variation technologies within a single sensor [3]. A software plug-in built around the CMP application provides all of the necessary tools and analysis for this application within the S mart CMP control interface.

The microdisplay enables projection of different fringe patterns onto the surface to be inspected, generating a confocal image of the surface. The confocal image is a greyscale map of the surface, where pixels have brighter signal if they are in the focus plane, while those out of focus appear completely black. By performing a vertical scan on the surface, it is possible to collect a stack of confocal images and obtain an axial response of the focus for each pixel. Processing the axial responses makes it possible to generate a 3D reconstruction of the surface.

By combining this metrology approach with an appropriate immersion objective, the S mart sensor can measure the pad asperities while the pad is still on the polisher.

Using the same immersion objective with Focus Variation technology, groove depth and width can be quickly determined in order to detect and monitor groove occlusion.

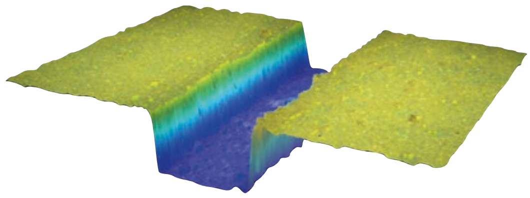
Groove occlusion monitoring

Provided with Focus Variation technology, S mart CMP is able to measure a pad groove within a few seconds. This allows characterization of the groove width and depth, enabling groove occlusion monitoring along the process. Automatic analysis is made possible for production environments thanks to a function within the CMP software plug-in that determines both the width and depth of the groove independently of groove orientation.

Evolution of pad groove width and depth along 12 hour CMP processing

Monitoring of pad glazing

Thanks to microdisplay Confocal microscopy, adapted to work in water immersion conditions, S mart CMP is also able to characterize pad asperity following conditioning and polishing phases. This not only allows monitoring and thus determination of the right point in time for conditioning, but also permits characterization of the optimal conditioning time required to regenerate the pad surface. All these aspects help to extend usable (and valuable) pad lifetime, reduce the need for control wafers and additionally optimize the process – thus also avoiding re-processing of otherwise completed wafers.



3D measurement of a new pad groove

Image showing evolution of the pad asperity height during the polishing process. After several hours of polishing a 'glazing peak' appears in the surface distribution. By monitoring the pad surface at intervals during the polishing process, the pad surface can be duly conditioned (intervention) in order to revert the surface condition to the initial state.

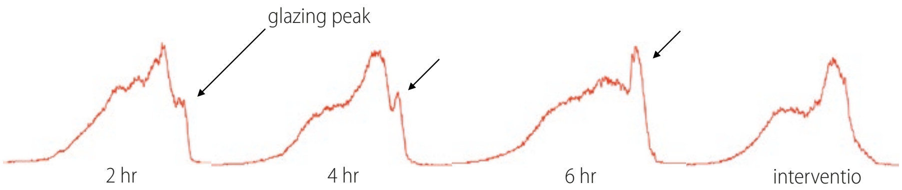
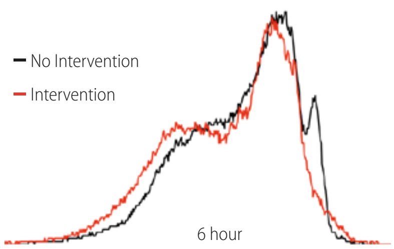
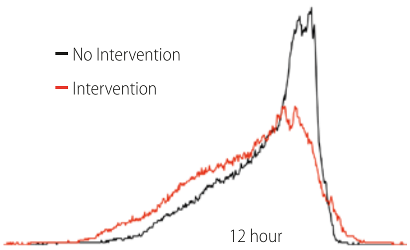
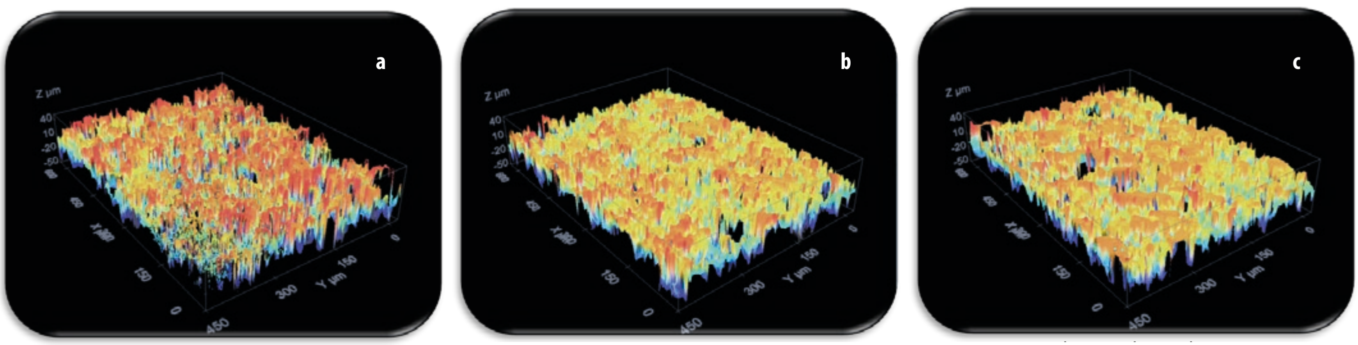


Image showing comparison for the pad before intervention (black) vs the pad following intervention (red). The image on the left side was for the surface after 6 hour polishing process and the right one is after 12 hours.





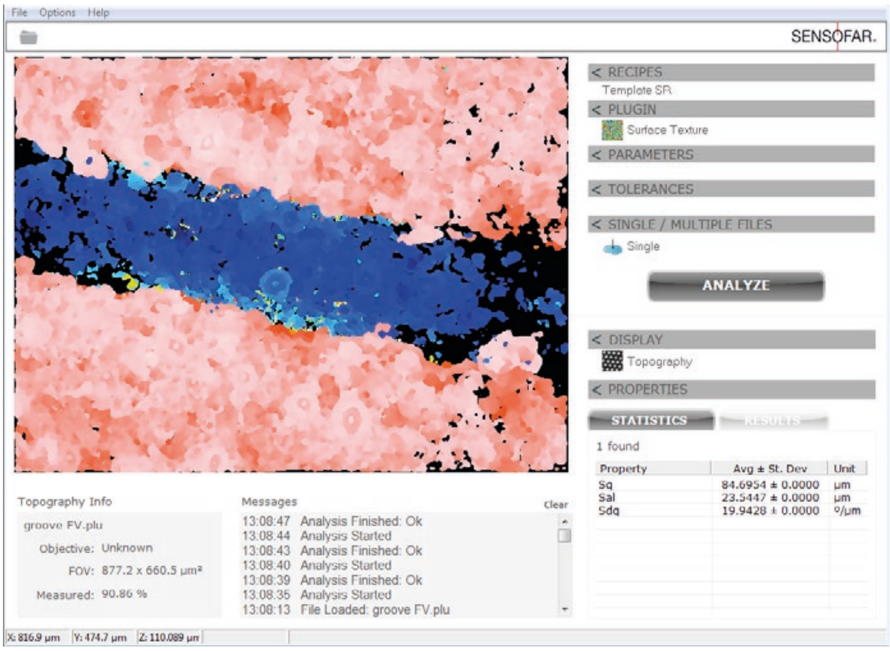


(a) New pad; (b) Good pad after 10h use; (c) Bad pad after 3h use

Automatic analysis

To simplify surface parameter control, the analysis of the acquired data can be automated. The operator then simply places the sensor over the pad surface and focuses on it, and once the acquisition has started the software will automatically show the target parameter value.

Special analysis algorithms developed for this application can automatically detect groove width and depth to monitor groove occlusion, while a different algorithm is designed to analyze the critical parameters of the asperities on the pad surface in order to detect pad glazing.

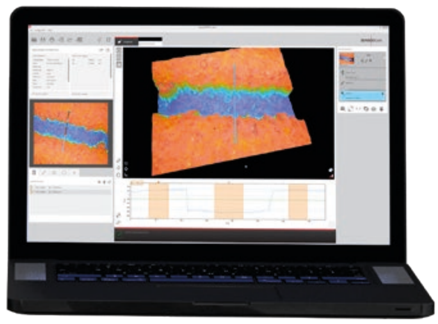


References

1 J. McGrath, C. Davis. Polishing pad surface characterization in chemical mechanical planarization. ***Journal of material processing technology***, **153-154** (2014).

2 T. Moore, N. Schwarz. NEOX Ex-Situ CMP Pad. NCCAVS, ***CMP Users Group Proceedings*** (2013).

3 R. Artigas, F. Laguarta, C. Cadevall. Dual-technology optical sensor head for 3D surface shape measurements on the micro- and nanoscale. ***Optical Metrology in Production Engineering***, **Proc. SPIE 5457** (2004).



TECHNICAL SPECIFICATIONS

SENSOR		OBJECTIVE				CONFOCAL		FOCUS VARIATION	
Dimensions	Weight	Magnification	Working Distance (mm)	Field of View (µm)	Optical Resolution (µm)	Vertical Resolution (nm)	Measurement Time (s)	Vertical Resolution (nm)	Measurement Time (s)
26x28x37cm 10.2x11x14.6"	9 Kg 19,8 lbs	20X (Immersion)	2.00	877x660	0.31	20	20	15	5

SENSOFAR® METROLOGY

SENSOFAR is a leading-edge technology company that has the highest quality standards within the field of surface metrology

Sensofar Metrology provides high-accuracy optical profilers based on confocal, interferometry and focus variation techniques, from standard setups for R&D and quality inspection laboratories to complete non-contact metrology solutions for in-line production processes. The Sensofar Group has its headquarters in Barcelona, also known as a technology and innovation hub in Europe. The Group is represented in over 30 countries through a global network of partners and has its own offices in Asia, Germany and the United States.

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CS00-05B-EN-CMP