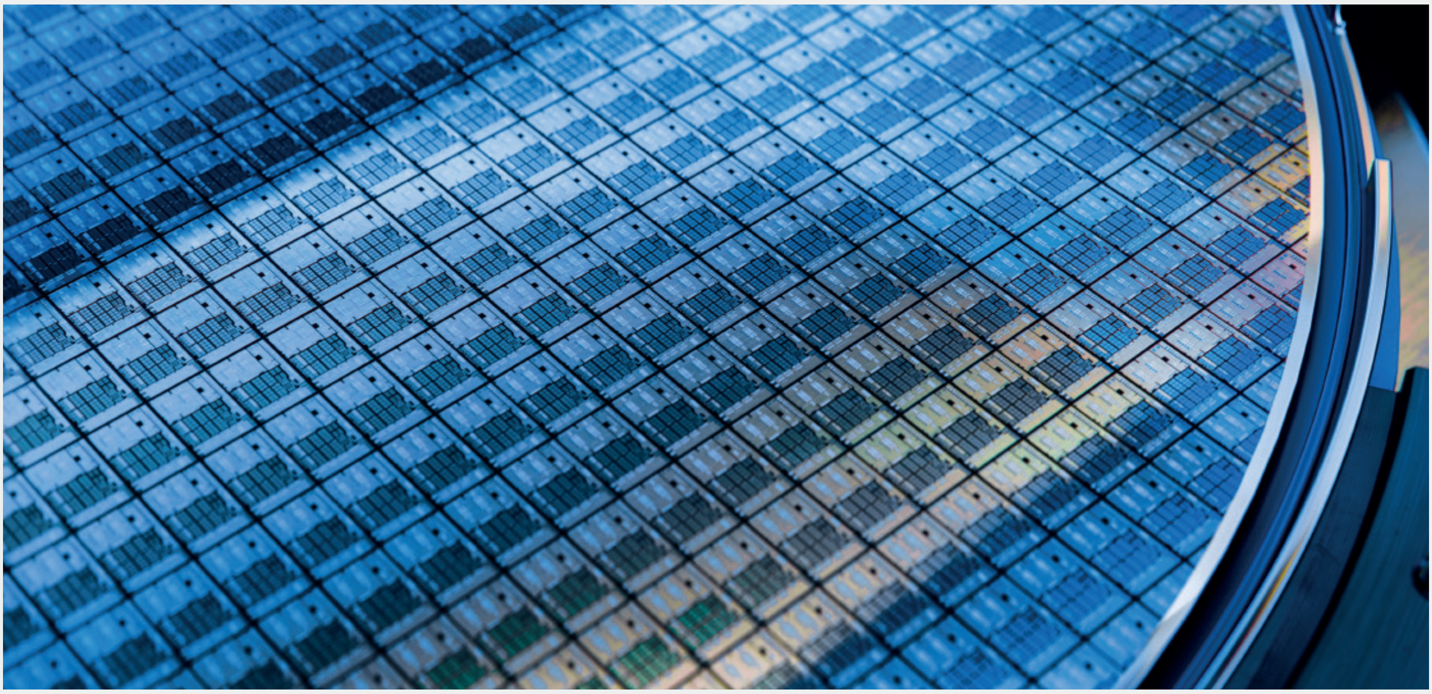
Phemet®: Revolutionizing Semiconductor Metrology with Cutting-Edge Precision and Efficiency



When working with semiconductor wafers, metrology tools allow us to analyze the properties of materials with the highest level of detail. They are essential for achieving the meticulous measurements needed to create cutting-edge technology, as wafers can suffer numerous deformations during processing. Wooptix introduces a universal metrology tool based on its proprietary Wavefront Phase Imaging (WFPI) technology, capable of detecting any defect on the wafer's surface with maximum precision and within sparse seconds, guaranteeing impeccable quality control.

Semiconductors are an invisible but essential part of modern life. Today, almost all devices have semiconductor-based chips, and we could compare them to the neurons in the human brain. Under conditions we can control, semiconductors can act as both conductors and insulators, regulating the flow of electricity. They are the backbone of digital electronics, and countless industries make use of them, such as smartphones, computers, or artificial intelligence, but also solar panels and wind turbines. They're even in the household appliances present in every home, such as refrigerators or microwaves. If you use an electronic device, it's very likely it hides semiconductors inside.

However, semiconductor chips are extremely delicate devices and vulnerable to any defect.

During their fabrication, the silicon wafers that hold them can develop small deformities with serious consequences for the integrity of the chips. These defects can be irregularities that escaped the initial polishing, or appear as result of one of the steps, such as the overlay errors that can happen during the lithography process. If they make it to the final product, they destroy the precision that the circuits need to work, so it's necessary to check that the pattern has been etched correctly and to remove any unwanted parts.

To face this problem, Wooptix presents its Phemet® device as the solution. In a single image, this tool measures the uniformity, nanotopography, and roughness of the entire wafer, capturing more than 16 million data points. But its metrics are not limited to quantity, since thanks to its quality it's able to reach sub-nanometer height resolution, processing all the information gathered in just 14 seconds.

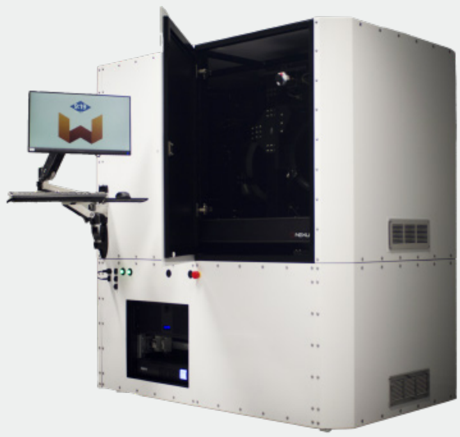


Figure 1. Phemet® Labtool

Our product and its capabilities

In environments of such high precision as semiconductor factories, there are times when there's real parades of unforeseen events and difficulties. Phemet® is designed to deal with a wide collection of these problems and lighten the load on the personnel's shoulders. Its most basic functions include in-depth wafer analysis and control of the printed circuits, but the tool's design allows for great versatility. All versions of Phemet® can analyze 200 and 300 mm wafers with different analysis windows, and the lab-focused design also supports 150 mm wafers. However, one of its strongest points, and what separates it from other solutions, is the ability to predict dense distortion maps. It also has the added benefit of low noise generation thanks to a lack of moving parts, completely removing the need to worry about vibrations. It's a universal tool for all types of samples.

Of course, there's a fundamental problem whenever wafers are treated for analysis. When working with such a minuscule and sensitive reality, the very elements of the environment can be the source of many defects that we want to avoid, and the main one is gravity itself. Gravity shackles everything on the planet, but Wooptix has developed a way around this obstacle. Phemet® uses steel studs to hold samples vertically, so that the system performs a comprehensive analysis of both sides simultaneously and without gravity being able to manipulate them.

Figure 2. Technician in laboratory

Along with these advantages, the system offers raw data and in a wide range of metrics in each of its measurements, giving its user all the information it may need to consult. The following are some of the main measurements available to operators:

- Warp and bow
- In-plane displacement
- Tension-induced local curvature
- Changes in wafer thickness and flatness
- Nanotopography of wafer front and back sides

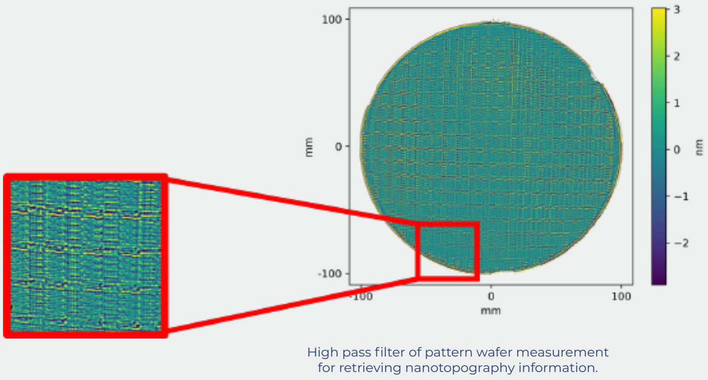


Figure 3. Example of Phemet®'s nanotopography analysis on patterned wafers

Figure 4. Phemet® Fabtool

Measurements can be obtained regardless of wafer type, as the system accepts both blank and patterned models. This flexibility makes it an ideal tool for semiconductor work.

In direct response to the different needs of laboratories and semiconductor factories, Wooptix has developed two versions of Phemet®. Phemet® Labtool has an even higher level of quality and support for 150 mm wafers, focused on the in-depth study of wafers in the laboratory and with an output of 10 wafers per hour, operator dependent. Furthermore, Labtool has a high degree of freedom and allows to quickly customize its features, such as the measurement cavity.

On the other hand, Phemet® Fabtool is designed for productivity inside controlled environments, such as factories, capable of automatically analyzing between 60 and 120 wafers per hour. This tool can be pre-programmed for a specific type of wafer, and its maintenance can also be programmed. Fabtool not only improves the efficiency of the work environment, but also opens the doors to automating the analysis of large quantities of 200 mm wafers, the most used size in chip fabrication. Both versions boast a lateral resolution of 65 µm x 65 µm, guaranteeing a high level of detail.

Phemet® works thanks to the WFPI technique developed by Wooptix. This technique analyzes the intensity of the light distribution reflected by the silicon wafer in two conjugated planes. These planes allow us to get data from both sides of the wafer and compare the position of light to build a topographic map of its surface. WFPI only uses intensity images, so there is no need to rely on interference. This is done thanks to an algorithm that calculates the phase shift between the two images and allows the system to create maps of the wafer with a physical limitation of only 3.2 µm. The device can operate with a maximum tilt of ±0.25°, which corresponds to a slope of at least 4.36 µm/mm.

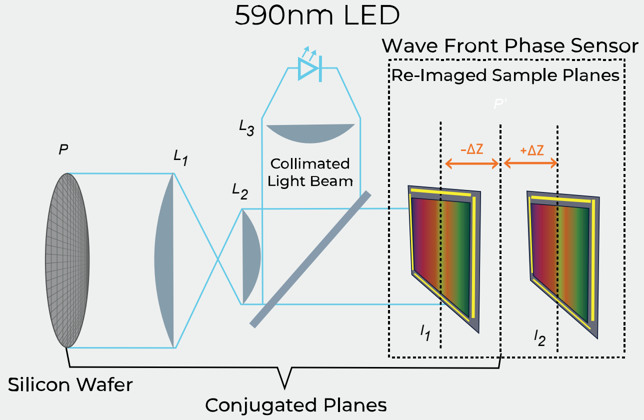


Figure 5. WFPI measurement method of retrieving shape data from intensity images

An LED acts as a non-coherent light source that projects a collimated light beam of a size equal to or larger than the sample.

Thanks to using collimated illumination, speckle distortion is prevented. The light beam reflects off the wafer, undergoes distortions that alter it, and on its way back goes through the lenses and the beam splitter until it finally reaches the digital image sensor, which records both intensity images. The algorithm then processes the images, and the resulting map is exported to the computer with all the information the operator might want.

Phemet® has several advantages over the other options on the market, such as the wide variety of metrics mentioned above. Its main rivals are interferometers, but their high sensitivity makes them vulnerable to threats against which Phemet® has managed to defend itself. As they are extremely vulnerable to vibrations, they need acoustic isolation and require much more time to complete their tasks. All this also prevents them from being coupled with other instruments to improve task efficiency and facilitate their automation.
Wooptix's tool resists vibrations up to half the resolution size (65 µm/2), and amongst its other capabilities includes being able to make topographic images from transparent films. However, the most eye-catching of its advantages is the reduction in time and costs it brings to its users by optimizing the processes in which it's incorporated.

Experimental process

To verify Phemet®'s efficiency, three different silicon wafers were studied, and the results compared with previously made IPD predictions.
These wafers mimicked the characteristics of the models used in semiconductor production, where local stress marks can vary in different regions of the surface. Wafer 1 was a reference model that received no additional treatment. Wafer 2 and 3, on the other hand, had a thin 52nm SiN film applied, which caused an umbrella-shaped change of approximately 80 µm. Subsequently, an etching process was applied to wafer 3 in which half of the nitride was removed to generate an intrafield stress pattern.

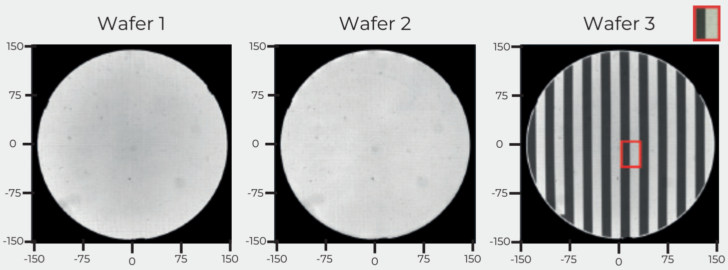


Figure 6. Intensity images of the three wafers used in the experimental process

The predictions were made from the back-side of the wafers, since this way the topography effects of the front-side aren't captured and give a good picture of the deformation caused by the processing. As for the three wafers, measurements were made before and after processing to analyze the Delta shape (Δw), the shape change introduced by the processing itself. The first step consisted in measuring the free shape of the wafers, in order to subsequently obtain the IPD to compare to the predictions.

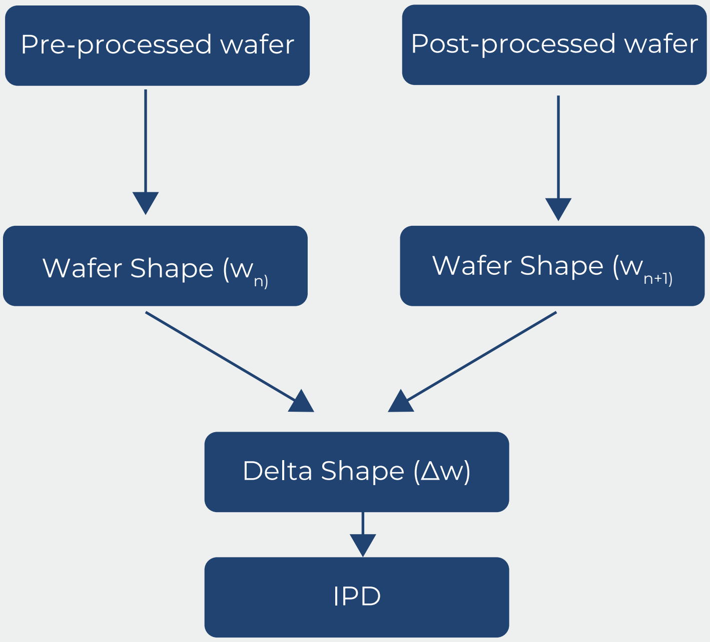


Figure 7. Procedure used to generate IPD maps from the wafer.

Each of the wafers was inserted into the device and analyzed from the back-side, since the front-side measurements were not useful. After removing the second order content it was found that the free form data was similar between the three wafers, a clear indication that most of the induced part was of the second order on both sides.

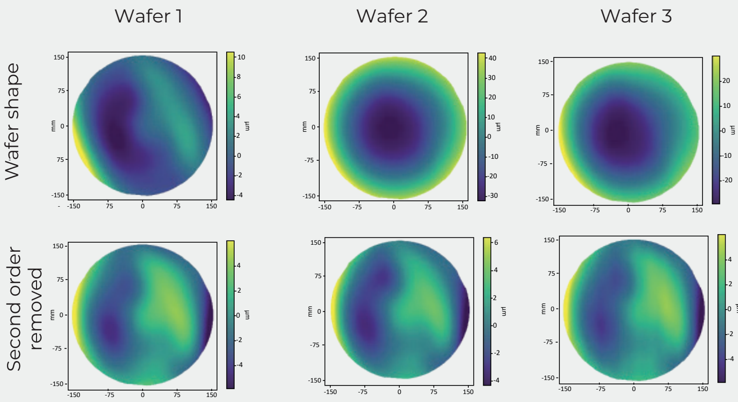


Figure 8. Back-side shape measurements: The top row shows the global wafer shape while the bottom row has the second order removed from the global wafer shape.

The final results were in line with the predictions, with only a minimal deviation from the expected values. This way, we were able to prove the viability of the Phemet® system for semiconductor analysis.

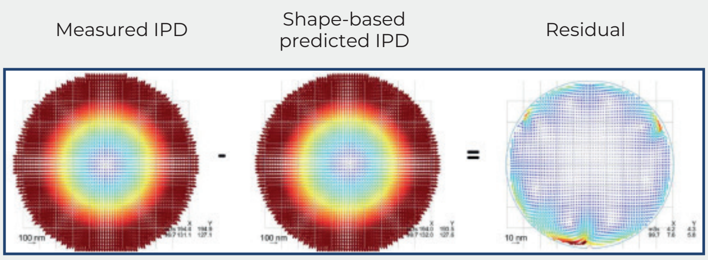


Figure 9. Comparison of the measured IPD and the wafer-shape based IPD prediction on a 100 nm scale. The differences between the two are shown on a 10 nm scale.

Applications

Thanks to its versatility, the Phemet® system can be applied with great success in the chips industry, and others that take advantage of semiconductors. Its inclusion not only helps achieve a vast improvement in the efficiency of the process, but also to solve problems that otherwise would be a large obstacle for its users, such as making dense distortion maps.

Its applications include making IPD analysis, analysis during the whole OPO process, and the high-precision study of the wafer's geometry. Every single one of these processes is made in a fraction of the time of the other options available on the market, combined with the possibility to automate them and a design that takes a reduced area in the workspace. The Labtool version has the added advantage of a high level of freedom, allowing to customize it according to the needs of his study. All Phemet® versions are also protected against vibrations and gravity, the biggest threats to accurate results.

The tool is also not limited by a specific type of wafer. Whether glass or silicon, or of 300 mm or 150 mm in diameter, Wooptix's device can observe them all with the same level of quality. Just like a Swiss Army knife, it adapts to the needs of the team and its working environment.

Phemet® is the next step in the evolution of semiconductor manufacturing. A ray of light to discover the secrets hidden on the surface of wafers.

Daniel Cuartero and Juan Trujillo

Source: Paper published the 21 November 2023 in SPIE: ***"New technique for measuring free form wafer shape to enable wafer distortion predictions"*** *by Kiril Ivanov Kurteva, Guillermo Castro Luis, Juan Trujillo-Sevilla, Jan Gaudestad, Richard van Haren, Leon van Dijkc and Ronald Otten..*

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