New Wafer-like and Reticle-like Sensors Deliver Fast, Easy Measurements Inside the Process Chamber

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Sensors are available for a range of routine and specialized applications. The two newest sensors offer significant advancements in terms of performance and range of application.

SETUP AND MAINTENANCE OPERATIONS FOR semiconductor manufacturing tools can be tedious, time-consuming, and expensive, incurring both direct costs for personnel and resources and indirect costs for lost tool time during extended commissioning of new tools and requalification of repaired or serviced tools. Wafer-like (and reticle-like) sensors (WaferSense® from CyberOptics) provide fast, easy access for measurements inside the process chamber. Over the years, sensors have been developed for many routine measurement tasks, including leveling, vibration, humidity, particles, gapping, teaching, and resistance. Two new teaching sensors provide enhanced capabilities for fine-tuning the movement of position-critical internal components like robot end-effectors and wafer carriers. In some applications, these sensors can reduce the time required to perform setup and maintenance operations by a factor of ten or more.

Introduction

There are a number of critical in-chamber measurement operations that may impose inordinately large costs when they are required. They may be occasional, associated with tool setup or major maintenance and repair, or they may be routine, such as monitoring for particles or measuring gaps to ensure tool matching. They are often simple in concept but made difficult by poor access and limited space inside a process chamber. Their measurement cycles are often extended by the stringent requirements of the process environment for cleanliness, demanding lengthy cleaning and requalification cycles when anything foreign has entered the chamber.

Consider something as simple as aligning a wafer chuck or a robot arm. It can be done with hand tools, perhaps a ruler and a level, but the challenge comes in gaining access to components inside the process chamber. The more the chamber is opened to allow access the greater the risk of contamination from the tools, the operator, or the ambient fab environment, and the more time it takes to return the tool to service.

These are the challenges that led to the development of the first wafer-like sensors – if you want to see what a wafer sees inside the chamber, wouldn't it be good to look like a wafer. The same logic led also to the development of sensors designed to mimic reticles. Sensors are now available for leveling, vibration, humidity, gapping, teaching, and resistance (**FIGURE 1**). All sensors are battery powered and communicate with the host by radio (Bluetooth).

Figure 1. Sensors are available for leveling, vibration, humidity, particle, gapping, teaching, and resistance applications.

Wafer-like and reticle-like sensors can:

- Save time and reduce cost
- Improve yields and increase tool uptime
- Increase throughput
- Reduce resource needs

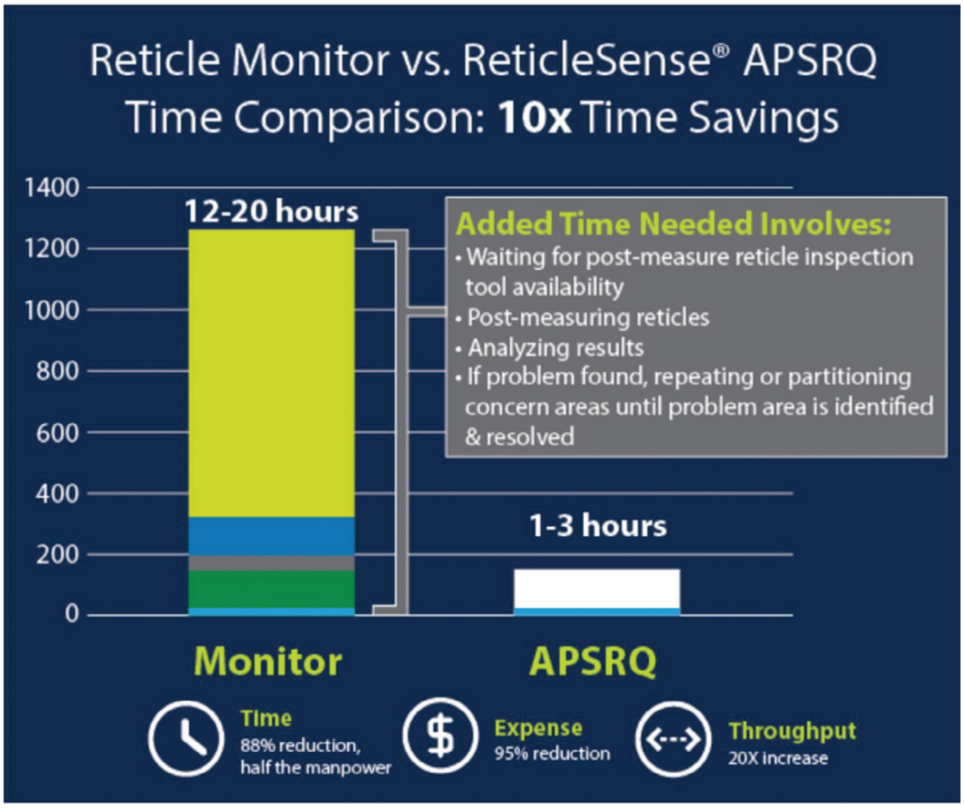

Figure 2. One comparison between conventional particle monitoring (cycling monitor reticles through the tool and counting the number of particles added) and particle counting using a reticle-like sensor reported up to 88% time savings, 95% reduction in costs, twenty times the throughput while requiring half the labor for the sensor-based approach.

- Speed equipment set-up, maintenance cycles, troubleshooting, qualification, and release to production
- Speed tool optimization, stabilization, and standardization
- Streamline fab processes
- Establish repeatable and verifiable standards

By way of example, one study compared conventional particle monitoring (cycling monitor reticles through the tool and counting the number of particles added) with particle counting using a reticle-like sensor. The sensor mounts a particle detector on the reticle-like substrate to provide continuous, real-time counting of particles in the local environment. It allowed engineers to shorten equipment qualification, release to production and maintenance cycles, all while reducing expenses. The comparison found that using the sensor delivered up to 88% time savings, 95% reduction in costs, twenty times the throughput while requiring half the labor (**FIGURE 2**). In addition, the real-time nature of the sensor technology allows the operator to correlate instantaneous changes in particle count rates with particle-generating events in the operational cycle, such as the opening or closing of a gate valve. Such correlations are not possible with monitor reticles.

Teaching sensors

Teaching sensors are used to monitor and tune the accuracy of wafer and reticle handling operations. They use cameras that are accurately located with respect to the edges and surfaces of the wafer- or reticle-like substrate to evaluate the position of the sensor relative to visible references, such as a mark indicating the center of a chuck. They can quickly report offset values to monitor accuracy or provide data for training/fine tuning robot transfers. They eliminate operator-induced variability from the measurement. Their radio communication and vacuum compatibility allow the tool to remain sealed throughout the measurement, often reducing equipment downtime from hours to minutes. The camera can also be used for inspection and other tasks, such a searching for lost wafers or verifying that a pedestal is free of debris, without opening the tool.

New wafer-like teaching sensor

A new wafer-like teaching sensor (CyberOptics Auto Teaching System, ATS2™ - **FIGURE 3**) expands on the capabilities of previous sensors. Notably, it has cameras on both the top and bottom surfaces. Both cameras are high resolution color cameras with white light illumination, and have a faster video imaging rate. The upward looking camera provides inspection and measurement of components above the sensor, such as showerheads and photoresist dispensing nozzles. The sensor is thinner, for compatibility with more systems, and has a smoother bottom surface for better vacuum chucking. It provides more accurate offset measurements and can handle more complex alignment mark shapes.

In use, the sensor relies on the accurate positioning of the camera with respect to its wafer-like outline. This establishes an X-Y coordinate system, with the X direction defined by a notch in the sensor edge. For accurate measurements, the operator must ensure the sensor is positioned on the robot in the same way a wafer would be, and the notch is properly oriented. The scale of the coordinate system projected on the surface where the alignment mark is located is determined by a simple geometric relationship that requires accurate knowledge of the working distance between the camera and the surface. This can be supplied by the operator or calculated by the sensor based on measurements of a feature of known size on the alignment surface.

The sensor has three operating modes (**FIGURE 4**):

1. Manual centering – the operator manually jogs the robot to center the alignment mark under a cross hair on the video image.
2. Assisted manual centering – the operator places a visual indicator at the center of the alignment mark in the video image and the sensor calculates the offsets between the indicator and dead center of the coordinate system.
3. Automated centering – using image analysis, the sensor finds the alignment mark's precise position after the user has indicated the mark's approximate position using a visual overlay of a selected shape. The sensor can also find arbitrary mark shapes if the user can provide a template of the shape. When the user is satisfied with the position found by the sensor, the sensor calculates offsets.

The new wafer-like sensor delivers $\leq$50µm center measurement precision (3σ) and $\leq$50µm accuracy (average measurement bias against average center mark position of test target in verification fixture).

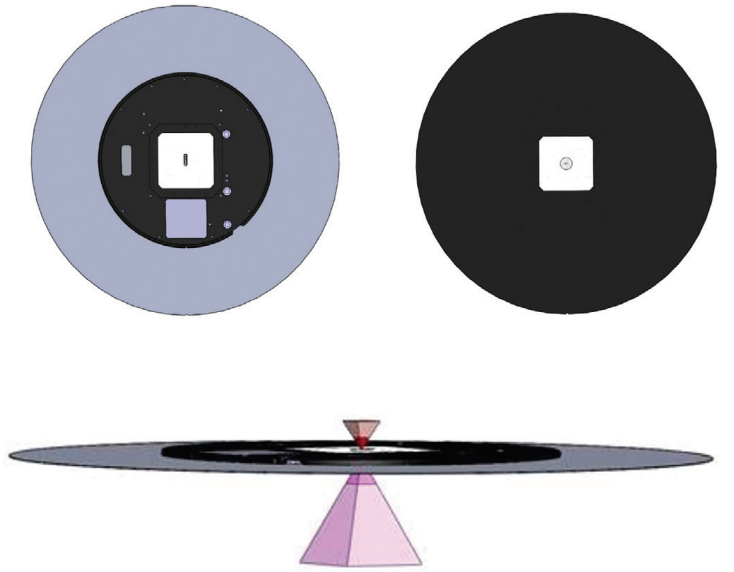

Figure 3. The new wafer-like sensor adds an upward looking camera to allow measurement and inspection of components above the sensor, such as showerheads and photoresist dispensing nozzles. Both upper and lower cameras are high-resolution, color cameras with white light illumination. The sensor is thinner and has a smooth bottom surface for better vacuum chucking. The ATS2 housing is constructed of chemically hardened glass and carbon fiber composite. The wafer shape conforms to the SEMI standards for 200mm and 300mm wafers regarding diameter and notch shape. The figure shows top (top left), bottom (top right), and 3D (bottom) views of a 300mm ATS2. The imaging optics are in the exact center of the wafer. Pyramids illustrate fields of view. The square white areas are the top and bottom illuminators.

New reticle-like teaching sensor (CyberOptics ATSR)

The new reticle-like teaching sensor (CyberOptics Auto Teaching System Reticle, ATSR™ – **FIGURE 5**) has five downward-looking, high-resolution, color cameras. Though it was developed to address a specific need to accurately position reticles within the cathode pocket of an etch system during the reticle manufacturing process, it will likely find broader applications. Positioning the reticle accurately within the cathode pocket is critical to ensure uniform etch performance and avoid damage to the reticle. Accurate positioning requires a camera located above and just inside each corner of the pocket so the camera can see the bottom of the corner where the walls and bottom intersect.

Accurate positioning of the cameras with respect to the straight sensor edges establishes both the origin and orientation of the X-Y coordinate system of the sensor. The user must supply the Z distance between the bottom of the sensor and the bottom of the pocket within an accuracy of 0.1mm. and ensure that the bottom of the pocket is level to gravity with 0.03°. The sensor detects the pocket corners and calculates the X and Y offsets and rotation angle that best center the sensor body within the pocket.

The centering process is complicated by the varying shapes of robot end-effectors, which may obscure one or more of the cameras when the robot is supporting the reticle. Positioning the reticle in the pocket is a multistep process in which the robot first positions the reticle over the pocket, then a portion of the cathode is raised to support the reticle and the robot is retracted. Finally, the raised portion of the cathode and reticle are lowered to reconfigure the full cathode with the reticle in the pocket.

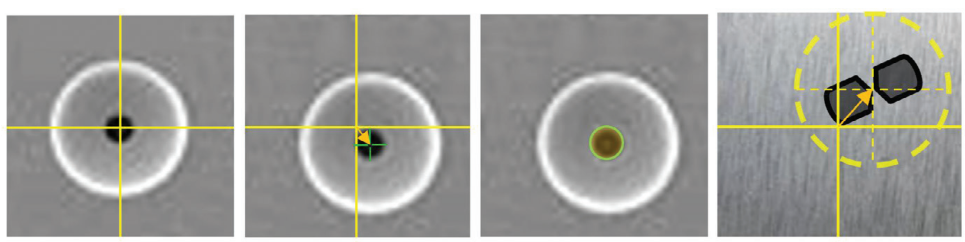

Figure 4. The new wafer-like sensor offers several operating modes: manual – the operator moves the alignment mark under a cross hair(left); assisted manual – the operator indicates the center of the alignment mark and the senor calculates offsets (center left); automated – the operator selects a mark shape and indicates and approximate position, then the sensors finds the exact location and calculates offsets (center right); if provided a template, the automated mode can also be used with arbitrarily shaped marks (right).

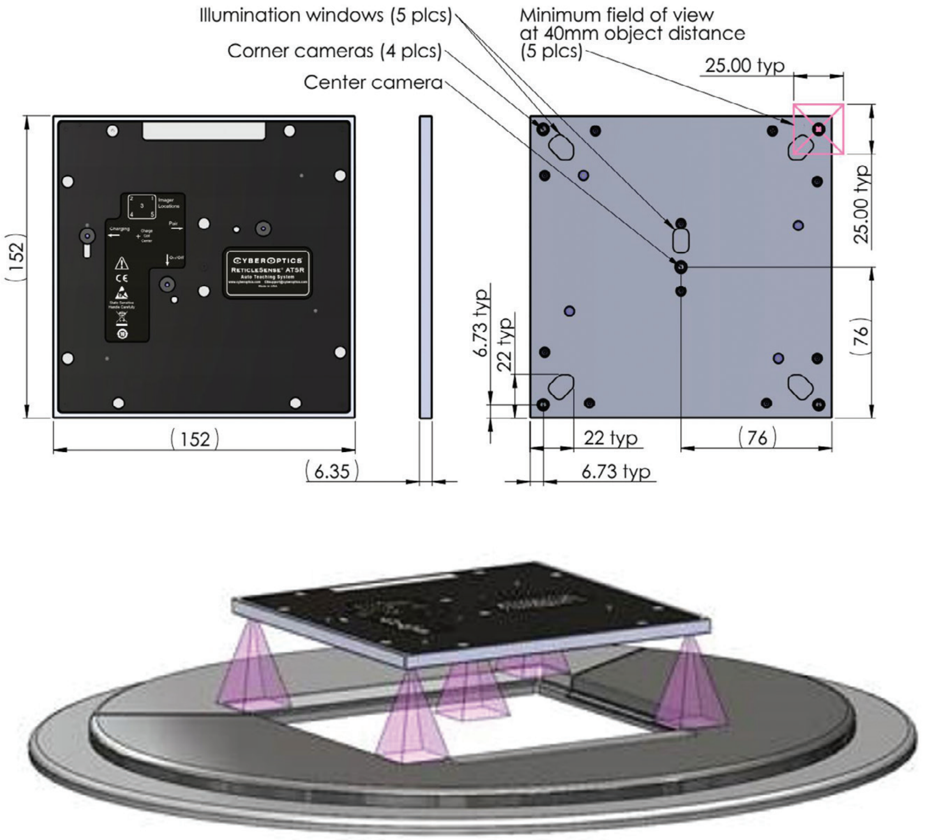

Figure 5. The new reticle-like teaching sensor has five downward-looking, high-resolution, color cameras, one in the center and one at each corner. The ATSR housing is machined from a quartz plate with a glass cover retaining the internal optics and electronics. The reticle shape conforms to the 6-inch SEMI reticle standard. The figure shows top (top left), bottom (top right) and 3D (bottom) views of the ATSR. Pyramids illustrate fields of view.

The measurement process is likewise multi-step, though all measurements are made with the sensor elevated above the pocket. When the robot positions the reticle over the cathode pocket, the two cameras distal from the robot are unblocked and can see the corresponding pocket corners. Images from these two cameras are enough to ensure that the sensor will settle correctly into the pocket when the partial cathode, which includes theses two corners, is raised. After the partial cathode is raised, which blocks the two distal cameras, the robot is retracted, and the center and the proximal corner cameras are unblocked. The proximal corner cameras can now see the corresponding pocket corners and the sensor can calculate the X and Y offsets and rotation angle that will best center the reticle within the full cathode pocket. The process assumes the transfer from robot to raised partial cathode does not disturb the position of the sensor. When the image analysis is completed, the robot calculates the offsets and rotation that will best center a reticle within the pocket and returns the sensor to the load area. The centering process can be reiterated if needed.

The user interface presents live images from all selected cameras. If a camera is not live the UI shows the most recently acquired image. Each image is overlaid with two sets of marker lines: the first set shows the known corners of the sensor projected onto the images as calculated from sensor calibration (which includes the corner XY positions), sensor tilt from onboard tip/tilt measurement, and user input Z height; the second set shows the extrapolated (squared off) pocket corners as measured from the images and corrected for tilt from onboard tip/tilt measurement and Z from user input (**FIGURE 6**).

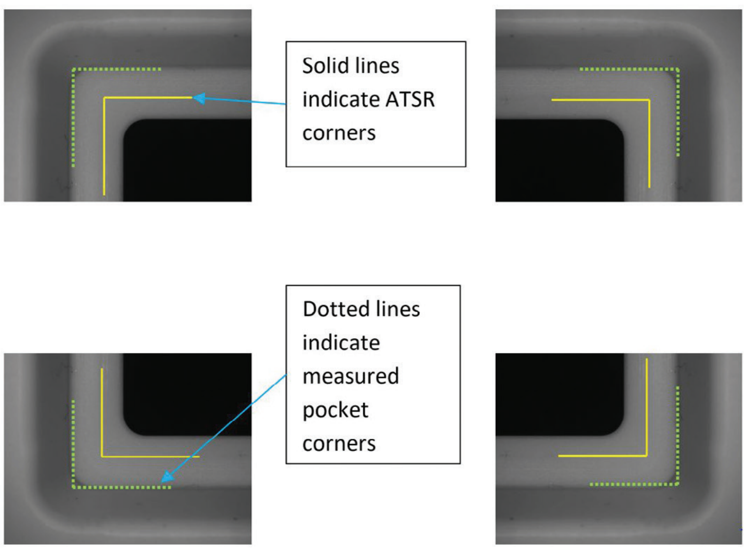

Figure 6. The reticle-like sensor presents images from cameras at each corner showing overlaid with marks to indicate the positions of the sensor corners (solid) and the extrapolated (squared off) pocket corners (dotted).

The new reticle-like sensor delivers ≤25µm precision (3σ) and ≤50µm accuracy (average measurement bias against standard corner position of test cathode in verification fixture)

Conclusion

Wafer-like and reticle-like sensors dramatically reduce the time and cost required for in-chamber measurements. Sensors are available for a range of routine and specialized applications. The two newest sensors offer significant advancements in terms of performance and range of application.