In-line Airborne Particle Sensing Supports Faster Response to Contamination Excursions

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ABSTRACT

Fine particles (less than 5 micrometers in diameter) do not affect most industrial processes, but they can have a disastrous impact on semiconductor manufacturing. From the earliest days, manufacturing facilities have deployed air filtering and recirculation to remove particles from the cleanroom, but particles may still be generated inside process tools, where they can cause defects and yield loss. Quickly identifying when and where airborne particles originate can be challenging, but it is critical to success. Conventional methods for monitoring and diagnosing contamination problems take considerable time to return results, and, because of their intermittent nature, they may not see contamination episodes until the damage is detected by downstream inspections. In-line particle sensing (IPS) provides continuous, real-time monitoring, shortening response times and potentially limiting damage to work-in-progress.

Keywords: Airborne, particulate, contamination, in-line particle sensor

1. INTRODUCTION

During the manufacturing process, semiconductor devices are extremely vulnerable to damage by particulate contamination. Manufacturers go to great lengths to prevent contamination. The process takes place in a cleanroom, where air is constantly recirculated and filtered to remove particles. Even within the cleanroom, when wafers are transported from tool to tool, they are enclosed in specially design air-tight containers and never exposed to the ambient environment. However, contaminants generated inside process tools can still cause defects and yield loss, and engineers carefully monitor tools to detect contamination. Most monitoring relies on the inspection of monitor wafers, which are run through the process tool routinely, or in response to a contamination problem detected by downstream inspection of product wafers. This approach has shortcomings. It is not continuous and may miss an event that occurs between samples. It takes tool time to measure monitor wafers that could be used to process product wafers. It is slow, taking considerable time to return results and potentially putting additional wafers at risk. A new in-line particle sensor addresses these shortcomings. It can be installed in the process chamber exhaust line, where it can monitor all gas flowing out of the chamber continuously and in real time, detecting particles larger than 0.1μm.

2. METHODS

An In-line Particle Sensor (IPS™, CyberOptics Corporation) was installed on an EUV photolithography system (figure 1). The sensor counts particles by directing a laser through the process exhaust stream and detecting light scattered by particles. It is usually placed in the vacuum foreline between the high vacuum pump (usually a turbo pump) and the roughing pump. In this case it was located just after the turbo pump that evacuates the process chamber. In this configuration any particles generated in the system are concentrated and conveyed through the IPS in the turbo pump exhaust stream. However, the IPS sensor can be placed in any area of a vacuum system where particles are expected to pass. Experience has shown that most particle "events" occur when the process chamber pressure is changing or when items are moving inside the tool.

Collisions between gas molecules and particles move the particles in the direction of the gas flow. Since the IPS is primarily intended for use in vacuum forelines, the pressure in the IPS sensing area is relatively low and gas flows much faster than any particles, often orders of magnitude faster. At very low pressures, (high vacuum) the particles do not flow at all because there are very few gas-particle collisions. Particle velocity therefore depends on pressure, gas flow velocity, residual gas type, particle size, and other factors. Electronic filtering in the IPS allows very slow particles to be sensed.

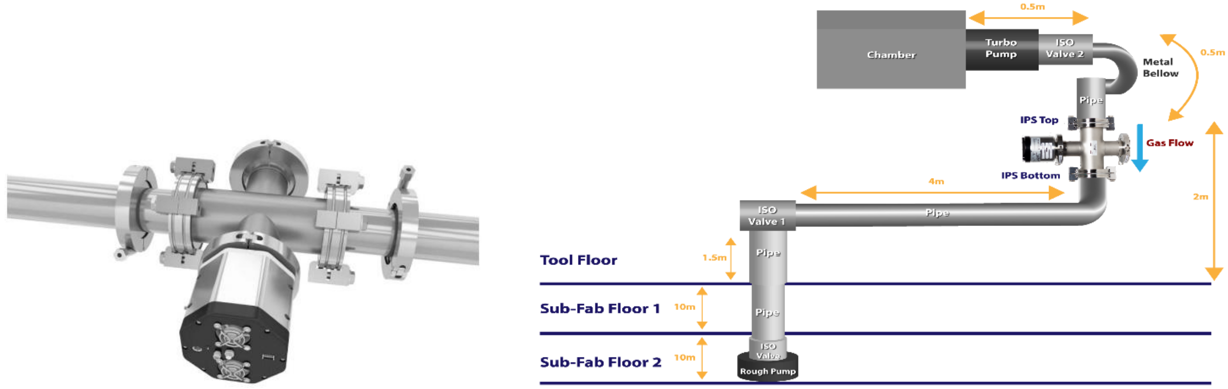

Figure 1. (left) IPS particle sensor, (right) the IPS is normally installed in the process exhaust stream, in this example just after the exit port of the turbo pump mounted on the chamber.

3. RESULTS

In this case. the IPS collected data continuously for over a month (figure 2). Particle counts began to increase steadily within a few days of installation, indicating a process issue. An investigation revealed the source. A technician performed the required maintenance and returned the tool to nominal performance. Early detection, and the prompt corrective action it enabled, prevented yield loss, and saved time and money.

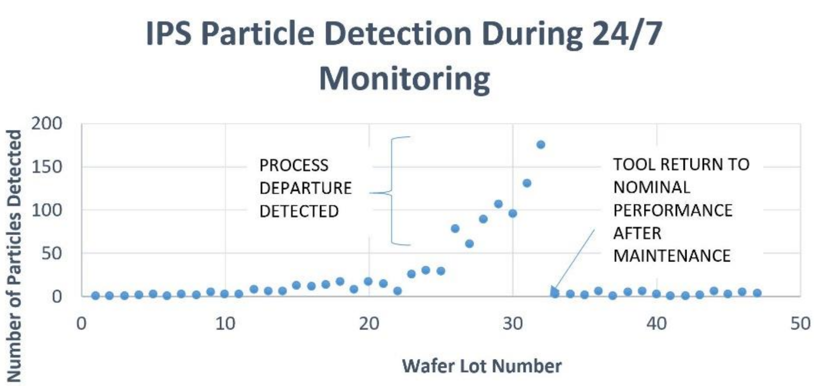

Figure 2. In this example, the IPS detected a significant increase in particle counts a few days after installation, indicating a need for intervention. Service personnel performed maintenance and the particle levels returned to normal.

4. DISCUSSION

EUV lithography is a critical process. It is used to create the smallest, most challenging structures in the circuit, i.e., the transistors that do the work. It is sometimes called a bottleneck process because, if it stops, the whole process stops. Moreover, EUV systems are capital intensive. Earning an adequate return on that investment requires the system to operate constantly at maximum throughput with little or no downtime. To paraphrase the real estate adage – there are three priorities in EUV lithography: availability, availability, and availability. Any time saved by early detection and rapid response to process excursions or contamination events is extremely valuable. Maximizing yield and tool uptime in photolithography environments requires best-in-class practices to achieve a contamination-free process environment. Unfortunately, identifying precisely when and where airborne particles originate is challenging with traditional methods.

There are three widely used methods for particle detection in photolithography environments: bench-top & hand-held airborne particle counters, monitor reticles (analogous to monitor wafers), and in-situ particle scanners. All three of these traditional methods have substantial drawbacks:

- Bench-top counters require long hoses to reach into the tool—and are often incapable of following the reticle path. Similarly, bench-top and handheld methods make it difficult (and often impossible) to reach all locations of interest. In some cases, equipment engineers must crawl through the scanner to make accurate measurements.
- Monitor reticle scanning is time-consuming, creating long delays for test results. The process has many steps and typically involves considerable waiting for tool availability and lost tool time while the tool executes non-productive test cycles: 1) premeasure the test reticle, 2) load the test reticle into the tool, 3) put the test reticle through a normal operational cycle, 4) Remove the test reticle and wait for inspection tool availability, 5) perform the post measurement, 6) analyze results. If problems are found, the repeat the measurement process. Monitor reticle scanning does not deliver results in real time, and cannot determine precisely when and where the reticle became contaminated.
- In-situ scanners are usually separate from the tool and look at particles deposited on a wafer, not in the air. They are good at identifying particles, but limited in their ability to pinpoint where in the wafer handling process the particles accumulated on the wafer. Like monitor reticles, they do not see the particles in real time and or provide timely alerts of the presence of particles, which could prompt proactive intervention to avoid contamination of product wafers.

These issues drove the development of a sensor that can detect airborne particles in vacuum and gas flow lines. IPS mounts permanently on a supply or exhaust line and detects particles 24/7. It can detect particles of 0.1micron size and higher. Its 10^{-6} Torr operating range allows installation of the IPS on any vacuum line, where it can detect any particles that pass through its interaction region without risk of leakage. However, its target range is higher pressures (lower vacuum) lines where substantial gas flows carry the particles with them at relatively high speeds.

The particle stream travels through the sensor in a straight line and the light source and sensing optics are configured along the orthogonal axis in the crossing arm of the vacuum fitting. When a particle passes through the laser beam in the area in front of the IPS sensor head, the particle scatters some of the laser light. That light is collected by an optical system and sensed by a photodiode. The particle sensing and analysis occurs on a microsecond time scale. Processing takes place in the sensor, and the information is transmitted via Bluetooth link to the host computer, where it is displayed in real time. A software application (CyberSpectrum™, CyberOptics Corporation) manages display, analysis, and storage.

Continuous, real-time, in-line particle sensing with the IPS has demonstrated a clear advantage in locating and troubleshooting airborne particles in photolithography environments. By recording particle counts versus time, particle generating events can be correlated with process events occurring inside the tool. The software graphically displays particle events over time as they occur and stores them in various formats for later analysis. EUV customers have shown clear correlation between IPS measurements and particle adder events

The laser based counting technology of the IPS is also incorporated in physical formats that mimic the form factors of wafers or reticles. The wireless WaferSense® and ReticleSense™ sensors can be used to measure particle counts when and where they occur as the counter transits the process tool. The wireless sensors count particles, bin them as large (>0.5µm) or small (>0.14µm) and communicate with a host PC over a Bluetooth link. They include active airflow to draw sampled gas and particles through the sensor. The system records data for analysis and permanent maintenance records, ensuring appropriate follow-up.

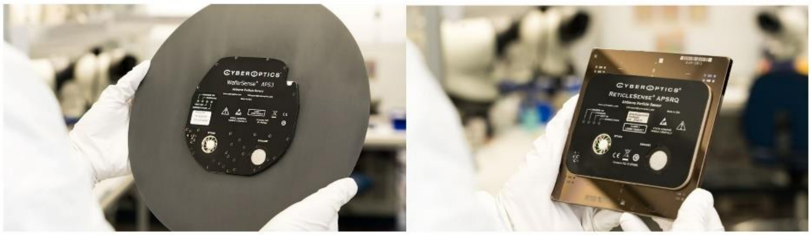

Figure 3. The same particle counting technology used in the IPS is incorporated in formats that mimic wafer or reticle geometry. These sensors help to localize particles sources as the sensor passes through the process tool.

Table 1 compares the steps and time required for monitor reticle and wireless particle counting techniques. Monitor reticles do not deliver results in real time, making it difficult to determine precisely when and where the contamination occurred. Wireless particle detection checks the entire reticle path inside the tool and is 10 times faster.

Particle Investigation Process or Procedure	Monitor Reticle Time Estimated	APSRQ Time Estimate*	Comment
Pre-measure reticles	N/A	1 hour**	APSRQ ready immediately
Load test reticles	5 minutes	5 minutes	APSRQ handles just like a normal reticle
Cycle test reticles	10 minutes or until problem until problem found	10 minutes	No waiting for APSRQ results
Take reticles out	5 minutes	5 minutes	
Wait for post-measure reticle inspection tool availability	2 hours**	N/A results immediate	Once APSRQ uncovers problem area, troubleshooting begins instantly
Post-measure reticles	1 hour**	N/A	
Analyze results	2 hours**	N/A	APSRQ results immediate, thus analysis immediate
If problems found, repeat and/or partition areas of concern until problem identied and resolved	8-16 hours** Note: sometimes days until problem found with Reticle monitor	1-2 hours Note: trouble-shooting and resolution begins immediately	With APSRQ, once problem area found all possible particle sources investigated in real time, i.e, exercise moving parts. ep
Summary	12 to 20 hours**	1-3 hours** Note: 10X APSRQ times savings over monitor method typical	APSRQ also requires signicantly less resources such as manpower and insection tool resources not considered

**All times listed are estimates based on past user experience and used here for example purposes only.

Table 1. The table compares monitor reticle and reticle-format wireless particle sensing.

5. CONCLUSION

The need to maximize process yield and tool availability drives requirements for best-in-class practices for a contamination-free process environment. Conventional methods for particle detection are not fast enough to support real-time alerts of contamination events and not good at identifying the particle source. IPS and wireless wafer and reticle format counters can detect particle sources exactly when and where they occur, with results available in real-time, or stored for later analysis. IPS mounts permanently in the supply or exhaust line and delivers continuous monitoring. Wireless wafer and reticle-format sensors travel through process tools, allowing them to pinpoint the contamination source within the tool. Rapid results speed the determination of root causes and shorten repair and maintenance cycles. Real-time monitoring supports proactive and preventative maintenance, potentially eliminating unplanned downtime events and consequential damage to work-in-progress – ultimately improving yields and processes.