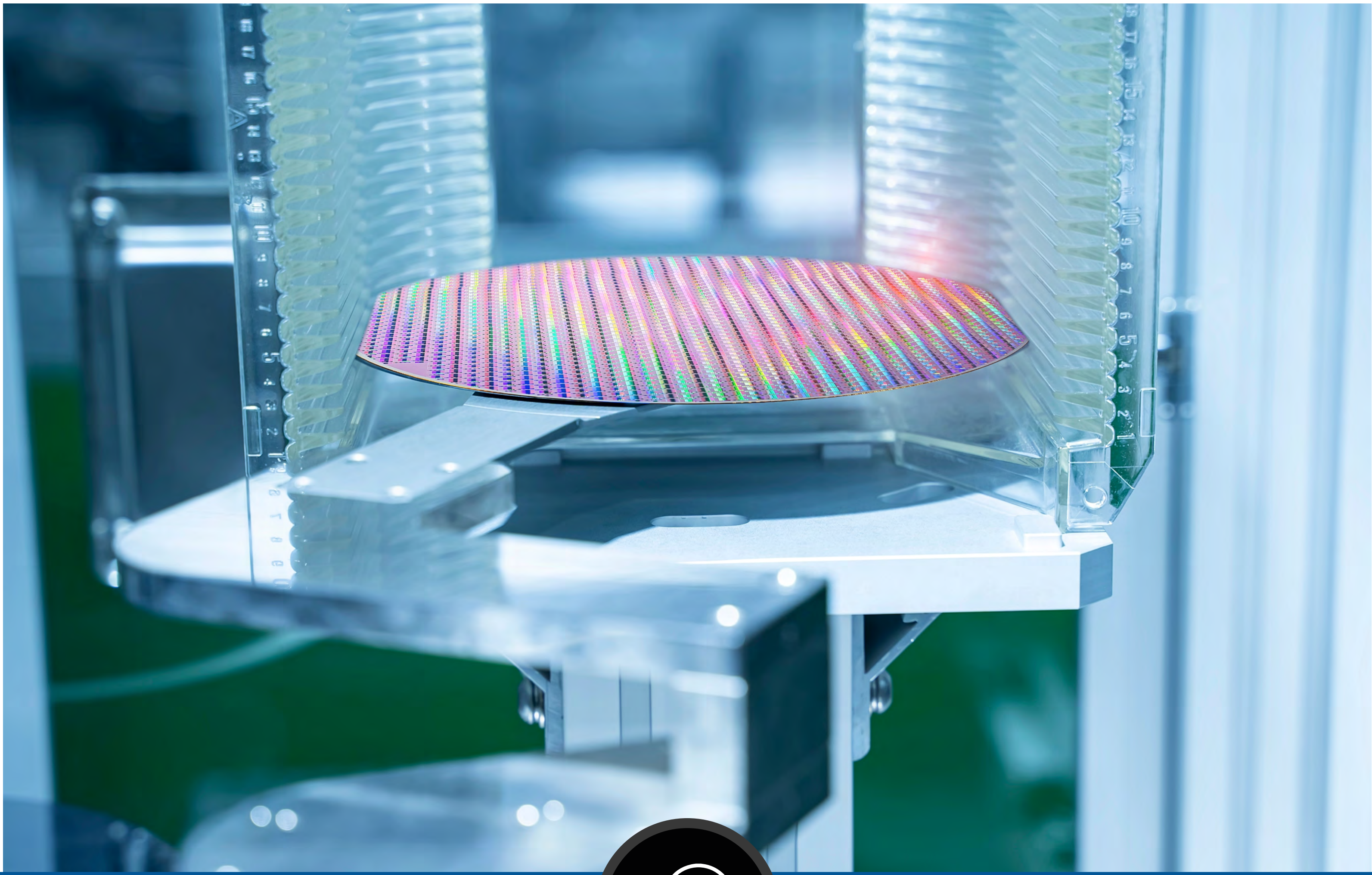
# USING REAL TIME MONITORING SYSTEMS IN THE SEMICONDUCTOR INDUSTRY TO IMPROVE PRODUCT YIELD

Lighthouse Worldwide Solutions



# Overview

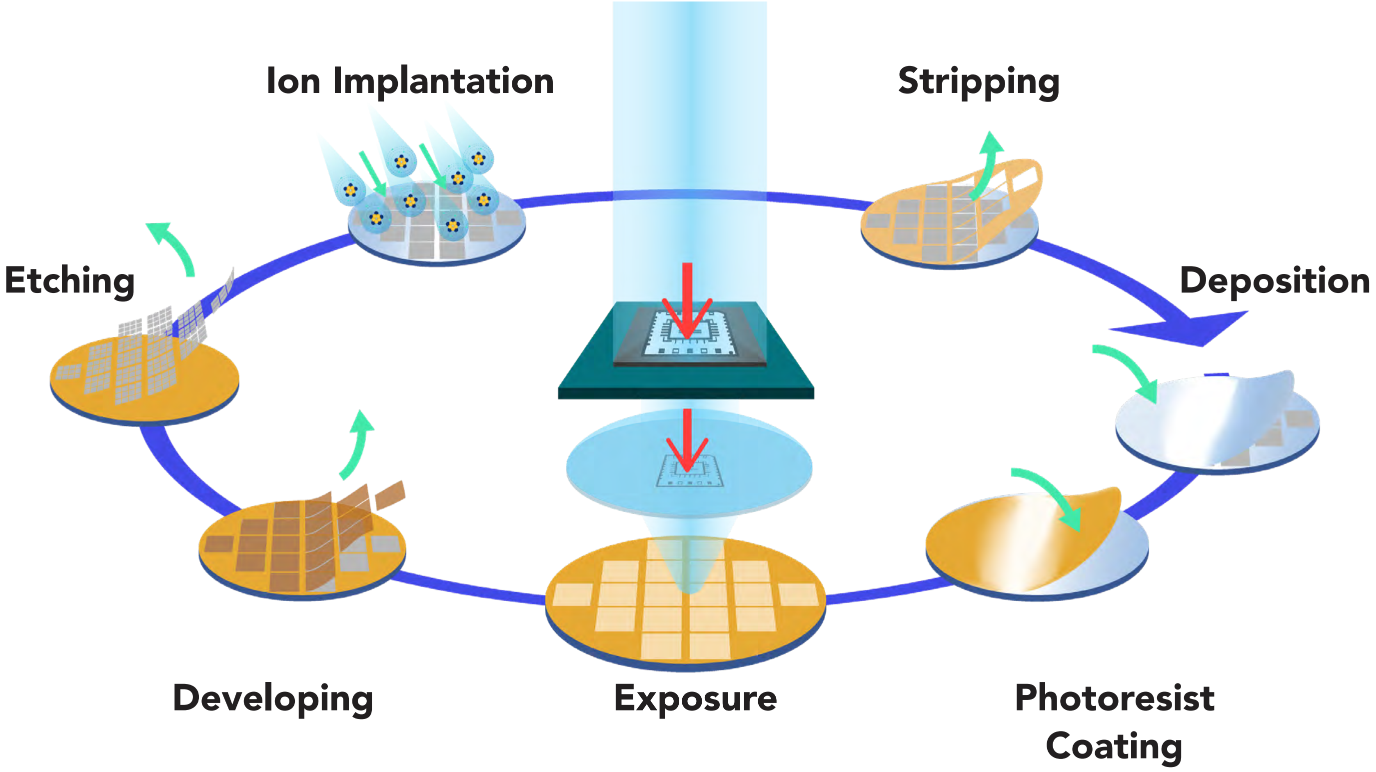
It takes numerous steps and processes to manufacture semiconductors. There is much room for potential contamination in the process, which can result in yield and time loss. This can be frustrating and costly. A Real Time Monitoring System can help detect issues immediately and allows for mitigation of these issues.

# Introduction

The manufacture of semiconductor products is an arduous and complicated process. A typical wafer fab is where integrated circuits are manufactured. The process and the various stages of development of the silicon wafer to a final microchip involve many steps. It is critical that the products are free from contamination. This contamination, if unmonitored, can have detrimental effects on product yield and product quality.
The process of manufacturing semiconductors or integrated circuits (commonly called ICs or chips) typically consists of more than a hundred steps. During this process, hundreds of copies of an integrated circuit are formed on a single wafer. The process generally involves the creation of 8 to 20 patterned layers on and into the substrate, ultimately forming the complete integrated circuit. This layering process creates electrically active regions in and on the semiconductor wafer surface.

Contamination control involves the control of particulates, transition metals, heavy metals, organics, and any other undesirable contaminants that result from IC processing. In this paper we will focus on particulate contamination monitoring and control.

# Wafer Production



The first step in semiconductor manufacturing begins with production of a wafer--a thin, round slice of a semiconductor material, usually silicon. In this process, purified polycrystalline silicon, created from sand, is heated to a molten liquid. A small piece of solid silicon (seed) is placed on the molten liquid. As the seed is slowly pulled from the melt, the liquid cools to form a single crystal ingot. The surface tension between the seed and molten silicon causes a small amount of the liquid to rise with the seed and cool.

The crystal ingot is then ground to a uniform diameter and a diamond saw blade cuts the ingot into thin wafers. The wafer is processed through a series of machines, where it is ground smooth and chemically polished to a mirror-like luster. The wafers are then ready to be sent to the wafer fabrication area where they are used as the starting material for manufacturing integrated circuits.

# Wafer Fabrication

The heart of semiconductor manufacturing is the wafer fabrication facility where the integrated circuit is formed in and on the wafer. The fabrication process, which takes place in a cleanroom, involves a series of principle steps described below. Typically, it takes from 10 to 30 days to complete the fabrication process.

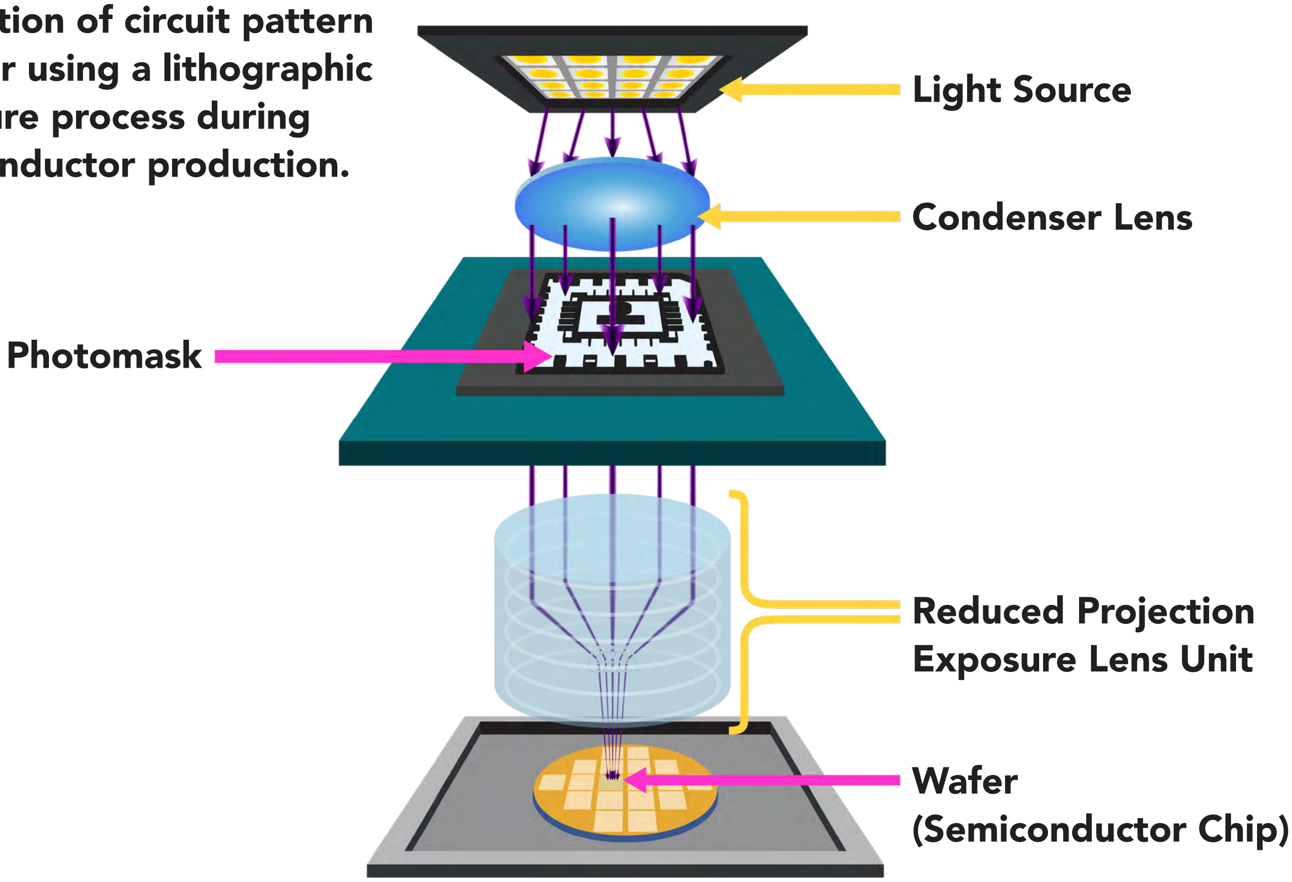
# Thermal Oxidation or Deposition

Wafers are pre-cleaned using high purity, low particle chemicals. This is important for high-yield products. The silicon wafers are heated and exposed to ultrapure oxygen in the diffusion furnaces under carefully controlled conditions, forming a silicon dioxide film of uniform thickness on the surface of the wafer.

# Masking

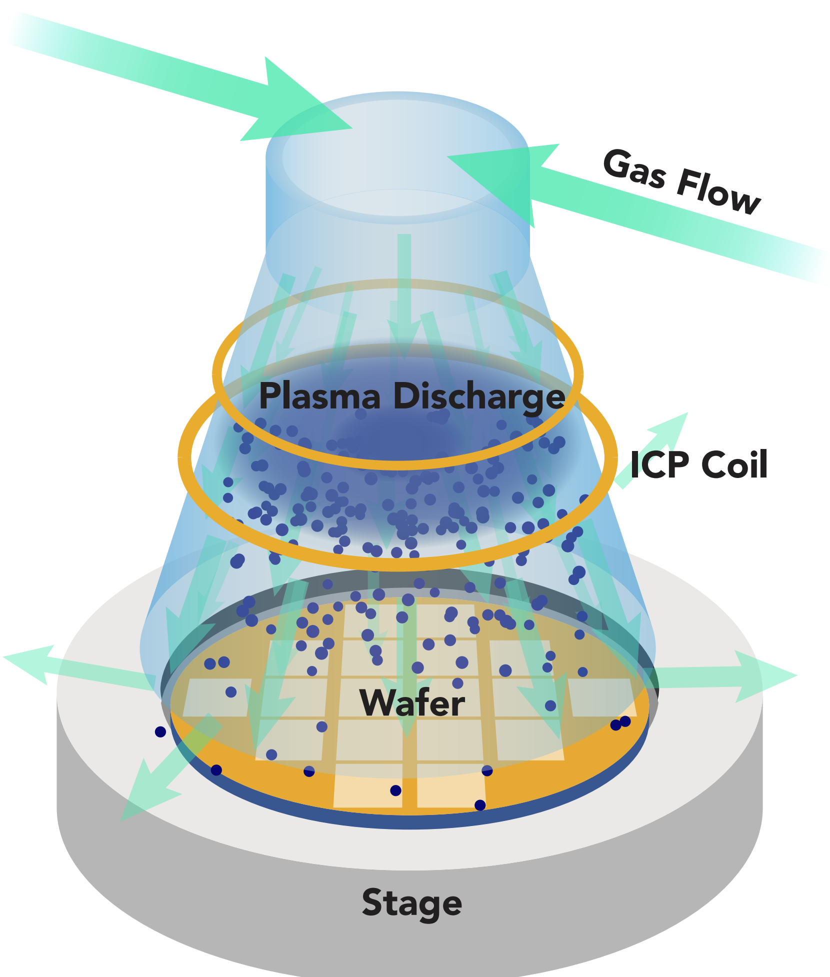
Masking is used to protect one area of the wafer while working on another. This process is referred to as photolithography or photo-masking. A photoresist or light-sensitive film is applied to the wafer, giving it characteristics similar to a piece of photographic paper. A photo aligner aligns the wafer to a mask and then projects an intense light through the mask and through a series of reducing lenses, exposing the photoresist with the mask pattern. Precise alignment of the wafer to the mask prior to exposure is critical. Most alignment tools are fully automatic.

**Illustration of circuit pattern transfer using a lithographic exposure process during semiconductor production.**



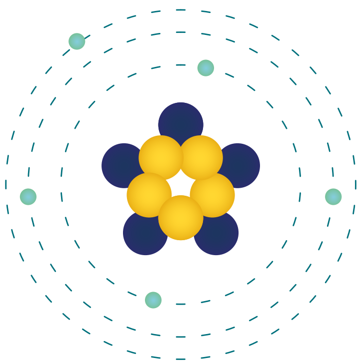

## Etching

The wafer is then "developed" (the exposed photoresist is removed) and baked to harden the remaining photoresist pattern. It is then exposed to a chemical solution or plasma (gas discharge) so that areas not covered by the hardened photoresist are etched away. The photoresist is removed using additional chemicals or plasma. The wafer is inspected to ensure the image transfer from the mask to the top layer is correct.

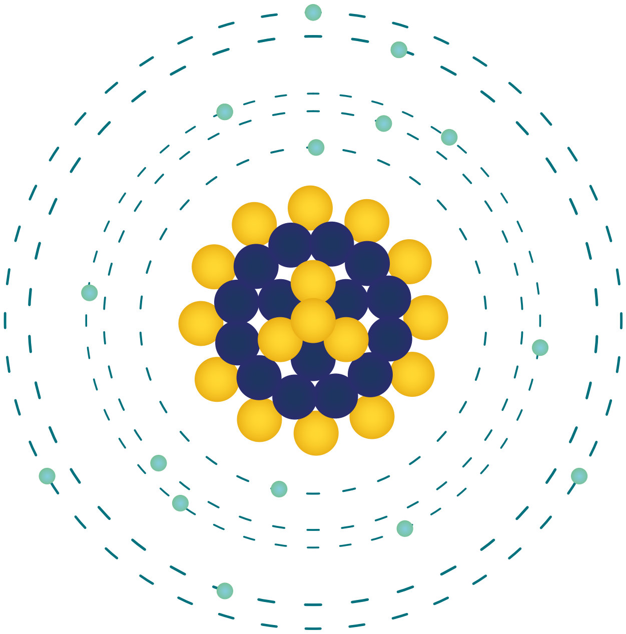


# Doping

Atoms with one electron less than silicon (such as boron) or one electron more than silicon (such as phosphorous) are introduced into the area exposed by the etch process to alter the electrical character of the silicon. These areas are called P-type (boron) or N-type (phosphorous) to reflect their conducting characteristics.



Boron



Phosphorus

# Repeating the Steps

The thermal oxidation, masking, etching, and doping steps are repeated several times until the last "front end" layer is completed. This is when all active devices have been formed.

# Dielectric Deposition and Metallization

Following completion of the "front end," the individual devices are interconnected using a series of metal depositions and patterning steps of dielectric films (insulators). As of 2018, the most complex ICs may have over 15 layers of interconnect. Each level of interconnect is separated from each other by a layer of dielectric.

# Passivation

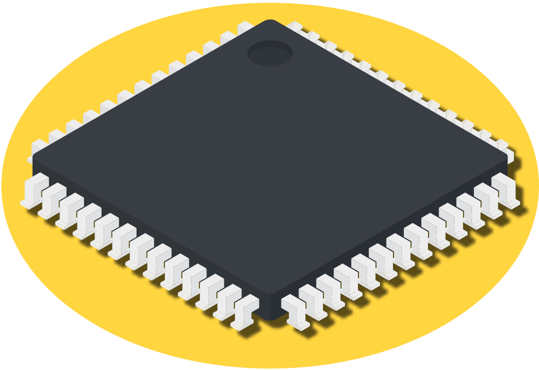
After the last metal layer is patterned, a final dielectric layer (passivation) is deposited to protect the circuit from damage and contamination. Openings are etched in this film to allow access to the top layer of metal by electrical probes and wire bonds.

# Electrical Test

An automatic, computer-driven electrical test system then checks the functionality of each chip on the wafer. Chips that do not pass the test are marked with ink for rejection.

# Assembly

A diamond saw typically slices the wafer into single chips. The inked chips are discarded, and the remaining chips are visually inspected under a microscope before packaging. The chip is then assembled into a package that provides the contact leads for the chip. A wire-bonding machine then attaches wires, a fraction of the width of a human hair, to the leads of the package. Encapsulated with a plastic coating for protection, the chip is tested again prior to delivery to the customer. Alternatively, the chip is assembled in a ceramic package for certain military applications.



# How is Each Process Monitored for Contamination?

Now we have a good overview of the journey a silicon wafer takes from development to assembly, and we see there are many processes involved. Based on the IC layers involved, the process can take from up to 8 weeks.  All these processes have a level of risk involved in terms of contamination. Determination of what and where to monitor for contamination can be daunting. By understanding the wafer fabrication process and following a well-developed risk assessment, what to monitor and where to monitor becomes easier to identify. Risk Assessments are widely used in the Pharmaceutical Industry and this paper does not go into full detail on how to perform a risk assessment, but we shall cover some of the basics.

# The Risk Assessment

The risk assessment is based on knowledge of the process and understanding the weak points of that system. It is recommended that senior management take on this responsibility and assign a team of process and cleanroom experts to develop the risk assessment. The team should collectively be able to identify locations and processes where contamination of product or process is a possibility.

You should:

1. **Consider what can go wrong.**
2. **Determine how bad the outcome would be (consequences).**
3. **Determine how likely it is to happen (likelihood).**
4. **Calculate the risk level.**

For example, before the Thermal Oxidation or Deposition process, chemicals are used in the pre-cleaning of the wafer. These chemicals would need to be routinely tested for particulate contamination. You do not want to introduce contamination into the process, so using liquid particle counters to monitor the cleaning chemicals makes sense.

| Likelyhood | Consequences | | | | |
|---|---|---|---|---|---|
| | **Insignificant** *Risk is easily mitigated by normal day to day process* | **Minor** *Delays up to 10% of Schedule Additional cost up to 10% of Budget* | **Moderate** *Delays up to 30% of Schedule Additional cost up to 30% of Budget* | **Major** *Delays up to 50% of Schedule Additional cost up to 50% of Budget* | **Catastrophic** *Project abandoned* |
| **Certain** *>90% chance* | High | High | Extreme | Extreme | Extreme |
| **Likely** *50% - 90% chance* | Moderate | High | High | Extreme | Extreme |
| **Moderate** *10% - 50% chance* | Low | Moderate | High | Extreme | Extreme |
| **Unlikely** *3% - 10% chance* | Low | Low | Moderate | High | Extreme |
| **Rare** *<3% chance* | Low | Low | Moderate | High | High |

During the Masking process, the immediate environment should be carefully monitored to ensure the air cleanliness levels are within specified design parameters and HEPA and ULPA filters are providing clean air to pass over the process.

During the Etching process, gases are introduced, and these gases also need some routine monitoring to ensure they are not a source of contamination. Gas suppliers are required to provide certificates that indicate the purity of the gases; however, in a risk assessment, in-house monitoring of batches of gas should be undertaken to ensure the quality of the gas remains intact.

The Risk Assessment should identify these types of scenarios and focus on areas of the process where other products such as chemicals, liquids, and gases are introduced. Other areas of concern are based on operator interaction with the wafers. Cleanroom operators are one of the greatest risks to product quality. We are all aware of the amount of particulate shedding - even while cleanroom operators are fully gowned up. It is, therefore, critical to ensure the points where cleanroom operators and technicians interface with the wafer are monitored using air particle counters.

# Yield and Yield Management

Line yield and defect density are two of the most closely guarded secrets in the semiconductor industry. Line yield refers to the number of good wafers produced without being scrapped, and in general, measures the effectiveness of material handling, process control, and labor. Die yield refers to the number of good dice that pass wafer probe testing from wafers that reach that part of the process. It is intended to prevent bad dice from being assembled into packages that are often extremely expensive and measures the effectiveness of process control, design margins, and particulate control.

Yield improvement is the most critical goal of all semiconductor operations as it reflects the amount of product that can be sold relative to the amount that is started. Yield is also the single most important factor in overall wafer processing costs. Incremental increases in yield (1 or 2 percent) significantly reduce manufacturing cost per wafer, or cost per square centimeter of silicon. In the fab, yield is closely tied to equipment performance (process capability), operator training, overall organizational effectiveness, and fab design and construction.

Continued device miniaturization in the semiconductor industry and the trend to larger and larger die sizes means that particulate contamination has an ever-increasing impact on yields. Today, over 80% of yield loss of VLSI chips manufactured in volume can be attributed to random defects.

# Particulate Monitoring in the Semiconductor Cleanroom

From the Risk Assessment the persons who undertake the assessment should have the experience and process knowledge to identify the weak points in the wafer fabrication process. If the expertise is not available internally, then external consultants can help with the Risk Assessment. In the examples above we see there are three applications where particle counters can be used to monitor: (1) liquids, (2) gases and the (3) cleanroom environment. With the advances in technology, Real Time Monitoring Systems (RTMS) that incorporate liquid, gas, and environmental monitoring are ideal for such applications.

Real Time Monitoring enables faster decisions to be made. Consider the cost of a batch of wafers nearing the end of the process. That cassette of wafers could be worth $150k or more and there could be 100 cassettes undergoing processing. What if one of the tools or the environment was compromised? The time it can take to realize such an issue and the time a decision is made could impact greatly on product yield. With Real Time Monitoring Systems (RTMS) that time to make a decision to halt the processing and investigate the issues could literally save many hundreds of thousands of dollars. By using this technology, informed decisions can be made faster and more efficiently.

## What are the advantages of a RTMS?

- **Immediately flags and alarms out of norm environmental conditions.**
- **Monitor tools and process locations.**
- **Make fast decisions for closer inspections.**
- **Trend Analysis of cleanroom performance.**
- **Monitors HEPA and ULPA filter performance.**
- **Provides location classification reports.**
- **Preventative maintenance indicators – pick up issues before they become terminal.**
- **Live data with the ability to send personal notifications and alarms.**
- **Web connected, network connected, LDAP and Active Directory friendly.**

Which departments need to monitor for particulate contamination and what type of monitoring is recommended? Each step in the process will have unique monitoring requirements. As we have outlined the wafer fabrication is an intensive process which can take up to 8 weeks based on the multiple layers and transistor load of the circuitry design. Table 1 highlights the departments that should consider using particle counters. Remote and portable liquid and air particle counter sensors can be integrated into the RTMS, and all departments can access the RTMS to view the whole facility or to just focus on their area. The RTMS can also monitor door sensors, temperature/humidity, room pressures, and even airborne molecular contamination monitoring devices can be connected into the RTMS.

| | |
|---|---|
| Facility Dept. | • Air and Liquid Particle Counting - Portable and On-Line<br>• ESC, ESD and Ionizer status - Portable and On-Line. Monitoring general room environment<br>• Airborne Molecular Contamination – Portable, online and batch sampling. (we can do batch sampling through Balazs)<br>• Temperature and Humidity<br>• Differential Pressure |
| Quality Assurance | • Air and Liquid Particle Counting - Portable and On-Line<br>• ESC, ESD and Ionizer status - Portable and On-Line<br>• Airborne Molecular Contamination – Portable, online and batch sampling. |
| Photolithography | • Air and Liquid Particle Counting - Portable and On-Line.<br>• ESC, ESD and Ionizer status - Portable and On-Line. Most interested in ESD events inside the stepper.<br>• Airborne Molecular Contamination – Portable, online and batch sampling. |
| Thin Film | • On Line Particle Air Counting<br>• Airborne Molecular Contamination – Portable, online and batch sampling. |
| Etch | • On Line Air Particle Counting<br>• Airborne Molecular Contamination – Portable, online and batch sampling. |
| Diffusion | • On Line Air Particle Counting<br>• ESC, ESD and Ionizer status - Portable and On-Line<br>• Airborne Molecular Contamination – Portable, online and batch sampling. |
| Implant | • Airborne Molecular Contamination – Portable, online and batch sampling. |
| Inspection | • On Line Air Particle Counting<br>• ESC, ESA and Ionizer status – Surface charge of wafer<br>• Airborne Molecular Contamination – Online sampling |

**Table.1 Outline of Departments and Process requiring monitoring.**

Table 1 identifies the different processes and the level of monitoring recommended. The facility department typically undertakes site monitoring activities in relation to cleanroom standards. ISO 14644-1:2015 is the current cleanroom standard for particulate monitoring followed worldwide by the cleanroom industry. Each room is classified based on the level of contamination observed in a cubic meter of air sampled. Table 2 is the current ISO 14644-1:2015 classification table. ISO 14644-1:2015 specifies classes of air cleanliness in terms of the number of particles expressed as a concentration in air volume. It also specifies the standard method of testing to determine cleanliness class, including selection of sampling locations based on the area of the room to be sampled.

| ISO Class number (*N*) | Maximum allowable concentrations (particles/m³) for particles equal to and greater than the considered sizes, shown below[a] | | | | | |
|---|---|---|---|---|---|---|
| | 0,1 µm | 0,2 µm | 0,3 µm | 0,5 µm | 1 µm | 5 µm |
| 1 | *10*[b] | [d] | [d] | [d] | [d] | [e] |
| 2 | 100 | *24*[b] | *10*[b] | [d] | [d] | [e] |
| 3 | 1 000 | 237 | 102 | *35*[b] | [d] | [e] |
| 4 | 10 000 | 2 370 | 1 020 | 352 | *83*[b] | [e] |
| 5 | 100 000 | 23 700 | 10 200 | 3 520 | 832 | [d, e, f] |
| 6 | 1 000 000 | 237 000 | 102 000 | 35 200 | 8 320 | 293 |
| 7 | [c] | [c] | [c] | 352 000 | 83 200 | 2 930 |
| 8 | [c] | [c] | [c] | 3 520 000 | 832 000 | 29 300 |
| 9[g] | [c] | [c] | [c] | 35 200 000 | 8 320 000 | 293 000 |

a All concentrations in the table are cumulative, e.g. for ISO Class 5, the 10 200 particles shown at 0,3 µm include all particles equal to and greater than this size.

b These concentrations will lead to large air sample volumes for classification. Sequential sampling procedure may be applied; see Annex D.

c Concentration limits are not applicable in this region of the table due to very high particle concentration.

d Sampling and statistical limitations for particles in low concentrations make classification inappropriate.

e Sample collection limitations for both particles in low concentrations and sizes greater than 1 µm make classification at this particle size inappropriate, due to potential particle losses in the sampling system.

f In order to specify this particle size in association with ISO Class 5, the macroparticle descriptor M may be adapted and used in conjunction with at least one other particle size. (See C.7.)

g This class is only applicable for the in-operation state.

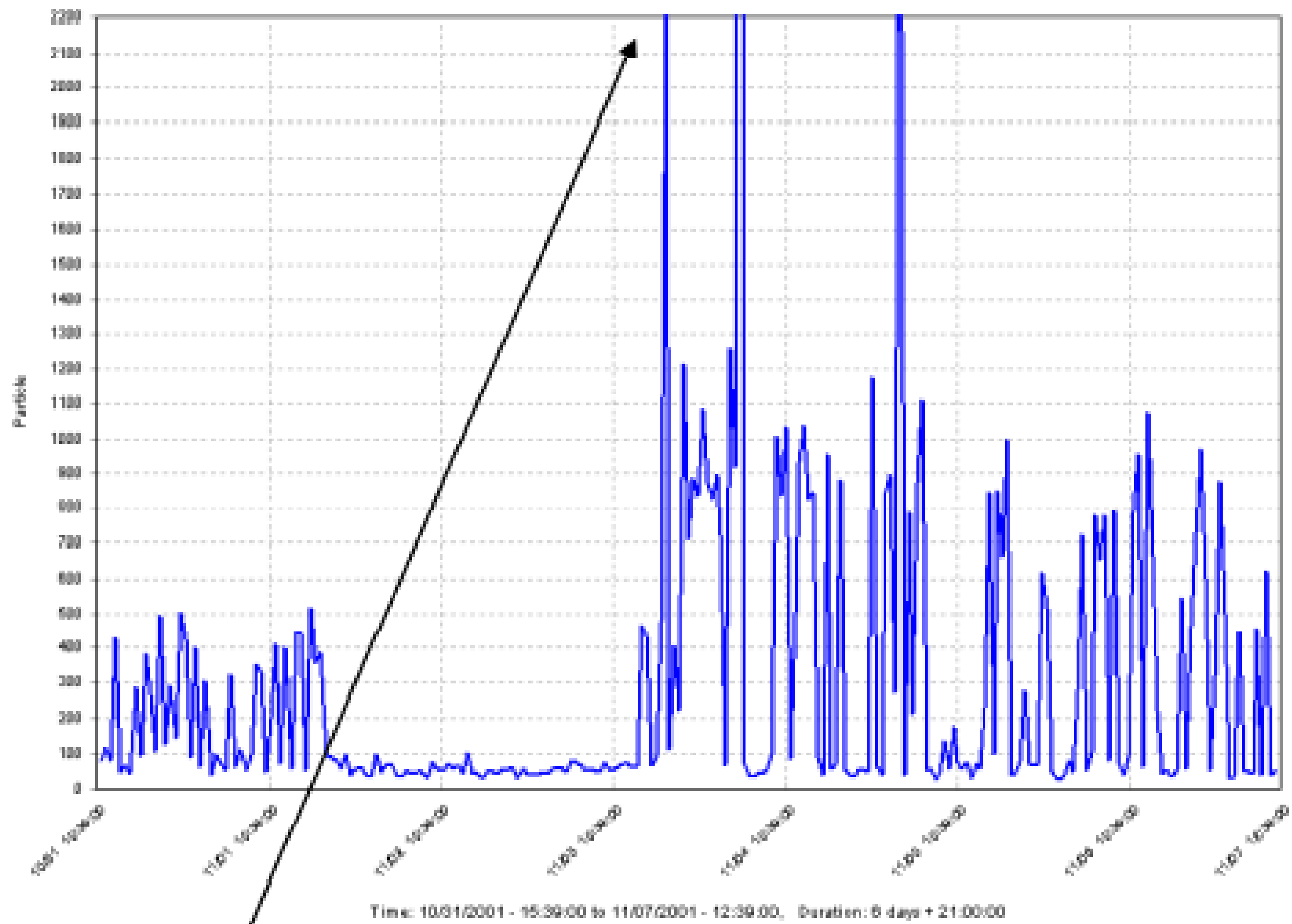
**Table 2 ISO 14644-1:2015 Max allowable particle concentrations per m³**

There is a difference between cleanroom certification and routine monitoring. Portable airborne particle counters are typically used to certify the cleanroom and ISO 14644-2 is followed to comply to the frequency of the cleanroom certification. From the table above, each ISO Class number from 1 to 9 represents the level of cleanliness based on particle concentrations of a sample of one cubic meter. Semiconductor cleanrooms are typically from ISO 1 to ISO 5 based on the risk of contamination to the process. The higher sensitive processes are typically lower ISO Class numbers with ISO 1 being the cleanest environments with only 10 0.1um particles per cubic meter of sampled air allowed.

In areas where real time monitoring is not always necessary based on process risk, the use of manifold systems may be considered. Manifold systems are a form of sequential monitoring. Most particle counters and monitoring systems update at a frequency of once per minute. A manifold system only uses one particle counter but may have up to 30 locations to monitor. A special device rotates each location and connects it to the particle counter. So based on a 1-minute sample, if the manifold system was to monitor 30 locations, then each location would be updated every 30mins. In some processes that level of monitoring frequency may be acceptable. Choosing the monitoring frequency and type of monitoring equipment should be determined during the Risk Assessment.

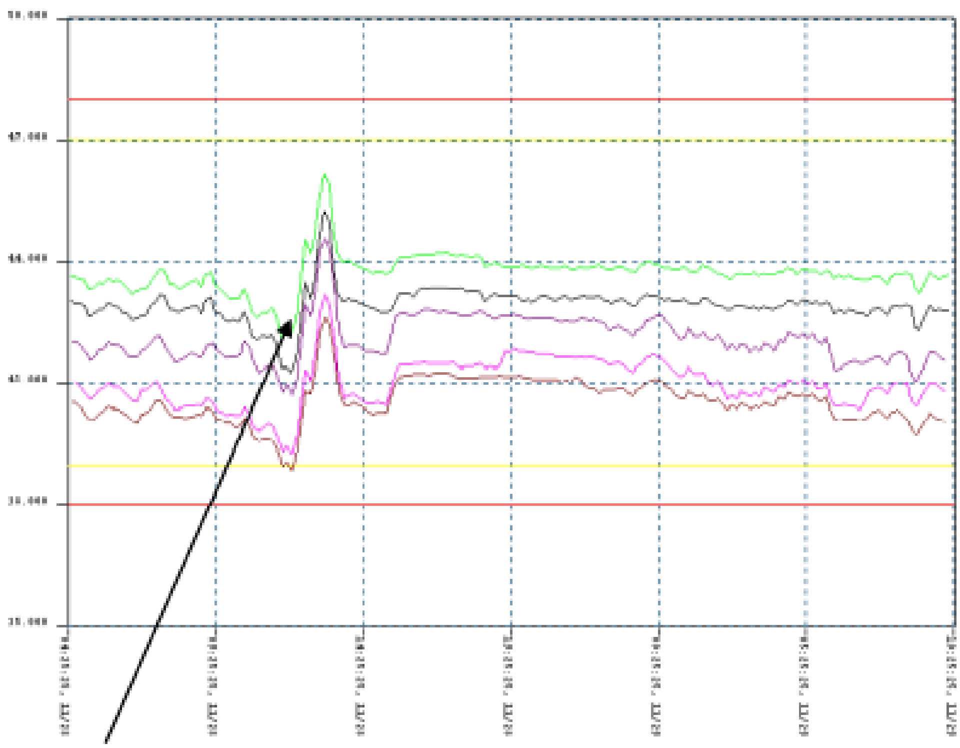
In RTMS, the monitoring is done 24/7, typically using remote particle counters. The RTMS is used as a process diagnostic tool to ensure critical locations and toolsets are not indicating high levels of particle counts. As we have seen these high levels can impact on product yield and the RTMS early warning detection is a very valuable tool in enabling fast decisions to be made.

## Examples of RTMS and Early Notification Warnings




**Major shift in particle counts was identified using real time sensors.**

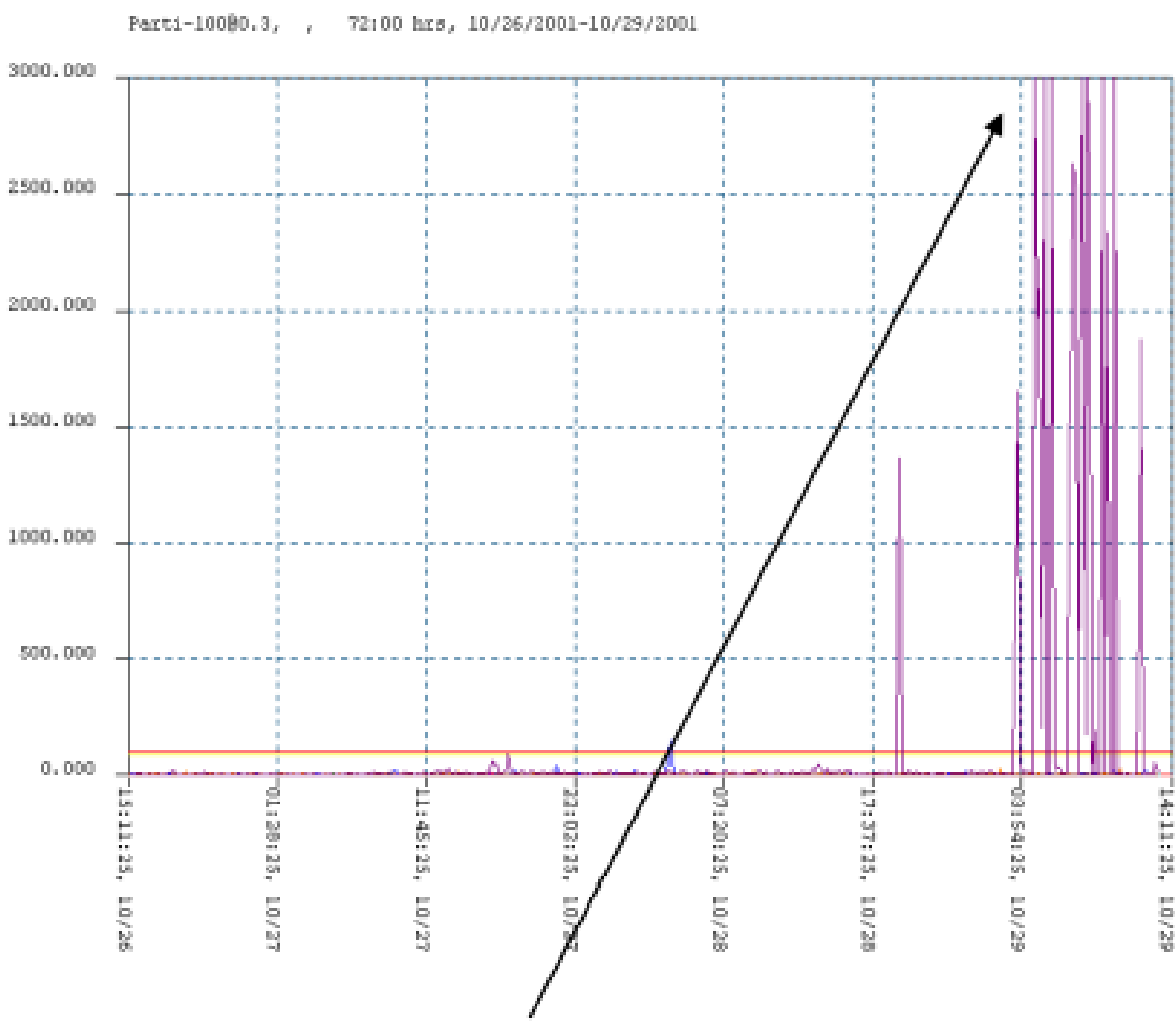
In the example above, the RTMS immediately picked up an event in one of the environments where wafers were being scanned for surface contamination. DMA tools are used in the process to systematically monitor wafers from a batch during the process to determine wafer condition during the process. If the surrounding environment did not have a particle counter monitoring that environment, the issue could have been a major one. The technician would have reported that the wafers have high contamination and would be looking at the previous processes to identify the failure. That would have been futile as the origin of contamination was coming from the room environment where the DMA tool was located. Without this knowledge, the root cause may have taken a long time to address. How much product would have been lost here? How much down time would there have been to conduct the investigations? In this issue, the location was observed immediately, and the root cause of the contamination was found to be a puncture in the HEPA filtration system. The issue was corrected within an hour.



**TRH HVAC was accidently reset to increase humidity levels. Their Lighthouse system identified the issue and corrective action was taken.**

Here we see that humidity levels were accidently triggered to increase. Since the HVAC system is unable to monitor itself, the independent TRH sensors connected to the RTMS picked up the shift in humidity levels and notified the facility manager who made the corrections quickly. Imagine if this event went on for several hours or a couple of days. Cleanroom operators would notice their comfort levels have decreased due to the higher humidity and the higher humidity would influence electrostatic occurrences. That is something you do not want to see in a wafer fabrication facility.

In the example below, the RTMS captured a high particle concentration event. The ISO 7 room and ISO 5 room door did not fully close due to a pneumatic failure of the door arm. The ISO 5 room started to get high particle count ingress from the ISO 7 room. The facility manager was able to manually shut the door and activate a service call for the cleanroom door company to come out and repair the actuator.




**A door between an ISO 5 and ISO 7 room was left open and thus particle counts in this location increased dramatically.**

The above examples highlight the benefits of a RTMS. The RTMS is the watchdog for the wafer fabrication cleanroom. Depending on the type and number of sensors connected, that watchdog can be a very valuable tool. In these three examples time was a major factor. The longer the event went by without notice the higher the probability of contamination and yield losses.

## Further Benefits Using a RTMS

- **View conditions of all cleanrooms in real-time using maps.**
- **Warning and catastrophic events alarms.**
- **Provides visual, audible, electronic, or pager notification to engineers and operators.**
- **Automates sensor data collection.**
- **Analyzes and measures cleanroom performance.**
- **Highlights contamination problems.**
- **Correlates problems to other parameters and yields.**
- **Identifies trends and provides early warnings.**
- **Reduces failure analysis times.**
- **Assists in post-mortem analyses.**
- **Aids in more efficient facility shutdowns and re-starts.**
- **Shows your customers that you are proactively managing the manufacturing environment.**

# Applications for Airborne and Liquid Particle Counters

Below are some applications of airborne particle counters used in a wafer fabrication facility.

- **Cleanroom Certification**
    - **Every 6 to 12 months, depending on cleanroom class level**
- **Daily Routine Testing to comply to ISO 14644-1**
- **Continuous Monitoring of General Locations**
    - **Aisles**
    - **Chases**
    - **Gowning area**
    - **High Traffic Areas**
- **Continuous Monitoring of Critical Process Locations**
    - **Stockers**
    - **Tool Load Locks**

  - **Mini Environments**
  - **Inside process tools (stage for Stepper or Scanner)**
  - **Wafer Inspection**
  - **Photomask Stocker and Inspection**
- **Garment Testing with Helmke Drum**
- **Monitoring of tools using chemical solutions and liquids**
- **Monitoring of DI water and ultra clean water loops used in the process**
- **Monitoring of gases introduced into the process**

# Overview of Particle Counters & Systems

We've listed out plenty of benefits, but what particle counters and systems do you need to reap those benefits? ApexZ Portable particle counters are widely used for cleanroom certification and routine monitoring applications. Today's technology enables digital connection to RTMS. Digital data to be captured and eliminates using paper inside the cleanroom. They are also small and lightweight, making them ergonomically friendly with long lasting battery capacity (11hrs) for full portability. They are suitable for particle sizes above 0.3µm and can be used in manifold systems and in gas monitoring.



The Solair 1100LD is used in applications where 0.1µm measurements are required. The Solair 1100 LD is a portable particle counter with a measurement range from 0.1µm.  For specific process applications, this model can also monitor gases and be connected to a manifold system.

Manifold Systems as discussed offer sequential sampling in locations that are not as critical.  A fully loaded manifold can sample each location for 1 minute every 30 minutes.  It is not quite real time monitoring, but enables many locations to be monitored using only one particle counter.


Handheld Particle Counters are great for spot checking since they are easy to carry and position in locations to troubleshoot. In one example we discussed a HEPA filter leak, and the exact location of the leak was found using a handheld unit. The smallest particle size resolution goes down to 0.2µm. Handheld particle counters have a flowrate of 2.83L/min and are not really suitable for cleanroom certification where 1 cubic meter volumes are required as the time it takes to collect 1 cubic meter is nearly six hours as opposed to the ApexZ50 which only takes 10minutes to sample 1 cubic meter.

Remote particle counters are used in RTMS since they have a small footprint. The ApexR is used by many industries using cleanrooms. Remote particle counters come in different flowrates and with or without internal pumps.

The smallest size range is down to 0.2µm. The models shown here are widely used in semiconductor applications.

Locations for these sensors should be based on a Risk Assessment for monitoring critical zones along the wafer fabrication processes including support tools and rooms such bays where cassettes are unloaded into tools for processing. Some facilities have hundreds of sensors connected to RTMS. These remote sensors provide a RTMS to events that may be detrimental to product yield and quality.


Water systems are used in wafer fabrication processes. In fact, to process a single wafer, over 1,000 gallons of water are needed. Ultrapure water systems need to be monitored. In line and off line water monitoring is enabled using liquid particle counters. The Vertex50 LPC has a resolution down to 50 nano meters with almost perfect resolution.

The Vertex50 can be located at critical locations along the water system to monitor the efficiency of the filtration system. Since so much water is used in the wafer fabrication processes it is prudent to monitor this water for contamination. After all you can have the cleanest cleanroom in the world but when you introduce contamination into the system all of that is in vain.


Remote Liquid Particle Counters can also be used to monitor ultrapure water systems and can support the Vertex50 locations where particle sizes to be monitored are larger further upstream of the process. These sensors can monitor particle sizes down to 0.1µm (100 nano meters).


The Lighthouse Scan Air provides an easy-to-use means of checking HEPA / ULPA Filters and their seals for leaks and efficiency.
The Scan Air incorporates an Isokinetic probe specifically designed for a sampling flow rate of 1.0 CFM (28.3 LPM) across a wide area. The Scan Air includes a Remote Start/ Stop button and 7.62 meter (25-foot) cable. The Remote switch features hands-free operation of the SOLAIR portable particle counter enabling the user to efficiently sample in compliance with ISO 14644

The onboard alarm buzzer and LED quickly notify the user if a count exceeds the alarm threshold, even when the Scan Air is being used in a high noise environment. The twist-lock connector quickly and easily connects or disconnects the Scan Air from a Solair portable particle counter.

The Solair and Scan Air can be used as a portable contamination detection system throughout the cleanroom environment.

# In Summary

By establishing effective monitoring systems based on science and knowledge you can empower your facility and mitigate against product yield losses. RTMS offer "live data" and production managers, quality managers, facility engineers and line managers can be notified in real time if events will have a critical impact.

The wafer fabrication process is a very labor and machine intense process with up to 100 processes. There are many areas to monitor, and this paper outlines the best options and applications to monitor and identifies the right monitoring equipment.

As environmental contamination can adversely affect product yield, monitoring environmental conditions is mission-critical.

A single excursion can cost hundreds of thousands of dollars in product loss. With RTMS redundant data collection, your data will be automatically recorded to two databases simultaneously. With mirrored databases, if the main computer fails, the secondary will automatically take over data collection, thus providing you with uninterrupted data collections and alarming on out of specification conditions.

In the examples shown using a RTMS and the events alarmed you can see that the RTMS is a valuable process monitoring tool. This RTMS tool enables faster decisions to be made and it can in some cases locate root causes of contamination. Time is money in this industry and downtime results in harmful and expensive product yield losses.

If you are looking to implement a RTMS then it is recommended to form an internal team of subject matter experts or hire external consultants and engage with a vendor that understands your processes and can assist in the project. Developing a Risk Assessment is the first step and a well-developed RA will definitely pay dividends with the installation of a RTMS. Use a quality vendor with quality products and a proven track record in the semiconductor industry.

## References:


1. *ISO 14644-1:2015 Cleanrooms and associated controlled environments — Part 1: Classification of air cleanliness by particle concentration.*

2. *INTEGRATED CIRCUIT ENGINEERING CORPORATION – Yield and Yield Management*

3. *S. Smith et.al., "Rapid yield Learning Through Data Integration," Semiconductor International, June/July 1996*

4. *W. Kern, "handbook of Semiconductor Wafer Cleaning Technology," Noyes Publications, New Jersey, 1993*

5. *Introduction to Integrated Circuit Technology 5th Edition written by: Scotten W. Jones 2012*