Mini-environment Benefits and Design Considerations

Overview

Cleanrooms in laboratory-type facilities used for research require the control of particle sensitivities that approach the 0.01micron size. In these facilities and in microelectronics production facilities, costs, expressed as a function of silicon wafers, are increasing dramatically. Researchers and manufacturers are concerned that this escalation rate will exceed the rate of device integration, a trend that threatens to reverse traditional economics and increase the cost per function of the silicon wafer. Additionally, when the production of new devices moves from the research laboratory to large cleanrooms, these production facilities cannot purge particles this small. Increased silicon wafer costs are driven by: process complexity, escalating equipment costs, facility construction costs, and operating costs, which address the increasingly stringent contamination requirements. Energy-efficient laboratory-type facilities incorporating mini-environments can help contain these costs by reducing the first costs of construction and the life-cycle energy use of the facility. [O'Reilly and Rhine, 1995]

Mini-environment concept

The mini-environment is located in a class 1,000 ballroom environment with locally isolated environments of class 1 or better. The idea is to reduce the volume of ultra-clean areas to a minimum by enclosing only the immediate environment of the contamination-sensitive products. During the whole production cycle, the products remain completely isolated from personnel and the surrounding environment by either a physical barrier or an air curtain. The mini-environment has three advantages:

- reduction of ultra-clean areas minimizes the investment and operational costs of the environmental conditioning systems,
- isolation of the product provides contamination control at the product level, and
- minimum enclosure size of the mini-environment maximizes flexibility. [Gath et al., 1995]

Mini-environment benefits

Mini-environments have proven to substantially reduce capital and operating costs while improving cleanliness. The direct benefits of mini-environments include the following:

- reduced air handling capacity,
- reduced power consumption,
- decreased particle contamination, and
- reduced gowning requirements. [O'Reilly and Rhine, 1995]

An indirect benefit is the superior contamination control performance of the mini-environment, which eliminates the need for new air-handling and contamination control systems with each generation of processing tools. Thus, it is now possible to develop laboratory-type facilities that bridge several generations of device technology. The success of older-generation cleanrooms validates this capability. Other cleanrooms with mini-environments have made successful transitions to sub-micron processing.

Mini-environments air supply

Early in their development, mini-environments used the same supply of clean air from the filter ceiling as the conventional cleanroom. Ultra-clean air was supplied through the ULPA filters suspended from the existing ceiling grid mini-environment. The trend toward stand-alone mini-environments, as well as the requirement of optimized flexibility in tool layout, has led to the use of dedicated fan filter units as air supply sources. [Gath et al., 1995]

Only air volumes within the clean air enclosure need to be controlled to desired class specifications, typically 20% or less of the total cleanroom air volume. The air outside the enclosures can be maintained at Class 1,000 and Class 10,000, while the air within is at Class 1 and Class 10 environments.

Barrier isolation and the mini-environment

Mini-environment isolation enclosures can be grouped into four primary types:

- canopy enclosures constructed of clear plastic panels with localized clean air source,
- wall enclosures with ceiling clean air source (the "clean bay" approach),
- hanging curtain enclosures with ceiling clean air source,
- air curtain containment systems. [Briner, 1986]

Mini-environment enclosure

The mini-environment encloses each piece of process equipment or tool in a local Class 1 ultra-clean area; continuous positive pressure in the enclosure prevents influx from the less stringently maintained ambient atmosphere. The ultra-clean air for the mini-environment can be provided either by integrated filter-fan units on top of the enclosure or through connections to the plenum of the cleanroom ceiling. [McIlvaine, 1992]

In general, the mini-environment is composed of three elements:

1. An isolation enclosure for the process or measurement tool, coupled with a source of clean air for the enclosure,
2. A container to hold and transport the product, and
3. An Input/Output device to extract parts from the container and present them to the process tool. [Bonora, 1993]

Originally, mini-environments were designed to enclose the whole process tool, resulting in a "tool in the box." Mini-environments have become smaller and now typically only enclose the product handling area of the process tool. Smaller environments decrease air circulation volumes and improve maintenance access to the tool.

Mini-environments hard wall enclosures

Hard wall enclosures are not always used to create mini-environments. Modules can be furnished with HEPA-filtered air curtains utilizing direct-drive motor blowers to provide portable Class 100 areas. The units may be self-contained modules with their own motors and blowers or terminal modules on the central air supply. Self-contained units are recommended because the majority of air is recirculated, which reduces energy costs. Self-contained units are equipped with a separate motor/blower with speed control to obtain control of air velocity. Air curtain directional adjustments can be made easily; directional mass control of laminar air flow can be manipulated.

Inert gas microenvironment

A mini-environment is very clean space in which a physically isolated manufacturing tool operates; it may include a single tool or a cluster. In mini-environments, such as clean hoods or environmentally controlled enclosures around tools, tool adjustments or maintenance intrude into the controlled area, which can lead to a gradual degradation in cleanliness. A step beyond the mini-environment is the so-called microenvironment, which isolates the clean space with an inert gas, such as ultra-pure nitrogen, rather than air. A microenvironment encloses only the area necessary for successful processing of the product; most of the tool remains outside the microenvironment for ease of maintenance operations

Mini-environments air curtain enclosures

The air curtain, in addition to providing a mini-environment barrier, produces an important side benefit. The low-pressure area created by the air curtain starts a slight horizontal component to the vertical air flow in the mini-environment. The effect of this horizontal component is to create a sweeping action whenever the vertical air contacts a horizontal or irregular surface within the mini-environment. This horizontal flow serves to evacuate particles.

Mini-environment Performance

Airflow Uniformity:	± 10% @ 72FPM
Cleanliness:	≤ 0.1 particels/ft @ ≥0.1µm
Mini-environment Pressure	≥ 0.005" H_2O w/ respect to ambient
Recovery time:	Less than 1 minute

Mini-environment results/case studies

Mini-environments cost significantly less to construct than full-scale cleanroom facilities.

In 1970, the initial cost of building and equipping a high-volume, state-of-the-art production cleanroom was $30 million. By 1990, this cost had increased tenfold to $300 million. The use of the mini-environment can offer savings in reduced initial construction costs for environmental conditioning systems, commensurate reduced annual operating costs, a highly flexible equipment layout, and reduced costs for personnel and operator gowning procedures. [McIlvaine, 1992]

The volume of clean air required to maintain acceptable contamination levels in the cleanroom is dramatically reduced. According to Cleanrooms - 1992-2000, Rooms and Components Vol. Three (1992) to maintain

... A conventional cleanroom of 40,000 square feet uniformly clean to Class 1 standards requires the recirculation, conditioning, and filtration of over four million cubic feet of clean air per minute. Operating the required air handling equipment consumes approximately ten million kWh per year of electricity. This can cost as much as $1 million per year at an assumed cost of $0.10/kWh. A [small] fraction of the ... clean air volume is required in an equivalent mini-environment cleanroom because, while the local environment around the product and the processing equipment is kept ultra-clean, the rest of the room is kept at a much lower level of cleanliness. [The McIlvaine Co., Illinois, Correspondence, October 1995]

Different cleanroom design concepts and their energy consumption have been compared by Lynn (1991). All four of the concepts studied are currently being used in industry to obtain Class 1 Performance.

1. Clean Bay Return Chase (This concept is a common configuration in Class 10 or better cleanrooms.),
2. Clean Bay/Supply Air to Chase,
3. Ballroom, and
4. Mini-environments.

To compare these concepts on equal terms, the process equipment load and building exhaust flow were held constant; the only variation among the four concepts came from varying air-flow rates for the cleanroom recirculation systems.

Total energy consumption varied by site location, but energy consumption for the mini-environment was the lowest for both locations modeled: New England and San Jose, CA. While the percent differentials among concepts varied by location, the mini-environment concept ranked the lowest in each location.

The San Jose location yielded a variation of 29% between the annual maximum and minimum total energy consumption. [Lynn, 1991]

Fan energy consumes a greater percentage of the total energy in San Jose than in New England, resulting in a wider variation in energy use between these two geographic locations. Colder climates require more heating energy; therefore, the total energy impact of fan energy savings is reduced. Cost savings for reducing fan energy can be significant in milder climates. Minimizing total cleanroom air flow directly affects the operating costs of a facility.

In another case study, a 50,000 sq. ft. cleanroom was designed to produce 30,000 wafers per month. According to O'Reilly and Rhine (1995), "the design used Class 1000 open ballroom, with mini-environments to provide Class 0.1 where wafers were exposed."

In this case study, savings were found in both construction and operating costs. The final design reduced the number of air handling units by 52 percent, reduced the number of ULPA filters required by 54 percent, and reduced the clean air volume flow-rate by 49 percent. "Savings for operating costs were calculated at $2 per wafer." according to O'Reilly and Rhine (1995) and an additional benefit that was not foreseen "was the increase in ramp-up of the process, which gave them a 4 month advance on getting product to the market."

In another case study noted by O'Reilly and Rhine (1995), "the requirement was for a Class 100 cleanroom for development of optical devices." However, because of a limited budget, "[a] general Class 10,000 cleanroom [was designed instead] with mini-environments. The air handling volume was reduced by 75% with a better than Class 10 level for the equipment was maintained."

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