Designing a Cleanroom to Accommodate Roll-to-Roll Processing Equipment

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MANUSCRIPT

1 INTRODUCTION

Cleanroom design continues to advance as technology changes. Product requirements drive the need for cleaner air, gases, liquids, and power. Concurrently, the use of roll-to-roll equipment is becoming more attractive. However, roll-to-roll equipment presents another set of challenges due to special size and material handling needs. This presentation will discuss how to design a Cleanroom that will operate with both sophisticated products and roll-to-roll equipment.

2 KEY TERMS

2.1 Key Definitions

We will start by defining a couple of key terms that will be used throughout this presentation. These key terms are:

Geometries

- Minimum dimension that needs to be produced to create a given technology. Typically, this is listed in microns. A human hair is about 100 microns in diameter. A red blood cell is about 5 microns across.

Cleanliness

- How clean the environment needs to be to produce the product. This is often listed as Cleanroom Class.

Form Factor

- Size of the substrate or starting material used in manufacturing. This is defined in millimeters or inches.

2.2 What is small?

Why do we need a cleanroom in the first place? Current electronics products are based on very small geometries. A typical silicon wafer is 8 inch or 200 mm in diameter. One wafer can contain several hundred microprocessor die. Each die is about 1 cm by 1 cm. Features on this die are often less than 0.1 microns.

2.3 Killer Size Defect

When you are working in such small geometries, very small defects can kill your yield. A particle that was not a killer defect due to its size in earlier generations of product can now totally destroy your yield.

Figure 1: What is a 'killer defect'?

2.4 Defects and Yield

Defects have a direct impact on yield loss. More defects cause more yield loss. More yield loss leads to higher costs. The goal is to minimize yield loss caused by defects that are large enough to impact yield.

2.5 Cleanroom Classification

Cleanrooms are typically classified based on particle counts. Particle counts are lowered by adding filter coverage and increasing air changes. The cleaner the room, the more filter coverage and the more air changes per period. Moving more air requires more energy. This raises your operational costs. Cleaner rooms are also more expensive to construct. Table 1 shows typical cleanroom costs and cleanliness levels.

$/Sq Ft	Class	0.5 micron particles per cu ft (Fed 209D)
$2,250	1	1
$1,800	10	10
$1,425	100	100
$900	1,000	1,000
$700	10,000	10,000
$75	Support (Facilities)	N/A

Table 1: Typical cleanroom costs and cleanliness levels

2.6 Wafer Form Factor

In the 1960's, wafers were typically 1.5 to 2 inches in diameter. By 1980, the industry was using 3 and 4 inch wafers. By 2000, new wafer fabs were using 8 inch wafers.

2.7 Flat Panel Form Factor

The first flat panel areas appeared in the late 1980s and used Gen 1 glass (typically 330 x 400 mm). By 2000, panels had grown to 730 x 920 mm (Gen 4). Since then, the growth has been very rapid. Current factories are now Gen 8. These panels are 2200 x 2500 mm. This is over 7 by 8 feet in size.

2.8 Panel Form Factor Driver – Revenue

Why the growth in panel size? The answer is tied to revenue. A Gen 7 (1870 x 2200 mm) panel can produce eight 40" Diagonal LCD TVs or six 46" Diagonal LCD TVs. A Gen 8 (2200 x 2500 mm) can produce eight 46" Diagonal LCD TVs.

2.9 FPD Future: Flexible Displays

Flat panels are currently very strong in TV and monitor markets. However, their future may have a new area of application as flexibility becomes more common. Flexible panels can be used in items such as:

- Clothing and Wearable Displays
- Foldable Displays
- E Book
- Electronic paper

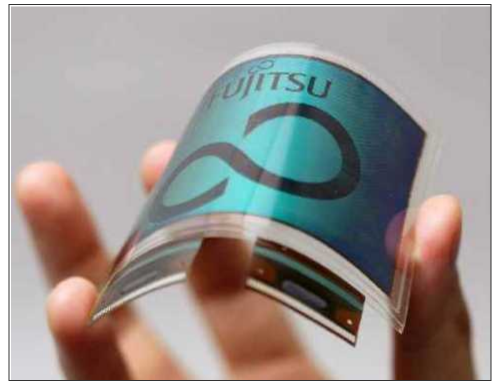

Figure 2: Courtesy of Fujitsu

Figure 3: Courtesy of Seiko and E Ink

Figure 4: Courtesy of Philips

2.10 Flexible Display Evolution

Production of flexible displays will start with small form factor. After there is growth into a larger form factor the need to automate and/mass produce will develop. This will drive the industry to use Roll-to-Roll Manufacturing.

3 DESIGNING THE CLEANROOM

The design of the cleanroom can be divided into:

1. Tools or equipment
2. Utilities
3. Building Cross Section
4. Cleanroom Concepts
5. Air Management
6. Chemicals
7. Other Design Considerations

3.1 Tool Needs

To determine total equipment needs you must determine quantity of each type or model. This is typically done via some type of capacity model. The utility needs for each tool type has to be researched. This data is combined with cleanliness level and footprint to determine the proper layout. As part of the layout you must also consider how to allow a proper move-in path.

3.2 Tool Layout – Correct Technique

There are several specific items to remember when you are doing tool layout. The tool should:

- Have plenty of maintenance space
- Allow accessibility to rear of tool
- Leave plenty of room for utility connections
- Allow space for material handling
-

3.3 Tool Layout Options - Bulkheading

Bulkheading is a good way to lower costs. The machine to product interface is on the clean side, with the tool bulkheaded into the chase. Often, the largest part of the tool sits in the chase (less expensive) environment. Maintenance can then be done in lower cost areas (the chase).

3.4 Tool Spacing for Material Movement

Typical wafer tools have an area space factor of **1.3**. A typical tool has a footprint of 100 square feet. This means the tool and the area necessary to access it require 130 square feet. These tools can be placed very close together and the aisle between them can be 6 feet or less wide. This allows more than adequate room for operator and product movement.
Continuous web processing equipment has an area space factor of **1.75**. This equipment is much larger. A typical tool is 784 square feet. The access area required around the tool is also much larger. The maneuvering of the lift carts causes aisles to be 15 feet wide and 11 feet of space between tools. This means the tool and the area necessary to access it require 1,372 square feet. This space requirement can be reduced with future improvements in the lift carts.

3.5 Utilities – Planning and Analysis

Many individual spreadsheets and/or "home-grown" software applications exist throughout the industry. Each application has its own assumptions, analysis methodology, cost and process data, and "frame of reference." Separate databases or spreadsheets used for different projects often contain contradictory information, resulting in confusion.
Information is not validated by observing process tools in use. Accuracy of vendor data is not verifiable by Architects/Engineers who sometimes do this type of planning. It requires process and operations expertise to get an accurate database and "by-project" analysis. Data is not easily diversified for varying utility usage in phased projects. A detailed utility matrix is required to solve these problems.

3.6 Utility Matrix

The items typically required for a project include:

- Database system which quantifies, totals, and summarizes the utility requirements for the user's equipment.
- Various utility parameters that are tabulated and quantified include:
  - Liquids
  - Exhausts
  - Electrical
  - Process and house gases
  - Process supplies (other chemicals)

This data is combined to give you:

- Total fab requirements (by area or bay and by fab)
  - Process gases, liquids, and supplies
  - Electrical requirements
  - Exhaust capacity
  - Drain needs
- Heat load to the room
  - Needed for accurate HVAC sizing
  - Accounts for exhaust and process cooling water reductions in load.

3.7 Facility Research

It often becomes necessary to verify what already exists in a facility. Items which need to be verified include:

- Capacity of Systems (all upstream components) – per base build specifications
- Location – verified per base build specifications

- Termination
- Expandability
- Flexibility
- Accessibility / Mounting etc.
- Purity Verified - per base build specifications
- Quality Verified - per base build specifications

3.8 Building Cross Section

Determining the building cross section is a critical step. One option is the single floor or slab on grade. It is the least expensive. The second option is raised floor and/or subfab. This is much more expensive. It may require additional vibration isolation for sensitive equipment and process.

3.9 Slab on Grade (Low Sidewall) Return

- Least expensive option because it doesn't require a raised floor
- Least flexible because space must be left in the wall for air flow
- Higher pressure drop across smaller wall openings requires more fan energy

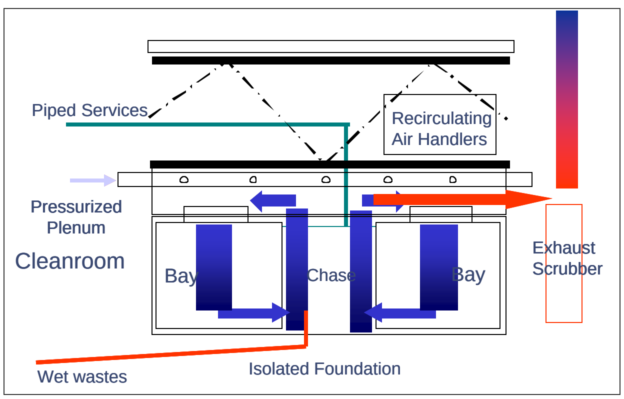

Figure 5: Slab on Grade

3.10 Raised Floor Return

- Require a raised access floor with tool pedestals for vibration sensitive tools
- Very flexible because air passes below the tools, better laminarity of air flow
- Lower pressure drop across all floor area, better vertical laminar flow
- Space below floor can be used for drains and to distribute power and some gases

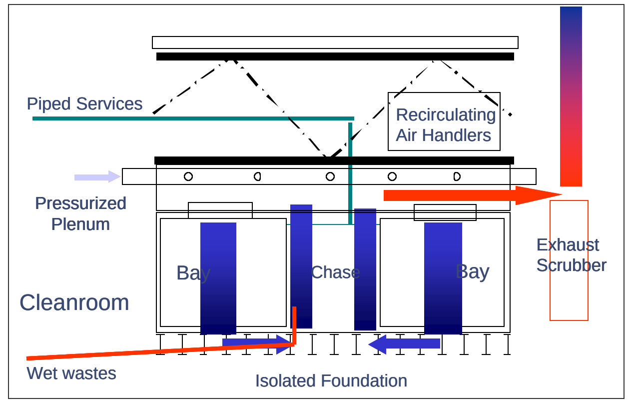

Figure 6: Raised Floor

3.11 Subfab Return

- Air passes through the cleanroom and down into the subfab
- Space in subfab can be used for support equipment such as pumps and gas cabinets
- Highest cost but conserves cleanroom space

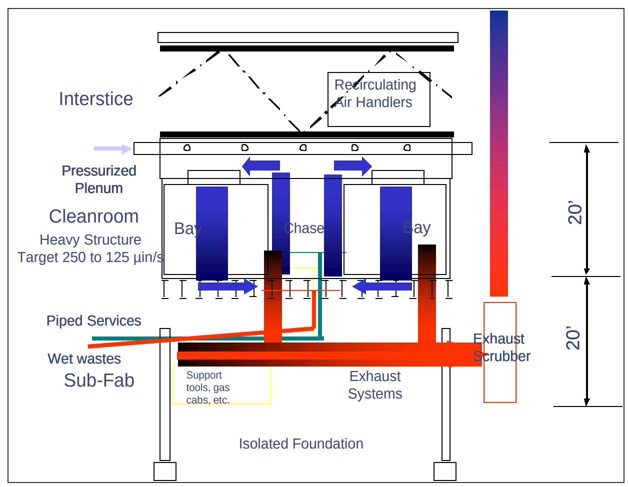

Figure 7: Subfab

3.12 Bay / Chase Cleanroom Concept

The bay/chase layout is the most common cleanroom layout. It provides for maximum flexibility with least area under filter. It allows for services and maintenance for the "back" side, or the chase. It enables you to bulkhead tools in the chase so that only the machine to product interface is in the clean zone.

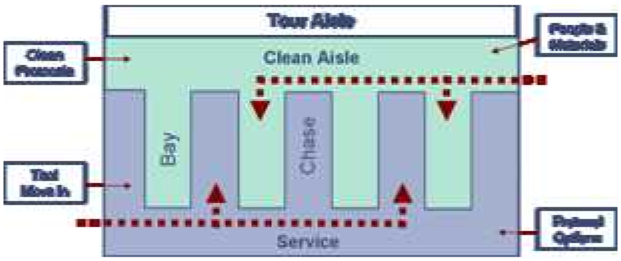

Figure 8: Bay/chase

3.13 Ballroom Cleanroom Concept

The ballroom layout is used primarily for Class 1,000 or 10,000. Ballroom layouts can be used with mini-environments for some processes. The problem is people, product, and equipment share the clean zone. This layout can be very flexible for tools requiring few utilities such as CDA, N2 and power.

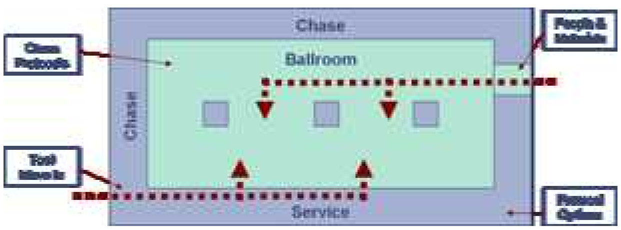

Figure 9: Ballroom

3.14 Air Management Strategies

There are three main air management strategies. They are ducted, fan filter, and pressurized plenum.

- Ducted System
  - Flexible locations for filters
  - Air handling equipment is located outside the clean zone
  - Usually lowest operating cost of system options
  - Requires most interstitial height, increases building height
- Fan Filter Units
  - Flexible locations for filters, not related to wall locations
  - Can have lower first cost
  - Fan and filter maintenance is done inside the cleanroom
  - Can fit in reduced access ceiling space
  - Can be individually controlled and monitored
    - If one unit malfunctions, the clean space can still operate
    - Each unit can be replaced individually
  - Difficulty identifying fans or filters that are out of services
  - Fan noise is a significant problem
  - Temperature control with varying heat loads can be a problem
  - No local humidity control
- Pressurized Plenum
  - Flexible locations for filters
  - Equipment maintenance is outside the cleanroom
  - Fairly low operating cost, comparable to ducted filter option
  - Provides local sensible cooling to return air
  - Less height required than ducted supply
  - Can combine ducted and open return for more local air separation
  - Walls are limited to locations of plenum boxes, (can supplement with FFUs)
  - Must measure exact size for fit – field modifications costly.

3.15 Chemicals

Chemicals are usually provided either at the point-of-use supply or through a chemical distribution system. The point-of-use system is the most flexible and lowest cost.

Figure 10: Point-of-use chemicals

The chemical distribution system is more complex, more costly, and less flexible. However, it is very good for moving large volumes of chemicals.

Figure 11: Chemical distribution system

3.16 Other Design Considerations: Piping

Cleanliness of Pipe

- Pipe is the carrier of process gases and fluids
  - 316 electropolished stainless steel, 304 Stainless, or Type L copper for gases.
  - PVDF (teflon) or polypropylene or PVC for DI water/chemicals
- Filtration and purification, sterilization – all add cost
- How clean is the plumbing of your process equipment?
  - Wet hoods
  - Wet processors
  - Gas manifolds
  - These are nearest to "point-of-use"

3.17 Other Design Considerations: Environment

In addition to particle counts, other Room Conditions are also critical. These include ESD (electrostatic discharge) temperature and humidity control. Cleanliness at the substrate surface is critical during processing but may not depend only on room abatement. Items such as clean process tools/equipment and minienvironments (localized fan powered HEPAs, with or without temperature/RH control) can change requirements.

3.18 Other Design Considerations: Facility Conditions

- Building
  - Site plan, available square footage
  - Available Square Footage for each intended use
  - Area available for support, air handling and utilities
  - Available height for cleanroom envelope
- Vibration Issues
  - Sources such as HVAC equipment, traffic, trains
  - Areas with critical vibration requirements – metrology, lithography, SEM
  - Techniques for abatement
- Electromagnetic Interference and ESD
  - Sources such as overhead or underground power lines, transformers, light rail systems, bus and truck traffic, heavy doors
  - Tools and areas with critical EMI requirements- SEM
  - Electrostatic discharge- can attract particles
  - Abatement techniques
- "House" Utilities: Clean Dry Air, Nitrogen, DI water
  - Quality of these also determines process environment
  - Particle count/size
  - Contaminates
  - Dew point of Air

3.19 Other Design Considerations: People Issues

Several people issues must be considering for proper layout. These include:

- Number of people working in each area
- Gowning
- Viewing
- Communication
- Supervision
- Maintenance Access
- Security
- Lighting

3.20 Other Design Considerations: Material Handling, Storage of Supplies, Equipment Needs

Items such as material handling and the storage of supplies can change your layout.

- Product – within the tool, intrabay, interbay, stockers, MGV, AGV, monorail options
- WIP philosophy-experiment storage
- Standard Mechanical interfaces (SMIF)
- Production Supplies
- Maintenance supplies/parts
- Garments and gowning protocol

- Record keeping methods
  - Notebooks and Pens, Computers
  - Documentation- electronic or paper formats
  - WIP tracking system – location of terminals
- Tools and toolboxes
- Equipment Staging
- Wipe down areas, pump rebuild areas

4 CONCLUSIONS

Designing a cleanroom to accommodate roll-to-roll equipment can appear to be an overwhelming task. However, if you break it down step-by-step, you can make it manageable.

4.1 Major Steps

There are several major steps for designing a cleanroom. These include determining:

- The product you will make
- The geometries required
- The form factor you will use
- The cleanliness levels needed
- The tool set to support your demand
- The utilities needs (utility matrix)
- The building cross section
- Air management strategy
- Clean Class

4.2 The Living Utility Matrix

It is important to keep the utility matrix a living document. The utility matrix you've created must continue to be updated throughout the life of your factory. The benefit of continuing to review and update your utility is future equipment and process engineers can use it to more accurately design utilities for future fabs. You can also evaluate opportunities for future cost savings based on actual utility usage.

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