ISSUES FOR CONSTRUCTION OF 300-mm FAB

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ABSTRACT: The cost of constructing and tooling a semiconductor facility, which is currently more than $1 billion, is expected to double by the year 2000, driving semiconductor chip manufacturers to adopt strategies to minimize cost to maximize the return on investment. What seems to be an inevitable transition to the larger, 300-mm wafer will have a widespread impact with massive economic implications. Preliminary tool designs and process approach standards suggest increased automation of material handling and storage systems, increases in utility consumption, tool height and weight requirements, and schedule compression. Moreover, the contamination sensitivity of the 300-mm wafer might require modification in the fab construction protocol, which in turn could affect labor productivity. Such changes will have a significant impact on construction methods, materials, and management techniques. This paper discusses the key areas in which research is necessary, focusing mainly on issues that have the maximum impact on design and construction of 300-mm fabs. While not providing solutions, this paper is intended to act as a catalyst for further research as 300-mm technology moves closer to becoming a reality.

INTRODUCTION

The cost of constructing and tooling a semiconductor facility has risen sharply from $14,000,000 in 1996 to the current staggering sum of more than $1 billion. This cost is increasing exponentially and is expected to double by the year 2000 (Lineback 1998). The large capital investment required to bring a new fab on-line is driving semiconductor chip manufacturers to adopt strategies to minimize cost to maximize the return on investment.

Historic trends show that a reduction in line widths and an increase in wafer size are the two main strategies adopted by semiconductor manufacturers to reduce cost by increasing the number of chips per wafer. From 100-mm wafers and 1.0-μm line widths in the 1970s, the semiconductor chip manufacturers have steadily increased the wafer size and reduced the line widths. Currently, a majority of the fabs operate 200-mm wafers with 0.25-μm line widths (Johnson 1998). Increasing the wafer size to 300 mm is expected to bring 0.13-μm line widths. However, increasing the chips per wafer requires increasingly complex process tools and a more controlled environment, driving up the overall cost of the fab. To date, the benefits realized from the technological transition have more than compensated for the increase in the cost of the fab. However, Moore's second law (Ross 1996) states that the growth in the cost of the factory will be the limiting factor in the development of future technology.

300-mm TRANSITION

As demand for semiconductor chips continues to increase, 200-mm fabs may no longer be able to meet the demand or to maintain profitability. While reducing the line widths can provide a short-term alternative, the transition to a larger wafer size is inevitable. In December 1994, delegates from every semiconductor producing region in the world met in Tokyo and agreed that 300 mm would be the next wafer standard (Lee 1997). Unlike previous wafer diameter increases, the 300-mm transition is likely to generate an entirely new set of design criteria for the factory.

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Because the transition to 300 mm has such a widespread impact, with large economic implications, no company can single-handedly lead the transition. Thus, industrywide consortia were formed to pursue this progression. Semiconductor Equipment and Materials International's (SEMI), International 300-mm Initiative (I300I) Conference, and Japan's 300-mm Semiconductor Technology Conference (J300) have cooperated to form a consortium to establish a set of factory guidelines defining end-user requirements. The consortium will represent the first opportunity in the industry's history for equipment manufacturers to accommodate U.S. and Japanese standards within a single tool (Lee 1997). This ''I300I/J300 joint guidance'' presents a roadmap and sets standards for semiconductor equipment and materials used in the 300-mm fab.

DESIGN AND CONSTRUCTION OF 300-mm FACILITIES

While I300I and J300 address the process and tool changes required for 300-mm fabs, no concerted effort exists to study the implications on design and construction. Preliminary tool designs and process approach standards presented by the consortium suggest increased automation of material handling and storage systems and increased utility consumption as well as increased tool height and weight requirements. These process and tool changes will have a significant impact on construction methods, materials, and management techniques. For instance, construction techniques will have to account for the increase in floor and ceiling loads and spans, possibly restricting the choice of structural material. Space and access issues related to routing the increased utility piping will also need to be addressed. Moreover, the contamination sensitivity of the 300-mm wafer might require modification in the fab construction protocol, which could then affect labor productivity. All of these issues need to be resolved before the 300-mm fab is to become a reality.

In addition to the obvious ramifications of change in technology, the 300-mm fab poses another major challenge (i.e., the challenge related to schedule compression). SEMATECH (the national consortium for semiconductor manufacturers and their suppliers) has set the goal of delivering a new fab, from design to first wafer out, in 12 months [Semiconductor Industry Association (SIA) 1997]. This means that the design and construction must be completed in 9 months, which is a major reduction in project delivery time when compared to the current 18-month schedule used for 200-mm fab construction. According to the *International Technology Roadmap for Semiconductors'* (ITRS) Table 56, Facilities Construction Requirements (SIA 1999), there are no known solutions for construc-

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tion times of <10 months. The cost of the 300-mm fab is expected to reach almost $2 billion, heightening the necessity for reducing project delivery time. This enables clients to maximize the return on their investment, because the value of a new semiconductor product is maximum in the first 6–12 months of its life (SIA 1997). The high cost, aggressive schedule, and design uncertainties together pose a major challenge for designers and constructors to successfully deliver the 300-mm fab.

It is evident that the issues related to 300-mm wafer fab transition are numerous. Consequently, careful thought and analysis must be performed to identify and examine the obstacles in the transition's path to success. The paper discusses the key areas in which research is necessary to enable the design and construction of 300-mm fabs. The discussion gives a broad overview of the issues, focusing mainly on issues that have the maximum impact on design and construction. While not providing solutions, this paper is intended to act as a catalyst for further research as 300-mm technology moves closer to becoming a reality.

TECHNOLOGY TRENDS IN SEMICONDUCTOR MANUFACTURING

According to Moore's law, the quantity of information storable on a computer chip doubles every 18 months while the cost of making those chips drops by 50%, which means that semiconductor customers receive a twofold improvement in product performance every 18 months for the same cost (Moore 1996). Thus over the past decade, inexpensive and more powerful technology has been provided by continuously condensing computer devices (Robertson and Allan 1998). The driving forces of expanding information storage and processing capabilities on a chip, while reducing the cost of manufacturing, are decreased feature size, increased microprocessor chip size, increased throughput, and a periodic increase in wafer sizes (Myersdorf 1997).

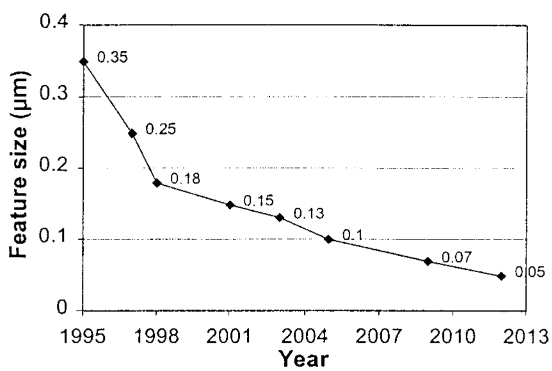

FIG. 1. Feature Size Trend (SIA 1999)

Decreased Feature Size

An integrated circuit (IC) consists of a microscopic map of transistors and other electronic components interconnected with electrical pathways that are etched into the wafer. One way to fit more components on an IC is to shrink the dimensions of its transistors and electrical paths in each of its features. In 1999 the SIA released the ITRS, which attempted to define the technical challenges for each device generation. Fig. 1 shows the current and expected feature size trend for the semiconductor industry. Each generation was defined by the year of first dynamic RAM shipment and minimum feature size (SIA 1999). Historically, a 12–14% feature size reduction has resulted in a 7–10% increase in equipment productivity (Deininger 1997). Consequently, decreasing feature size has been the predominant way in which IC manufacturers have improved information storage and processing capabilities while keeping costs under control.

Increased Wafer Size

As the semiconductor equipment and materials industry creates more complex tools that work more efficiently and on smaller feature sizes, the cost of the tools increases. For instance, the current cutting edge microlithography machine that can map out chips with a feature size of 0.25 μm costs about $10,000,000 (Myersdorf 1997). To recapture the high cost of establishing a manufacturing facility full of such expensive equipment, chip makers demand equipment that can work on more chips simultaneously, a process that requires larger wafers.

The transition in wafer size from 100 mm (4 in.) to 150

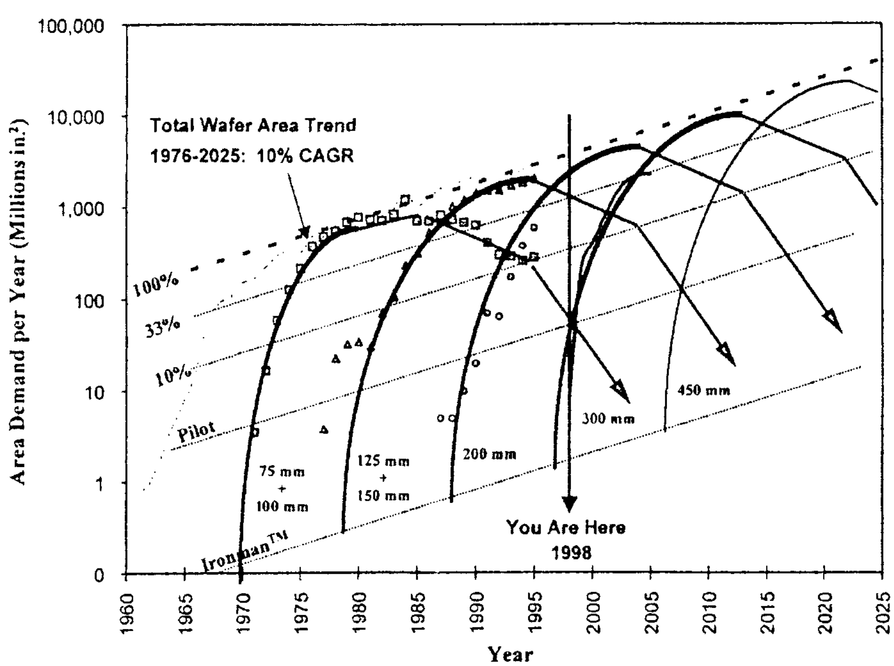

FIG. 2. Historical and Projected Wafer Size Trends (*I300I* 1998)

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mm (6 in.) took place in the mid-1970s, followed by the conversion from 150-mm (6-in.) wafers to 200-mm (8-in.) wafers in the late 1980s (SIA 1997). These transitions are shown graphically in Fig. 2. The transition from 200- to 300-mm (8- to 12-in.) silicon wafers is the next in this series and was expected to occur by 1999. Currently, 300-mm plants are being started, but these new facilities are being constructed around the 200-mm (8-in.) wafer, with the transition to 300 mm yet to take place. Many issues for the 300 mm have yet to be resolved as outlined in this paper (Chasey and Merchant 1999).

In December 1994, delegates from all semiconductor producing regions in the world met in Tokyo and agreed that 300 mm would be the next wafer standard (Deininger 1997). Owners, equipment suppliers, and wafer manufacturers are aligning their goals with the hope of making this new technology happen quickly and in the most cost-effective manner. The success of the 300-mm wafer transition is necessary to accommodate 59% more bits per year in accordance with Moore's law. The number of chips produced per wafer is directly proportional to the square of the wafer diameter; therefore, a larger wafer diameter translates to a greater output per wafer. This impacts the economies of scale and significantly lowers the manufacturing cost per chip.

Increased Throughput

The other major factor in reducing price while improving performance of the chip is the increase in overall throughput of the fab. To achieve this increase, IC manufacturers must process wafers faster and more efficiently. The economies of scale associated with increased throughput has resulted in the development of megafabs, which process 200-mm wafers weekly totally more than 5,000 (Deininger 1997). Such volume production in the past has helped bring down the cost of production considerably.

NEED FOR TRANSITION

Historic data shows that the industry has been growing at an average rate of 17%/year for the past three decades, and it is predicted that the industry will achieve and exceed this growth rate in the years to come (Yancey 2000). Microprocessor speeds are doubling every 18 months, even faster than Moore's 1975 prediction of 24 months (Ross 1996). Therefore, to keep up with the anticipated growth in the industries market, semiconductor owners are looking at 300-mm wafer technology to increase yield and to reduce the wafer cost per chip, to help maximize the return on their investment.

According to Ghatalia (1998), the three main factors that will drive the shift to 300-mm wafer diameter production are as follows:

- Reduction in cost
- Improved productivity through standardization, automation, and fab efficiency
- Long-term demand growth in IC

Reduction in Cost

The economic justification for 300-mm wafers is that the chip output increases disproportionately relative to the wafer area increase. The physical transition from a 200-mm wafer to a 300-mm wafer increases the wafer area by 2.25 times. This increased wafer area provides a larger raw surface area for processing, which means the potential exists for at least 2.25 times more chips per wafer versus the 200-mm wafer (Hubach and Spears 1997). The number of 20 $\times$ 20 mm chips produced from a 300-mm wafer is expected to almost triple those from 200-mm wafers. More chips per wafer could result in a 20–30% reduction in cost per square centimeter of wafer, which would translate to a 30–40% overall cost savings per chip (Hubach and Spears 1997).

Another factor that affects manufacturing cost is linked closely to the increase in levels of integration. The increase in circuit complexity requires more area on the device. As the chip size increases, the 200-mm wafer will soon become too small to achieve realistic economic yields (Hubach and Spears 1997). Logic and Application Specific Integrated Circuit (ASIC) makers fall in this category. Because logic/custom chips are becoming increasingly larger, it is more cost-effective to manufacture chips from larger wafers than smaller ones for the same unit cost. A SEMI survey shows that logic manufacturers might be the first to implement 300-mm wafers, a reversal of the common notion that dynamic RAM makers would be the first (Fuhs 1998). This is attributed to logic manufacturers having higher profit margins and, hence, being able to afford the move, allowing them to maintain, if not to increase, their profit margins.

Improved Productivity

The economics of the 300-mm transition is not merely about cost but, also, about productivity in general. In addition to the well-known increase in performance of devices through feature size scaling, productivity growth has come from periodic increases in wafer diameter and improved equipment productivity and product yields. The industry's transition to 300 mm embodies all of these elements (Robertson and Foster 1997). Standardization and automation are the two key areas that distinguish the productivity improvement potential of the 300-mm transition from previous transitions (Ghatalia 1998).

I300I and J300 have cooperated to establish a set of factory guidelines that define end-user requirements to the standard development process in SEMI (Ghatalia 1998). Development of such industrywide standards for a broad array of factory systems presents a unique opportunity to minimize the cost and improve the productivity of 300-mm factories. The capabilities required to support factories can now be designed into the equipment from the beginning, minimizing the costs of development and operations. Standardization of all the factory components will facilitate the maintenance of systems and will improve operational productivity.

According to the guidelines set by the I300I and J300 consortium, total factory automation becomes a necessary for 300-mm fabs. A move to total factory automaton is believed to enhance productivity largely due to improvement in tool utilization rates. It also reduces the tool downtime caused by unavailability of operators and improves yield due to a reduced chance of damage to wafers during transport (Johnson 1996).

Long-Term Demand Growth in IC

Despite the extraordinary cost investment arising from 300-mm wafer operations, demand for chips, in general, has been increasing due to the expanded use of chips in electronic and automotive products. The microelectronic chip content represents 15% of the retail price of a typical electronic system, twice as much as 10 years ago and 5 times as much as 20 years ago. In personal computers, IC content amounts to as much as 40–50% (Myersdorf 1997). The proliferation of chip content in various products enables semiconductor manufacturers to capture a greater portion of product value in the expanding markets. As a result, as long as demand exceeds supply, prices can be adjusted to make a profit. However, as competition increases, only large volume production can be economically justifiable.

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CHALLENGES FOR 300-mm TRANSITION

The semiconductor industry has grown from a $200,000,000 industry to a $144 billion business in a span of <50 years and is forecast to continue to grow at an annual rate of 17%. The transition to an increased wafer size and the reduction of line width have been the two main strategies adopted by semiconductor manufacturers to remain profitable and keep up with the increasing market demand. Given the current industry circumstances, transition to an increased wafer size (300 mm) is considered necessary to keep the industry on its historic growth curve.

The transition to 300-mm wafer production is not a matter of ''whether or not,'' but a question of ''how'' and ''when.'' As a result, a detailed analysis needs to be done to study the implications of the transition on all of the different aspects of designing, constructing, equipping, and maintaining the fab.

The transition to 300-mm technology is in some ways similar to, yet in many critical ways different from, the technological leaps that are characteristic of the semiconductor industry. Although it may be tempting to regard the conversion to 300-mm manufacturing as the latest move in a perpetual string of technological upgrades, it is different from all previous wafer transitions. This move cannot be achieved by simply changing a few tools and moving a few walls, which was the case in earlier transitions (Behrens 1997).

The semiconductor industry has changed dramatically since the relatively smooth transition to 150-mm production; however, a growing awareness exists that the transition to 300-mm will not be a business-as-usual conversion. Although previous technology changes have all resulted in an increase in the size and complexity of fabs and their operations, the advance to 300 mm threatens to wield a disproportionate impact on the industry. The following issues differentiate the 300-mm conversion from the challenges of past upgrades.

Capital Intensive

The semiconductor industry as a whole is very capital intensive. Unlike previous transitions, supporting the transition to 300 mm is beyond the scope of an individual company (Lee 1997). According to *Dataquest*'s estimates, developing an infrastructure to support the commercialization of these larger diameter wafers is expected to cost the industry nearly $30 billion (Myers 1995). A new 300-mm fab is expected to cost anywhere from $1.7 to $2.1 billion (Lee 1997). With such a major capital investment, reduction of risk is of major importance to semiconductor manufacturers. Consortiums such as I300I and J300 have been formed to help reduce the overall impact on individual companies.

High Automation Level

Previously, the use of an automated material handling system (AMHS) was not essential for manufacturing success. Although such a system had limited use earlier, in the 300-mm era the use of AMHS becomes a necessity, largely as a result of the ergonomic complexity of handling 300-mm wafers and carriers. The 300-mm fab AMHS needs to be designed to transport the product from tool to tool, requiring the standardization of carriers, load ports, communication protocols, and equipment protocol. In brief, total fab automation will demand an entirely new concept for fab design and operation (Myersdorf and Tazhizadeh 1998).

High Product Quality

Because the value of processed 300-mm wafers is expected to be 10 times greater than that of the 200-mm wafers (Myersdorf 1997), new fabs are expected to manufacture high-quality products and must operate at even higher line and chip yield. The risk of contamination, scratches, misprocessing, scrap, and rework must be minimized. This is expected to be accomplished through advanced computer integrated manufacturing, AMHS, standard mechanical interfaces, and minienvironments (Myersdorf and Tazhizadeh 1998).

High Production Volume

Future fabs need to have a high throughput to make investments cost-effective; therefore, 300-mm fabs are expected to have a higher production volume than current 200-mm fabs. The product mix of these lines may also consist of several devices with different process flows. To reduce and prevent equipment waste and improve throughput productivity, a throughput evaluation as well as periodic review and update of overall equipment efficiency is essential.

Accelerated Time to Market/Short Cycle Time

In order to stay competitive, new fabs should minimize the facility ramp-up time. The current 200-mm fab ramp-up times are in the 18-month range. In contrast, the desired total time from breaking ground to first wafer out for 300-mm fabs is 12 months (Myersdorf 1997). The ITRS indicates that meeting the customer's on-time delivery through reduced time to ramp-up facilities is continuing to be a difficult challenge for the construction industry (SIA 1999). The manufacturing cycle time should also be minimized. This is achievable through effective AMHS, better scheduling and dispatching software, elimination of non-value-added activities, and better bottleneck and work-in-progress (WIP) management techniques. Because of high production volume, WIP management systems become critical to fab cycle time. Excess WIP in the fab will increase the cycle time as well as the production cost of the products, jeopardizing the time-to-market advantage of the company (Myersdorf and Tazhizadeh 1998).

High Flexibility

With demand change becoming a reality in the semiconductor manufacturing industry, 300-mm fabs must be able to react quickly to changing markets and be able to manufacture new products. The learning and time-to-market periods should be as short as possible. This requires layout and automation flexibility. The layout should facilitate tool move-in, future expansions, and tool reconfigurations. Automation (especially AMHS) should support layout flexibility through extra transport capacity and ease of track rerouting and modification as well as interface standardization. Completely new approaches may be need to facility design and construction (Jansen 2000).

IMPACT OF TECHNOLOGY CHANGES ON CONSTRUCTION

A majority of the technological changes are interrelated to each other and are primarily a consequence of the increased wafer diameter. For instance, the AMHS has become a necessity because of the increased size and weight of the 300-mm wafer. The tool design is thus impacted as space for the front open unified pod interface needs to be provided within the tool footprint. The use of the front open unified pod goes hand in hand with minienvironments, thus impacting the cleanliness requirements of the cleanroom. Utility consumption also increases because of the larger wafer size. In addition to these changes, the reduced construction schedule of 9 months, as forecast in the SIA's ITRS, severely impacts the construction of 300-mm wafer fabs (SIA 1999).

Although the technological changes likely to accompany the 300-mm transition are numerous, five areas have been iden-

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tified as having a significant influence on the design and construction of 300-mm facilities:

- Increased automation of the material handling system
- Changes in process tool designs
- Increase in utility consumption with corresponding pressure to conserve natural resources
- Change in cleanliness requirements
- Change in project delivery techniques associated with the compressed schedule

Of these five areas of change, the increased level of automation of the material handling system is considered to be the driving force instigating changes in technology as well as design and construction related areas. Automated material handling therefore needs to be given due consideration while researching ways to mitigate the impact of the 300-mm transition on design and construction issues (Colvin 1999).

The impact of the five technology changes from a construction standpoint can be classified into the categories of space, layout, structure, materials, and project scheduling. These changes are all interrelated. For example, the 300-mm process tools are likely to need more space to accommodate the larger wafer and the buffer for WIP material storage as well as the interfaces for the AMHS. This increased space could result in an increase in tool height or footprint. Support space required for the tool could also increase, which would demand more subfab space. The overall changes in space requirement would influence the fab layout, requiring multilevel or modular fab approaches. The layout of the fab and tool changes would directly impact the building structure that would have to be designed to accommodate the revised tool and layout specifications. The change in structure may require new materials or methods of construction. Together, all of these changes would influence the construction schedule, which would need to be managed very carefully for the fab to be ready for wafer-starts in a 12-month time frame.

The AMHS, tool, utility, and cleanliness issues are related to changes in 300-mm wafer process requirements, whereas the project time issue is a result of the reduced construction time. Even the reduced project delivery time impacts most of the construction-related issues and is therefore considered along with the other technology changes accompanying the 300-mm transition. Specific research opportunities are available that arise due to the impact of technological changes on construction, space, layout, structure, material, and schedule.

Space

The cost of a semiconductor facility is a major investment for the semiconductor manufacturers, and these costs are increasing. Almost 30% of the total cost relates to the construction cost, which is directly proportional to the footprint of the cleanroom. Therefore, if construction costs are to be controlled, the fab footprint needs to be controlled.

The transition to 300-mm wafers makes controlling the fab footprint very difficult because the increased wafer size increases not only the tool size but also has signficant impact on the material handling and storage as well as process utility requirements. For instance, if the height of the stocker unit is maintained at the current height, the 300-mm stocker units would require 2.2 times as much floor space as the 200-mm wafer stockers to accommodate the same number of process wafers. To maximize the cost benefits of the 300-mm transition, fab owners are trying to maintain the 300-mm fab footprint as closely as possible to that of the 200-mm fab. This means that the footprint of the tool might remain constant; however, the height will increase to provide the additional space required for wafer processing. Similarly, the height of stocker units could also increase; they are expected to reach 5 m (16 ft).

To maintain the cleanroom footprint, the process equipment is likely to require additional subfab space for support equipment. Options of suspending stockers below the cleanroom are also being considered. Such alternatives would help minimize the cleanroom footprint, but would intensify the space issues in the subfab. The subfab would now have to address the issues of increased support equipment, suspended stocker units, and increased process piping.

The space issue represents research opportunities for identifying solutions for optimizing the use of fab and subfab space. If stockers are to be suspended in the subfab, then cleanliness requirements of the subfab will also need to be redefined. Could this result in a structure that has two levels of cleanroom space? How would this impact the airflow and the design and construction of the structure? Would using a mezzanine, as opposed to a two-level subfab, solve the space issue more efficiently? Is it possible to make more use of the space above the fab level? Could there be an issue in installing and integrating the life safety systems within a cleanroom that has a web of tracks running on the ceiling?

How will the increased utilities in the subfab affect the installation of piping? Would maintaining the tool footprint, while increasing process utilities connected to the tool, cause installation problems? What is the ratio of the cubic foot cost of the fab to the square foot cost?

Layout

The fab layout has a direct impact on the cost-effectiveness of the fab and can influence the fab's productivity and enhance its space management capability. The layout defines the location of the tools and supporting utilities for optimum product flow and thus has direct impact on the facilities' time and cost of construction. Facility layout optimization is therefore one of the key areas for construction research.

The 300-mm wafer fab transition presents enormous opportunities and challenges for designing the fab layout. The increased level of integration among the material handling system and the process tools allows enormous flexibility of tool layout. Tools would no longer need to be grouped according to their process requirements. ''Virtual bays'' could allow tools to be placed anywhere in a cleanroom and yet be treated as if they were in one process bay. Although this integration opens up tremendous opportunities for tool layout design, it also presents a challenge. The facility building, tools, AMHS, and utilities start to become synergistic with one another. The layout needs to accommodate the requirements of each of these systems from the very start of the project, to ensure perfect integration between the different systems. The extremely close integration between all the factory systems means that an installation or construction difficulty in any one of these systems could impact the schedule of the project as a whole. It also means that unless methods are developed to reduce the interdependence of these systems (in particular the AMHS) with the building structure, system choices will have to be made significantly in advance of the start of the fab construction.

Because the cost of constructing new fabs is increasing at such a rapid pace, research in this area needs to address issues related to the flexibility and extendability of fab life. Could modularization and standardization provide a solution to flexibility and extendability? At what level (fab, tool, process, etc.) should modularization be implemented to provide the optimal cost and scheduled advantage? Would standardization help reduce construction schedule? What factory components, if standardized, would provide maximum benefit? Could standardi-

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zation ensure complete compatibility of the facility building with the different infrastructure systems?

In addition to these issues, the constructability of the 300-mm fab could also be an issue that needs to be investigated. For instance, if a fab layout can give excellent productivity in terms of wafer throughput, but is impossible to construct and maintain, it cannot be implemented.

Structure

The structural issues continue to take the forefront of the issues that need to be resolved to achieve a smooth transition to 300-mm facilities. The building structure forms the framework for the new facility, and, if it cannot meet the needs of the technology, then facility construction might prove to be the limiting factor for transitioning to 300-mm wafer fabs. Structural issues need to be identified and new approaches developed to address these issues before they become critical. The issues specific to the 300-mm fab structure can be attributed to the following four likely changes in fab specifications:

- Increased loading requirements
- Increased vibration specifications
- Reduced structural tolerance specifications
- Increased height of the structure

Preliminary tool and AMHS specifications suggest that the 300-mm structure will need to be designed for increased floor and ceiling loads. Floor loads of up to 16,750 Pa (350 psf) could become the norm for 300-mm facilities. This is a significant increase over the existing 12,000 Pa (250-psf) specification of 200-mm fabs. Present structural systems will therefore need to be reexamined to check their applicability to 300-mm fabs.

The vibration sensitivity of 300-mm process tools is likely to be reduced, which in turn will demand stiffer structures. This more demanding specification is more a result of migration to 0.18-μm and below technologies, rather than to the increased wafer size. In any case, the vibration performance of fabs will need to improve to meet future processing needs. Improving the vibration performance of the structure would be extremely difficult if not impossible, because most 200-mm fab structural systems are already designed to their maximum stiffness (C. Gordon, personal communication, October 30, 1998). Therefore, to construct structures stiffer than existing ones, a paradigm shift will be necessary. Tool bases will need to be properly designed to ensure proper stiffness. New materials, pedestal designs, and methods of construction need to be explored (Leung and Papadas 1999).

Another complexity in the 300-mm fab structure is that the ceiling height for cleanrooms is likely to reach 6 m (20 ft), making the structure very unstable. This increased verticality of the structure could make it impossible to retrofit existing 200-mm fabs for 300-mm processes. It could also present a challenge in designing new 300-mm facilities to meet the required stiffness criteria (C. Gordon, personal communication, October 30, 1998).

The installation and operation of the AMHS could also present a challenge to constructing the 300-mm fab. The AMHS reduces the tolerance specifications of the structure. Thus, designing and constructing structures to meet these reduced tolerances need further research.

How will the structure be designed to meet the stringent vibration and tolerance specifications of the 300-mm fabs? What new materials or methods of construction need to be developed to address this concern? How would it impact the distribution of utilities in the subfab? What existing construction techniques can meet both the loading and stiffness requirements of 300-mm structure?

Materials

As seen from the above discussions, the 300-mm wafer transition impacts the factory design and construction in multiple ways. Of all the technology changes, the change in fab cleanliness requirements is likely to have maximum direct impact on materials and their selection. Ionic contamination is more important as line widths decrease. Changes in other areas can also have significant indirect impact on material selection. For instance, the change in process tools results in increased floor loads, impacting the building structure. If some of the existing structural materials cannot handle these increased loads, then the choice of materials would be limited or might result in a need to research new construction materials. Similarly, a change in cleanliness requirements of high purity gases could require new materials for process piping to obtain the lower parts per billion purity levels (D. Jones, personal communication, October 29, 1998). Materials research needs to be done in three main areas: (1) The identification of existing construction materials that will not be able to meet the 300-mm technology needs; (2) the identification of new materials (e.g., titanium or steel) that can replace the existing ones to meet these needs; and (3) how these new materials will impact the fabs' cost and schedule.

Schedule

The growth in factory cost is creating a similar increase in investment risk for fab owners. The facility cost of the 300-mm fab is expected to be around $2 billion. This is a large capital investment. Thus, owners are looking at ways to minimize this risk of investment. Accelerating the fab construction and start-up time is one of the widely used methods to reduce the time for investment recovery. According to the SIA technology roadmap (SIA 1999), the desired total time available for facility construction in the year 2005 is 10 months. Achieving this tight schedule will require extensive research to identify different construction approaches to reduce construction time and to improve project delivery. Methods such as incremental or modular factory construction need to be researched further to reduce long start-up times and to more evenly spread the massive capital investments. Implementing smaller, more modular, ''just enough, just-in-time'' increments of capacity that would allow factories to better match revenue generation and improve return on investment, while reducing risk, also need to be studied. Possibilities of reducing the tool, utility, and AMHS installation time by using standardization also need to be researched. The application of modeling and simulation tools that can help determine construction difficulties and possible bottleneck situations in the early project planning stages needs to be researched further. Because of the restrictive construction schedule, sequencing and coordination of the different construction activities will also become a big issue. Constructors will need to develop new ideas and methods to be able to design and construct a fab that ramps up quickly and works efficiently in an uncertain and changing environment (Jansen 2000).

RESEARCH NEEDS

Due to the speed of product development required to meet market windows, facility construction time will be compressed. The issues for constructors of the new 300-mm fabrication facilities will need to be researched, and solutions developed through consortia of industry and academia. The knowledge exists within the construction industry, but the time for research does not. If industry/university cooperative research centers are used, results can be provided to those who can see the advantage of this unique partnership. Table 1 outlines the research needs developed in this paper.

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TABLE 1. Research Needs for 300-mm Fab

Item (1)	Research needs (2)
Space	Impact of airflow • Increased utility versus subfab space • Increase due to added infrastructure for utility conservation • Minienvironments versus ballroom versus bay and chase • Impact of AMHS
Layout	Modularization needs • Impact of modularization on construction schedule • Impact of AMHS on facility layout
Structure	Impact of AMHS on structure • Stiffness requirements • Vibration requirements • New materials to meet ionic contamination requirements
Materials	Impact of increased purity level • Existing materials that do not meet 300-mm technology needs due to outgassing • Impact of new materials on cost and schedule
Schedule	Impact of AMHS on cleanroom schedule • Modularization technique to improve schedule • Identify different construction approaches

CONCLUSIONS

This paper developed a relationship of 300-mm technology changes to facility design and construction changes. Five technology areas—AMHS, tool, utility, cleanliness, and project time—were identified to have the maximum influence on space, layout, structure, materials, and project schedule. These areas of facility construction changes represent realistic research opportunities to resolve the uncertainties and challenges that surround the design and construction of 300-mm wafer fabrication facilities.

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