GLOBAL DELIVERY OF SEMICONDUCTOR FABRICATION FACILITIES

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Semiconductors are one of the fastest growing sectors of the world economy and promise to be a key industry in the future. Semiconductors are manufactured in complex facilities that are very costly to build. Semiconductor fabrication facilities are generally delivered under critical time, cost, and quality constraints. The costs of these projects currently run about $2 billion (US) for a 10,000 m^2 semiconductor facility. At current cost growth rates, the cost for a similar facility is expected to increase to $10 billion (US) by the year 2010. The industry has set cost goals for real cost increase per wafer cm^2 of 1% per year. The industry requirement for the total time to first wafer start for a project in 1997 was 23 months, and is expected to be 13 months by the year 2006. For these expectations to be met, the construction industry must develop better methods of delivering these facilities faster and more efficiently.

This paper documents a research program and current work in progress to help clients better deliver these advanced technology facilities globally. First semiconductor fabrication facilities are introduced and described. Next the challenges in delivering these facilities are described from a manufacturing perspective and then from a design, vendor and construction perspective. The industry, as it is currently structured, is poorly equipped to solve this problem. A justification for a novel industry-university research collaboration approach is discussed. Finally a proposed research program is presented.

A better method of constructing these projects can be created by re-evaluating the process flows, removing non-value adding activities and improving other activities. These best practices and ideal process flows can be used to deliver these advanced technology projects with high levels of quality, and within the time and cost requirements of the client and industry.

1.0 Introduction and objective

The objective of this paper is to define a set of research issues related to delivering microelectronics fabrication facilities and to propose research that could solve these issues. This paper will introduce semiconductor fabrication facilities and describe challenges in delivering these facilities. The balance of the paper justifies and describes the proposed research program.

2.0 Semiconductor fabrication facilities

The advanced technology (semiconductors, biopharmaceutical) market is steadily growing worldwide. This industry plays a major role in developed countries such as Japan, Asia-Pacific, Europe, and the United States. In the United States alone, the semiconductor industry has grown 9% each year since 1987, compared to less than 4% in other major industries. While global sales in the semiconductor industry were projected to drop 1.8% in 1998, global sales are projected to increase 17-19% annually in the following 3 years.

More than 120 new fabrication facilities (usually referred to as cleanrooms) in various stages of construction have been started in the past year with a total cost exceeding $115 billion (US). Costs for the industry standard facility (200 mm) stand at $1 billion (US) with state-of-the-art 300 mm facilities likely to be more than double that cost [1]. Projected costs for a state-of-the-art fabrication facility by the year 2010 are expected to reach $10 billion (US)

2.1 Cleanroom processes

The start of any semiconductor facility begins with the definition of the owner's criteria for the space. This consists of the definition of the manufacturing process, the tool requirements, the level of contamination control (class), vibration control, and temperature and relative humidity control. These elements define the cleanroom specifications and allow design of the structural and mechanical systems to commence.

The manufacturing process and the needed process equipment (tools) must be defined before any facility can be envisioned. Tools may account for 75% of the facility cost. The tool matrix essentially defines the manufacturing tools to be used in the facility, and their complex support network of process chemicals, ultrapure water, exhaust and waste scrubbing/ purification. Because the tools are continually changing with technology and due to their long lead times, owners want to select tools as late in the project as possible.

2.2 Cleanroom facility systems

Currently fabrication facilities are constructed in three typical configurations, tunnel, ballroom and mini-environment [2]. Each configuration has positive and negative attributes. A ballroom configuration allows the maximum amount of flexibility in process arrangement. A tunnel arrangement reduces the large spans required in a ballroom, thus reducing the cost of the structural system. Mini-environments reduce the load on the HVAC system by providing small enclosures at a cleaner class e.g., Class 1, and 10, within a class 1,000 space. This eliminates a lot of contamination by operators and reduces the air flow requirements of the mechanical system. Use of the mini-environment configuration type is expected to increase, currently accounting for 10% of the fabrication facilities built since 1995. The structural system for a mini-environment is usually simpler than for the ballroom configuration.

The design of the structural system is a critical component at the beginning of the delivery of these facilities [3]. By minimizing the complexity of the structure, the amount of time spent on this design stage is reduced and construction of the facility can begin quickly. In addition, with more flexibility in the structural system there are more possible design solutions. With more solutions, an economic, and easy to fabricate and construct system can be selected.

3.0 Challenges in delivering microelectronics fabrication facilities

The issues affecting delivery of microelectronics fabrication facilities can be discussed under three subject areas.

3.1 Manufacturing driven requirements

The Factory Integration Technology Working Group, in the 1997 National Technology Roadmap for Semiconductors (NTRS) [4], highlighted four difficult challenges for factory integration that must be addressed (Table 36, NTRS Report). The challenges applicable to the construction industry are:

3.1.1 Factory Cost – Cleanroom costs for large fabs (9,000 m^2) are rapidly rising to over $48,500 (US) per square meter as users demand design and construction schedules that put from 750 to 950 square meters of cleanroom ($36-45 million US) in place per month at submicron quality standards. Escalating factory capitalization and operational costs are impacting profitability of semiconductor manufacturing companies. According to the NTRS, factory costs have increased by 20% annually and the depreciation costs associated with them represent 45% of the wafer cost/cm^2. To remain on the historic improvement curve, operating cost/cm^2 must improve 1% annually.

3.1.2 Factory Investment Risk Management and Time Factors – The rapidly diminishing time allowable to recover initial and recurring factory investments requires that facilities be delivered faster with higher certainty. To reduce capital expenditures and start up times, facilities should be delivered in modular units just as they are needed. Several key metrics are:

- Minimum economical capacity increment. Efficient and profitable factories will be sized at 30-40K WSM (wafer starts per month) in the near future. This will require modular “just enough, just in time” additions to capacity.
- Time to first wafer start. The time from groundbreaking to first wafer start has doubled over the last 12 years. Elements of factory construction and production preparation must be shortened in duration and performed in parallel. Specific goals for 2006 are to cut design time to 3 months, construction time to 7 months, tool selection and delivery to 7 months, tool installation and qualification to 5 months and time to first wafer start to 13 months. Current best practice time to first wafer start is almost 23 months.
- The NTRS states that solutions exist, but in reality, design, construction and tool selection and hookup time continues to increase slightly or stay the same.

We need to better benchmark the state of the industry and develop methods to eliminate non-value-adding activities.

3.1.3 Process / Factory Complexity – Processes and factories are constructed and operated with increasing amounts of material, process and technology change in an increasingly interdependent environment. NTRS lists a goal for factory effluent reduction of 80% by 2006 and more importantly of 50% by 1997. Tool manufacturers are struggling to make even modest reductions in effluent. The facility designers and constructors must develop solutions to efficient waste recovery. Tool manufacturers must better understand the energy costs, waste disposal and input chemical costs before designing families of tools. Designs with high chemical, gas, water and power usage, and effluent are significant impacts on facility first costs and operating costs. This research program will address the information management issues.

3.2 Design, vendor and construction challenges

Solutions to the above mentioned manufacturing needs are driven by several construction challenges which inhibit their solution. Five key challenges follow:

- Owners use many different project delivery systems to install the facility. Which one delivers the best results for given circumstances? To date there has only been one study comparing the cost, schedule, and quality differences between projects delivered using different US delivery systems [5]. Only one fifth of the projects in this study were in the high tech area. Owners do not have a good tool to help them decide which delivery system to select. Many are driven by low price purchasing practices used in buying commodities.
- Large fabrication facilities require the mobilization of large workforces of highly skilled workers. Often these areas have labor shortages resulting in poor productivity, excessive overtime, late startup and significant rework. A thorough understanding of productivity measurement, forecasting and improvement is needed.
- The rapid pace of design coupled with frequent tool changes is hampered by antiquated communications and contracts in the design and construction market.
- Many designers oversize facilities due to the industry's lack of standards for reliable structural, acoustic, electrical, illumination, HVAC and energy systems. Energy usage is greater than actual need, therefore resulting in unnecessary energy and maintenance costs.
- Many of these facilities are built off shore in remote locations with a workforce unfamiliar to the typical US design builder. The challenge is to blend international practices to deliver a sound facility.

3.3 Startup and operations challenges

Three major measures of a successful operation are: time to first product, time to full production, and wafer yield. The design and construction process exerts a major influence on the successful achievement of these three goals. Therefore it is critical that the design and construction team involve the users in all equipment and operational testing, and provide appropriate turnover, training, and startup of the facility for the user. The team delivering the project will become more involved in achieving these three goals as the required delivery time decreases.

4.0 Industry's perspective of problem

Even though many of these problems have been identified by industry and are known to leading companies in this field, they have been unable to make progress on solving them for several reasons. These reasons are explored next and will be addressed in the proposed research approach.

The industry is fragmented into design, fabrication, construction, startup and maintenance segments. Within each of these segments, companies specialize by system and by product resulting in hundreds of specialty designers, suppliers, contractors and maintenance companies. The company that benefits from an integrated solution is the facility user, who is typically the owner. The facility owner who benefits from better project delivery therefore has the incentive to support this type of research. However construction is not their main line of business. They focus and fund product research and development, not process or facility research and development. They are under the misconception that the design and construction professionals will do this – however they do not.

Design and construction professionals do not support this research for several reasons. First, the competitive market has resulted in low fees, usually from 1 to 4%, being paid for services rendered. This does not leave any funds for system or facility wide R&D. Second, the participants on a project may never work together again, hence there is little or no transfer of lessons learned and improvement in team communication, integration and coordination to other projects. The litigious society that has evolved over the last few decades has forced design and construction contractors to shed risk and to avoid innovation. In addition, recent downturns in the cyclical microelectronics industry have made everyone risk averse and have minimized development of long term delivery solutions.

A third group of players is the vendors and specialty subcontractors who usually put the most work in place and have the greatest ability to influence the outcome of the project. These organizations have lower prestige and are brought on later to the project than designers and construction managers and general contractors. In many cases they are selected by low fixed price, which preclude the owner's ability to create a team atmosphere and to react cost effectively to change.

5.0 Research approach - an industry-university research collaboration

This discussion indicates a need for a team-based approach to research into the total facility delivery cycle. Suppliers, specialty subcontractors, designers, and contractors must be orchestrated and have data collected by an impartial research team with experience at collecting data from actual project situations. Some additional reasons that an industry-university joint approach will work are:

- Owners are R&D driven yet their R&D focuses on physical systems and products and not processes. Our researchers are process driven. In addition, the sensitive nature of these projects is such that the university researchers are in the best position to focus on data and not benefit from exposure to proprietary technology.
- Case study research needs field data collection by a highly trained unbiased third party. The construction research field is new and design and construction companies are not trained nor do they have the fees to support unbiased good research. The proposed team has a track record in industry-university research, and their results will be more credible by all parties involved.
- The last benefit is that the unit cost of outsourcing the research to our team is far less than doing it in house and the researchers could become employees of the sponsors upon their graduation. This will help provide staff for the anticipated year 2000 boom in building these facilities.

6.0 Proposed research program

This research will be conducted in several phases:

1. Form a research team comprising leading professionals from facility owners, tool manufacturers, designers, specialty contractors, general contractors industry consortia, (e.g. SEMATECH), funding agencies, and university researchers and students. This group will have strong industry-university interaction and involve students in all workshops and research.
2. Develop a comprehensive set of metrics for evaluating projects. These include cost, schedule, quality, environmental (green), safety, etc. metrics. Several factors known to affect the performance of the facility are: project delivery system, project team attributes, facility systems, and the project environment are classified for each project. Benchmark top-performing projects using several cost, time, quality, and facility performance metrics.
3. Model the best practice processes using the IDEF process modeling methodology. Identify best practices found on these projects. A process model of the delivery of advanced technology projects will be based on these best in class projects. Develop an upper level generic process model for 300 mm technology facilities sized at 30-40K WSM.

4. Apply lean production principles and other relevant analyses to streamline the best practices and to achieve breakthrough methods to deliver projects according to the NTRS goals mentioned above. Better methods of constructing these projects can be created by re-evaluating the process flows, removing non-value adding activities and improving other activities. Principles of lean production include the elimination of waste in the flow, creation of integrated teams with decision-making ability, and continual process improvement. These best practices and ideal process flows can then be used to deliver these advanced technology projects with high levels of quality, and within the time and cost requirements of the client.

7.0 Research experience

There are four key activities upon which the research can be built.

7.1 Expand industry-university cooperation program

The Partnership for Achieving Construction Excellence (PACE) was established in 1992 as an Industry-University cooperation program at Penn State University. Member companies meet in October in a roundtable discussion to determine critical topics to the industry. Students then research those topics and present results in April of each year. Topics in the last three years have focused on method to better deliver advanced technology facilities. Member companies include contractors and specialty subcontractors focused on advanced technology projects.

7.2 Develop metrics for benchmarking project performance

Comparing Project Delivery Systems - Compared the cost, schedule and quality aspects of 351 projects delivered in the United States using design-bid-build, construction management at risk and design-build delivery methods. This study quantified significant differences in seven performance metrics and seven quality indicators. Developed a tool for owners to evaluate projects and select a project delivery system. One family of projects studied included advanced technology projects.

7.3 Model the process to provide a facility

The Integrated Building Process Model (IBPM) and Information Architecture [6] are models of the essential functions required to manage, plan, design, construct, and operate a facility and the information required to support that operation. The Project Evaluation Process Model and is a model of the decision on whether to pursue a local or international project and the information and environment surrounding that decision

7.4 Use lean production to improve process

From two main production philosophies (craft and mass production) lean production is emerging as the new production philosophy for automakers and all manufacturing industries. Lean production is a philosophy that stresses ‘pulling’ product through the manufacturing process, thereby providing component parts just-in-time for installation and using multi-skilled crews to perform work. Specific principles of lean production are as follows:

- Reduce the share of non value-adding activities.
- Increase output value through systematic consideration of customer requirements
- Reduce process variability
- Reduce cycle times
- Simplify by minimizing the number of steps, parts, and linkages
- Increase output flexibility
- Increase process transparency
- Focus control on the complete process
- Build continuous improvement into the process
- Balance flow improvement with conversion improvement

The lean production system takes the advantages from both of the craft and mass production methods, which results in economically small production amounts, low units costs, short delivery times, high degrees of flexibility, and excellent quality. How does 'lean production' deliver these results? Lean production eliminates waste in the production process and develops the work force to perform several functions, of which none is more important than quality control and continuous process improvement.

With lean production at the forefront of the main manufacturing industries how does the construction industry implement this philosophy as 'lean construction'? A change in management and control of our projects will involve a change in the philosophy of how we perform work with our clients, partners, subcontractors, and competitors.

For example, Harris Semiconductor implemented principles of lean construction on their Project Raptor, a new semiconductor fabrication plant that produced the world's first 200 mm power discrete wafers [7]. The project was completed in thirteen months and broke many paradigms regarding planning, construction, equipment, and facility startup. The Project Raptor team held team meetings with the architect, constructor, and suppliers to layout equipment, plan purchases, and exchange information on equipment requirements. The architect provided phased construction drawings to the contractor, which allowed construction to start prior to completed design. Lastly, equipment was installed and the startup process commenced before the facility was completely finished. This project serves as a best-in-practice example of the implementation of some lean construction rules.

For lean construction to work effectively, the industry needs to learn how to pull materials through the production process. This is exceedingly difficult on a building project as the final assembly stays fixed and the work crews move within the building to add parts. Therefore, the assembly line effectively becomes the movement of crews throughout the building. This movement should be planned and tracked closely to ensure that the project progresses as planned. In addition the following rules can be applied to the development of the organization that will deliver the facility.

8.0 Conclusion

The semiconductor industry is definitively one of the most developing industries in the world today. Moore's laws states that on the average of every 18 months the power of semiconductors will double and that their prices will halve. For this industry to continue to be successful and meet these projections, technologies will have to be developed to fabricate the chips and the manufacturing process facility will have to be delivered faster, cheaper, and with high levels of yield. While the semiconductor industry itself is making strides to develop new technologies to fabricate the chips (X-rays, nanotechnology, etc.) the construction industry has fundamental problems to solve in order to provide the necessary facilities to meet the demand of this enormous industry.

The construction industry must develop a more cost-effective and time-effective solution for delivery of a fabrication facility for the semiconductor manufacturer. Originally the manufacturer may have been the designer of the chip, but it is becoming more common for the chip designer to subcontract production due to the high risk involved in the construction, operation, maintenance, and renovation of these fabrication facilities. The production operations are being contracted to companies such as Bell Micro, Amkor Technology / Anam Group, and Tawian Semiconductor Manufacturing. There are many gains to be made if the construction industry can develop solutions to alleviate the risk involved in the production process.

The research program outlined in this paper is the first step in meeting the demands of this industry. By utilizing best practices, applying manufacturing principles, and utilizing new technologies within the semiconductor industry a new delivery process can be modeled that breaks current paradigms in this field.

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