Semiconductor Manufacturing: Using Modern Scheduling Systems to Deliver to Customer Demand

Optessa

MLS-SC

(formerly NETAPS)

White Paper

Executive Summary

The semiconductor manufacturing industry is a rapidly growing industry. In 2005, the industry value was estimated around $285 billion [finance.yahoo.com]. As the use of electronics pervade more into everyday life in the form of computers, cell-phones etc., there is immense pressure on the semiconductor manufacturers to increase product variety and reduce delivery times.

From make to stock where volumes maybe high and product varieties low to make to order where volumes maybe low and product varieties high, the industry functions between these two extremes of manufacturing philosophies. Due to rapid development, the industry is moving towards fully automated manufacturing systems.

Building to demand shortens order to delivery lead time, reduces cost through leaner manufacturing, and can free capital tied up in idle inventory of raw material, work in progress, and finished goods.

High volumes and increasing product variety make building to demand a complex proposition. The manufacturing plant must be flexible. Equally important is an effective planning and scheduling system to manage the complexity.

The problem of developing an optimal production schedule in the horizon of a week to a day for a semiconductor manufacturing system is an extremely hard problem. The Optessa MLS-SC system for scheduling semiconductor manufacturing, is a specially configured version of Optessa MLS sequencing and scheduling system. Optessa MLS-SC uses modern stochastic search techniques to rapidly find a near optimal solution, even for large problems.

Semiconductor Manufacturing Scheduling: A Very Complex Problem

The semiconductor manufacturing environment is unique and extremely complex.
The process typically consists of four main sub-processes/stages: wafer fabrication, wafer probe, wafer assembly and wafer testing [Uzsoy et al. 1992].

In the wafer fabrications stage, the basic integrated circuit (IC) is built up layer by layer by going through complex processing steps such as photolithography, etching and diffusion in factories known as wafer fabs. The wafer fabrication stage is the most complex stage of production, typically consisting of 300 to 500 process steps which are performed by complex tool-groups. Each of the mix of products has its own process flow with a certain number of steps in the flow.

In wafer probe, the newly manufactured circuits are tested for basic functionality and the functioning IC's are sent ahead to the wafer assembly stage where they are packaged.

In the final step, the packaged IC's are tested for quality and reliability before being sent to the customer. Figure 1, is a step-wise representation of the wafer fabrication stage.

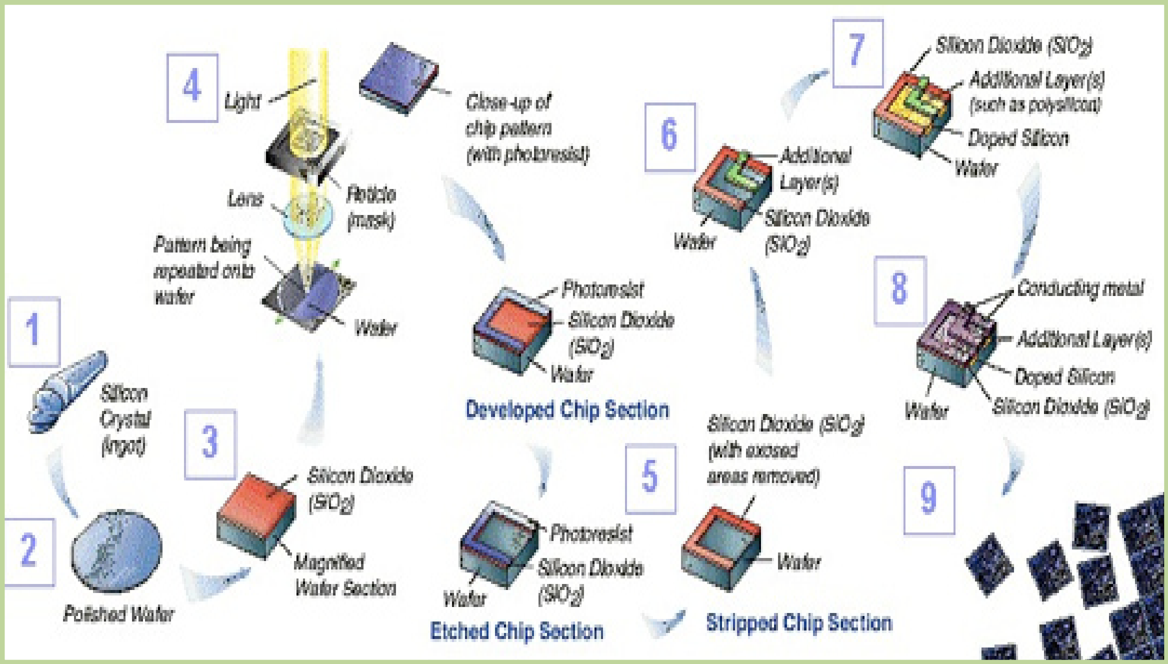

Figure 1: Wafer Fabrication Stage [www.sematech.org]

As mentioned before, the wafer fabrication stage consists of 300 to 500 processing steps. There are a number of unique features/requirements in these steps that make the problem of optimally scheduling them for different products complex. Some of these as are:

- Re-entrant flows: Wafers can revisit the same workstation at different stages of their process flow, so that wafers at different stages of their manufacturing cycle compete with each other for resources.
- Non-Uniform Load: Due to the diversity in the production system, cycle times vary by tool and process step. Further, tools can process wafers in batches or process single wafers. Thus machines can off-load multiple lots onto tools that are capable of processing only one lot at a time. This results in non-linear loading or flow of products in the factory.
- Setup Times: Some tools have significant sequence-dependent setup times that need to be considered in generating an optimal schedule.
- Downtimes: The manufacturing system can have random tool failures.
- Rework: During the course of processing, some wafers in a lot may need to go for rework after which they regroup with the lot. Reworked wafers need to be prioritized as the lot will wait for before proceeding to the next processing step.
- Rejection of Lots: Some wafer lots or batches may need to be rejected because of defects.
- Hot Lots: During processing, it may happen that some lots are given higher priority or gain precedence over other lots in the factory to meet delivery due-dates or other processing requirements.
- Matching of Tools: In the wafer fabrication system, to obtain optimum processing results, some tools in the flow may have to be grouped together. For e.g., wafers processed in tool A may give optimum results if in the subsequent process step it goes through tool B.
- Auxiliary Resources: At different processing steps in wafer fabrication, there might be a requirement of auxiliary resources. These auxiliary resources are limited in number and it is required that the appropriate auxiliary resource required by both the tool and lot is available at the required time and these resources be released after the lot finishes processing.

- Test/Monitor Wafers: Along with the main demand, there might be some test or monitor wafers in the systems which are being used for testing/ experimenting with new technology. Also there might be a requirement that the system cannot handle more than a certain number of test wafers or it needs a minimum number of these wafers.
- Send Ahead Wafers: In the processing, it may be required that some wafers of a lot be sent for processing after which they are inspected. Based on the outcome of the inspection the remaining wafers of the lot are processed and merged back into the same lot.
- Trial Lots: It may happen that a process engineer might want to change the process flow/ steps of a particular product for analysis.
- Processing Time-Windows: In certain processing steps in the flow, for e.g., a batch processing furnace operation following a clean or etch operation, it may be required that the second process needs to be carried out within a certain time window of the first process.
- Utilization of resources: Due to the high cost of equipment in wafer fabs, one of the main requirements is to keep the utilization of resources high.
- Rules/Constraints for Scheduling: Each step in the process flow might have a wide range of rules/constraints that govern the way products and processes are scheduled.

The fab scheduling system must schedule the lots of wafers taking all the above listed requirements into consideration. The system should also be able to reschedule, in real-time, to accommodate any change in the manufacturing system. This involves exploration of a gigantic solution space to find the best schedule or solution, which either meets all constraints or minimizes the cost of constraint violations. And, in order to be useful in practice the scheduling and rescheduling steps need to be done rapidly.

The Optessa MLS-SC is based on a state-of-the art optimization algorithm that rapidly and efficiently explores the entire solution space, taking into consideration all the requirements and constraints, to generate globally optimal schedules.

Enter a New Breed of Solvers

A new class of optimization techniques has emerged that can yield high quality solutions for problems in which classical methods fail. Consider the analogy of hill climbing – the object is to find the highest point in a mountainous area (see Figure 2).

Greedy heuristics (also called "one-pass" or "multi-pass" schemes) are analogous to the strategy: keep climbing till you cannot climb any higher. This strategy leads to a situation where one can get stuck on any one of the innumerable peaks far from the true peak; in other words, the result can be a solution that is far from optimal.

Other methods, based on constraints technology or operations research techniques, attempt to follow a route until arriving at a dead end and then backtrack to find another route. With nearly infinite routes there is no guarantee of getting close to the true peak.

On the other hand, modern stochastic search optimization techniques sample the entire solution space. An initial set of solutions is progressively refined through millions of iterations, which apply

Figure 2: Modern solvers can get very close to the tallest peak

special operators to generate new candidate solutions. Candidate solutions are evaluated and accepted or rejected on the basis of acceptance criteria. In the hill climbing analogy, this ensures that one is not stuck on one of the many secondary peaks, and that the final position is close to the true peak.

The Challenge of Applying New Solvers

New solvers typically require huge computational power to execute. For example, a single schedule may run for days on a supercomputer.

Scheduling run times are proportional to the number of units to sequence and the number of constraints or rules. The number of rules is in turn a function of the variety of units to be produced and the lead time. A practical system should readily handle of the order of 4 million unit-rules (e.g., sequencing 20,000 units against 200 rules) in under an hour - by evaluating a million or more candidate solutions.

Consequently, the key to making these techniques work is to make the evaluation of candidate solutions very fast.

Existing Scheduling Systems: Drawbacks

Some of the drawbacks of the scheduling systems available today are:

- Most legacy systems do not consider all rules and constraints when generating schedules. Also, there is no quantitative assessment of a generated schedule.
- Existing systems consider only local information, and make decisions to gain short-term benefits; this can force the system to make poor decisions over the longer term, resulting in inefficiencies.
- The existing systems do not have a notion of incremental rescheduling which hampers their ability to truly react in real-time to real-time changes in the system. The lack of speed at the re-optimization stage proves to be a deterrent in providing a truly optimal schedule.
- Dispatching or event based systems only use rules that are (at best) tested through off-line simulations. There is no attempt to optimize the schedule in any way, and decisions based on off-line simulations can often do poorly in a live environment. This is because simulations are generally inefficient tools for finding the best rules, and only a limited set of choices and test environments can be considered.
- Existing systems are not very flexible and often times are hard-wired and configured for a specific environment. This makes it difficult to make modifications at a model and/or technical level.
- In most existing systems, the user has to spend a lot of time adjusting the generated sequence to reflect changes that take place in real-time.
- Most existing systems do not provide the capability of fully evaluating the quality of the generated schedule and troubleshooting incase of an issue/problem.

Optessa Solver: Benefits Over Existing Systems

The Optessa MLS-SC has the following advantages over existing legacy systems:

- The Optessa MLS-SC generates schedules that optimize a cost function, after considering all rules and constraints. The cost function value provides a quantitative and qualitative insight into the generated schedule.
- The computational engine at the core of Optessa MLS-SC optimizes the entire solution by a multi-pass iterative process involving millions of evaluations. This is a superior approach to solution methodologies found in existing systems. The result will be a high quality schedule that maximizes resource utilizations, minimizes changeovers and delays, and reduces costs.
- Conventional wisdom has it that it is not possible to apply optimization methods to semiconductor wafer fab scheduling because of a) the complexity of the problem b) the need to reschedule frequently on a change event basis. The speed of the underlying algorithms allows Optessa MLS-SC to overturn this CW in the following way:
    - An initial optimal schedule is generated on the basis of the best available information once in a time period (a shift, or a day).
    - Changes in the scheduling environment (on an event by event basis) are accommodated through incremental rescheduling. In particular, the speed of Optessa MLS-SC algorithms allows this re-optimization to be done in real-time.

- The core advantage of the Optessa MLS-SC system is its ability to quickly optimize and generate schedules. Instead of using a subset of rules, the Optessa MLS-SC performs optimization considering all rules and constraints and this is done in real-time and in a live environment as opposed to running simulations off-line to test the rules and constraints.
- In contrast to dispatching systems that operate on the basis of local information, -Optessa MLS-SC generates an initial optimal schedule that takes into account the global state. Further, changes are handled by re-optimizing, also considering the global state. Given this, Optessa MLS-SC can make truly intelligent decisions that provide long-term benefits, such as improving the overall utilization of resources within the system.
- Another benefit of Optessa MLS-SC is that it is fully configurable / parametric, and there is no hard-wiring to a specific environment or machine configuration.
- Due to the optimization technology in the Optessa MLS-SC, the user will not be required to spend several hours manually adjusting the optimal generated sequence, as is the case with suboptimal solution techniques.
- The Optessa MLS-SC system comes with an excellent visualization tool that aids the user in evaluating the quality of the generated schedule and also aids in troubleshooting. Using the visualization tool, the user can dig down to the root of a problem and take corrective measures.
- The system is pre-configured to support classes of rules commonly encountered in most manufacturing systems. The representation model in the system is very powerful. Changes in plant configuration can be immediately setup. New classes of restrictions can also be quickly programmed.

Other Benefits from Scheduling with Optessa

The powerful modern solver is able to handle the original problem with all of its complexity – hundreds of constraints without simplifications. And, it does so rapidly.

The following are just some of the numerous benefits:

- Reduce order to delivery lead time by more frequent and closer-to-delivery scheduling
- Eliminate in process buffers and control parts inventory
- Reduce costs by considering all constraints
- Reschedule quickly to respond to changes
- Eliminate the need for the significant time and effort previously expended by line supervisors/planners in refining a sub-optimal solution

Scenario Planning Reduces Capital Expenditures in the Plant

Changing situations, such as market demand or new model introduction, raise the question: "Can we meet this new demand with the existing infrastructure?" The solver can test whether the existing production rules and new capacity limits can both be satisfied. Capital expenditure worth several million dollars can be avoided in some cases.

Re-sequencing Improves Response to Changing Market Demand

Armed with modern solvers, the manufacturer is more responsive to the marketplace by taking orders more frequently. These orders are scheduled almost immediately and the impacted suppliers notified quickly. Any changes in situation (e.g., supplier delivery problems) are handled in real time, as local re-sequencing can now be done in a matter of seconds. The iterative planning cycle is dramatically shortened, with disproportionate impact on the business economics.

Optimization Results in Reduced Dealer and Finished Goods Inventories

A shorter lead time directly translates into reduced finished product inventory in the pipeline and in dealer lots with consequent reduction in the need for incentives like discounts and cheap financing.

Optimization of Supplier Restrictions Results in Smoothed Schedule for Suppliers

Supply chain constraints – such as the daily capacity of the suppliers – are now considered by the solver. Since the orders placed with the supplier (based on solutions consistent with the declared constraints) are at or near its capacity, the supplier does not need to build big buffers to handle the spikes in demand that might otherwise generate huge contractual penalties. By eliminating the need to cater to huge variances in order, there is a significant opportunity to reduce in-plant capital expenditures.

References

http://finance.yahoo.com

[Uszoy et al. 1992] R. Uzsoy, C.Y. Lee, L.A. Martin-Vega, "A review of production planning and scheduling models in the semiconductor industry. Part 1: system characteristics, performance evaluation and production planning", IIE Transactions on Scheduling and Logistics, 24, 47-59, 1992.

http://www.sematech.org

Contact

Head Office and Sales
Optessa Inc. 905, 5555 Calgary Trail, Edmonton, AB T6H 5P9, Canada
Phone: 780-431-8426 Fax: 780-485-0944

USA
Optessa USA Inc., 105 Reids Hill Road, #4, Aberdeen, NJ 07747, USA
Phone: 732-203-9715 Fax: 732-203-9705

Web:
http://www.Optessa.com

Email:
info@Optessa.com