The trends in Semiconductor Process Control in the Generation Device

Patricia GABELLA

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In 1965, Intel co-founder, Dr. Gordon Moore made the prediction that the number of transistors on processors would double every two years, and the semiconductor industry has marched to the beat of his prediction ever since.

Since 1970, semiconductor technology advances have led to 30% annual declines in the price of microprocessor performance (measured in one million instructions per second (MIPS)). No other industry has achieved such technological success. Over the last 10 years alone, the semiconductor industry has grown at a rate of 15.7%, almost three times that of the U.S. economy. Capital spending for the last 10 years is eight times greater for the semiconductor industry than other high technology areas.

The 1997 revision of the National Technology Roadmap for Semiconductors has shown that semiconductor device development had accelerated from the previous roadmap, which was issued in 1994, from a three year development cycle to a two year development cycle. This acceleration affects the development of equipment, materials, process control, and all support infrastructure for device manufacture, too. These facts constantly challenge the participants in the semiconductor industry to manufacture more effectively, utilize the equipment and materials more efficiently, make decisions quicker and ramp yields faster. A large component for success in the future will rely on improved, fast cycles of learning which are dependent on data acquired on wafers, process, equipment and manufacturing indices which has been summarized, decisions made upon and implemented with minimal to no human intervention.

Process control provides solutions in the form of automated data collection, summary/filtering of data to make it more useable (data-to-information), attaching knowledge information to the data point or set, modeling and algorithms applied to make decisions on the data and then those data sets and decisions can be taken to the next level which is to provide feedback to the system (on which the data is collected) and improve the system (process, equipment, manufacturing indices). Improvement can come in the forms of improved tool cost of ownership (CoO, Table 1), better overall equipment efficiency, more repeatable process and repeatable device performance, and better factory performance (cost, output, cycle time, quality). Though this article is focused on wafer processing, some of the same methodologies can be applied to factory automation, facilities and manufacturing indices.

“If it was possible for the auto industry to achieve similar technological progress to the semiconductor industry, the FORD Taurus that first sold in 1986 for $10,000, would cost about $150 today.” (SIA, 1998)
1. Why is Process Control and Diagnostics Important for the Future?

The semiconductor business is transforming from a commodity supplier model to a service model. The device manufacturers are being driven to get to market faster, serve smaller markets with application-specific designs, shorten the time to high yields and speed the rate of learning. Reduction of cycle time increases the manufacturing complexity. As you drive down cycle time and improve quality the unit volumes increase, and thus, the data volume and variance increase. Demands on new equipment, new materials and new processes require more sophisticated and fast characterization methods. Engineering and manufacturing science requires data. Measurement methods collect data, data allows you to make decisions and solve problems. Data and the analysis of data helps “visualize” the system capability and system problems. You cannot understand (and fix) what you cannot measure. Problem solving, and gathering new insights requires a constant search for the appropriate measurement technology. Cost effective manufacturing requires that metrology to be used in a judicious fashion. As learning occurs, and equipment and processes become well characterized, the need for frequent and multiple metrology decreases. This new knowledge and new metrology technology can now be applied to the next generation of device manufacturing. When a method helps the factory to be more efficient, it will become second nature that that method will always be part of the manufacturing systems. Twenty years ago, statistical process control methods were rarely practiced in the semiconductor industry. Today, you would not run a factory without it. Ten years from now, similar statements will be made regarding process control methods.

2. What are the challenges facing the semiconductor industry in the near future?

- post-optical lithography
- timing to change to post-optical
- how far does optical go
- cost of development of post-optical lithography systems
- cost of development for the lithography infrastructure
- resist, tracks, mask/reticles, metrology
- new materials / processing methods
- copper for interconnect
- low-k dielectrics for interconnect
- high-k dielectrics for gate
- incremental changes
- next wafer size: 300mm
- increasing scale of integration
  - more transistors in same amount of space
  - more functionality on one chip
- improved manufacturing
- improved equipment productivity

3. How process control and diagnostics can help?

At today’s high wafer values, the factory needs to be proactive not reactive, and on-line and in situ metrology and process control assist with being proactive because data-to-information occurs quickly, decisions occur quickly and it accelerates the learning curve. For example, factories with in-line inspection exhibit a 5% yield advantage over factories that do not utilize in-line inspection. Table 1 list some benefits to equipment cost of ownership that can be realized with process control. Table 2 shows some of the additional benefits that can be had from both the device manufacturing perspective and the equipment supplier perspective.
4. Now and future metrology and process control scenarios

One method of classifying/describing the measurement tool is by physical location in the factory and how the metrology equipment is used in manufacturing. (Table 3). These descriptions help in communicating various levels and capabilities of tool use.

Table 3 Measurement Tool Description

<table>
<thead>
<tr>
<th>Measurement Tool Description</th>
<th>Off-Line: outside of the fab, usually destructive or contaminating</th>
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<tbody>
<tr>
<td>At-Line: in the fab, monitor wafers since unable to measure pattern wafers; could also be destructive, or contaminating</td>
<td></td>
</tr>
<tr>
<td>In-Line: is or can be part of process flow routing, can measure pattern wafers</td>
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4.1 Today's metrology and control scenario

At-line or in-line metrology tool takes measurements on the wafer(s) from the last process, that data is charted, statistical process control methodology used to determined "goodness" of process and often "goodness" of equipment, material committed, repeat measurement on a frequency rate as determined by risk of not catching "bad" manufacturing. The measurement is perform on product (in-line; as processed wafers, patterned wafers) or on monitor wafers (at-line, unpatterned). Product is saleable, monitors are not. Yet some measurement techniques cause some damage to the wafers, have a high risk of contaminating the wafers or the measurement resolution is compromised due to the pattern, in those cases, monitors wafer are used. Some data analysis performed, mostly one parameter analyses with the start at multi-parameter
4.2 Transitioning to metrology and control scenario

Measurement data is automatically collected and some filtering/analysis is performed to determine “goodness” and turn data-to-information, perform fault detection (“go” or “no go” decision), and occasionally data analysis performed that produces input information/parameters which is fed back into the equipment and process to adjust their function which tightens the overall distribution on the material being processed (either “sneaker” method or automatically). (“Sneaker” method - a human takes the new calculated input parameters back to the process tool and readjusts the operating parameters by hand.) Data is collected via at-line, in-line, and occasionally on-line and in-situ. A lot of data analysis performed, still mostly one parameter analyses with the start at multi-parameter analysis. Expert methodology is getting broader application across the equipment and the process.

4.3 Future vision for the metrology and control scenario

Automated measurement and data collection, with heavy utilization of on-line and in situ metrology systems. Wafer state, equipment state and process state measurement capable by the metrology systems. This data is available to the factory data management and analysis systems. Often the data is filtered and labeled to provide information for independent decisions to be made. It certain cases control algorithm output parameters will be applied back to the process and equipment to improve the overall process capability, real time. Equipment will notify the factory when it needs preventive maintenance, or when it discovers out of control processing, and will help to qualify itself (shorten the qualification cycle). Expert methodology and data mining will be employed to preserve the knowledge base (source problems, found solutions) and locate data patterns to source problems more quickly. Multi-parameter analysis and methods utilized to expand characterization knowledge of the process and equipment. This knowledge enhances the factory’s ability to control the equipment and process and tighten the overall distribution, thus producing more predictable and reliable product. (Note: various parts of the “now, transition and future” scenarios may exist in one factory today as the semiconductor manufacturer strives for improvements.)

Table 4 list some of the future opportunities for use of additional metrology and process control for semiconductor processing.

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5. Challenges for the future of process control

More interface layers are added, as complexity of the equipment, process, automation and communication increases. These interfaces must be well defined, and standardized for quick access and "hook-up". Tools have become more modular and clustered to meet the demands of the process and device requirements. In a similar fashion, system controllers have to become somewhat analogous. Complexity is ever increasing, time-to-market is ever shortening, cost must be contained; additional data is required to maintain current capability. Thus, new things, new data types (such as new sensor hardware), will always need to be tried, and the user needs easy access to the data and the methods they use to turn data into information. And it is not one data stream, it is several. And it is not one analysis methods, it is several. Equipment will become "intelligent" systems and additional metrology and process control are integrated in the system. Table 5 lists some of the business factors that will help tool integration.

Table 5  Business Factors for Integration to Occur

- Business Needs (Drivers) of
  - IC manufacturer
  - Equipment supplier
  - 300mm
  - Shrinking dimensions (e.g., linewidth)
  - Shrinking die size
  - Environmental, safety, and health (ESH)
- Integration must be profitable
  - Increased productivity
  - Creates a competitive edge
- Integration must be feasible
  - Hardware/software changes spawned by 300mm (i.e. insertion node)
  - Availability of commercial sensors & sensor bus
  - Viability of software suppliers
  - Emergence of controller consultants/trainers

Software content will continue to increase, and thus improved software quality methods need to be employed. Other industries have employed various levels of process control methods to their manufacturing. The semiconductor industry should learn from these other industries, and adapt what works. As more layers are added to the equipment and process, more business interfaces are also created. So now to complete new development on tools and processes with new metrology and control, to meet customer requirements, you have multi-party relationships instead of two party relationships. The ability to manage multi-party relationships for program success will be a requirement for suppliers in the future.

The National Technology Roadmap for Semiconductors 1997 envisions future metrology to evolve into more integrated systems with the process tools, employing process control methodology. The nature of the business of semiconductors will encourage this integration to occur, for continued improvements for device manufacture.

"The FORD Taurus has more computing power than the original Apollo that went to the moon [in 1969]."  
Alex Trotman, Ford Motor Co. Chairman & CEO, 1997
References


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2. Integrated Measurement Association: www.integratedmeasurement.org

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