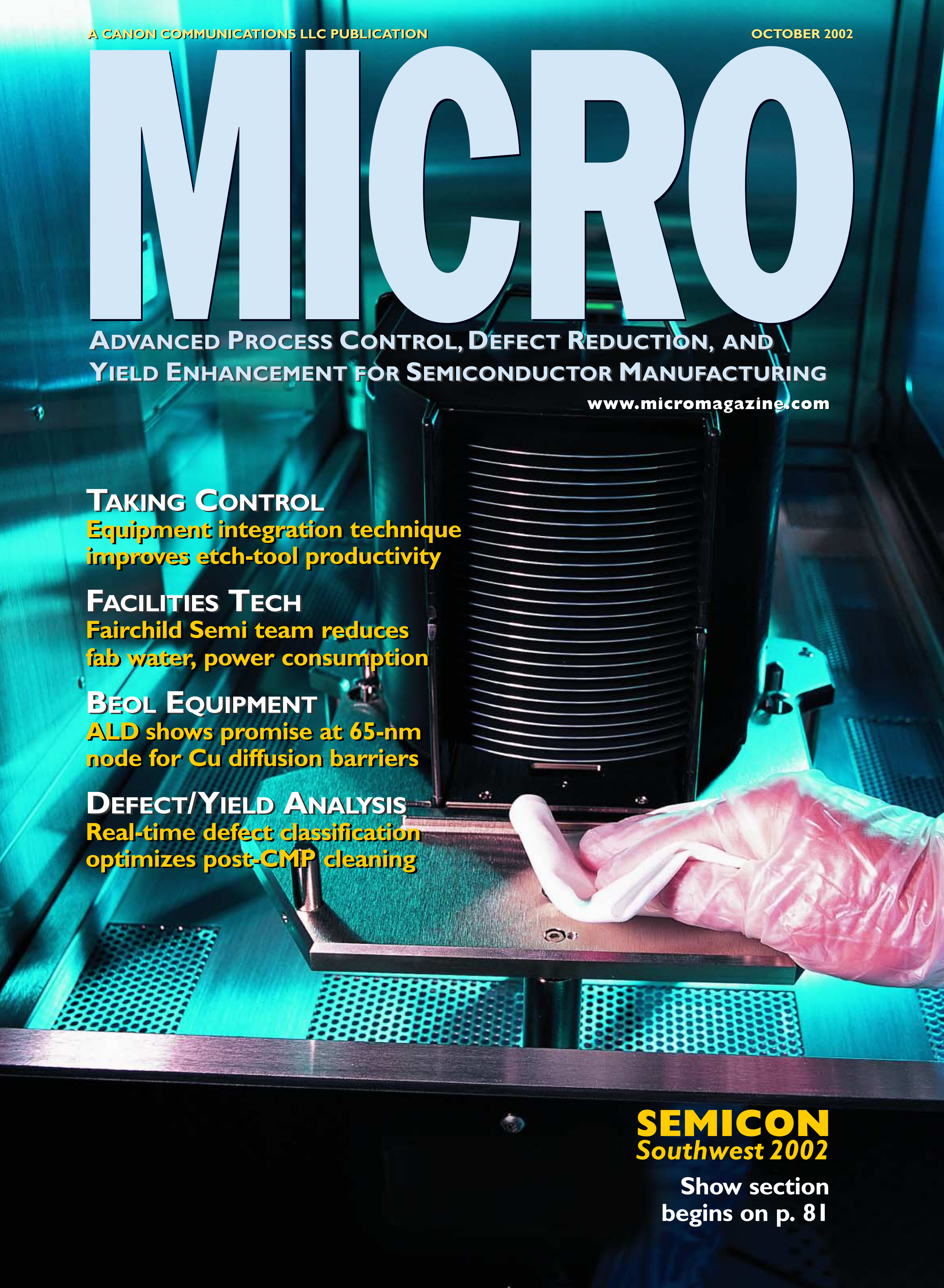
A CANON COMMUNICATIONS LLC PUBLICATION

OCTOBER 2002

MICRO

ADVANCED PROCESS CONTROL, DEFECT REDUCTION, AND YIELD ENHANCEMENT FOR SEMICONDUCTOR MANUFACTURING

www.micromagazine.com



TAKING CONTROL
Equipment integration technique improves etch-tool productivity

FACILITIES TECH
Fairchild Semi team reduces fab water, power consumption

BEOL EQUIPMENT
ALD shows promise at 65-nm node for Cu diffusion barriers

DEFECT/YIELD ANALYSIS
Real-time defect classification optimizes post-CMP cleaning

SEMICON
Southwest 2002

Show section begins on p. 81

Adopting e-manufacturing in the semiconductor industry

Joseph R. Monkowski

E-manufacturing promises to greatly increase the effectiveness and efficiency of semiconductor device processing. Particularly over the past year, much has been written about the advantages of this technology.[1–3] In a number of cases, benefits are already being realized. Nonetheless, the general acceptance of the technology has been long in coming; even today, its adoption appears to be very slow and definitely out of line with its touted advantages. Why this discrepancy? The answer, perhaps, is that end-users have unrealistic expectations about the potential benefits of e-manufacturing and are unsure who will provide the appropriate technology components.

How the System Works

In order to understand the reasons for these unrealistic expectations, it is useful to picture how an e-manufacturing system is structured. Figure 1 presents a hierarchical view of an e-manufacturing system's components.

The connectivity level refers to the combination of hardware and software that allows a connection to be made to the various data sources, which include the process tool and the tool's components and subsystems. One of the most fundamental connecting points is the tool's Semiconductor Equipment Communications Standard (SECS) port, which is particularly convenient for retrofitting tools already installed in the field. Unfortunately, a SECS port does not make a great amount of information available to the user.

To get at that additional information, it is possible to connect directly to the tool's subsystems or components, although work may be required to create an appropriate communications interface. One such system is the Symphony Equipment Server (SES) from Advanced Energy Industries (Fort Collins, CO), which has been installed on different types of tools from a variety of equipment manufacturers. The SES system allows users to connect to different data sources concurrently, such as the SECS port and the subsystems. It also can connect directly into the tool's internal communications network, if one exists. Although connecting into the tool's subsystems, components, or internal communications network typically requires an interface to support the specific data source, such connections usually make much more information available than SECS-port connections and are faster.

As e-manufacturing becomes more mainstream in the semiconductor industry, connections will eventually be established with tools directly. One such approach involves connecting into the tool's real-time control system. A more likely approach, however, is to connect into a separate diagnostics port, such as the equipment data acquisition (EDA) port now undergoing standards review. Either way, such a connection must be designed in by the tool manufacturer and made accessible to end-users. It may take a while, perhaps years, before on-tool connectivity is made available for most tools.

The data management level of the e-manufacturing system deals with managing collection plans, implementing data collection and storage, and making all potentially valuable data available. Data can include status variable IDs, equipment constant IDs, events, and alarms. Key attributes of the data management system include the ability to collect data at a very high rate, organize them effectively and efficiently, and make them available in a well-organized manner at a very rapid rate to any number of potential users—all the while minimizing the required level of administration. The Symphony system's data management components include the data collection manager and the InfoPlus.21 real-time database from Aspen Technology (Cambridge, MA), which was chosen for its ability to simultaneously write and read many tens of thousands of points per second. In addition, it is extremely efficient at data compression, often using no more than single-digit gigabytes of disk memory to store a year's worth of tool data.

The applications level is where data are turned into information. Applications programs can perform a range of functions, such as statistical process control, fault detection, fault classification, or run-to-run process control. One applications program, the Symphony equipment tuner, is used by equipment engineers as a type of oscilloscope for analyzing and diagnosing tool behavior and applying statistical process control and fault detection rules to multistep semiconductor processes. The program also can be implemented through a published application programming interface, in which case it functions as an infrastructure component that allows OEMs and other applications providers to create fast-time-to-market custom applications.

The content level at the top layer of Figure 1 is actually embedded within the applications program, but it is shown separately because applications programs do not automatically have all the information they need to carry out their work. For example, in order to detect a fault in a particular subsystem or process step, the applications program must have information on that subsystem or process step. Ideally, that information will be in the form of a physical model allowing the user to interpret any deviation directly. Alternatively, the model can be phenomenological, where certain patterns are recognized as within the appropriate specification and any deviations will be flagged by the program. In another approach, the applications program learns the permissible behavior of the tool, process, or subsystem over time. That system often requires human intervention.

Countering Unrealistic Expectations

Although there are undoubtedly many reasons why users have unrealistic expectations about e-manufacturing, practically all of them have one thing in common: The lack of recognition that all five layers of the e-manufacturing model are required in order to make the system work properly.

Some early e-manufacturing offerings came from sensor manufacturers. Examples included in situ particle monitors and gas analyzers. Typically, the goal was to define a set of measurements that would be considered normal and to send an alarm every time that an actual measurement fell outside normal boundaries. Unfortunately, defining normalcy was extremely difficult. First, it was necessary to establish a correlation between the level of what was being measured and the effect that it had on the wafer. Given the wide variety of processes and variables involved in semiconductor manufacturing, establishing this correlation was very difficult and time-consuming. Second, the effect on the wafer often depended on the particular process step being run.

If sensors are analyzed in light of Figure 1, it can be seen that they fall partly in the category of data management and partly in the category of applications. Sensor data were being collected and analyzed according to whether or not they fell within normal ranges. In many cases, however, no connection to process tools had been established, so that the applications programs were unable to assess measurements in the context of particular process steps. Most significant, however, was the missing content. Since establishing the correlation between measurements and wafer results was difficult, applications programs lacked the content that would enable them to register alarm conditions and lacked the context to link wafer results to process steps, recipes, devices, etc.

Figure 1: Hierarchical Structure of an E-Manufacturing System

'Potential users of e-manufacturing should ensure that they have the connectivity, data management, applications, and knowledge or content.'

It has long been the desire of tool owners to have a system that provides a go/no-go signal. But because it has been difficult to establish exactly when an alarm should be sent, they have been provided with a deluge of data instead. Customer reaction to the idea of gathering trace data is reminiscent of the reaction of many tool owners, as noted in an article on data collection: "When I asked the customers how they liked the software's trace data capability, they replied that it is of little benefit because it is too difficult and time-consuming to pore through reams of trace data looking for potential problems that may not even exist."[4] Having to pore through reams of data is a major letdown when the expectation is a system that provides a green light or a red light.

Some sensor manufacturers and applications software suppliers have tackled this problem by selling a complete package that is serviced by one or more applications engineers to analyze the data. In effect, the applications engineers provide the content.

Unrealistic expectations can also be generated when device manufacturers, recognizing that there are benefits to be gained from e-manufacturing, begin by purchasing network infrastructure. They frequently do not have a clear goal in mind, but they understand that they must connect to the tool and manage data. Consequently, they purchase connectivity and data management systems, but then are disappointed to learn that they cannot immediately put that infrastructure to good use to enhance productivity. Their disappointment grows if they discover that the infrastructure they have purchased is not an open system and cannot connect many valuable applications.

Who Does What

The first major step toward setting realistic expectations is to understand the need for all levels of the e-manufacturing model. The second major step is to understand who is best suited to provide each of the levels.

If we view the connectivity and data management levels of the model as tool subsystems, analogous to power delivery or gas delivery subsystems, it becomes apparent that they are best supplied by subsystems suppliers. Companies at that level of the supply chain are in the best position to deliver reliable products, including continuous software updates. Since such suppliers can sell components for a wide spectrum of tools, their unit costs are much lower than those of equipment and device manufacturers who might attempt to offer their own subsystems. An added benefit of using components supplied by subsystems manufacturers is that a common platform can be used across different tool types.

The best providers of applications programs understand the specific task at hand. For example, subsystems suppliers

Figure 2: Potential Locations of E-Manufacturing Components and Information

1. Interfab
2. Fab
3. Tool
4. Subsystem

'Advanced process control software and information will be split between the tool and fab level, depending on whether inputs and outputs are on one or multiple tools.'

are best suited to provide programs for detecting and diagnosing the faults common to specific subsystems. Third-party suppliers are the best source for general-purpose programs, such as the statistical process control packages and advanced process control software into which process models can be loaded. Such vendors may or may not supply other subsystems, but they must be experts in software design.

Equipment and device manufacturers are the best sources of process knowledge. They will be the primary suppliers of the process models that will enable effective run-to-run control and fault detection at the process level. Process models will enable them to add significant value to their products and create a point of differentiation between themselves and their competitors. Device manufacturers also will seek to gain a competitive advantage by developing relevant process models.

For advanced process control that cuts across multiple tools, device manufacturers may be in the best position to provide the applications content. However, they will not be interested in writing software, since such programs would be used only on the tools in a small number of fabs. Therefore, having software that can readily load required content will be valuable. Third-party software suppliers (or subsystems suppliers with software expertise) will be the best source of such applications programs.

Situating e-Manufacturing Components

Where will the various components of the e-manufacturing system reside? Although this issue does not appear to have held back the acceptance of e-manufacturing, it will play a strong role in helping to create a well-organized system in which different components can be easily combined and integrated.

Figure 2 presents a hierarchical view of where software and information can reside. In general, there will be a trend to push the e-manufacturing infrastructure and information to the lowest possible level. For example, in the short term, software used for predicting faults in a particular subsystem may reside at the fab level, while in the future it will most likely reside inside the subsystem itself. An obvious benefit of the latter approach is that it will reduce network traffic, since the only information the subsystem will need to provide to the fab network will be succinct pieces of information related to current or future problems. All of the required data collection and number crunching, on the other hand, will be performed within the subsystem itself.

Advanced process control software and information will be split between the tool and the fab level, depending on whether all of the inputs and outputs are contained on one tool or span multiple tools. Information on tool utilization and comparisons across tools will have to be performed at the fab and interfab levels.

Conclusion

E-manufacturing promises to greatly increase productivity and performance in the IC industry. To achieve those advances, however, the industry must agree on what it takes to implement a successful e-manufacturing system and what should reasonably be expected of it.

Potential users of e-manufacturing systems should begin by clearly defining their goals. Then they should ensure that they have everything they need to make the system work, from the connectivity, data management, and applications to perhaps the most important thing—knowledge or content. With a clear understanding of what must be done and who is best qualified to do it, the industry can continue to push forward with the adoption of e-manufacturing and begin to realize the tremendous benefits it can provide.

References

1. D Bloss and D Pillai, "E-Manufacturing Opportunities in Semiconductor Processing," *Semiconductor International* 24, no. 8 (2001): 88–96.
2. B Shade, "Increase Productivity through E-Manufacturing," *Semiconductor International* 24, no. 8 (2001): 101–108.
3. J Schmitz, "A View on Advanced Control Techniques from a Wafer Fab Manager's Perspective" (paper presented at the Third European AEC/APC Conference, Dresden, Germany, April 10–12, 2002).
4. J Goldman, "Trace Data: Yesterday's News or Key to Vastly Superior Equipment Performance?" *MICRO* 19, no. 3 (2001): 38–43.

Joseph R. Monkowski, PhD, is senior VP of Advanced Energy Industries. He joined the company following its 1998 merger with RF Power Products, where he was senior VP and general manager of the electronics technology business group. Before that, he was president of the instruments group of Pacific Scientific, VP and general manager of Photon Dynamics, and executive VP and chief technical officer for Lam Research. Monkowski has published more than 60 papers in technical and scientific journals and holds seven patents. He received BS, MS, and PhD degrees in electrical engineering from Pennsylvania State University (University Park), where he also served as a professor. In addition, he earned an MS in materials science from Penn State and completed a postdoctoral fellowship at the University of Nijmegen, The Netherlands. (Monkowski can be reached at 408/284-0298 or joseph.monkowski@aei.com.) ■