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Education in Semiconductor Manufacturing Processes through Physically-Based Dynamic Simulation

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Education in Semiconductor Manufacturing Processes through Physically-Based Dynamic Simulation

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Abstract

We have developed physically-based dynamic simulators relevant to semiconductor manufacturing processes, which realistically reflect the time-dependent behavior of equipment, process, sensor, and control systems using commercial simulation software (VisSim™) under Windows. Following on their successful research use for engineering design, we are applying them to manufacturing education and training. Because they reflect quantitatively and visually the detailed response of the system to user-initiated actions in real time, these simulators promise a new paradigm of active learning through "hands-on" operation of sophisticated, expensive processing equipment. The student experience is open-ended, offering not only guided exercises but also the chance to experiment freely with the virtual equipment. Simulator modules are in development for use by both experienced engineers and manufacturing operators, with enhanced graphical interfaces tailored to the student and application.

Background

Research and development of physically-based dynamic simulators for semiconductor manufacturing education is a byproduct of our successful development and exploitation of corresponding simulators in engineering design, analysis, optimization, and control applications for the semiconductor equipment and manufacturing industry.[1] The success of R&D applications is attributed to the ease with which such simulator platforms enable the construction of mathematical relationships which faithfully represent the physics and chemistry of equipment, process, sensor, and control system behavior as a function of time.[2] In commercially available simulation tools such as the one used here, VisSim™ from Visual Solutions[3], mathematical functions are readily interconnected to represent physical or chemical, as well as mathematical, relationships and their evolution in time, while the user may alter parameters of the simulation on-screen during its execution. For R&D these characteristics facilitate the construction and simulation of complex models having sufficient system-level description to provide clear indication of manufacturing and environmental metrics, leading to profound research advances in semiconductor process optimization and control. These same characteristics offer exciting possibilities for manufacturing education and training.

Indeed, the microelectronics industry and other high-tech industries place increasing emphasis both on worker training and on manufacturing as an educational discipline, driven respectively by the cost and competitiveness of the industry and by the lesser significance placed on manufacturing (cf. engineering and R&D) in the U.S. Qualitatively new approaches to education and training are increased productivity (e.g., using process control) prescribed in such documents only add to the need for more effective education. Finally, human resource costs are significant; in addition, technical approaches to improved productivity are thwarted if manufacturing personnel are not prepared to successfully implement them.

Dynamic simulators in manufacturing education and training

The application of dynamic simulators to manufacturing education and training is most strongly suggested by the ability of such simulators to provide active, hands-on learning. Because the simulators respond realistically to any sequence of learner actions, the student has an open-ended invitation to exercise the virtual equipment - even to break it - and to learn from all his experiences with it. Immediate feedback in response to student actions on the simulator should enhance the ability of the student to quickly develop effective metaphors for how the equipment works. When guided by instructions and assignments to facilitate his ability to use the simulator, a profoundly new type of learning experience is anticipated. Furthermore, since the simulator responds to student actions in real time as actual equipment would, the amount of pre-programming needed (e.g., as in conventional computer-aided instruction) is significantly reduced.

Finally, the dynamic simulator vehicle - as a software entity - permits the use of additional software tools for assessing and accelerating student progress, e.g., improving the simulator, providing on-demand backup instruction, and recreating events. Artificial intelligence (AI) techniques may be employed to assess student learning behavior and customize exercises for specific individuals' needs. Ergonomic features such as color, shade, sound, and multimedia can be chosen to reduce stress and adapt the system to the user learner's learning style (e.g., text, video, audio, etc.).

The dynamic simulator approach should benefit both the teacher and the student. The teacher can prepare real-time and relevant exercises while explaining theory and concepts, therefore reducing the gap between theory and practice. The teacher can also create various faults and improve troubleshooting skills of the student. However, it must be emphasized however that the dynamic simulator can by no means replace a good teacher, but instead offers a valuable complement.

We anticipate a broad range of applicability for such dynamic simulators. In order to test their effectiveness, we are designing simulator modules - usable as self-contained virtual laboratory exercises, self-study tools, or instructor demonstration kits - at two disparate levels. For learners with relatively little technical background (e.g., manufacturing operators, vocational students), the simulators permit the learner to operate equipment and understand its principles, such as vacuum and gas flow, heat transfer, and chemical reactions. Visualization, sound, and hypermedia encourage the learner to develop appropriate metaphors, while context -sensitive simulator response to learner error provides immediate and specific feedback. The physical sophistication of the simulators also enables engineering design exercises for more sophisticated learners (e.g., graduate students or practicing engineers). For example, simulator modules for process control and for statistical aspects of multi-step manufacturing are built upon dynamic simulator elements for the sensors, control systems, and sequential processes.

Equipment description

The dynamic simulator approach to manufacturing education and training is illustrated here for the case of a chemical vapor deposition (CVD) reactor system, for which the VisSim™ simulator screen is shown in Fig. 1. The CVD reactor is linked to a central wafer handler (CWH) and then to a load lock (LL) chamber, both of which are employed in the transfer of wafers from the outside into the process reactor(s) and return. In current semiconductor manufacturing, the CWH in fact acts as a robot to move wafers between multiple process chambers attached to it, while the LL serves as the entry for wafers to the processing system and to isolate the CWH from the room ambient. These three chambers are separated by valves, through which wafers can pass when open. Each chamber is evacuated by a dedicated pump connected through a valve. On the simulator screen, chamber and pump pressures are directly indicated, while all the valves can be opened and closed by a mouse click. Because the valve actuators trigger changes in the status of variables in the simulator, resulting pressure changes are reflected in the chamber pressures at a realistic rate.

To establish reaction conditions, the user can adjust a mass flow controller (MFC) to determine the flux of reactant gases admitted to the CVD reactor through a downstream valve V1, as well as modify the setting of a throttle valve between the reactor and its pump; the combination of MFC and throttle valve settings determine reactor pressure. The CVD reaction to deposit a film on the wafer requires both reactant pressure and temperature control. In the CVD process model block, the user can adjust the wafer temperature. This temperature and the reactor pressure determined by the current equipment state are input to kinetics and transport portions of a chemical reaction calculation, which generates the instantaneous deposition rate and its integral, the thickness of the deposited film on the wafer; these results are displayed on the simulator screen in Fig. 1 as vertical level indicators.

When the VisSim™ simulator is running, the user can change all valve conditions, the MFC and throttle valve settings, and the wafer temperature, and see a correct depiction of the resulting time-dependent changes in pressures, deposition rate, and cumulative deposition thickness. This provides a virtual CVD reactor system for his exploration and learning, not unlike the well-known Flight Simulator software program for airplane piloting simulation. The internal operation of the simulator is not, and need not, be obvious or understood to enable operation and learning from the equipment. On the other hand, for teaching purposes at a variety of levels, the lesson can unveil the simulator structure to explain in greater depth why the system behaves as it does. This illustrates the broad range of learner expertise for which we believe the dynamic simulator approach is valuable.

Simulation software

VisSim™ provides a considerable variety of mathematical functions, including arithmetic, logical, linear, nonlinear, integrating, and transcendental functions, as well as optimization, neural network, signal generation, and display capabilities. The user manipulates pull-down menus to add desired mathematical elements and exploits a mouse to connect these elements in arrangements which replicate the problem of interest as a mathematical model. A nested, hierarchical structure of simulators is enabled by combining multiple functional blocks into compound blocks. VisSim™ also offers a specific option in its simulation engines which causes the next iteration of results to be updated only after an amount of real time has elapsed which equals the chosen simulation time step. This is critical to education and training applications because it means that the simulator (virtual equipment) displays changes in status at the rates which the real equipment would - i.e., the simulator response looks "real". This feature and other attractions led us to choose VisSim™ for our work, though a number of dynamic simulators are commercially available.

Software connectivity and integrability are also important. VisSim™ provides capability for dynamic link library (DLL) blocks to insert special user-written functions; dynamic data exchange (DDE) for real-time communication with other applications (e.g., visualization tools); real-time interfacing to permit interaction with hardware (e.g., for mechanical sensors, controllers, actuators); and C-Code generation for producing faster executables.

Graphical user interface

We anticipate that a rich variety of visualization, animation, and multimedia functions will be very desireable for effective education and training modules, VisSim™ provides a reasonably effective set of graphical and visualization/animation functions, and enhancement of such capabilities can be anticipated from the various simulator suppliers in successful software releases. At this point we have chosen to concentrate on constructing GUI representations of the equipment which are as logical as possible and/or close matches to existing equipment controller screens, and to strive for educationally-effective integration of these with appropriate simulator functions, direction and feedback to students, and lesson plans, with more sophisticated multimedia representations to follow later.

We are currently developing a software architecture which will permit the use of Visual Basic (or Visual C++) GUI's which link bidirectionally (e.g., through DLL's) to the VisSim™ simulator. Such a structure would facilitate the use of a sequence of GUI's appropriate to the growing level of expertise associated with the student's progress.

Learning modules

Simulators like that depicted in Fig. 1 are being developed as self-contained modules for student and/or instructor, so that they can be readily inserted into the sequence of conventional classroom lectures and labs. The information in these modules is organized in a hypermedia structure, so that user can click on the keywords to transfer to desired sections. Following good software design practice, easy access to the list of available sections will be maintained on-screen at all times. Each simulator module will include sections on:

- Overview of concepts to be learned
- How to use the simulator module and dynamic simulator
- Guided tour through the use of the dynamic simulator to accomplish specific tasks
- Assignments using the dynamic simulator
- More comprehensive explanations of concepts, including bibiographic references
- Suggested open-ended exercises for student exploration

Modules for manufacturing training at a level like that shown in Fig. 1 are being developed for vacuum and gas flow, heat transfer, and chemical reactions. More sophisticated simulator modules will be constructed for engineering design exercises in process control and in statistics and optimization. These modules will be the focus of a program of testing, assessment, and refinement based on experiences with a variety of industry personnel in semiconductor manufacturing and equipment supplier companies, as well as in academic settings.

Conclusion

Physically-based dynamic simulators provide exciting new possibilities for manufacturing education and training, primarily as a consequence of (1) their direct feedback to the student's initiative, constituting a virtual piece of semiconductor manufacturing equipment, and (2) the open-ended, hands-on, active learning experience this represents. The approach requires substantial integration of software, educational content, as well as effective interfacing to more conventional mechanisms of teaching. If successful, dynamic-simulator-based manufacturing education and training may establish new, cost-effective pathways to effective learning for a broad variety of students. Finally, the simulator tools utilized for learning could well accompany the learner into the job setting, serving a follow-on role as the operator's or engineer's assistant on the job.

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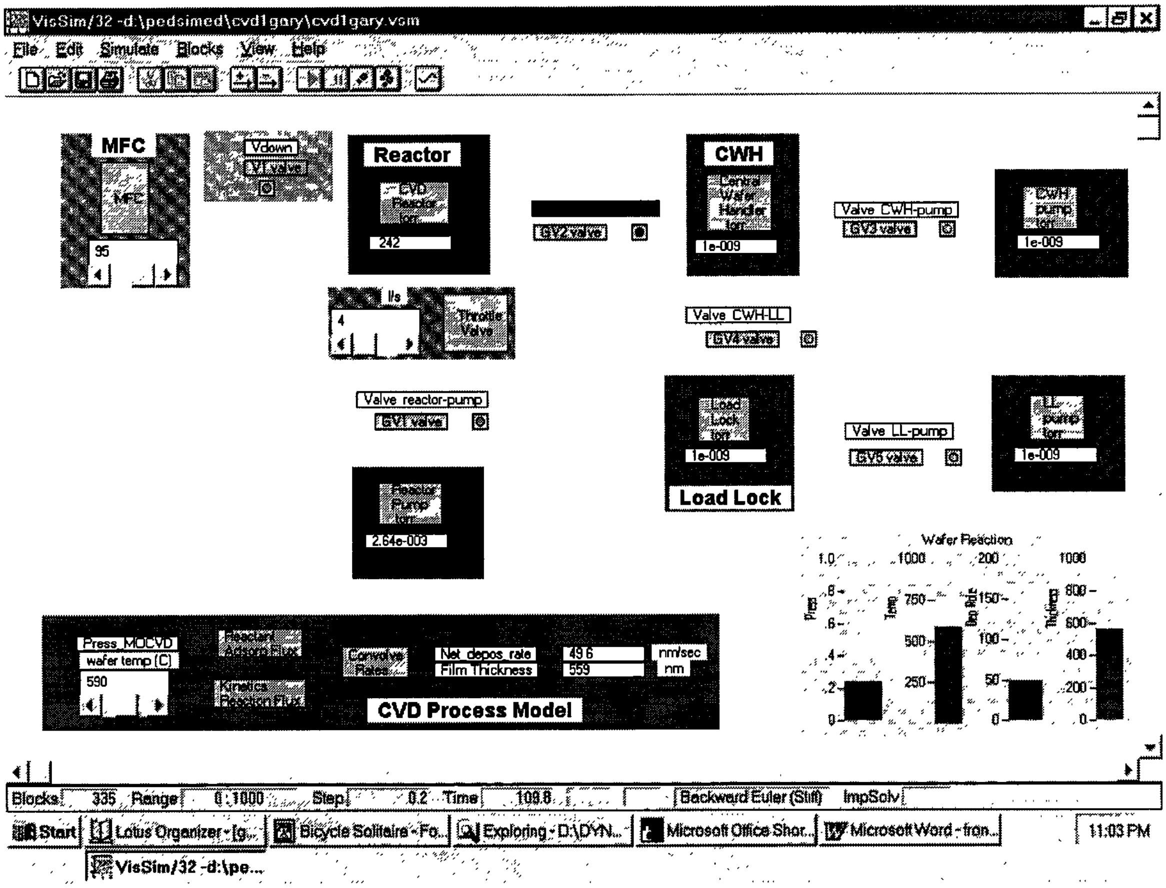

Figure 1. Example of VisSim™ dynamic simulator screen for CVD reactor, central wafer handler, and load lock. Mass flow controller (MFC) and throttle valve settings, valve conditions (open/closed), and wafer temperature can be adjusted by student. This results in realistic time-dependent changes in chamber pressures, deposition rates, and wafer film thicknesses depicted on-screen, as determined by physically-based simulator models.

References

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