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OUTLINE

• Simulation-based learning systems
• Environments to support exploration and experimentation for active learning
• Learning histories for tutorials, collaboration, and consulting
• Software architecture for authoring
• Application modules
• Conclusion and invitation

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Institute for Systems Research

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Simulation-Based Learning Systems

• Dynamic simulators reveal time-dependent behavior critical to semiconductor manufacturing equipment, process, sensor, and control system behavior

• Physics-based simulators are readily constructed, validated against experiment, and used in engineering

• Enhanced simulation environments can bring real-life experiences to students and workers for active learning
  – Anytime, anywhere
  – Individual and group
  – Collaboration and consultation
EquiPSim Learning Modules
(Equipment and Process Simulation)

Physics-based dynamic simulation

Active learning through exploration, anytime, anywhere

Powerful learning aides
Tightly coupled guidance
Learning histories
Distance collaboration & consultation

Extendible authoring architecture

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Learning Module – User Interface

- **Focus Window**
- **Control Bar**
- **Guidance Window**

**Lamp heating of wafer**

Wafer heating can be accomplished by using high power heating lamps to deliver light (optical radiation) onto the wafer through a transparent window on the process chamber. Lamp heating is particularly important to use in rapid thermal processing (RTP), in which the high radiative power of the lamps (800W) can cause the wafer to heat rapidly (in a few seconds) to temperatures as high as 900-1000°C. Typically, quartz halogen lamps are used to illuminate the wafer.
Learning Module – Architecture

- Dynamic simulator
  (VisSim simulation platform tool)
- DLL dialog
- Enhanced user interface
  (Delphi visual development platform)
- Guidance materials
  (web site, html)
Dynamic Simulator
Environments for Exploration and Experimentation

- Hierarchical scaffolding of guidance materials, from introduction to in-depth background information
- Terms used in guidance materials tightly coupled to simulator image of system
- Suggested experiments and exercises
- Changeable system design parameters
- Lab notebook to assist annotation of experiments, results, and conclusions
- Timer/stopwatch for experimentation
- Email tool to share results and questions with peers and/or instructor
Guidance Materials

Folder/tab hierarchy for instructional scaffolding

Focus Window

Guidance window
Graphical elements associated with technical term are highlighted in focus window

Cursor placed over technical term in guidance window
Hands-On Exercises

EXERCISE (with Chemical Reaction Module)
Testing low temperature deposition rates

- Use chemical reaction module to achieve about a 1 torr partial pressure of SiH4 in the reactor.
- Use manual temperature adjustments to fix the wafer temperature to about 500°C.
- Observe the deposition rate in the chemical reaction panel.
- Change the temperature by about 50°C to see how much the deposition rate changes.
- Return to the original temperature and change the SiH4 partial pressure by about 2X to see how much the deposition rate changes.

Observation: The deposition rate at low temperatures depends on temperature, but not significantly on SiH4 partial pressure.
Experiments and Lab Notebook

Stop watch to time experiments

Learner experiments freely with system design parameters

Learner annotates results of experiments into lab notebook

Lab notebook:
- automatic date/time and parameter settings
- learner’s comments

Send results/questions to peer or instructor

Print lab notebook
Learning Histories

• Generic capability to capture record of simulation experience (what the user did)
• Review simulation experience as visual history
• Replay simulation as it happened
• Revise and annotate history

• Applications
  – Preparing tutorials and demonstrations
  – Distance collaboration with peers
  – Distance consultation with instructor
Learning Historian - Record of Events

- Record, revise, replay, and annotate event histories in simulation experiments
- Use for
  - tutorial generation
  - questions to teacher/expert
  - peer collaboration
Learning Historian - Replay of Simulation

Pumpdown

In Pumpdown 1, you use the mechanical pump to pump down the reaction chamber. This has two limitations:

- Typically, the bypass takes a long time to approach a steady-state condition.
- The base pressure achievable with only the mechanical pump is not low enough to remove the reactive contaminant species (e.g., water or hydrocarbons from previous air exposure).

The base pressure achievable with only the mechanical pump is not low enough to remove sufficient reactive species and achieve low enough base pressure in the reaction chamber to take a measurement with the reaction chamber still at Reaction Chamber Temperature (RT).
Module Architecture for Authoring

• Enable independent authoring of
  – engineering/technical material vs.
  – user interface and software design

• Provide effective authoring tools to engineering expert
  – minimal if any software knowledge required
  – reusable library of simulator objects

• Provide effective authoring tools to software/interface designer
  – minimal if any engineering knowledge required
  – reusable library of user interface and software objects

• Anticipate sequence of learning modules which can bring learner from novice to knowledgeable practitioner status
  – learning tool becomes on-the-job assistant
Separable Authoring

Enhanced user interface
(Delphi visual development platform)

Dynamic simulator
(VisSim simulation platform tool)

Guidance materials
(web site, html)

Software/user interface designer

Engineering content expert

DLL dialog
Simulator: Local and Remote Control

Local/remote control switch on simulator:

Local - simulation controlled by “actuators” on simulator itself
Useful for engineers with domain knowledge
Enables continuous improvement of simulator’s physical fidelity

Remote - simulation controlled by “actuators” from user interface
Allows simulator control from user interface
Removes need for interface designer to have domain knowledge
Authoring - User Interface

Developer kit provides authoring instructions and flexibility to change pointers.

Developer’s pop-up facilitates definition of system parameters to be integrated on simulator and user interface sides.
Application Modules

EquiPSim
- Vacuum
- Gas flow
- Heat transfer
- Chemical reactions
- Optimization & statistical variation
- Process control

Other
- Water recycling in semiconductor fab
- Cluster tool operation
- Factory logistics
- Hydrology of the Nile River basin
- Highway traffic operations
Process Integration and Yield Modeling

- Simple device (capacitor) example
- Illustrate

  *Process integration*
  *Yield consequences*
  *Statistical variation*
  *Uniformity variation*
Process Integration and Yield Modeling

- Excel-based learning system for process integration and yield
- Across-wafer nonuniformity
- Process centering
- Statistical variation
Water Recycling in Semiconductor Fabs
Discrete Event Simulation and Factory Operations

- Cluster tool simulators
- Factory logistics simulators
Conclusion and Invitation

• Technology and laboratory experiences can be brought to the student – in class, at home, or in the workplace
• Simulation provides the basis for active learning experiences
• Powerful software methodologies provide value to learning, collaboration, consultation, and authoring

• We invite input and collaboration to serve the learning constituencies in the semiconductor industry