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THE SIMULATION OF CLUSTER TOOLS: A NEW SEMCONDUCTOR MANUFACTURING TECHNOLOGY

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ABSTRACT

Semiconductor manufacturers can improve product yields and decrease chip geometry by using cluster tools to improve their process manufacturing environment. A cluster tool consists of wafer processing chambers, one or more internal robots to transport wafers, and one or more load locks where the wafer-to-cassette exchange takes place.

This paper presents a flexible, cluster tool simulation model built using a general purpose simulation language. This data-driven model serves as a template which can be easily configured to emulate actual cluster tool configurations, providing statistical and graphical output. Wafer process routings are also defined through easy-to-use data input tables. The flexibility of this model is discussed, including robot parameters, tool configuration options, chamber options, and wafer processing steps. The advantages of this flexible, cluster tool simulation model as both an analysis tool and as a marketing tool are presented.

1 INTRODUCTION

A cluster tool is an integrated, environmentally isolated, wafer manufacturing system consisting of processing chambers, internal robots to transport wafers, and load locks where the wafer-to-cassette exchange takes place. The primary function of a cluster tool is wafer processing. Wafers enter the cluster tool inside a cassette, loaded at a load lock location. Each wafer undergoes a number of sequential process steps before leaving the tool. Each step in the wafer routing enhances the wafer material or adds material to it.

In traditional processing, wafers are transferred from tool to tool in atmosphere. Atmosphere exposure can be destructive to the wafer film, reducing product yields. In comparison, cluster tools provide a means of grouping a number of evacuated, isolated processing chambers together in an evacuated area. This evacuated cluster improves the 'clean room' environment and in turn, improves product yields and cycle times.

Semiconductor manufacturing equipment (cluster tools) continues to increase in complexity. Throughput rates, cycle times, and chamber utilizations can no longer simply be related to wafer processing times. Cluster tool attributes such as cassette loading options, robot parameters, chamber options, and wafer routing options complicate throughput rates and cycle times. Because of the seemingly infinite tool configurations and wafer routing combinations, simulation has become a necessity in predicting the cluster tools' performance. Recent applications in simulation modeling provide the ease, flexibility, and accuracy required to predict the performance of any cluster tool configurations.

2 FLEXIBLE SIMULATION MODEL

The application of simulation software packages to manufacturing problems typically presents two conflicting issues. Pure simulators traditionally are easy to use, but much is lost in the area of flexibility and model accuracy. On the other hand, simulation languages greatly improve model flexibility and accuracy, but ease-of-use is sacrificed. By utilizing a powerful simulation language and limiting the problem domain, the best of both worlds is achieved, as shown within this model.

The scope of this model is limited to a specific type of cluster tool. The tool itself is constrained to function within specific boundaries. These boundaries include a wide range of options for all areas of the 'cluster.' The cluster tool model, built using *AutoMod,* provides for all possible boundary combinations and 'configurations' the specific tool might encompass. The simulation software provides the flexibility needed to accurately develop the 'cluster tool' model. The interface associated with the software provides for ease-of-use in 'configuring' the cluster tool model.

The model design implements a unique user interface providing a spreadsheet application used to edit the model input files prior to run time. This interface allows input to be altered, without forcing the model to recompile. In addition to easy-to-use data input tables, the user interface (shown in Figure 1) provides many runtime options such as selecting a data set to use, setting a

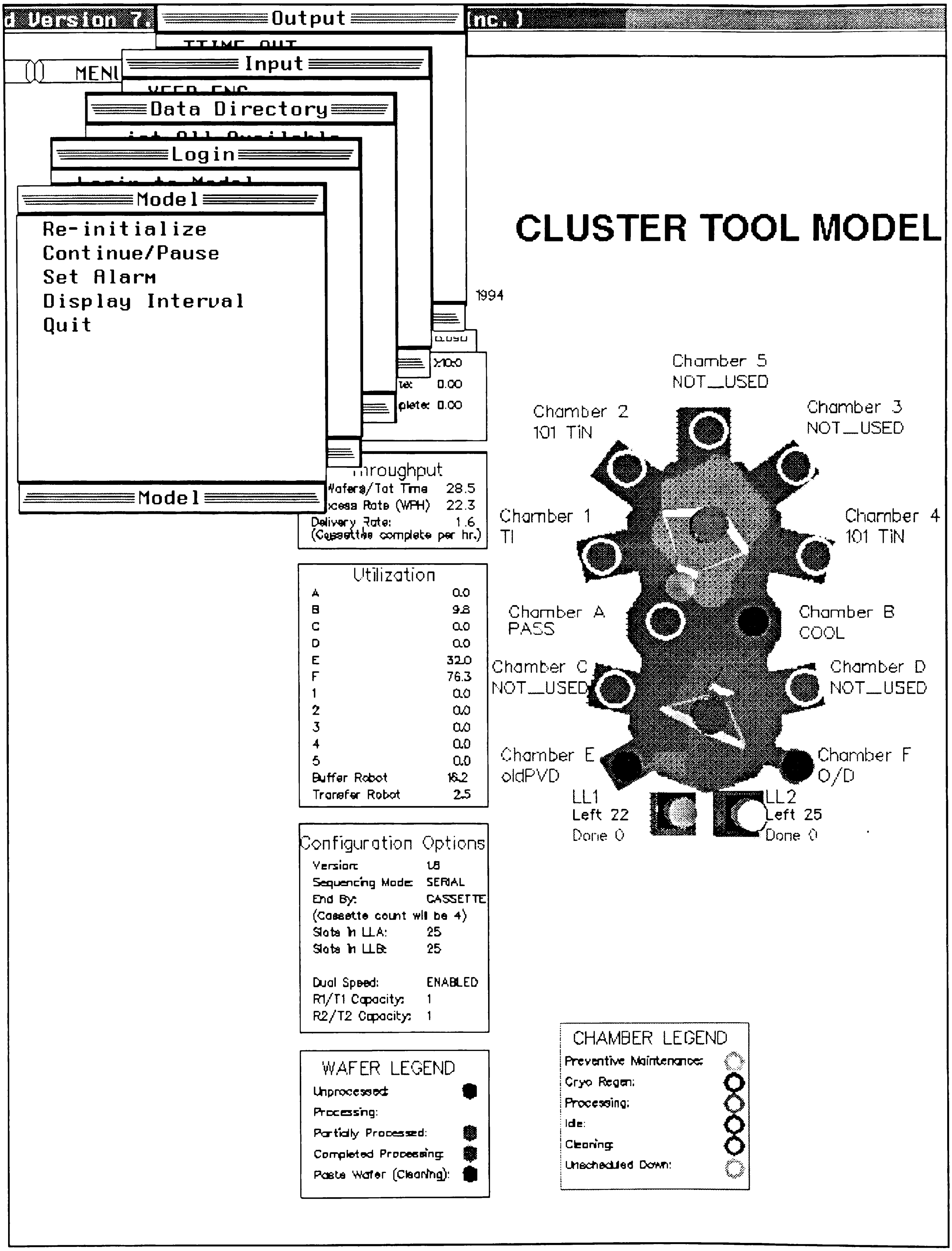


Figure 1: Cluster Tool Model

break-point, or re-initializing the model. Different tool configurations and wafer routings are stored in data sets. A data set is a directory containing many data input files used to define the cluster tool behavior and wafer routing. Data sets are read by the model prior to run time and are used to 'drive' the model. Output files containing tool and wafer statistics are written to the current data set at the end of every run and can also be accessed through the user interface. This allows the user to quickly accomplish many different case runs or 'what if' scenarios without leaving the run-time environment.

3 DATA INPUT

Easy-to-use edit tables facilitate data input and model flexibility. The model options found in each of the data input files can be altered to achieve any tool configuration and wafer routing possibility. Data can be entered manually, or by choosing the entry from a field-specific select table. Nine data input files make up the data set defining the 'cluster' configuration and wafer routings. The number of data input files may seem complex. However, for any set of 'what if' scenarios, typically only one or two files are altered between runs. Four catagories of data input define the cluster tool: cluster options, robot options, chamber options, and wafer routing options.

3.1 Cluster Tool Options

A cassette loading file, a down time file, and a system configuration file define specific attributes and options relating to the entire 'cluster.'

The cassette loading file contains data which controls interactions between the load lock, cassette, and wafers. The file defines how the cassette is to be loaded (either manually, by a front-end loader, or by an AGV) into the cluster tool, and how wafers are to be loaded and unloaded from the cassette. This file provides the flexibility to unload wafers from one cassette, and after processing, to load the wafers to a different cassette.

The down time file allows the assignment of down times to specific chambers and robots. Down times associated with each chamber are randomly generated depending on the distributions entered for each chamber. When a chamber is down, it is unavailable to process wafers. Likewise, when a robot is down it is unable to transport wafers. A second distribution identifies how long the chamber or robot remains down before it is again able to process or transport wafers. These two distributions relate to MTTR and MTBF.

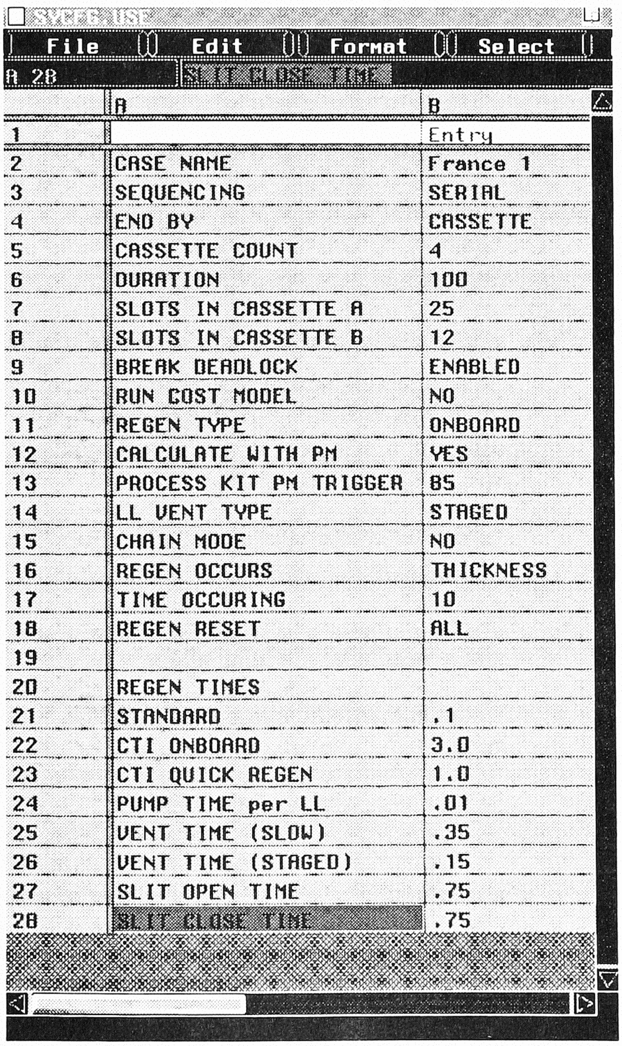
The system configuration file is used to define numerous tool attributes. A few of these attributes are discussed as follows:

- Serial or parallel processing is specified. If serial mode is selected, all wafers will follow the same routing steps. If parallel mode is selected, wafers from different cassettes will be processed with different routings.

- The model duration is set to end by time or by cassette. If time is set, the model will terminate at the time specified. If cassette is set, the specified number of cassettes will be processed before the model terminates.

- Pump times are specified. Pump time is the time required to evacuate the tool after the cassette has been loaded and prior to wafer processing.

- Vent times are specified. Vent time is the time required to vent the tool after the wafers have completed their processing steps, returned to the cassette, and are ready to return to atmosphere.



	A	B
1		Entry
2	CASE NAME	France 1
3	SEQUENCING	SERIAL
4	END BY	CASSETTE
5	CASSETTE COUNT	4
6	DURATION	100
7	SLOTS IN CASSETTE A	25
8	SLOTS IN CASSETTE B	12
9	BREAK DEADLOCK	ENABLED
10	RUN COST MODEL	NO
11	REGEN TYPE	ONBOARD
12	CALCULATE WITH PM	YES
13	PROCESS KIT PM TRIGGER	85
14	LL VENT TYPE	STAGED
15	CHAIN MODE	NO
16	REGEN OCCURS	THICKNESS
17	TIME OCCURING	10
18	REGEN RESET	ALL
19		
20	REGEN TIMES	
21	STANDARD	.1
22	CTI ONBOARD	3.0
23	CTI QUICK REGEN	1.0
24	PUMP TIME per LL	.01
25	VENT TIME (SLOW)	.35
26	VENT TIME (STAGED)	.15
27	SLIT OPEN TIME	.75
28	SLIT CLOSE TIME	.75

Figure 2: System Configuration

- Cassette capacity is set. The cassette capacity defines the number of wafers each cassette will hold.

- Cryo-Regen parameters are set. Cryo-Regen takes the entire tool down for the Regen application at the time specified.

3.2 Robot Options

Two files define specific attributes related to the internal robots. The first file identifies the distance each robot must rotate and extend to accomplish a wafer transfer into or out of the specified chamber. These values are used by the second parameter table to calculate robot move times. The second table identifies the velocity and acceleration at which the robots can rotate, extend, and retract. Times are given for both loaded and unloaded robot conditions. The resulting times are used by the robot to accomplish any move. Input from these files is reflective in both the animation and the statistics.

3.3 Chamber Options

Two files are used to configure the wafer processing chambers in the cluster tool. These files include the chamber options file and the position assignment file.

The chamber options file defines all possible processing chambers and their default attributes. A few of these attributes will be discussed:

- The chamber name and chamber description are set. If this chamber type is assigned to a tool position, the chamber discription will graphically appear by the tool position assignment.

- The default temperature for this chamber is set and can be used to determine processing time.

- The default processing rate is set and can be used in the processing time calculation.

- The default periodic clean rates and clean times are set.

- The chamber clamp and unclamp times are set.

- The chamber elevator lift and lower times are set. These are the times it takes the chamber elevator to lift the wafer off the robot when entering the chamber, and lower the wafer onto the robot when leaving the chamber.

- The preventive maintenance (PM) frequency and times are set.

- The Cryo-Regen frequencies and times are set.

- The default post-processing time is set.

- The chamber is configured as having a slit valve or not. If this chamber does have a slit valve, then the slit open and close times are used.

The position assignment file is used to configure the tools chamber positions to different chamber types. This position assignment file associates each possible chamber position of the tool with a specific chamber type (one of the chamber types defined in the chamber options file). The chamber position will takes on the attributes of the associated chamber type.

3.4 Wafer Routings

The wafer routing files define the sequence of process steps each wafer will follow. There are two files associated with wafer routings. Both files are identical in structure. The first wafer routing file is used when running the model in serial mode. If the tool is configured to process the wafers in parallel mode, both routing files are used. Parallel process allows two different process sequences to occur in the tool simultaneously. The routing files contain the following information:

- The process sequence and the associated chamber(s) in which the wafer is processed.

- The tempurature for this step (and chamber) can be set. This temperature value is used in the default calculation for the pre-processing time.

- The pre-process, process, and post-process times are defined. The thickness will automatically calculate the processing time required based upon the information in the chamber options file. Processing time can also be set manually.

- An "after every wafer" clean flag and associated clean time can be set. If clean is needed, then the associated clean time will be taken by the chamber every time a wafer finishes processing at this step.

- The process can be defined as a 'Point' process. If the process step is identified as a 'Point' process, the robot moves the wafer into the chamber for processing, but the wafer does not leave the end of the robot. It is processed while still on the robot.

4 MODEL OUTPUT

The model provides both graphical and statistical output. After the model has been configured (through the easy-to-use data input tables), the model can immediately be run. During the model run, the user can switch between graphical animation or no graphics. The graphical animation provides visual verification that the model is performing as intended. The animation can be slowed or accelerated during the simulation. Running the model without the animation graphics provides very fast simulation speed: approximately two hours real machine time compressed to one minute of computer run time.

The results of the simulation run provide accurate determination of the defined system throughput (wafers per hour), process chamber and robot utilization. The model results are compared to real system performances to verify data and configuration. Validation of the model is thorough and rigorous, comparing respective components of tool and model. The difference between the real system and the model results are less than 5 percent in error. The accuracy of the model, with existing configurations, provides confidence that the model will accurately predict the performance of proposed tool configurations and different 'what if' scenarios.

STD.OUT

File | Edit | Format | Select | Print

A 10 | #Wafers/Tot time

	A	B	C
1	REPORT FOR: France 1	DATE: Mon Mar 28 15:42:17 1994	
2			
3	COMMENT: 2 ch etch, 1 strip		
4			
5	Elapsed Time	0:1:7:45	
6	Wafers Complete	50	
7	Cassettes Complete	2	
8			
9	THROUGHPUT		
10	#Wafers/Tot time	34.7	
11	Process Rate (WPH)	39.5	
12	Delivery Rate	1.8	
13	(Cassettes Complete per Hr.)		
14			
15	CHAMBER	TYPE	UTILIZATION
16	A	PASS	19.3
17	B	COOL	32.5
18	C	NOT_USED	0.0
19	D	NOT_USED	0.0
20	E	oldPVD	44.2
21	F	O/D	34.5
22	1	TI	34.4
23	2	101 TiN	29.6
24	3	NOT_USED	0.0
25	4	101 TiN	29.6
26	5	NOT_USED	0.0
27	Buffer Robot		85.2
28	Transfer Robot		67.5
29			
30			

Figure 3: Standard Output Report

5 MODEL AS MARKETING/ANALYSIS TOOL

After the model has been validated, the model can be used as an analysis tool. The model is used primarily to determine throughput (WPH, Wafers Per Hour) for customer specified cluster configurations (chamber configuration, routing, etc.). The model is also used to optimize configurations for maximum WPH. Optimization is not always straightforward for these complex systems because of the dynamic interaction of robot, chamber, routing, and wafers. The following example may highlight this point: for a sequence of three steps (130,100 and 40 seconds respectively), making the third step longer (60 seconds) increased throughtput by 10 percent. Though this may seem counter-intuitive, the increase resulted from the robot performing tasks in a different order. The tool is also used to achieve desired WPH and at the same time avoid wasteful configurations, such as extra chambers.

As the model gains acceptance, other model users have expanded its analytical use to include a variety of "what-if" scenarios. Some of the scenarios include the analysis of faster robots, faster processes, different routings, different rules, and more complex integration.

6 CONCLUSION

The increasing complexity and versatility of cluster tools has led to the need for simulation in order to accurately predict the tools' performance. The integration of the tool options, robot options, chamber options, and wafer routing options, which provide a seemingly infinite number of configuration and routing possibilities, can easily be simulated through flexible simulation modeling. This flexible simulation model provides the understanding necessary to optimize the use of cluster tools. In addition, the graphical output accompanied by the statistical output has proven valuable in marketing the various cluster tools.

REFERENCES

Moslehi, M.M., C. J. Davis, A. Paranjpe, L. A. Velo, H. N. Najm, C. Schaper, T. Breedigk, Y. J. Lee, and D. Anderson. "Single-Wafer Processing Tools for Agile Semiconductor Production," Solid State Technology, January 1994.

Modular Equipment Standards Committee, Global Marketing, "Cluster Tool Communications Draft version 1.1," 1994.

AutoSimulations, Inc. 1993, AutoMod User's Manual.

AutoSimulations, Inc. 1993, AutoSched User's Manual.

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