EFFICIENT CFD MODELING OF SINGLE WAFER SYSTEMS FOR CLOSED LOOP EVALUATION*

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General finite element models of single wafer systems that describe both the dynamics of the solids as well as the gases are usually unsuited for quick design iterations, because of the computational complexity. In this paper a computationally more efficient alternative is proposed. The solids can be modeled efficiently and sufficiently accurate using a finite volume approach. The gases are modeled by finite element CFD software, and are approximated by a static map by iteratively coupling the solids model to the CFD finite element model. The static gas model can then be coupled directly to the finite volume solids model.

Introduction

Computer models of single wafer processes can be used for the design and evaluation of the chamber and related components such as control laws. To allow for quick design iterations it is highly desirable to have a computationally efficient, yet accurate, description of the system dynamics. Unfortunately, straightforward application of finite element methods quickly leads to large and computationally intensive models, especially when the dynamics of solids as well as gases are simultaneously taken into account.

This paper will develop an alternative to this modeling approach, by considering the separation of the dynamics of the solids and the gases. The idea is to use the results from finite element CFD models in the low order finite volume models of the solids. This separation is motivated by the fact that the thermal dynamics of the solids are significantly slower and not strongly coupled to the fluid dynamics, because of the difference in heat capacity. As a result, the fluid dynamics can be approximated as a static map, which can be used in the thermal dynamics model of the solids. Hence, the proposed approach can lead to an efficient yet reasonably accurate model of the total system dynamics.

Thermal Dynamics Modeling of Solids

At high temperatures the thermal dynamics of the chamber solids is dominated by radiative and conductive heat transfer. At lower temperatures the influence of convective heat transfer becomes increasingly important. Convection can added to the model by including heat transfer coefficients of the boundary layer at the free surfaces. These coefficients can be provided by the CFD model. The resulting system can be modeled efficiently using a finite volume approach, using general graphical nonlinear modeling and simulation software, such as MATRIXx SystemBuild [3], with the help of some routines to generate view factors etc.

The required model order (the number of elements, or volumes) can be fairly low, typically 100 to 300, where most of the elements are used to describe the wafer, which is generaly the most important component. Typical simulation runs take from several seconds to a few minutes on a fast PC.

CFD Modeling of Gas Flow

Modeling the flow of gas through the chamber is a relatively complicated task, that is commonly solved by running large finite element CFD models. Given a temperature profile of the chamber solids (included as boundary conditions) and an inlet flow rate, it is possible to calculate the flow field, and related properties, such as the convective heat transfer coefficient at the boundary layer. Generally a relatively large number of elements (several thousands or more) is required to yield an accurate solution. Consequently, running dynamic CFD simulations will require a large amount of time to run (hours to days), but steady-

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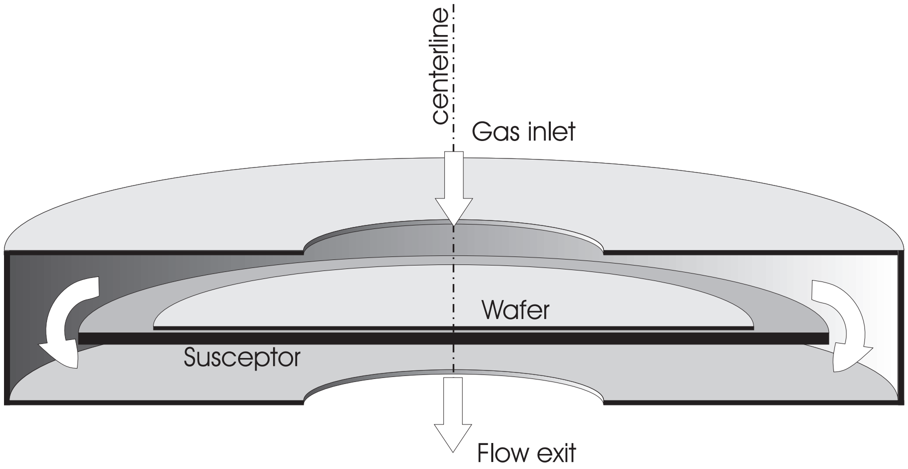

Figure 1: Generic single wafer system

state solutions can be computed fairly quickly (minutes to hours).

Coupling Solid and Fluid Models

By virtue of the fluid dynamics being significantly faster than the dynamics of the solids it is possible to approximate the fluid dynamics as a static map, and use that map in the thermal dynamics model of the solids. The key coefficient that relates the fluid dynamics to the thermal dynamics of the solids is the heat transfer coefficient at the boundary h, which is a function of the inlet flow rate v and the temperatures of the free surfaces Y_{SS}.

Using the results from a number of runs with the finite element model it is possible to construct a fairly accurate (nonlinear) static map $\hat{H}(\cdot)$ between h and the inputs v and Y_{SS} that is valid for a range of operating conditions that is of interest. This map can now be used for fast calculation of an approximate value of h.

Example: Generic Single Wafer System

The approach will be illustrated using a generic model of a single wafer system, see Figure 1. The thermal dynamics (under closed loop conditions) of the solids (see Figure 2) is modeled in MATRIXx SystemBuild [2], using a finite volume modeling approach. The gas flow is modeled in the finite element modeling software package ADINA [1]. Figure 3 shows a typical flow field as calculcated with ADINA.

To construct a valid map of the fluid dynamics it is important to use a rich data set. Therefore a number of cases are simulated, covering several operating temperatures and gas flow rates, using the loop as depicted in Figure 4. As a first step, only the steady-state solutions are considered. In this case h simply depends on v and the refence temperature Y_{SP} (since Y_{SS} depends directly on Y_{SP}). The use of the map $\hat{H}(v, Y_{SS})$ in model simulations is depicted in Figure 5.

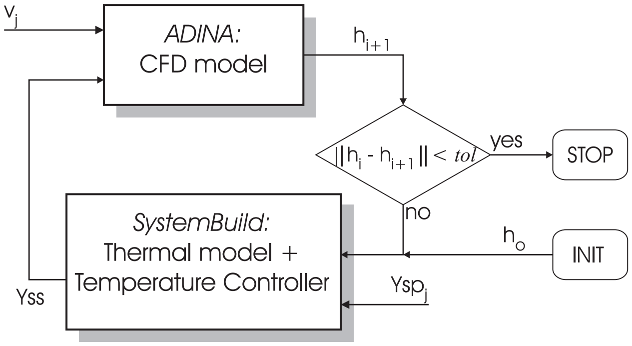

Figure 4: Procedure for building the map

Conclusion

Approximating the CFD model by a static map for modeling the thermal dynamics of single wafer systems allows fast yet fairly accurate simulations. This enables quick evaluations of the chamber and/or controller design.

In the work presented here only steady-state temperature results were considered when calculating the map. Future work may focus on extending this to include more temperature conditions, e.g., during ramp-up. Furthermore, the model can be extended to include CVD, which is of considerable interest.

References

[1] Adina R&D, Watertown, MA. *Adina Users Manual*.

[2] Jon L. Ebert, Abbas Emami-Naeini, and Robert L. Kosut. Thermal modelling of rapid thermal processing

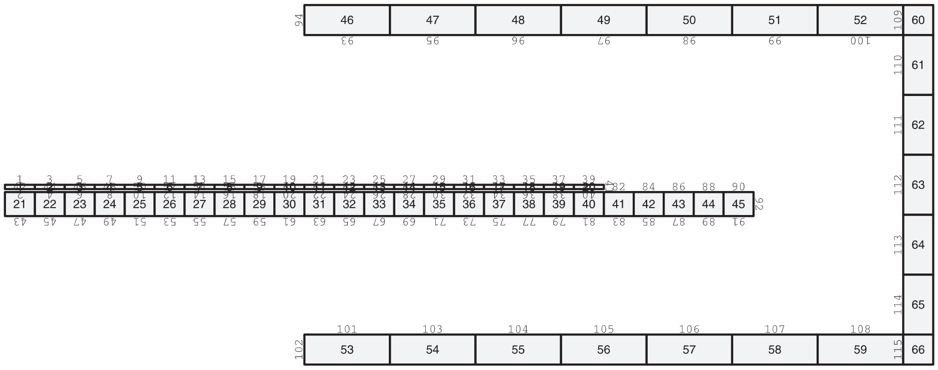

Figure 2: Finite volume model

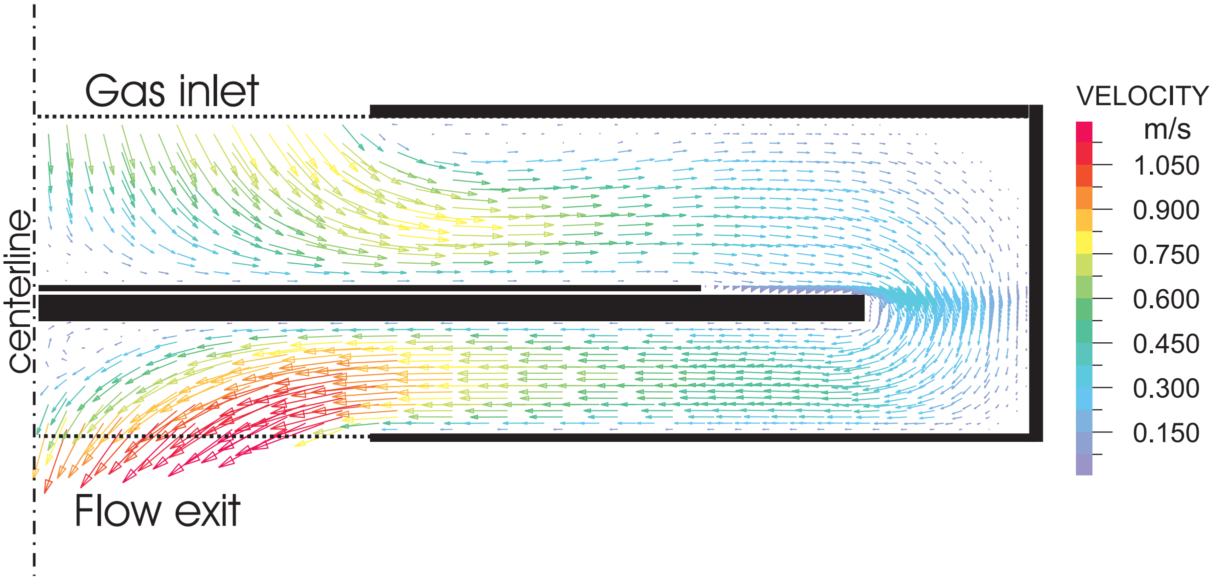

Figure 3: Flow field calculated with ADINA

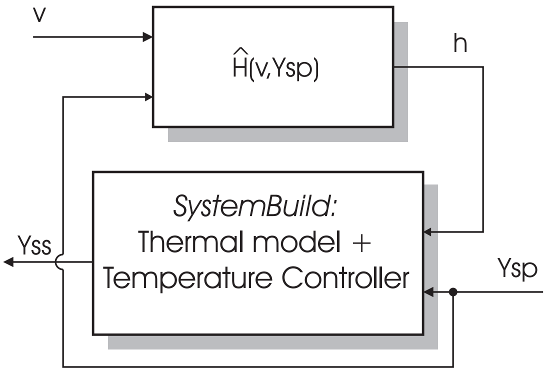

Figure 5: Resulting fast simulation model

systems. In Richard B. Fair and Bohumil Lojek, editors, *3rd International Rapid Thermal Processing Conference – RTP'95*, pages 343–355, 1995.

[3] Integrated Systems, Inc., 201 Moffett ParkDrive, Sunnyvale, CA. *SystemBuild Users Guide*.