Process Modeling of Dynamics-Driven Structural Design of High-Tech Semiconductor Fabrication Equipment

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Abstract: High-tech semiconductor fabrication equipment is dynamics-sensitive due to its ultra-precision requirements. Significant structural innovations have been made characterized by floating support and direct drive in order to eliminate effects of friction and vibration transfer. Nevertheless, complicate dynamic characteristics of multi-physics coupling, among electricity, magnetism, fluid, solid, heat, should be deliberately concerned in such kind of systems. Dynamics-driven design is essential to the success of development. However, lack of integrated design tool embarrasses the efficiency of design work and reuse of design knowledge. This paper proposes a process-driven dynamics design approach. Process control is involved to guide designers to accomplish design work. Dynamics model of components used in high-tech semiconductor fabrication equipment are abstracted and encapsulated as set of templates. In this paper, process meta-model based on XML are detailed, and a process test tool is developed to facilitate customization process modeling by simple graphical operations and attributes assignment.

1 Introduction

With the progress of semiconductor industry, the number of transistors that can be placed inexpensively into an integrated circuit chip (IC) doubles approximately every two years following the Moore's law. In front end process of IC production, high-tech IC fabrication equipments have achieved nano-precision level. It is well-recognized that the development of such kind of systems is strongly determined by dynamics-driven design. In the past two decades, significant structural innovations have made in IC equipments, characterized by floating support and direct drive, in order to eliminate effects of friction and vibration transfer [SB01][Sa02][KY03]. Nevertheless, these innovations also incurred multi-physics coupling problems among electrical, magnetic, fluid, solid and thermal variables [CC04], therefore, complicated, multi-physics coupled dynamics should be deliberately concerned during the whole design process of such kind of systems.

In this paper, a process-driven dynamics design approach is proposed, which is featured by template-based, process control and multi-disciplinary collaboration. In order to achieve process control, a process meta-model is detailed, which achieves the accumulation and reuse of process knowledge in the design process of IC equipment.

2 Process-driven dynamics design approach

The process-driven dynamics design approach is characterized by process control, template and multi-disciplinary collaboration, as illustrated in Figure 1. Designers can generate a design model of a component by instantiating templates of components, and then assemble the generated models of components into the multi-disciplinary model of the integrated system on a multi-disciplinary collaborative platform. The overall dynamic behaviors of the prototype of IC equipment affected by the multi-physics coupling can be analyzed, modified and optimized. All these operating processes are managed by the Process Controller. Designers can accomplish the whole design process of IC equipment step by step with the guidance of the Process Controller.

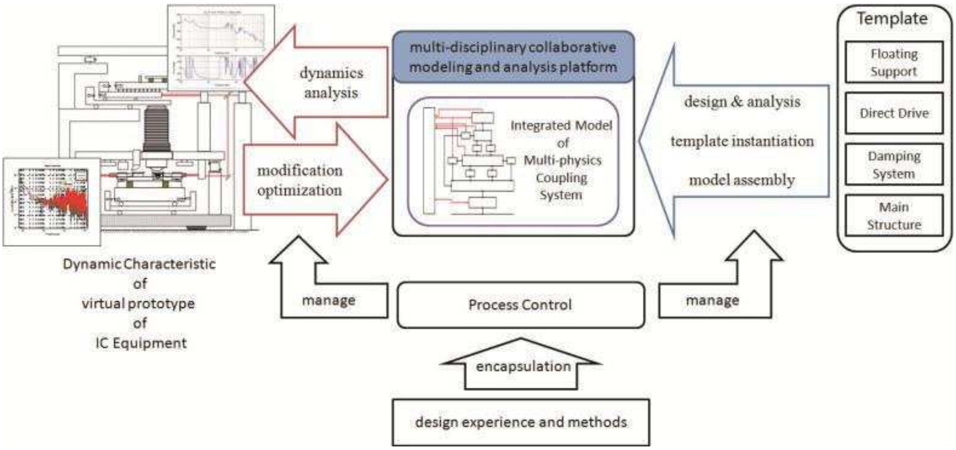

Figure 1: Process-driven dynamics design approach

In an IC equipment, components and subsystems, such as floating support, direct drive, damping system, present different structural characteristics and working principles. Corresponding templates are built for these components. A template of component or subsystem encapsulates all structural and functional characteristic variables, functions or equations of calculation and analysis [JL05]. A template also contains I/O interfaces, which exchange data with external modules and other templates, and call external softwares for analyzing of the multi-physics coupling effects in the component or subsystem. By assigning the characteristic variables and executing the intrinsic functions or external tools, the template is instantiated, and a parametric unified model of the specific subsystem or component is generated as the template instance. By linking all instances of components and subsystems according to structural connecting relationships, the integrated dynamic model is established on multi-disciplinary collaborative platform.

The Process Controller is able to accumulate and reuse of process knowledge in structural design of IC equipment. Design experience and methods which can be described as specific design or analysis process is modeled and stored to a process model file by Process Controller. And the specific process can be reproduced in the form of an executable process instance from the file to reuse the experience and methods. When a process instance is being executed, Process Controller manages the execution of tasks and data transference between tasks, controls the instantiation of templates in correct sequence, and leads the linking between template instances to construct the integrated system model. The Process Controller guides designers to accomplish the design, analysis and optimization processes with essential operating instructions step by step.

With assistance from the Process Controller, all template instances of components are assembled to the multi-disciplinary unified model of integrated system. Designers are enabled to modify and simulate the integrated model on the multi-disciplinary collaborative platform. Designers only need to modify values of characteristic variables in corresponding template instance or replace a new instance, for changing a component or subsystem in system. As soon as the simulation of integrated model is started, platform analyzes the linkage of template instances, checks and compiles the functions and equations in all instances to establish equations of whole system for solving dynamic characteristic of virtual prototype of IC equipment. Parametric models of all subsystems and components are calculated and updated via I/O interfaces of templates according to the linkage of instances, in order to achieve the multi-disciplinary collaborative analysis.

3 XML-based process model definition

Structural design process of IC equipment is featured by numerous node tasks, strict logic of executions of node tasks and complex relations of data transference.It is essential for process control to record the characteristic information of design process completely in an appropriate format, and maintain the process instance during execution. A process meta-model and corresponding maintaining rules are proposed, as illustrated in Figure 2.

Process meta-model consists of flow frame, nodes and arcs, with reference to workflow reference model [Ho06]. Flow frame generates the basis framework which describes the main features of specific process when process modeling, and manages the nodes and arcs contained in it. Nodes include action nodes and transition nodes which complete tasks and control executing routing in a process model. Action node calls template, third-party tool or external application to complete the assigned tasks when being executed. Transition node adjusts executing routing, and controls the executing sequence of nodes according to current executing state of process. Arcs which consist of control arcs and data arcs describe the relationship between the nodes they connect. Control arc represents the executing sequence between the two nodes linked to the arc. And data arc describes the data transference between nodes during executing of process. Specific process model is established by linking all nodes with arcs in the basic framework generated by flow frame according to the correct logical relationship.

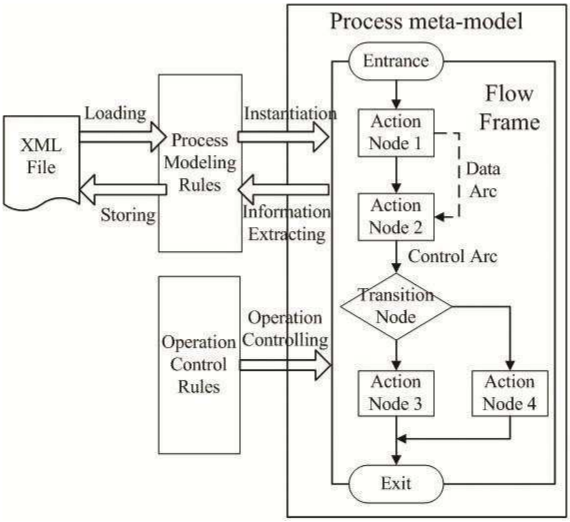

Figure 2: Process meta-model

In order to encapsulate process knowledge, it is essential of storing the structural characteristic information of specific process to files according to process meta-model. In process meta-model, the characteristic information is recorded in a classified and hierarchical data structure with several attributes in each object considering the difference of function and object type. With similar data structure to the tree structure in XML, the structural characteristic information of specific process can be saved to or loaded from XML file without inconvenient data conversion. And on the base that XML is communicated among modules in platform as the general data file, it is convenient that the process characteristic information is used by other modules on platform with XML file as medium. So it is feasible to save the structural characteristic information of specific process as XML file.

Process modeling rules manage the storage of the structural characteristic information of specific process to XML file, and control the generation of executable instance of specific process model from XML file. And operation control rules maintain the specific process instance when executing. during executing of process instance, nodes are executed one by one from the node declared as process entrance to the node declared as process exit, leaded by control arcs and controlled by transition nodes. And data is transferred from previous nodes to following nodes through data arcs. Correct executing permission is as essential as complete data input for executing a node. Referring to the concept of place/token in petri-net, similar receivers which ensure the completeness of data input and correct enable state of node are created [SW07]. Only when all receivers are filled with input data and executing permission, the node is permitted to be executed. When the execution of current active node is completed, the executing permission is shifted to the next node, and output data is also sent to the nodes connected with the current active node by data arcs.

A process test tool which is based on the process meta-model and maintaining rules, is developed to achieve customization and execution of process model. A simple analysis process of aerostatic bearing in IC equipment is tested. The corresponding process model is edited in the editing mode of process test tool by simple graphical operations and attributes assignment, as illustrated in Figure 3, and exported as a XML file in the prescribed format. In executing mode, Process test tool generates the executable instance by loading the XML file, as illustrated in Figure 4.

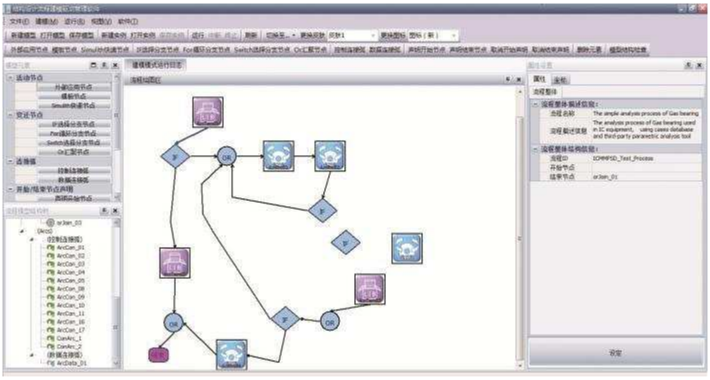

Figure 3: The test process model being edited

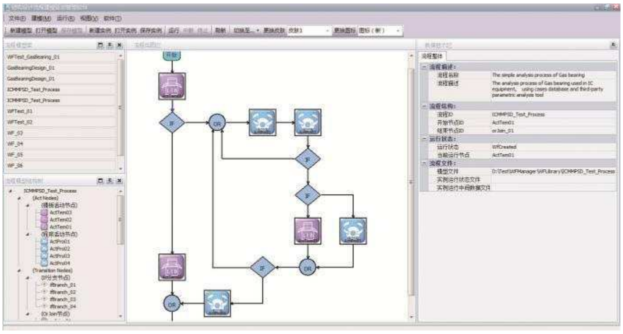

Figure 4: The executable process model instance

4 Conclusion

This paper proposes a process-driven dynamics design approach of high-tech IC fabrication equipment, with features of process control, template and multi-disciplinary collaboration, in order to facilitate design work of integrated system. By instantiating templates of components with assistance from process control, the unified dynamics model of integrated system is assembled and analyzed on the multi-disciplinary collaborative modeling and analysis platform quickly.

A XML-based process meta-model and corresponding control rules are also defined. With the process meta-model, a specific design or analysis process can be saved to or loaded from a XML file, to achieve knowledge encapsulation and reuse of experience and methods in design of IC equipment. A process test tool is developed to facilitate customization process modeling by simple graphical operations and attributes assignment to adapt to the changing requirements of customers.

Currently, the work of this paper is at the beginning stage, with much further efforts needed for the establishment of a multi-disciplinary process-driven integrate design tool of IC equipment.

Acknowledgements

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