Developing a Framework for Virtual Metrology and Predictive Maintenance

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Abstract

The implementation of novel APC techniques in semiconductor fabs calls for cooperative development. A barrier for sustainable joint activities is often the variety of fab infrastructures at different partners. Thus, in the ENIAC project IMPROVE, a fab-wide framework was developed to support the research of reusable APC components. This article describes the concept and integration examples of the framework.

The Advent of Novel APC Techniques

Facing the ongoing trend of increasing complexity of device and system integration in semiconductor manufacturing at reduced cost per function, new advanced process control (APC) techniques and production strategies have become key enablers for efficient manufacturing. In recent years, a variety of APC methods have been added to the semiconductor manufacturing environment, e.g., fault detection and classification, run-to-run control and integrated metrology. However, to further improve manufacturing efficiency, new APC technologies such as virtual metrology (VM) and predictive maintenance (PdM) have to be applied:

- The concept of virtual metrology addresses the prediction of physical and electrical parameters of wafers and devices from information collected from the manufacturing tools and from other available sources, e.g., production context information and upstream metrology.[1]
- Predictive maintenance aims to improve process equipment reliability while optimizing the maintenance frequency and increasing the equipment uptime.[2]

The European ENIAC project IMPROVE addresses the objective to enhance efficiency in European semiconductor manufacturing by the development and implementation of these novel APC technologies. A consortium comprising nine IC-manufacturing sites, 12 software solution providers and 14 academic institutions works toward the development of optimized algorithms and their implementation as new control methods in existing fab structures.

The Architecture of a Non-Fab-Specific Framework

Developing and implementing novel APC techniques in a single manufacturing facility is already a challenge. The challenge is even greater in a joint development project such as IMPROVE, where a variety of historically grown control infrastructures must be considered. Thus, a generic development approach was taken, so the developed solutions are reusable among the partners and so that duplication of efforts is avoided. This approach is split into two parts:

1. The development of reusable components for the individual APC solutions. (This aspect is not part of this article's focus.)
2. The realization of a generic framework architecture and implementation solution that enables the application of the new APC techniques in the different fabrication environments.

For the development of the generic framework architecture, intense technical surveys and workshops were conducted at the IC fabs of the partners, deriving their individual status and requirements for the new APC

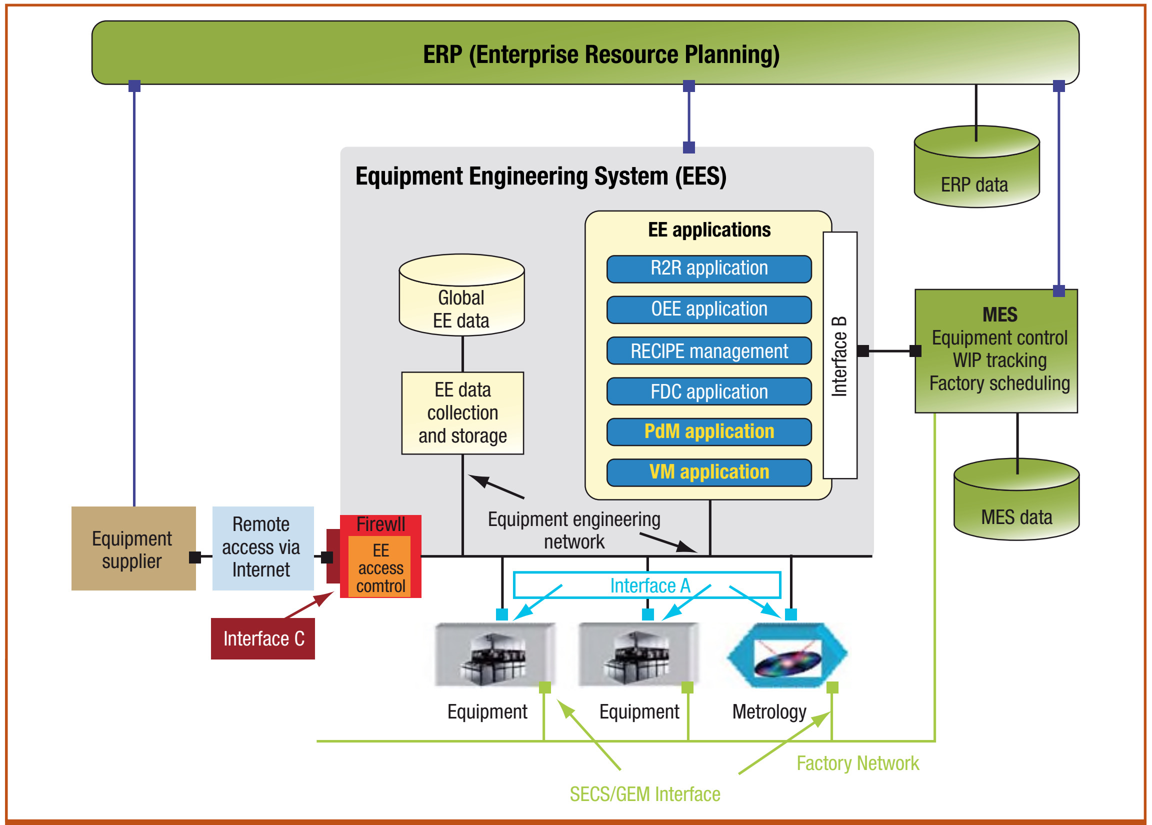

Figure 1. 'Ideal Architecture,' Defining VM and PdM as Equipment Engineering Applications on a Conceptual Level

technologies. These surveys were complemented by determining the state of the art beyond the IC area, e.g., in the electronics and automotive industry and dedicated collection of specific user requirements for virtual metrology and predictive maintenance. Based on the survey results, an “ideal architecture” was developed on a conceptual level that describes a framework for implementation of APC techniques such as VM and PdM (Figure 1). The architecture uses the concept of the equipment engineering system (EES), where the individual APC solutions are implemented as EE applications.[3]

Capabilities of the Framework

The primary goals of the IMPROVE framework are, on the one hand, the seamless and customizable integration of, e.g., VM, PdM and APC applications by providing uniform data access and data exchange; and on the other hand, a simple integration into existing fab infrastructures. The required generality in terms of data sources and targets as well as the computational approaches has been implemented in a service-oriented approach combining pluggable computation algorithms with adaptable work flows based on a generic data meta-model.

The data meta-model provides only a loose, but universal characterization of fab data using general contexts in the form of key-value pairs, which can be customized to accommodate for particular fab models. Adapters from fab-specific data formats for input to and output from the framework define its boundaries. The various EE applications are rendered as services; both native implementations and access as Web services are available. The interaction of the services is captured by work flows for orchestration. Configurable events, such as the arrival of new data, trigger processing steps in the work flows and thus in the services. The computational algorithms used by the EE application services for data processing may vary over time, and special support for transparent exchange of these computational engines is provided by means of plug-ins.

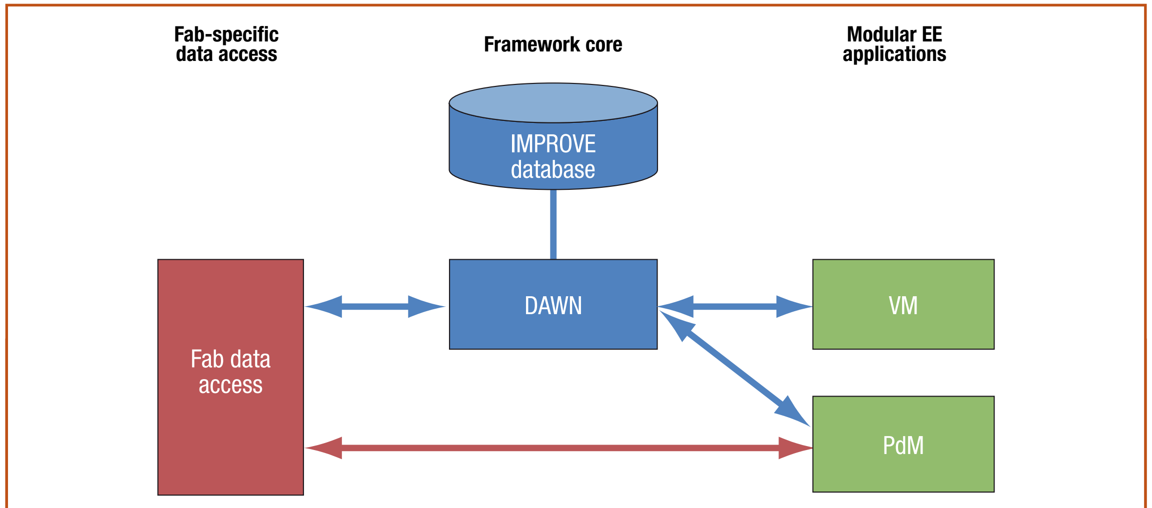

Figure 2. Overview of the Main Components of the IMPROVE Framework and Their Connections to the Fab Infrastructure

Figure 2 gives a general overview of the core of the framework and its integration in a fab’s landscape by using adapters. At the center of the architecture is the “data aggregation and work flow notification” (DAWN) component providing an abstraction layer for uniform data access. DAWN detects event occurrences and starts or notifies work flows in response to these event occurrences. A library of common data pre- and post-processing functions is also offered, rendered as (internal) services.

The framework architecture has been specified as a composite structure model in the “unified modeling language” (UML), the data meta-model as a UML class model. This analysis level is used for fixing principal architectural and interfacing decisions. It is complemented by UML class models that reflect the current implementation.

Implementation of the Framework

The open-source JBoss application servers were used for the actual implementation of the framework. JBoss acts as a container for the other modules and at the same time as communication backbone between all modules (Figure 3). One major advantage is that JBoss allows deploying new versions of services or work flows without needing to restart the server process. JBoss also includes an execution engine of process flows. These work flows can be described and deployed directly by the process engineers and require only minimal IT knowledge.

All input data from the fab infrastructure and the results of the EE applications are stored in the IMPROVE database. This database can be administered using practically any of the established database systems. In this architecture, there are two ways to access fab data. One is a specified interface of the DAWN component acting as server to which the fab clients can push data or request the results from PdM or VM calculations. The second possibility is to provide a data server with a specific interface through which fab data can be directly accessed transparently from within the IMPROVE framework.

Most of the framework services are implemented as enterprise java beans

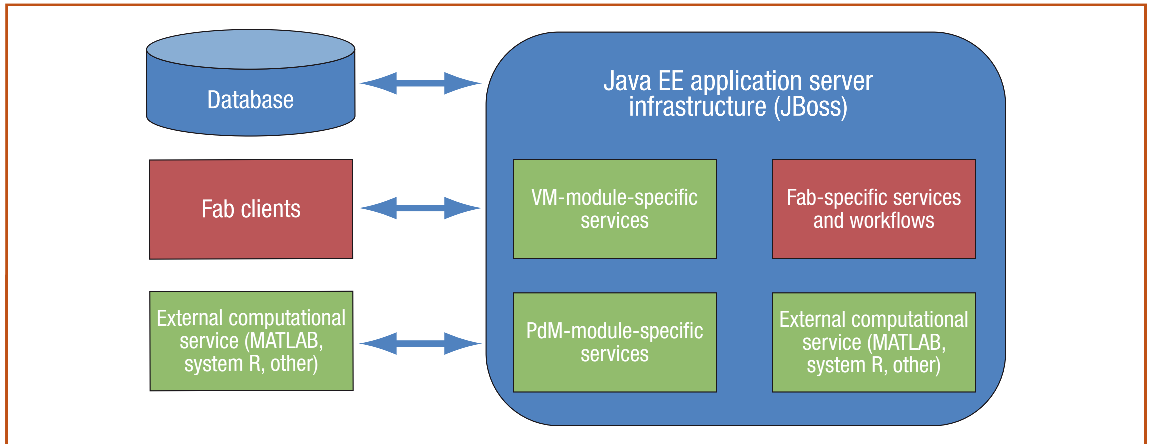

Figure 3. Implementation of the Framework and Available Services

(EJB), which are deployed in the JBoss server. EJBs provide functions such as data collection from equipment or from data streams (e.g., a sensor network) or calculations with VM or PdM algorithms. Due to their modularity, it is easy to maintain and to deploy new versions of EJBs for a specific functionality without affecting the others. The communication between clients and an EJB takes places via Web services. This protocol allows for a very heterogeneous architecture: Clients can be installed practically anywhere, running on any operating system.

Realization and Test of the Framework

The first prototype implementation, done at Infineon, uses a fab-specific data-gathering service to push new data into the IMPROVE database via the DAWN component described above (Figure 2). Following this data push, a PdM algorithm (EE application), which is implemented in MATLAB, is triggered. To enable this automatic trigger, the algorithm has to be previously registered with the DAWN component. Data is loaded via the data operation port into a value table within the memory of the framework. This value table is passed as an input to the MATLAB algorithm and converted and processed as a matrix. The calculated output is returned and an equivalent result value table is generated in the memory again. Finally, the result is stored back into the database and can be assessed to trigger further actions.

The second prototype is set up to predict an implanter ion source maintenance at austriamicrosystems' 200 mm wafer fab.

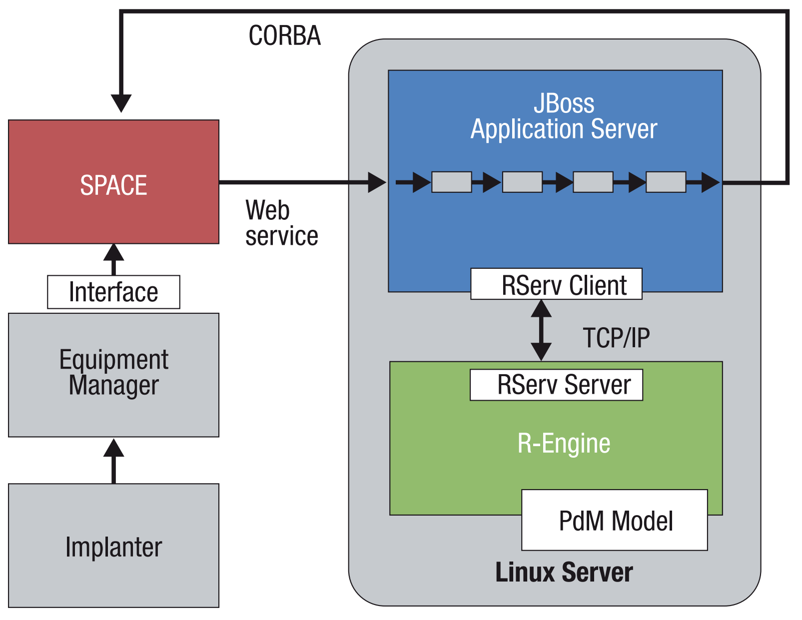

Figure 4. Integration of the IMPROVE Framework for Real-Time Prediction of Implanter Maintenance Using an 'R' Model

Here, the existing SPC software component camLine SPACE is used to push equipment raw data into the framework (Figure 4). The PdM model is programmed with the open-source statistics package "R" and delivers the output "time left until next maintenance," which is returned to SPACE and triggers an email to inform the responsible engineer about the remaining lifetime of the tool.

Conclusion

First tests of the framework in real fab environments were successful and proved the approach taken. The major advantage of the framework discussed here is that it enables the application of existing and the adaption of new SEMI standards, the integration of VM and PdM modules into common models, and the possibility of mapping the architecture to the individual IT structures in the fabs. The approach taken avoids singular solutions by establishing generic specifications and by utilizing a thorough analysis instead of ad-hoc solutions and work-arounds. Further development and fine-tuning of the framework is an ongoing task in the IMPROVE project. For additional project information, please visit www.eniac-improve.eu.

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