An Extended IDM Business Model to Ensure Time-to-Quality in Semiconductor Manufacturing Industry

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Abstract. Semiconductor manufacturing industry (SMI) has shifted from an IDM (integrated device manufacturer) to a fabless structure where technology is developed in an alliance to share high R&D costs and address time to market and time to volume challenges. In this fabless structure, EDA (electronic design automation) has emerged as a key stake holder to model increasing design and manufacturing interface complexities and its integration within design flow, but collaboration within alliances have resulted information sharing and technology transfer as the key challenges. We argue that IDM model is superior to a fabless structure due to its inherent ability for faster/superior knowledge capitalization. We benchmarked and analyzed a world reputed IDM with use-case and SWOT (strength, weakness, opportunity, threat) analyses to identify the limiting factors that led this transformation and found data and statistics as the core issues. We have proposed an extended IDM business model where engineering information systems (EIS) are tuned for design for manufacturability (DFM) compliance to achieve time to quality (time to volume, time to market) and yield ramp up rate at low cost but effective R&D efforts.

Keywords: SMI business models, design for manufacturing (DFM), time to market, (T2M), time to volume (T2V), yield ramp-up rate.

1 Introduction

SMI is characterized by the fastest change in the smallest period of time and has evolved as a market driven business model along with structural transformation from an IDM to fables model. Till 1980, SMI used to manufacture equipment in addition to the product design, manufacturing, marketing and sales; however first split in late 80s resulted in the OEM (original equipment manufacturers) and IDM models where equipment manufacturing was separated as a specialized task. ITRS (international technology roadmap for semiconductor industries) proposed a fabless model in late 90s by splitting IDM functions in design and manufacturing. In this model IDMs, design companies and foundries collaborate in an alliance for the technology platform

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development with EDA companies as mediators for the CAD (computer aided design) support. In comparison to this fabless model, an IDM includes both design and manufacturing facilities to effectively capture high market share; however success lies in our ability to quickly design, develop and ramp up the products. Shift in SMI business objectives from manufacturability and volume production towards yield ramp up rate resulted EDA with a new role to integrate DFM methodologies across design and manufacturing flows to facilitate information and knowledge sharing within design and manufacturing groups.

DFM is defined as the ability to reliably assess manufacturability and yield issues (model-to-hardware gaps) in early design stages [8] and is categorized as [10] product DFM (producing manufacturable design for the defined processes) and process DFM (develop process with less rework and high manufacturability). It is focused on the economic benefits by trading off cost-quality-time triangle [15]. SMI adopted DFM in 1980 (Fig.2) to mitigate increasing design for manufacturing interface complexities and time to quality business challenges; however biggest challenge is the diversified understanding of the DFM concept among stakeholders and responsibility for its effective integration. EDA has unified the last step in design with GDSII format (final design database) and now they are putting efforts to integrate DFM within CAD tools to support industrial motto “first time correct design”. We argue that an IDM has an inherent capability to model its design and manufacturing interface complexities and serve as a platform for faster and superior knowledge capitalization. It is only possible if we investigate the limiting factors in existing IDM model that restrict DFM integration across design and manufacturing flows and led SMI to the fabless model. We found data, statistics and unsuccessful data driven DFM efforts as the limiting factors that led SMI to a fabless structure; hence we have proposed an extended IDM business model supported by EIS and tuned for the DFM compliance by shifting data driven DFM efforts towards information and knowledge driven DFM.

This article is divided in 4 sections. Section-1 provides introduction and establishes the need for an extended IDM business model. Section-2 briefly reviews SMI trends, DFM concept, scope and evolution. Section-3 provides analysis of an IDM model and presents an extended IDM model. Section-4 provides conclusions and key issues to be addressed while tuning existing EIS to support this extended IDM business model.

2 Literature Review

Semiconductor industry *(208 billion USD, 2008)* [9] is characterized by the cyclic demand patterns and higher revenues (Fig.1). It is a fragile, rapidly growing and technologically most advanced industrial domain, governed by the Moore’s law [6] which predicts doubling electronic components per unit area every 18-24 months at the reduced cost and power consumption. Moore’s law was initially focused on the geometric scaling, but now it has emerged into “more Moore” *(equivalent scaling)* and “more than Moore” *(functional diversification).* This transition led to an increase in the revenues even at decreased demands and moved industry towards high value products *(system on chip, system in package and package on package)* along with increased design/manufacturing interface complexities.

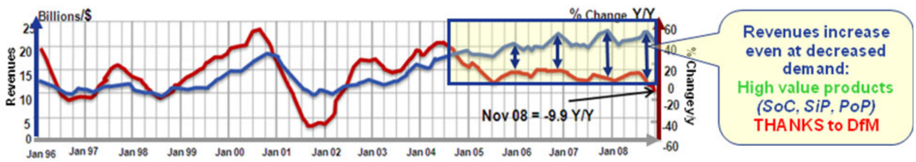

Fig. 1. Cyclic demand pattren and higher revenus

[5] LeBlanc (French) in 1778 and Eli Whitney (American) in 1788 coined an idea equivalent to "DFM" by proposing a system for the production of muskets that received industry wide recognition as "producibility through interchangeable parts". [2] Roger W. Bolz is credited for organized DFM methodology as an alternative term for "producibility", introduced in his book "The producibility handbook"; however "DFM" received industry wide acceptance around 1960 [3]. In 1980 the DFM concept was adapted as a yield enhancement strategy in SMI (Fig.2). The concept of DFM has also emerged in a diversification of terms like DFY (design for yield), DFV (design for volume) and DFT (design for test) etc. but all terms come under the umbrella of DFM along the product life cycle (PLC) as DFX having similar objectives of cost, quality, yield, time-to-market and time-to-volume where X refers to a stage in PLC [1]. DFM has become synonymous with DFX and the concurrent engineering (simultaneous development of a design and process) [8] where DFX tools are focused to provide the designer with predictability information on multiple issues across PLC.

Initially DFM efforts were based on the rough estimates of downstream effects and rest was expected to be controlled by advanced process control (APC) and advanced equipment control (AEC). It went well till 250nm (Fig.2) but after that increasing complexity of circuit layout and shrinking sub wavelength lithography (model to hardware gaps) eventually resulted multiple respins and yield losses. 130nm node is considered the cut-off point where need for DFM was felt to tackle increasing feature

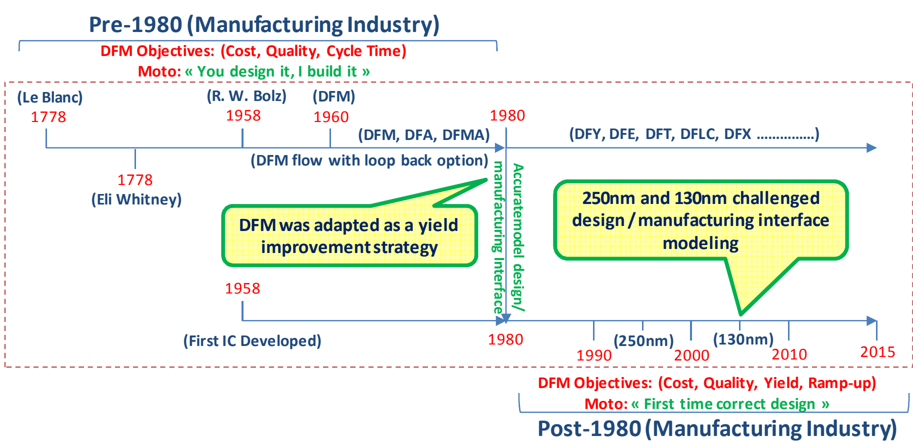

Fig. 2. DFM History and Evolution (pre and post 1980 eras)

limited and design limited yield losses [7]. From a designer's perspective, things are getting more difficult because process windows received from manufacturing are so tight that they are having a hard time getting design methodologies to work" [13].

Technology platform is characterized by a design reference flow, device, interconnect models, processes, equipment and engineering data analysis tools. It is developed in an alliance with partners to share high R&D costs based on partial product life cycle and is then deployed across the complete PLC for the new products (Fig.3). Design phase is critical as design costs are 10% of the total product design and development costs but 70-80% of manufacturing costs are decided in this phase [1, 4].

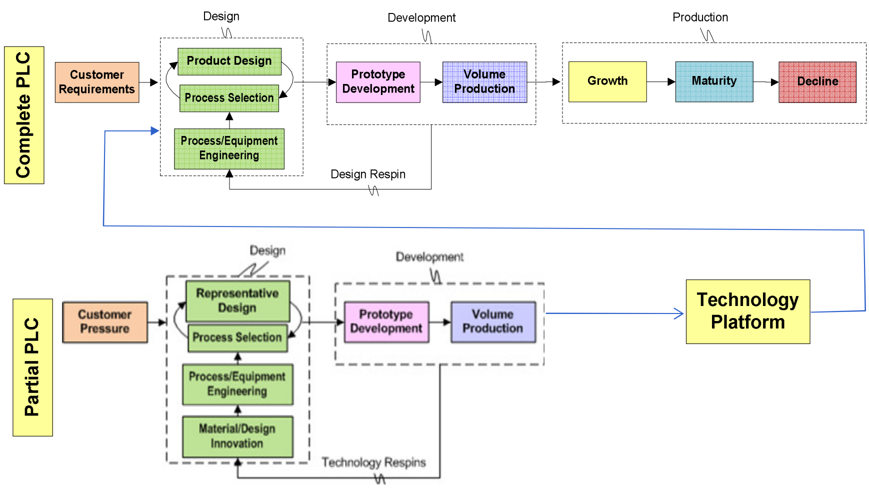

Fig. 3. Complete and Partial Product Life Cycles (PLC)

Operations within an IDM can be categorized as DFM (design for manufacturing) and MFD (manufacturing for design). DFM refers to the operations focused on concurrent design, process selection and prototype development for technical/economical design evaluation [8]; whereas MFD is focused on controlling repetitive operations dedicated to normal production (e.g. advanced process and equipment control APC/AEC). DFM and MFD follow design to manufacturing and manufacturing to design information flows respectively [13], supported by engineering information systems like AMHS (automatic material handling system), MES (manufacturing execution system), SPC (statistical process control), FDC (fault detection and control system) and engineering data analysis. These tools optimize production line capacities and support data driven DFM efforts; however R&D engineers spend most of their time in data extraction, cleaning and alignment before statistical analysis. Primary goals of DFM and MFD are to enlarge the process yield window [15, 16] and to keep manufacturing process in that yield window [11] respectively.

3 IDM Business Model and Qualitative Analysis

IDMs are focused on cost, quality, yield and performance and operate in collaboration with EDA, IDMs, foundries and customers in CAD, technology and product alliances respectively. We have benchmarked a world reputed IDM business model (Fig.4) for new technology development, characterized by device/interconnect models and DRM (design rule manual). Device and interconnect models refer to the FE/BE (frontend/ backend) technology and represent processes used to manufacture transistors and interconnects between transistors. Their output is compiled as rules and constraints in libraries, packaged in design and DFM kits used by the designer to simulate new product designs. These simulations assess the product functions against specifications and predict yield with which it can be manufactured for a given technology platform. Technology platform (Fig.4) developed in an alliance is called common technology platform (CTP) and when deployed in the manufacturing facility of an alliance partner, it is referred as internal technology platform (ITP). Products designed using an ITP having backward compatibility, can be manufactured at any alliance partners manufacturing facility (referred as outward manufacturing) and similarly products designed at alliance partners design centers can be manufactured at our manufacturing facilities (referred as inward manufacturing). Product manufacturing decision is taken by the customer based on yield and ramp up rate demonstrated by alliance partners.

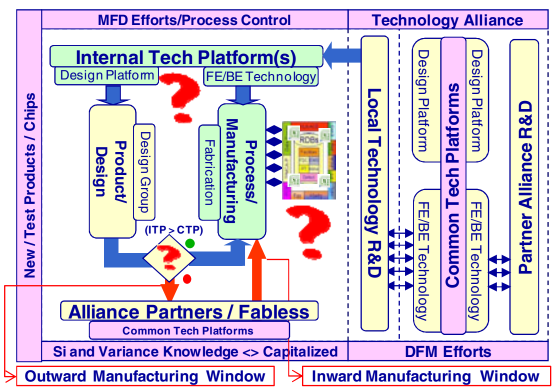

Fig. 4. Existing IDM Business Model in a Technology Alliance

To remain competitive, SMI need to send products quickly to the market with highest production yield and this is not possible without a robust/mature technology platform [12]. [6] Every new technology should have 2x transistor densities, ability to ramp quickly with multiple designs (focused on Design rules and DFM rules) and yield to be as good as or better than previous node (focused on trading off DFM constraints). DFM plays a significant role in technology development and manufacturing process improvements supported by EIS, however principal design of these EISs are coherent to operational efficiencies and support only data driven DFM efforts. Key objectives of an IDM in a technology alliance are to: i) ensure ITPs backward compatibility with alliance partners' CTP (keep intact outward manufacturing window) ii) continuously inject competitiveness by improving ITP (enlarge inward manufacturing window). Alliance partners have access to CTP, similar equipment and material but still one partner get more market share and enjoy high profit margin than others, why? Answer to this question is not trivial, so two questions are formalized and used within brain storming sessions during SWOT and use-case analyses as under:

a) do we have methods to improve device and interconnect models and product development process (Fig.4)?
b) can our manufacturing databases and EIS support continuous improvement in ITP (Fig.4)?

IDEF0 model is presented for the technology platform development process (Fig.5) to answer above questions; however detail description cannot be presented due to time, space and confidentiality constraints. Series of discussions and interviews were held with design, integration, modeling, engineering data analysis and DFM teams in a world reputed SMI. This analysis highlighted device and interconnect modeling as the key functions towards improving a given technology, characterized by improvements in the DRM. Efficiency and effectiveness within sub-functions PT analysis, Inline/PT correlation and inline (geometric)/PT (electrical) data extraction contribute to improve the interconnect modeling function and similar improvement in the device modeling function shall result in an improvement chain reaction ultimately leading to a new FE technology or improved process. It is also observed that the top ranked IDMs always

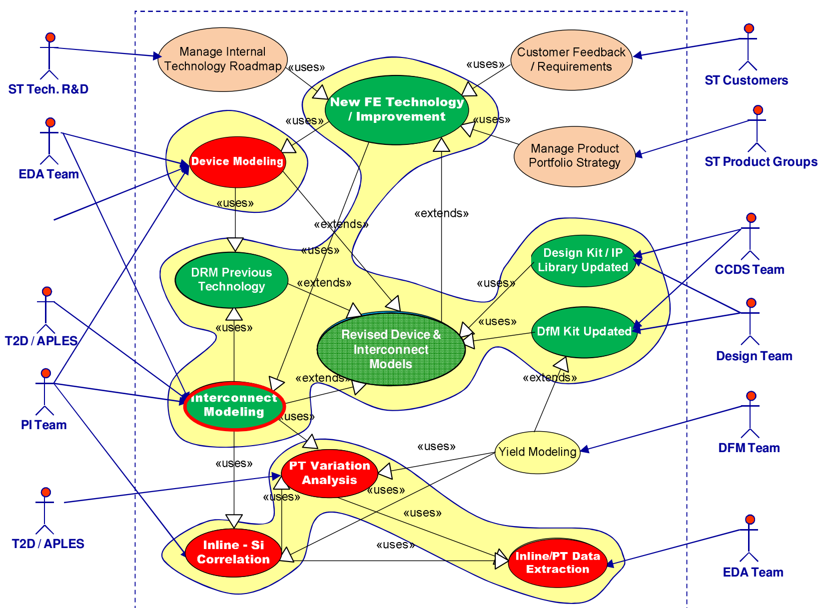

Fig. 5. Use-Case Analysis for Technology Platform Development Process

adhere to best practices and systematic approaches (maturity levels assigned to each step during process or model development); hence answer to the first question is yes, an IDM always use the best practices with the continuous improvement efforts.

A product in SMI is characterized by electrical parameters with target and corner values (SPECS) and models are mathematical equations that determine the behavior (current leakage, timing, delay etc.) of a component (IC) based on geometric shape and process variations. Failures resulting from the process variations force us to either apply MFD efforts (reduce dispersion) or enlarge parametric specs at the cost of area, power consumption and heat generation. During technology transfer models (device and interconnect) are received from the source plant and adapted at the receiving plant as per local environment; hence we perform process and equipment R&D to generate a process window close to the target process received with min geometric variations and dispersion. Success lies in our ability to quickly adapt internal models with those received from the source plant. This process requires simulation followed by validation using prototypes; hence inline-PT data extraction (measurement data), PT variance analysis (model validation based on electrical test results) and PT-inline correlation (root cause analysis against significant variation) enable us to quickly mature our models and deploy them within production lines. During analysis we made following observations:

a) multiple manufacturing data sources (relational databases) dedicated towards operational excellence do not support DFM/MFD efforts; hence engineers spend a lot of time in extraction, cleaning and alignment before analysis and in most cases, it results in zero value addition

b) manufacturing data resources have serious ontology issues (same parameter with different semantics in different databases), as a consequence it becomes difficult to align and correlate data resulting in a missed opportunity

c) unstructured evolution of local databases has resulted missing links which are key to perform a multivariate or predictive modeling across databases

d) Excel is widely used tool in SMI besides advanced statistical tools in an IDM but engineers prefer excel and that could result in misleading conclusions

From above facts we conclude that ontology issues, missing links between databases and transformation of relational databases into temporal multi dimensional structure is a must to support DFM and MFD R&D efforts during technology transfer or existing technology improvement processes. Based on these results we propose an extended IDM business model (Fig.6) where red arrows show local DFM and MFD efforts focused on continuously improving ITP by exploiting manufacturing data. It provides a flow of information and knowledge from manufacturing data towards technology platform and ultimately in the hands of designers through an updated design and DFM kits. This local improvement process interestingly highlights an inward manufacturing window from alliance partners design centers towards local manufacturing facilities. This extended IDM business model focus on keeping intact external manufacturing window while improving ITP to enlarge inward manufacturing window.

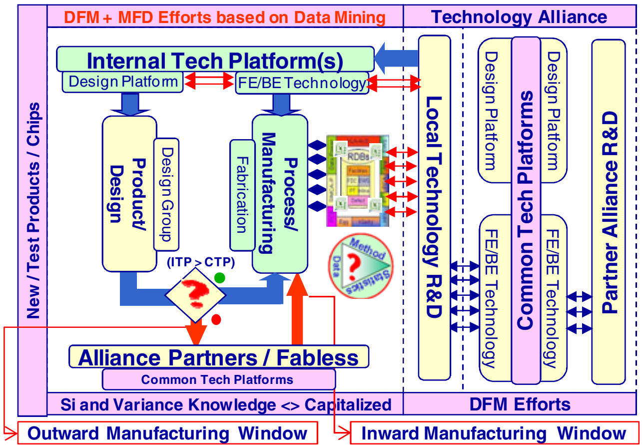

Fig. 6. Proposed Extended IDM Business Model

In order to analyze the conclusions made from use-case analysis and formulate a strategy to be used for smooth transition towards proposed extended business model we performed SWOT analysis (Fig.7). SWOT is focused on the top ranked objective "ramp up rate" because today ramp up rate is directly linked with the profitability and depends on IDMs ability to reduce cost and cycle time of the product. Questionnaire and brainstorming sessions were held with technology R&D, device engineering and process integration teams in this regard.

SWOT analysis resulted in the proposition of the 4 strategies as under:

a) **Strength/Opportunity Option:** This option suggest joint ventures with the top ranked IDM to best exploit our strengths e.g. intellectual capital, state of the art equipment, data and methods against potential opportunities (high revenues and market share).

b) **Strength/Threat Option:** This option suggest focus on the design, process, equipment and material innovation to mitigate threats like limiting physics laws, technology platform development and backward compatibility and dynamic customer requirements

c) **Weakness/Opportunity Option:** Ontology issues, missing database links, usage of excel for data analysis, min knowledge capitalization (correlation between geometric and electrical measurements); hence to exploit opportunities, It propose focus on the knowledge capitalization and improved coordination between R&D functions and should be applied in conjunction with option(d).

d) **Weakness/Threat Option:** This option suggest to mitigate threats by eliminating ontology issues, establishing missing links between database and tuning EIS by transforming relational data sources to multidimensional data structures coherent for advanced statistical analysis.

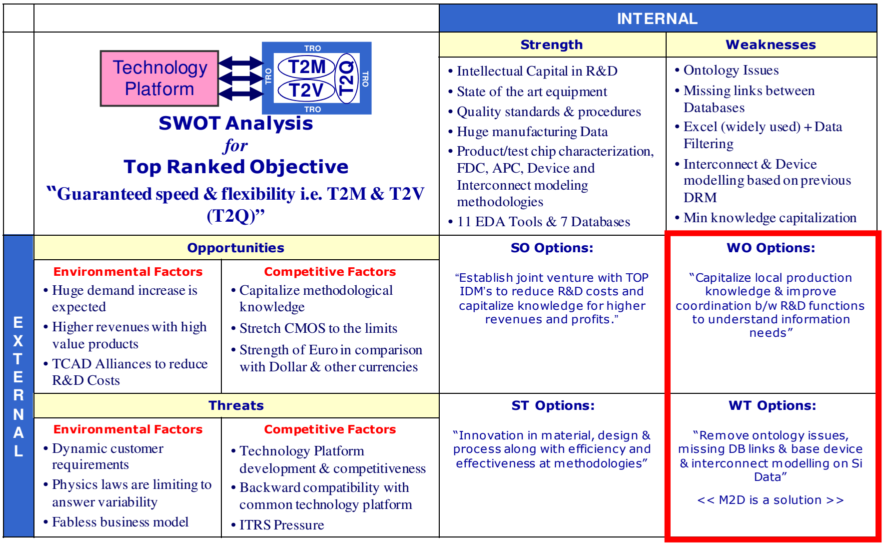

Fig. 7. SWOT Analysis Results

Strategies a & b are already deployed at the IDM under consideration i.e. establishing joint ventures with top ranked IDMs and incorporating every year a significant number of industrial PhD students as well as collaboration with LABS and industrial partners; however added value come from the weakness mitigation. It shall strengthen the opportunity window by minimizing threats; hence strategies c & d should be focused. Rectification of ontology issues, missing links and increase in silicon (results from the wafer measurement) knowledge capitalization must be enhanced. It cannot be achieved until and unless we tune our engineering information systems by transforming relational data sources to multidimensional data structures truly coherent with advanced R&D objectives.

Based on the above analysis and discussion we easily identify that DFM is dependent on data-method-stat triangle and success lies in our ability to accurately interpret knowledge from this data analysis. We propose the concept at very basic level for this term to be taken as data driven DFM efforts, which is truly inline with the global objectives to assess manufacturability, yield and yield ramp rate. In the current scenario when design and manufacturing interface complexities have risen to heights, we need to shift from data driven DFM towards information and knowledge driven DFM. This concept provides the basis for our proposed extended methodology which is focused on increasing knowledge and this is not possible until and unless we remove ontology issues and missing links between manufacturing databases.

4 Conclusions and Future Perspectives

The DFM concept has a wide range of understanding across manufacturing industries and has emerged in multiple diversifications like DFY, DFT, DFE, DFX etc. We have proposed a unified DFM concept based on data, information and knowledge and is strictly focused to address the extended shift of DFM objective (yield ramp up rate). Profitability within SMI is directly linked with this new phenomenon hence we need to accurately model design/manufacturing interface complexities. Industry has shifted to a fabless business model to address this extended DFM focus and resulted EDA vendors as the key stake holder to help DFM integration in the design flow. This collaboration among competitors from the past resulted in information sharing and technology transfer challenges. We argued that IDMs have an inherent capability to support faster and superior knowledge capitalization and proposed an extended IDM business model based on use-case and SWOT analysis. Analyses results concluded data, statistics and unsuccessful data driven DFM efforts as the limiting factors that led SMI to a fabless model. DFM efforts support manufacturability and yield assessment BUT yield ramp up rate could only be achieved if DFM and MFD efforts are joined together as proposed in our extended IDM business model which is focused on keep intact outward manufacturing window while enlarging inward manufacturing window. It is achieved by fine tuning existing EIS as DFM compliant systems by transforming the existing relational data sources to multidimensional data sources and incorporating agility within EIS for compliance with data model evolutions.

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