Whitepaper

Digital Engineering with XperiDesk

Version 1.0

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Abstract

Technology development in many high tech industries like semiconductor, photovoltaic, and MEMS becomes more complex every day. At the same time, development cycles need to be shorter and shorter. Due to the required increase in speed, the question arises, how organizations can cope with this ever increasing pace and gain efficiency through digitization in engineering. Because after the general movement to digitize manufacturing the next logical step is to digitize engineering.

In this whitepaper, we describe an approach to take the next step to improve engineering efficiency. Intelligent usage of software allows efficiency gains by digitizing and automatizing several tasks traditionally performed manually by engineers. These gains are enabled by the virtualization of experiments through simulation and emulation and by the holistic collection and management of all information generated by virtual and physical experiments.

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1 Introduction

The demand for semiconductor and Micro Electrical Mechanical Systems (MEMS) products has grown substantially in the last couple of years and is projected to continue to do so for the coming years [1], [2]. This growing demand introduces new technical and organizational challenges. On the one hand, design cycles have to become shorter to meet the market demands and cope with the increasing competition. On the other hand, product complexity has increased as each new product generation has more demanding specifications and performance requirements. One way to address these changing boundary constraints is that companies focus on their core competencies and start to collaborate with other organizations along the supply chain. The downside of this approach is that the coordination between the partners makes the development environment even more complex and getting everybody onto the same page becomes a challenge. To innovate collaboratively in ever-growing ecosystems in a faster and more cost-effective way requires new approaches and new technologies.

After the hype about Industry 4.0 and the overall digitization of manufacturing, the next logical step in the overall digitization movement is to digitize and improve efficiency in engineering. Technology development and engineering in many industries is driven by physical experimentation. Unfortunately, the data storage is done in silos by department or system. The omnipresent MS Excel plethora or partly even the usage of pen and paper aggravate the problem. In this realm intelligent digitization of the engineering infrastructure bears quite some potential efficiency gains. Not being open to the unpreventable movements towards more digitized engineering and staying with the traditional approaches is a dangerous approach, as can be seen from several examples in the manufacturing space. New and more efficient collaborative product engineering (PE) approaches, in conjunction with extended digitization in the engineering space are essential to keep pace with increased innovation levels. Possible approaches are to leverage new or maturing software technologies and to adopt more effective digital engineering methods. Both are required to align all involved parties, foster information exchange and improve the rate of innovation.

Characteristic to the Mico and Nano Technologies (MNT) industries (semiconductor, MEMS, nano materials, etc.) are the different application areas, the variety of technologies and the considerable number of small and medium sized companies active in these industries. The development of new products, their geometric design and their manufacturing steps are interdependent (i.e. manufacturing processes are generally application specific). This must be taken into account when collaboratively developing new products with several partners in an ecosystem. To survive in a market that becomes more competitive every day, a cooperative and distributed development approach must be used by those market players.

Cooperation and distribution consists of two levels or dimensions. First of all, internal development teams are in most cases multi-disciplinary. For example they need to cover the domains of process engineering as well as device / mechanical engineering. While the first groups' background is typically physics or electrical engineering, the device engineers oftentimes have their backgrounds in mechanical engineering, biology or chemistry. Difficult to overcome vocabulary

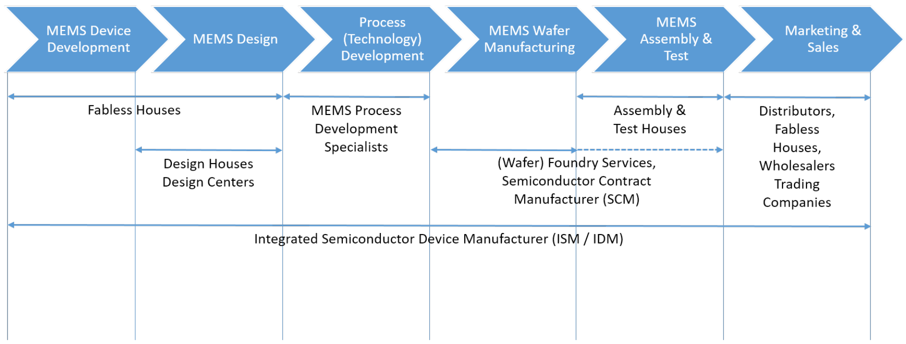

Figure 1: Supply chain and Business models in the MEMS and MNT industry

and mindset differences stem from these differences in background. Making things worse, distributed teams, potentially over several continents, add to the complexity in the workplace. Figure 1 shows the full value chain on the example of the MEMS and MNT supply chain. It can be easily seen that the value chain might cover multiple legal entities. Second dimension of complexity might be seen as a collaboration and distribution between different legal entities, increases the challenge to develop new MNT products fast and cost-effective even more. To successfully cope with these issues a digital engineering approach is needed.

A comprehensive digital engineering methodology must put the "customer" (as a purchaser of the desired devices or products) into the driver seat. The customer in this context needs to be interpreted in a very brought scope. A customer could be an end customer or user or it could be the internal product management, sales, CTO, etc. The digital engineering approach must give the customer control over the specification, design flow, and other steps as well as facilitate an agile development approach. Additionally, digital engineering must provide fast development cycle times and give the customer an early idea of the potential future product. Therefore, the voice of the customer needs to be carefully considered during the development process and his involvement in the development needs to be interwoven into the digital engineering process. An overview of the vision of the integration model of all involved stakeholders is outlined in Figure 2.

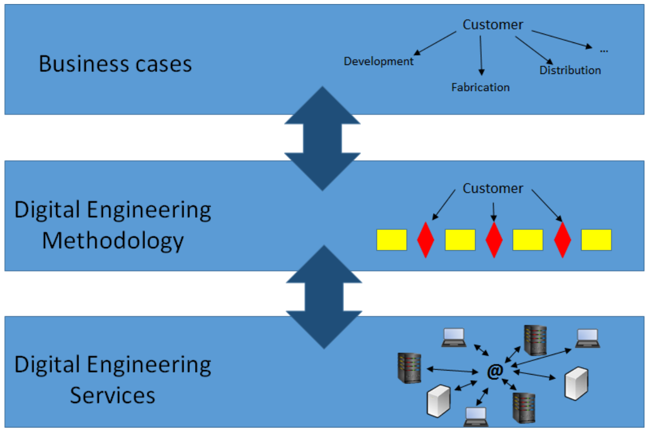

Figure 2: Hierarchical model of the MNT business

2 Solution approach

The question is, how this customer involvement can be improved without getting into a micro-management scenario. One solution is to have digital driven collaboration processes where the customer becomes involved regularly, but only when agreed milestones are reached. These milestones are rather fine granular set, like mini-approval gates for all completed tasks. This follows the Stage-Gate[3] product development methodology but on a much more fine grained level. More details about this approach, a complete business process map with stages and gate criteria and indicators for the required software landscape can be found in [4].

Because the complete process would be beyond the scope of this paper we want to focus on the critical question of the regular interaction with the customer. It is important to communicate the progress and to align on the vision, the target, and the intermediate steps. With this paper we propose to leverage the continuously improving manufacturing emulation, by surrogate models simplified simulation [5], and simulation software systems like Technology CAD (TCAD). With TCAD tools 2D or 3D structures can be generated representing more or less realistic approximations of layers, structures and devices as if they would be manufactured in a real facility.

The current problem with this approach is that each emulation or simulation software needs an expert to properly use it and each software tool has its own language. This leads to the challenging task to keep everything in sync. There could be e.g. an Excel sheet with the principle process flow, a description for the emulation tool, an input file for the TCAD simulator and finally the result images from processing. Oftentimes changes in one (e.g. an additional insulation layer is needed) are difficult to reflect in the other locations to be changed. And experts for the tools are a rare resource which prolongs the process or leads to projects "skipping" these important steps in favor of doing some experiments faster. So the real key to a successful digital engineering environment with virtual development steps is the data management and the support of multiple tools from the same data source.

New approaches layered even above the emulation and simulation tools must allow every process engineer to perform simulations without detailed knowledge about the emulator / simulator capabilities. This will enable the broader roll-out and adoption of simulation / emulation techniques. They can give the customer an early idea of the device which will be manufactured in the future and can be used to iteratively refine and become more specific on an indented structure and behavior. This approach involves the customer more deeply in the development process and prevents diverging from the requirements and intend. It helps to catch errors early, before expensive production runs are made.

To facilitate such an approach combining the different software approaches of Process Development Execution Systems (PDES), Technology CAD (TCAD) simulation capabilities and rapid virtual manufacturing / digital engineering tools allow easier communication between all stakeholders (e.g., process engineers, device engineers, customer, ...). Together with a matching methodology, comprehensive development coordination between all involved parties can be achieved. Furthermore, collaborative knowledge management is enabled.

3 Software driven approach

Combining software tools of the above-mentioned categories has several advantages. A PDES, like XperiDesk, can be used as a central and single front-end for recipe management, manufacturing flow design, simulation and emulation tools and holistic experiment tracking and tracing as well as information management. It is able to manage and execute emulations / simulations in parallel with different approaches or even different emulators/simulators from the same manufacturing flow design. The seamless switch between the calculations engine's even allows using concepts like abstract design. Such a design approach starts at very early design iterations when only principle step-based process flows are possible. These flows, on a level of deposit, litho, etch, can already be emulated (together with the intended mask design) resulting in rectangular/cubic like structures for a very first impression / manufacturing emulation. An example of such an early emulation is presented in Figure 3. Later iterations in the design cycle would become more and more physical simulations enabling predictions of real manufactured structures taking into account effects like undercuts, etc. An example of a more physical simulation is presented in Figure 4.

Furthermore, abstractions like models varying depending on the used equipment and their assignment to process flows allow the creation of complex simulator input files with a single button click. This approach has the big advantage of enabling process engineers to use different emulation and simulation tools without intimate knowledge of the emulator / simulator.

Another advantage of the integration approach is the comprehensive collection of process recipe and flow information, design intend, simulation results and experimental results in a centralized PDES. This allows seamless iterations over all domains. Therefore optimization loops of the simulation (e.g. recipes) can be performed because the full context of a production process is available. This is ensured by the PDES tools covering the full development cycle indicated in Figure 5.

Together with other verification tools, the new digital engineering workflow presented in Figure 6 can be established:

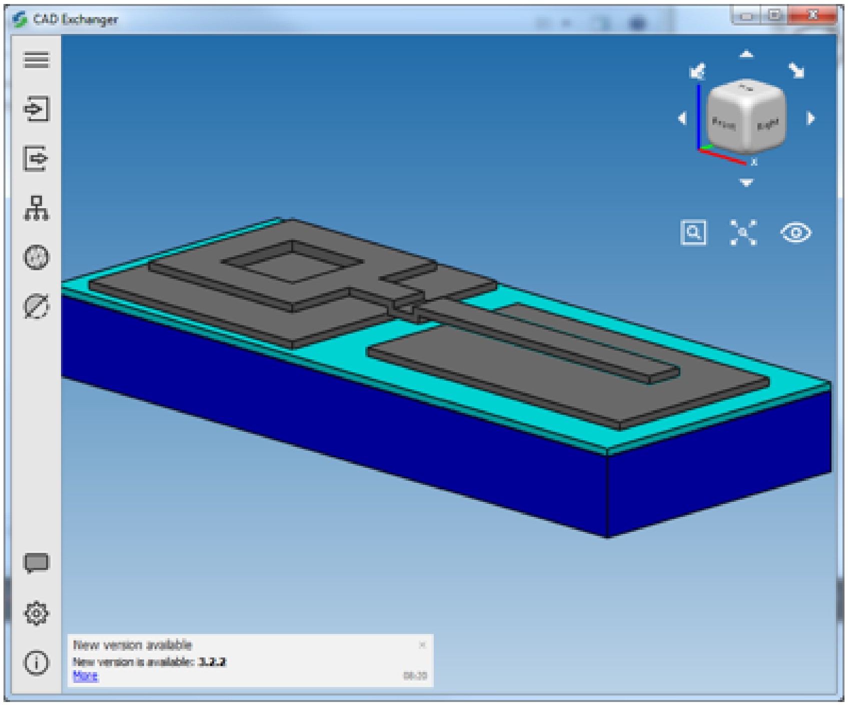

Figure 3: Example of a very early emulation result

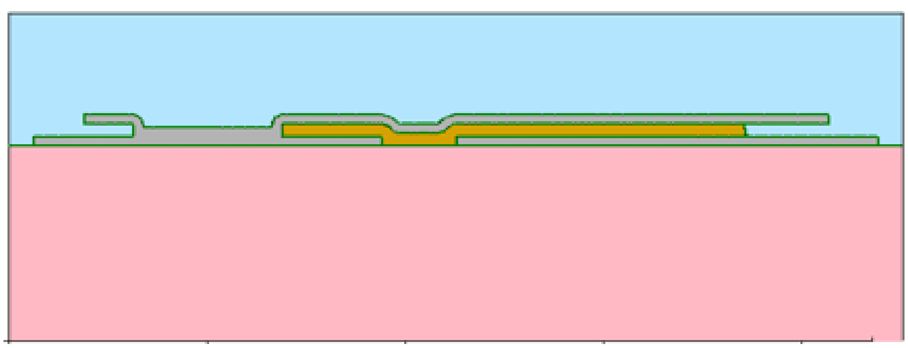

Figure 4: Example of a more physical simulation result

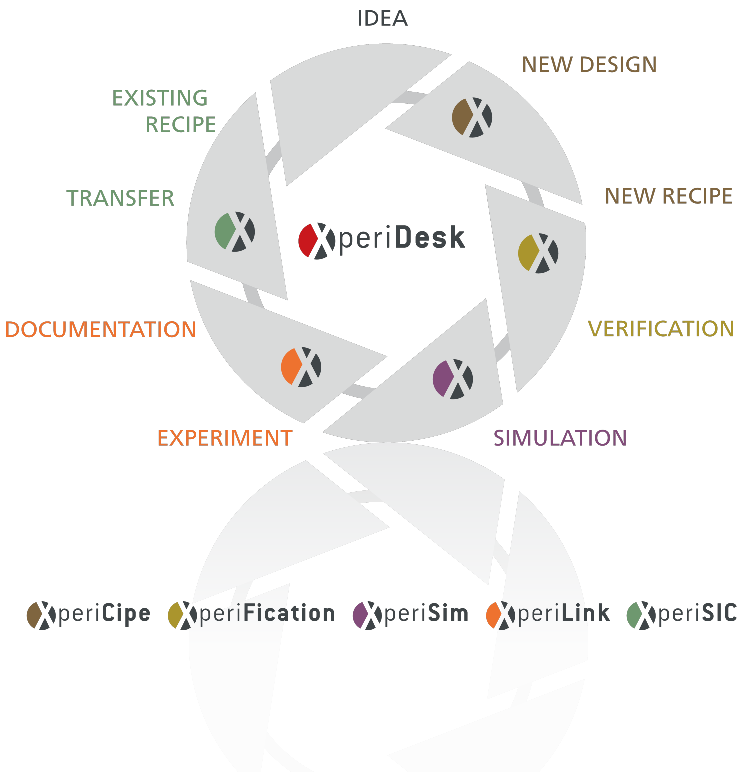

Figure 5: XperiDesk Development cycle

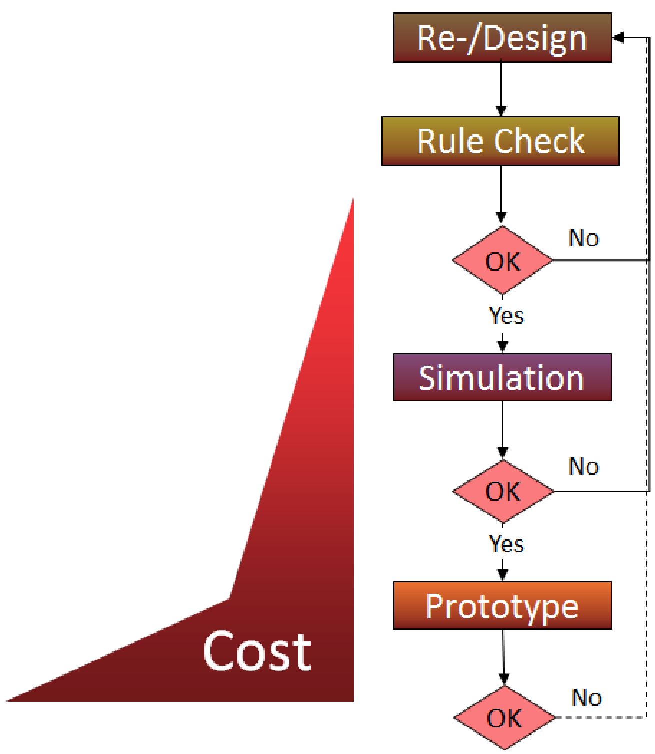

Figure 6: Cost curve along the verification flow

1. Verification of the process flow by a rule check (e.g. all cleaning steps are included, is the temperature budget met). Process flow design errors are caught early on.
2. An initial validation of the device and process is performed using fast emulation tools like LAM's SEMulator3D or SoftMEMS MEMSPro, driven from the same process flow as step 1 together with the corresponding mask set (see Figure 3). The mask layout can be verified in conjunction with the process flow. The ability to generate and share three dimensional models quickly and easy enables high-quality communication between process engineers, device engineers, product owners and especially the customer. Design and processing errors can be caught at this stage.
3. Detailed verification of the device using physical simulators like Silvaco Victory or Synopsys Sentaurus. The same information base as for steps one and two is used! These simulations require more calculation time but can provide more insight and take more physical effects into account (see Figure 4). Again design and processing errors can be caught at this stage.
4. Prototype production and verification by various measurements. The results are also stored in the PDES to deliver a reference base for further projects.

In workflows used today, step one is done manually by experts, or if available, by the Manufacturing Execution System (MES). With increasing complexities of the process flows, the manual evaluation becomes more and more error-prone. Additionally, an absent expert on vacation or on sick leave can hinder the progress of the complete project. The process recipes used at this early stage are often newly created and are not known good manufacturing steps with documented resulting properties. The PDES system functions as a library of known good recipes that are quickly identified and linked to the Foundry or Development fab where the recipe is currently run. By using a hierarchy new process steps can be easily created from existing known good recipes lowering the probability of wrong process steps.

The steps two and three are done today independent from the process development. So a changed parameter like a layer thickness must be transferred manually to the emulation or simulation model. If this is not done (e.g. by missing communication) the whole execution of the simulation is pointless.

A novel aspect of the proposed digital engineering workflow is the ability to quickly prototype devices and processes virtually in a 3D software environment using process emulation (step 2). These techniques allow process engineers to realize some of the benefits of 3D virtual manufacturing, without the difficulty and costs associated with the usage of more traditional process simulation (TCAD) tools. 3D models may be used to validate process sequences and device layouts, and even more importantly, to communicate ideas and requirements between process engineers, device engineers, and customers. Today such communication typically happens using sketched 2D cross-sections or abstract representations of devices. An interactive, accurate 3D model allows much higher quality communication between stakeholders and ensures that important details will not be missed or misunderstood. In addition, once a process and device design are chosen, the same 3D model can be given to yield management engineers, process documentation groups, and failure analysis engineers. The ability to drive process emulation from a comprehensive PDES, as well as to store and disseminate 3D models via said system, ensures that everyone has easy access to the same high-quality 3D models.

Step 3 in the above-outlined flow refers to more thorough, traditional but optional TCAD analysis. Compared to step two this step performs more physically based simulation but at the costs of higher license prices as well as much longer simulation run times. Therefore both, emulation as well as simulation steps, have their own right of existence.

Finally, step four is where the most data, like Scanning Electron Microscope images and other measurement results are generated. While not part of the virtual manufacturing but being part of the digital engineering workflow it can provide valuable information for the improvement of recipes, manufacturing flows as well as for models and simulation steps. Also, new rules for step one of the design verification process can be inferred from those results making the next application of the rule check even more comprehensive and building the basis for a learning system.

4 Conclusions

Digital engineering can be accelerated and made more robust by removing media breaks and feeding similar information into several different (calculation) tools. Because digital engineering can be grounded with real manufacturing process recipes, the time to transfer to manufacturing is minimized. Valuable resources in time, material and money can be saved by employing multi-step virtual verification of processing projects. This enables the engineers to have stable prototypes available faster and products to be on the market faster.

5 References

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