# Design to Succeed: Integrated MEMS Development

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## ABSTRACT

Designers of Micro-Electro-Mechanical Systems (MEMS) face many challenges by being forced to meet product specifications within the limitations of processing and thin-film material parameters. To create a successful MEMS product, there must be collaboration between experts in the target industry and MEMS experts in processing, materials, and other relevant technologies. The use of an integrated CAD for MEMS™ tool by all parties involved can greatly reduce the number of design and fabrication iterations required to successfully commercialize the product.

Leveraging Corning IntelliSense's over ten years of experience in the development of MEMS, IntelliSuite® provides a unified development platform for process development, thin-film material engineering, mask layout, and device and package analysis. Here we will outline a proven strategy for cost-effective, rapid product development.

## INTRODUCTION

Approaches to MEMS device development vary. However, the final goal – an economically feasible, functioning product – remains the same. And, anyone looking to commercialize a MEMS product must understand it, make it, and package it. If all designs involved readily understood behavior, standard processes, and off-the-shelf packaging, integrated development would not be nearly as important. However, the wide range of potential functional requirements for MEMS products invariably requires customization, integration, and innovation with the device, the process, and the package. Integrated development is the way by which all key elements of the product are considered from the earliest stages of design.

## CHALLENGES IN MEMS DEVICE DEVELOPMENT

As potential new products and markets emerge for MEMS devices, designers face continuous pressure to get the design done right and fast the first time. Whether or not they have direct access to a foundry, a fabrication run costs time and money that could be spent on additional product development. Corning IntelliSense has identified five significant challenges or cost components to MEMS development:

- Need for a multi-disciplinary design team
- Development of device-specific process flows
- Need for multi-physics analysis
- Inefficiencies during technology transfer
- Development of custom packages

### Understanding the Device

The range of MEMS markets and devices dictates that MEMS design teams have knowledge of many different disciplines. Traditional MEMS devices have required the expertise of process, material, mechanical, and electrical engineers. New devices may require input from biomedical, chemical, or RF engineers. While it is possible to create co-located teams containing all of the required personnel, there are high resulting fixed costs for hiring and retention of the employees.

Whether co-located or otherwise, all team members must be able to communicate design ideas. This can best be done through an integrated design platform, accessible to all of the designers. IntelliSuite provides such high levels of accessibility by providing a uniform design interface that also interacts seamlessly with external tools with which the designers may be familiar. This tool allows material engineers to enter properties resulting from specific process parameters and mask designers to generate mask layouts. Process designers can then select the appropriate process settings that will generate the required geometry and material properties from the masks given. Designers can simultaneously work on a model, automatically generated from the specified process flow, to confirm that all of the inputs indeed generate the desired output. The architecture of the CAD system is shown in Figure 1.

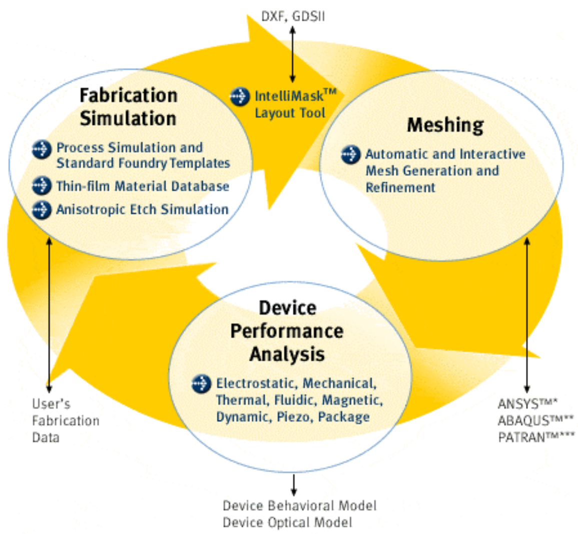


**Figure 1 Architecture of an integrated CAD for MEMS tool, IntelliSuite**

The design process typically begins with the entry of material properties, specific to the process parameters that will be used at the foundry, into a database. Simultaneously, the process steps themselves are entered into a related database. IntelliSuite currently provides over 100 pre-programmed materials and process steps from fabrication facilities worldwide, while also allowing the user to enter new, potentially proprietary, data.

Next is the development of the process flow itself. While standardized processes do exist, they are currently not optimal for any category of device, nor does Corning IntelliSense expect standardized processes to be adopted in the future for commercialized MEMS devices. Even though these processes have been used for proof-of-concept, there is no common element across all MEMS devices that will guide further standardization. Instead, commercial devices will rely on customized processes, able to capture range of inputs, outputs, and behavior required of the particular device.

While IntelliSuite does contain standard process flows, its primary fabrication function is to allow designers to create custom flows. This is done by selecting individual process steps, and then specifying each step's relevant process parameters. This process table forms the core of the design, incorporating the mask layouts and determining the final 3D geometry.

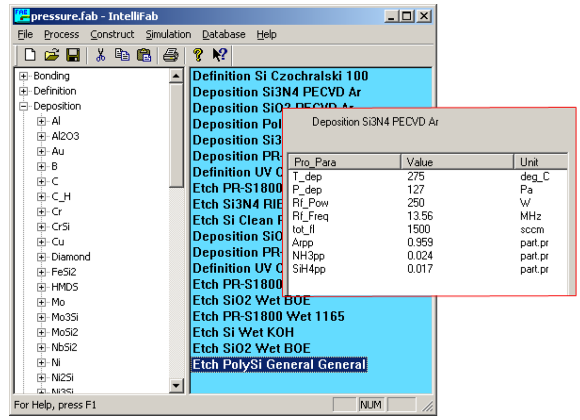


**Figure 2 Sample process database, flow, and step data**

Within this process flow are linked the mask layouts and material properties. Mask layouts are linked at Definition steps to IntelliMask™, IntelliSuite's layout tool. IntelliMask reads and writes GDSII and DXF files, as well as its own format. This tool allows mask designers to design within the IntelliSuite environment, import files from their other layout tools, and export files to their mask vendor while maintaining consistency of thought and files with the process engineer and designer. The effect of changing the mask can be seen instantly in the 3D model, and process or design changes can be quickly communicated to the mask designer.

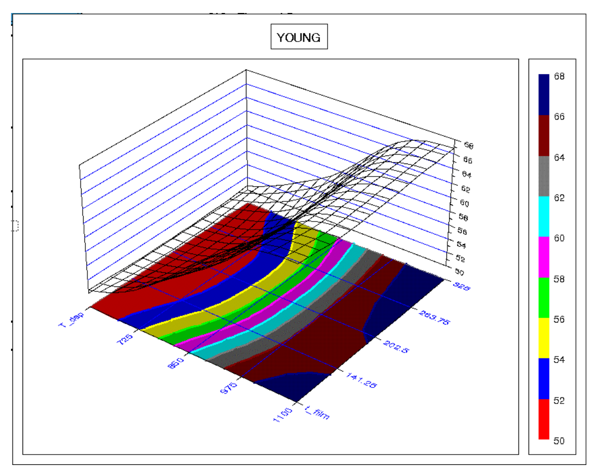


**Figure 3 Sample MEMaterial graph showing the effect of changes in the temperature of deposition and the film thickness on the Young's modulus of the material**

The final aspect at the process end of the software is thin film material engineering. MEMaterial® enables process engineers to evaluate the effect that changing the process parameters may have on the fabricated device. Also, the material properties resulting from the designed process parameters can be studied before fabrication to ensure that regions of high material variability, and therefore low process repeatability, are avoided. Figure 3 shows the effect variations in the temperature of deposition and film thickness may have on the Young's modulus of the material. This graph shows that while the film thickness plays little role for this material, the temperature can affect a 35% change in the Young's modulus over the range shown.

Once the process flow and masks have been defined, a 3D solid model is generated for analysis. The analysis engines within IntelliSuite encompass thermo-electro-mechanical, microfluidic, piezoelectric, and electromagnetic domains. Standard analysis tools do not capture the physical interaction occurring in MEMS devices; this level of integration is only captured by a CAD for MEMS tool.

CAD for MEMS tools capture the range of physics through a myriad of solvers, each potentially working on their own meshed domain, which is then re-related to the whole structure to generate a model with the resulting interdependency. While it does take some time to adapt to using such a diverse tool, it is this diversity that allows MEMS engineers with all categories of backgrounds to use the tool to optimize the device. Techniques and compatible file formats are included so that any trained engineer can relate their experience in IntelliSuite to another standard analysis package they have previously used. For example, design of a separation system such as the one shown in Figure 4 might require expertise from mechanical, electrical, material, chemical, and biomedical engineers.

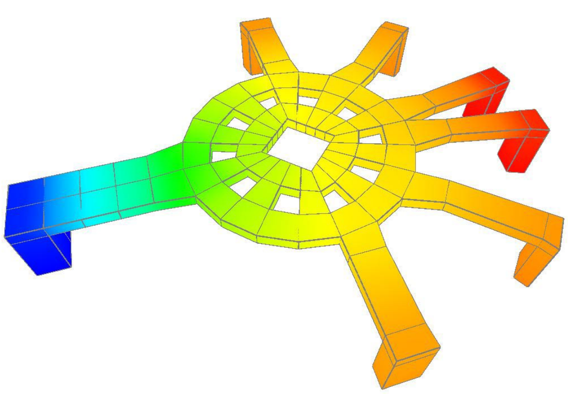

**Figure 4 Separation system**

## Making the Device

To make the device, coordination must occur not only between the design team and the process engineers, but also between the process engineers and the foundry. IntelliSuite enables these activities by providing an interface that can be used by both the process and design engineers. If a standard process is being used, a process template will provide easy communication to the fabrication facility; if a custom process has been generated, the process parameters have already been established during the model creation process and can easily be sent to the foundry. Finally, if there are changes made to the process at the foundry, they can be easily implemented in IntelliSuite and the design can then quickly be rechecked by the design team.

The second problem that must be overcome prior to manufacturing is technology transfer. Since few MEMS design teams have direct access to a foundry, there must be streamlined communication between the design team and the foundry. If both parties have access to an integrated design tool, this communication can be facilitated through the sharing of process and 3D model files. Sharing of these 3D files can greatly accelerate comprehension on both sides of the design and of any changes that may occur.

Another element of the technology transfer problem is the use of standard processes for prototypes and/or proof of concept and then a shift to a volume manufacturer or a customized process for manufacturing. This transition usually results in lost time, and in some cases inherent design changes. If such technology transfer is going to proceed smoothly, volume manufacturing equipment and techniques must be considered during the prototyping phase. This can be facilitated by having strong knowledge of the capabilities of volume manufacturing facilities and techniques. If the customer does not have this expertise, they must rely on the foundry. This knowledge gap, and the associated problems with technology transfer can be dramatically reduced by selecting a foundry geared towards volume manufacturing for the prototyping phase. The result is a continuous process, facilitated by a single team at the foundry familiar with both prototyping and volume manufacturing. By offering software, design services, development services, and volume manufacturing at a single facility, Corning IntelliSense has successfully addressed the technology transfer problem and proven that an integrated design and fabrication approach can bring a customer's product to market faster.

## Package the Device

The final challenge that must be addressed is the package. Some MEMS devices can be packaged like standard IC or sensor products. However, most MEMS devices have unique requirements for their interaction with the outside environment and therefore require custom packages. Simultaneously, the package itself can have an affect on the performance of the device, frequently detrimental but sometimes critical its performance. Therefore, it is important that a design tool be capable of simulating the package and it is important that the design team consider the packaging requirements from the earliest possible stages of design.

Corning IntelliSense offers package analysis with IntelliSuite and has a packaging team and packaging facilities associated with the foundry. This again allows the customer to interact with a single outside entity to move seamlessly and promptly from design, through prototyping, to manufacturing, and finally to packaging and assembly.

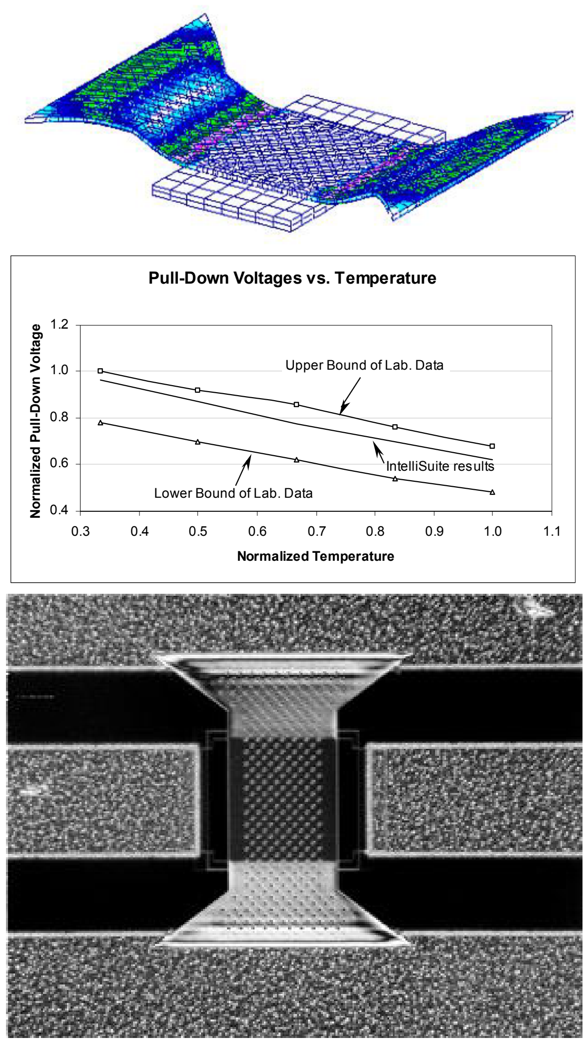


**Figure 5 Raytheon's RF switch showing IntelliSuite simulations (Von Mises stresses, recent voltage vs. temperature date) and fabricated device [1, 2]**

## BENEFITS OF INTEGRATED MEMS DEVELOPMENT

Bringing the product to market quickly is the goal of every design team. Within the highly competitive nature of MEMS industries, this is even truer. Utilizing an integrated development approach, where fabrication and packaging are considered from the earliest stages of the design process, and where potential hurdles are eliminated along the way will result in the fastest possible commercialization path.

Corning IntelliSense's customers have benefited from our complete knowledge of all aspects of the MEMS development process. Fabrication expertise shows throughout IntelliSuite, with the ability to model processes, engineer thin films, and perform test etches prior to entering a foundry. These capabilities are used by customers working with their own in-house or external foundries worldwide, as well as by customers who have selected Corning IntelliSense as a foundry partner.

At Corning IntelliSense we provide complete integration – from CAD through manufacturing – to the customer. By employing a multitude of engineering disciplines, encouraging process customization, enabling analysis of the widest possible range of MEMS devices, coordinating both prototyping and manufacturing, and providing packaging services, Corning IntelliSense can bring a concept from any stage of the design flow through to successful commercialization.

## CONCLUSION

There are many benefits to integrated MEMS development, all of which enable companies to develop products better and faster, resulting in more successful commercialization. Integrated development itself is the coordination of the design process with the manufacturing and packaging process. Successful integrated design will include consultation of all necessary engineering disciplines, consideration of the process from the earliest stages of development, analysis of all of the physics relevant to the device, transition of technology from prototyping to manufacturing, and generation of a packaging allowing for device specific communication with the environment.

REFERENCES


1. Yao, Z. J., Chen, S., Eshelman, S., Denniston, D., and Goldsmith, C., "Micromachined Low-Loss Microwave Switches", *IEEE Journal of Microelectromechanical Systems*, Vol. 8, No. 2, June 1999.
2. Unpublished data from direct communications with S. Chen (Raytheon), February 2002.