Leveraging Mainstream Design and Analysis Tools for MEMS

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ABSTRACT

Mainstream CAD/CAE tools are used to rapidly design and commercialize a broad product line of rugged MEMS-based optoelectronic devices for applications including telecom, oil and gas production, process monitoring, medical diagnostics, and scientific discovery. These tools deliver the robust capabilities previously available only with specialized, often expensive, MEMS-focused options.

This paper illustrates some of the considerations in choosing a MEMS CAD/CAE tool, and provides examples of mainstream tools successfully used in MEMS design and analysis.

Keywords: MEMS, CAD, FEA

1 INTRODUCTION

Now that MEMS technology has broken through from research to commercialization, companies around the world are in a race to deliver better, smaller, and cheaper MEMS-based alternatives in virtually every industry and field, including consumer products, automotive, medicine, scientific discovery, process monitoring.

Because time-to-market schedules are now measured in months and quarters, and engineering and manufacturing challenges make up the bulk of the critical path, it is imperative to leverage concurrent engineering practices, and take advantage of tools that help reduce the number of design iterations.

While some MEMS design and analysis challenges are not ready to be tackled by mainstream tools, many are. It is therefore worthwhile to consider the capabilities and advantages mainstream CAD/CAE tools offer:

- one standard CAD tool to design everything
- 3D visualization;
- associative photomask definition;
- sub-micron feature definition;
- design re-use and configuration management; and
- integrated finite element analysis (FEA).

2 3D VISUALIZATION

MEMS designers often use layout software that is inherently two-dimensional. However, solid modeling tools offer MEMS designers better design visualization. 3D gives designers a clear and accurate review of parts (Figure 1) and assemblies (Figure 2) early in the design cycle.

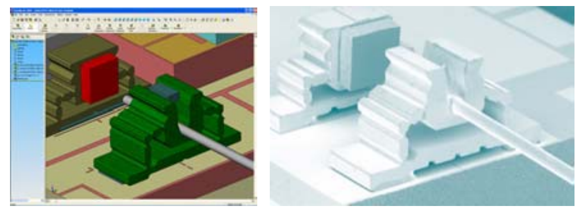

Figure 1: LIGA component model and SEM photo

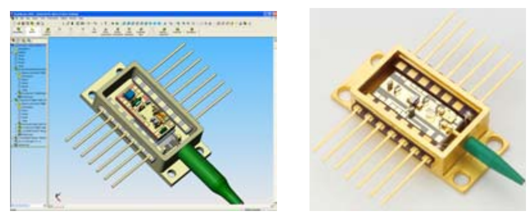

Figure 2: Miniature Spectrometer model and photo

The ease of use offered by mainstream 3D packages is of paramount importance. After all, many MEMS designers are not mechanical engineers or CAD “power users,” often driving the CAD system just a few hours per week. CAD/CAE tools built and running native on the ubiquitous Windows operation system leverage standard user interface paradigms such as drag-and-drop and menu structures.

3D visualization provides MEMS designers a first check of design intent, proper operation, collision avoidance, and package stack-up, helping identify potential problems early in the design cycle – before committing to a mask or processing wafers. Modeling and verification of all the components for the high-speed optical interconnect module in Figure 3 within one CAD model provided the confidence to quickly commit to tooling investments for the cooler, package, and assembly equipment.

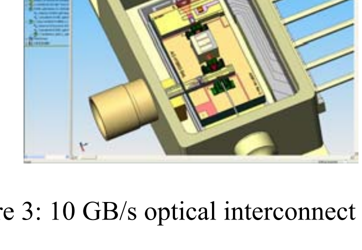

Figure 3: 10 GB/s optical interconnect module

For example, automated checking of clearance design rules can be particularly important for surface micromachining to ensure proper etching and separation of parts during lift-off processes. Any interference will stop motion between parts that contact and the point of interference can be highlighted.

True motion simulation, integrated into some mainstream CAD packages and long used by machinery designers, can now help the MEMS engineer simulate mechanisms, such as meshing gears, and showing their operation in the assembly. While not a substitute for all simulation (e.g., gear stiction due to Van der Waals forces), many common questions arising during design can be answered immediately.

Illustrated in Figure 4 is a miniature electrostatic jog motor for a lens focusing application, whose rotation is converted to linear actuation through use of a rack-and-pinion assembly. The rotation is gear-reduced first, resulting in very fine positional control. Even at these small scales, mainstream CAD tools can provide kinematic simulation.

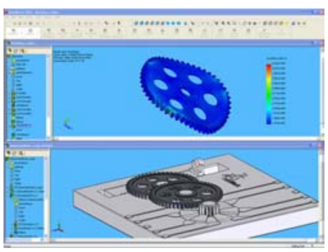

Figure 4: Miniature motor and gear assembly. (Courtesy Schiller Engineering)

3 DESIGNING TO SCALE

Given that dimensions associated with MEMS designs commonly range from fractions of microns to – in the case of package, system design, and assembly equipment – meters, there are advantages to designing to scale, and in 3D.

Not only can features such as optical gratings and micro-gears be designed to scale in 3D, but a MEMS package can be modeled in context of the chip design, and the assembly fixturing and machinery can be modeled in context of the package. Designing in the same scale, using the same CAD tools, it is possible to take advantage of the automatic design propagation that mainstream CAD packages can offer.

In response to needs of MEMS designers, some mainstream CAD packages can support the wide dynamic range of dimensions (for example, exceeding eight orders of magnitude) required by MEMS products and the associated equipment. Figure 5 illustrates a MEMS optoelectronic component, module, along with a model of the manufacturing equipment used on the production line. All of the designs are done to scale, and in the context of each other; a change in the MEMS component can trigger design changes in the module and related fixturing.

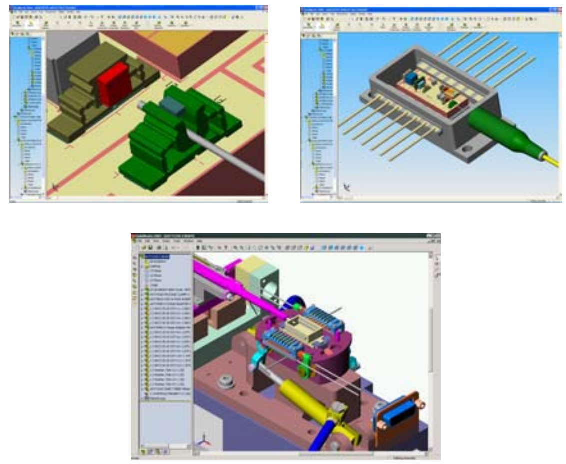

Figure 5: MEMS-based components and equipment

4 ASSOCIATIVE PHOTOMASKS

A common task in MEMS design is the creation of the photomasks associated with the various steps in the MEMS fabrication process. Bi-directional associativity in mainstream CAD packages enables change in one place (e.g., layout sketch for a single cell) to automatically propagate to all related documents (e.g., photomasks drawings), dramatically reducing the time required for engineering design changes, often from days to seconds. Figure 6 illustrates solid models and photomasks of silicon acceleration sensors. Changes in one file automatically propagate to the other.

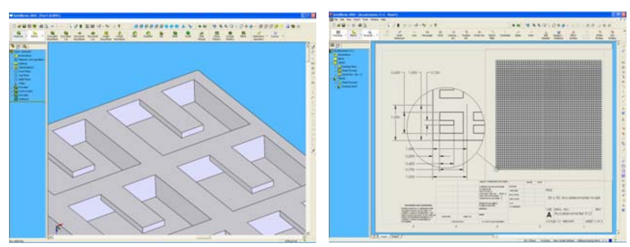

Figure 6: Solid models and photomasks

Masks for positive and negative photoresist can easily be fabricated directly from CAD files (Figure 7).

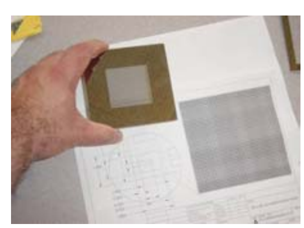

Figure 7: Photomasks created from drawing files.

For designs of even moderate complexity, generating photomasks for the various layers may be quite challenging with some CAD systems. With today's parametric solid modelers, generating 2D drawings of various cross-sections (e.g., different depths) is automatic. Figure 8 illustrates a MEMS-based variable capacitor solid model (left) and two-dimensional projected and cross-section views (right).

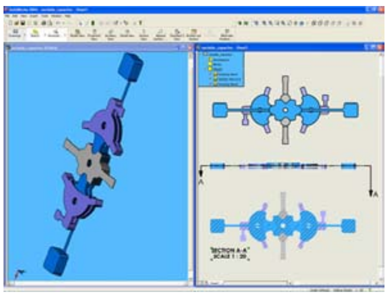

Figure 8: MEMS-based variable capacitor model (Courtesy Microfabrica, Inc.)

5 DESIGN RE-USE

New designs are frequently based on previous ones. Some mainstream CAD tools have rich capabilities to enable the designer to leverage existing designs through 2D and 3D file import.

Today's CAD systems have the ability to create a library of commonly-used features or parts as a powerful tool for designers who have already accumulated a large design database. The engineer can save time by simply dragging required components for a new assembly directly from the library and dropping them into the new design (Figure 9).

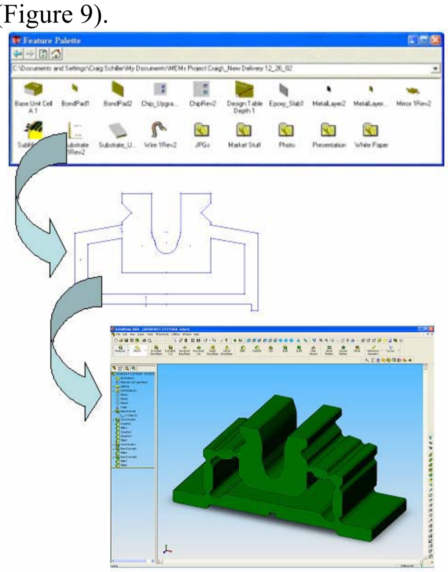

Figure 9: A sketch is dragged from the FeaturePallette in SolidWorks, and used to define a solid model of a LIGA component

In addition to reusing portions of previous designs, it is sometimes advantageous to incorporate design variants, or configurations, within a single file.

Configuration management enables the generation of multiple versions of parts, assemblies, and drawings in a single document with a minimal amount of time and effort. Configurations make use of design tables, derived design data, component properties, relationships, viewing states, and other attributes, storing part and assembly information in one area for greater efficiency. New configurations are easily developed from previously created designs to further speed development and meet market needs for data reuse.

An example application of this capability is illustrated in Figure 10. Several configurations of an optical bench assembly are created within a single SolidWorks model file for simplicity and easy design control. Selecting (activating) configurations requires a single click in the SolidWorks FeatureManager.

"What if" scenarios for different design requirements such as film thickness and modulus can be quickly explored by turning on and off various configurations of a part or assembly. Etched well dimensions and sizing of cutouts can be tied to design data for each chip size. As the chip requirements change, the necessary wafer level dimensions automatically update to reflect the new design.

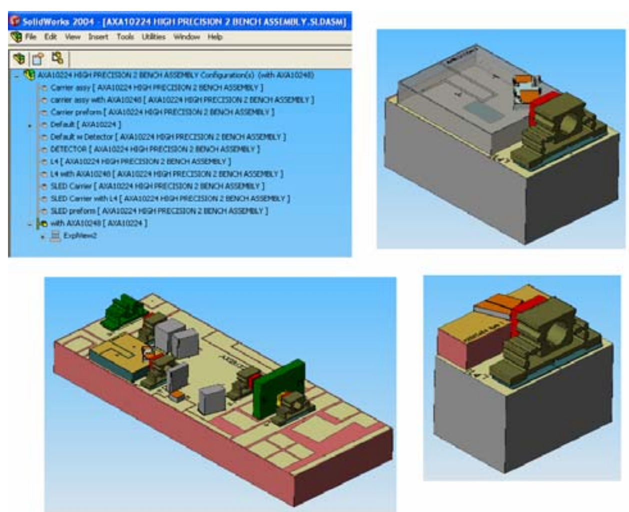

Figure 10: Multiple optical bench configurations

Components involving multistage processing, such as surface micromachining or LIGA, can easily be documented by using multiple configurations of a single part. Configuration management techniques can generate a discrete version of a part or assembly as necessary to reflect a separate version or in-process state. These versions can help compare designs, track expected performance, and develop process plans.

6 INTEGRATED FEA

MEMS products often require a diverse set of analyses, including thermal, stress, deflection, buckling, nonlinear, electromagnetic analysis, and computational flow dynamics (CFD).

Increasingly, mainstream finite element analysis tools can be relied on to meet some of these challenges, due to the tight CAD/CAE integration, relatively low cost, ease of use, and the ability to handle small dimensions and large aspect ratios.

Instead of recreating and meshing a model inside a stand-alone FEA package, the CAD solid model can be a starting point for analysis. Component material properties (applied to the product as it is designed in the CAD environment) can be automatically shared with the integrated FEA application. There is also no need to learn a new user interface.

As an example, consider Figure 11, a LIGA component used to precisely position an optical fiber. The COSMOS FEA suite [1], running inside the SolidWorks window, is used to compute the deflections associated with the forces imparted on the LIGA holder through a closed-loop alignment system.

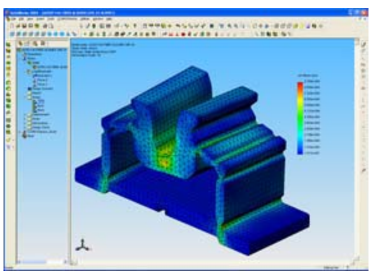

Figure 11: Finite element analysis of LIGA component

Another example is the MEMS-based electro-optic interconnect module in Figure 12. Designing the entire product – from the chip-level through to the entire system – in one CAD package, and analyzing it with just one integrated FEA package, saves not only upfront investment and training, but also the incremental efforts in design optimization.

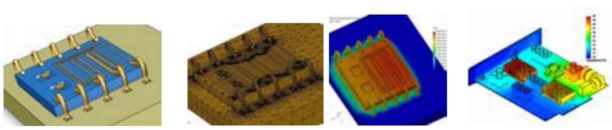

Figure 12: Thermal analysis of electro-optic interconnect module (Courtesy Schiller Engineering)

7 BUSINESS CONSIDERATIONS

MEMS designers number in the thousands, whereas mechanical designers in the millions. Hence, software tools that serve the mainstream market can amortize their development costs and debugging test cases across many more users. This typically results in software tools that are cheaper, easier to use, and with higher quality.

Because MEMS is a field advanced largely by universities and small firms, the tools' total cost of ownership and learning curve are of paramount concern. With pricing in the USD$4,000-$8,000 range, mainstream tools can offer dramatic savings over more specialized tools that often require proprietary hardware to run.

MEMS designers require powerful functionality from their design and analysis software, but it must be easy to learn and use, as they are not using it all the time. Because of the broad adoption of mainstream 3D CAD and FEA systems worldwide, and their presence in most engineering curricula, it is straightforward to find engineers proficient in these tools.

Another benefit is broad data interoperability. Using the same CAD and FEA tools as other designers within and outside the company will dramatically reduce data interoperability challenges, which typically manifest themselves as design errors and delays associated with remodeling parts from scratch.

Additionally, mainstream tools contain a great deal of useful functionality typically not available in more specialized tools. For example, mainstream CAD tools include extensive collaboration functionality, an increasingly important part of the development process, enabling designers to share designs easily with anyone, anywhere. Some mainstream CAD tools also offer a rich application programming interface (API), enabling the automation and customization of many engineering design tasks.

9 CONCLUSIONS

Advances in mainstream CAD/CAE tools' MEMS functionality, coupled with their power in addressing general design and analysis challenges, broad adoption worldwide, and availability of integrated complementary solutions, make them viable contenders for the MEMS engineer's toolbox.

REFERENCES

[1] SRAC, http://www.cosmosm.com/