

Modeling and Simulation Software in MEMS Design



Arpana Niranjana, Pallavi Gupta

Abstract - Micro-Electro-Mechanical Systems (MEMS) is a process technology that combines mechanical and electrical components to make micro-scale range devices. A considerable cost of the device can be reduced if we simulate the design. There are many available simulation software to choose from, which in turn is one of the major challenge. The paper explores the functional and technical features of some software used in MEMS designing. It further presents the keypoints which we should acknowledge while selecting software. Basic features are available in all MEMS Simulation software. However, if the design involves specific physics, geometry, material or meshing, the search must be done to find the appropriate software. If the user intends to fabricate the device then software with a virtual fabrication tool needs to be selected.

Keywords: MEMS, MEMS Simulation Software, MEMS Software, COMSOL, Coventorware, Ansys, Intellisuite

I. INTRODUCTION

The invention of the first bipolar transistor in 1948 by Bell Laboratories marked the present journey of the electronics era. In the year 1954 first working silicon transistor was developed by Bell Laboratories. In the same year, Smith [15] developed the piezoresistance phenomenon in semiconductors. This is often marked as the birth of MEMS. The prototype for a pressure sensor was given in 1961 and the journey of MEMS began. Since then various researches have been done and devices are developed commercially. They can be used as actuators, accelerometers, switches, sensors, etc. The key principals used in MEMS design are capacitive, piezoresistive, resonant and thermoelectric. They have found its usefulness in many industries like aerospace technology, biomedical applications, automobile, inkjet printers and the list increases every day. MEMS are manufactured from a variety of materials (semiconductors, ceramics, plastics, etc) and manufacturing methods (bulk micromachining and surface micromachining). Modeling MEMS often requires interdisciplinary knowledge of the mechanical and electrical background. Depending on the application user needs to have information about thermal, optical and biological background too. Primarily MEMS design process involves a Design goal, Structure design, Optimization, Fabrication, and testing. However, before fabrication, we need to be certain that design satisfies the original design goals, this is where the need of MEMS simulation software steps in.

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We design the model, simulate it and then use the 'trial and error' method for device optimization. Once the model is met with desired design goals, fabrication can be done. This saves a lot of time and cost to the designer. Modeling of the MEMS can primarily be done in two ways namely, theoretical modeling and numerical modeling [11]. Theoretical modeling comprises using one or more theories to achieve results. Theoretical modeling allows us to control all variables and efficient for simpler designs. If the design is complex (irregular and nonlinear geometry, two or more physics involved, different structure, etc) then it becomes difficult to perform theoretical modeling. It is useful for verification of FEA results.

Numerical modeling is widely used to simulate the MEMS design. The most common numerical method used is Finite element Analysis (FEA). FEA for MEMS can be seen as a method to analyze how MEMS design will behave in the real world. It allows us to model complex geometries, boundary conditions, etc. Using FEA tools can significantly reduce the cost of the device as it eliminates the need for several physical prototypes of the device.

Some major considerations while using FEA are that output results may vary in different FEA tools [10], the output may differ also when using different boundary conditions, meshing; etc. FEA tool requires a high-end computer for simulations and execution time may also be longer depending on geometry, boundary conditions, multiphysics and mesh element size.

II. MEMS SIMULATION PHASES

FEA tool is widely used in simulations of MEMS Devices. Typical steps involved in the simulation are defined as the design, choosing materials, boundary conditions, and load conditions analysis and display results. Figure 1 illustrates the flow graph for FEA Analysis in MEMS. Firstly, the problem is defined, the model is created, then defining geometry, materials, physics, boundaries, and meshing is done. The sequencing of these steps may vary depending on the software used. After following these steps results are calculated, interpreted and optimized. Afterwards, optimized results are compared with the desired design solution, if the design goal does not match then the 'trial and error' method is used by changing values in initial steps (Geometry, material, etc.) until the desired result is achieved. Once desired results are achieved user needs to decide whether he wants to display results, fabricate the device or use results for further simulation. In case of fabrication, a virtual fabrication tool needs to be selected, so fabrication steps can be defined and Design Rule Check (Foundry have its own set of rules for fabrication) can be done. Lastly, the results are used for Physical prototype manufacturing.

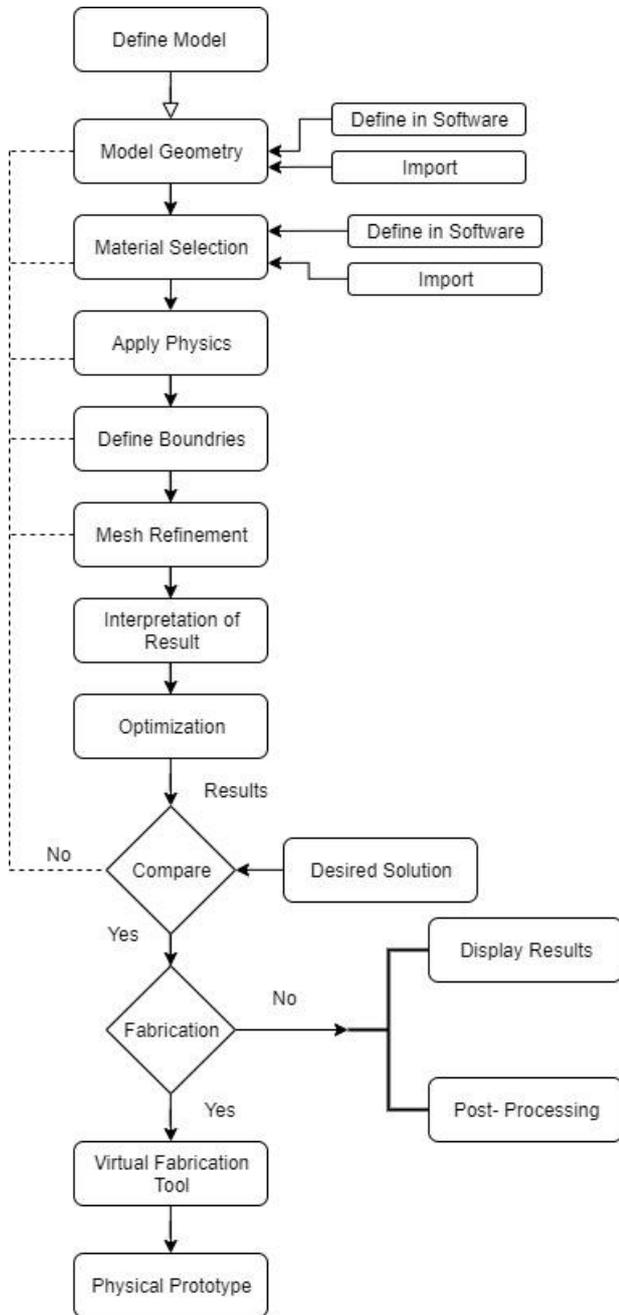


Fig.1 General FEA MEMS Workflow

In general MEMS simulation process can be defined into three phases namely preprocessing, Analysis and post-processing[7].

Preprocessing involves creating geometry, material selection, boundary conditions, and meshing. All MEMS software provides preprocessing steps. However, they also allow the user to import these if necessary, into the software. User needs to check software website to avail the list of allowed file formats and software interfaces.

The Analysis involves assigning loads and constraints and finally solves the model.

The postprocessing involves the viewing of the results and further processing (post-simulation). MEMS software provides analysis results for the device. It may be in the form of nodal displacements, Element forces and moments, Stress contour diagrams, Deflection plots, Excel, animation or PowerPoint. If the device is to be made using MEMS, it will require further connection to IC's. So the user may need

to connect the results from MEMS Software to other Software for further analysis. Figure 2 depict MEMS Simulation phases.

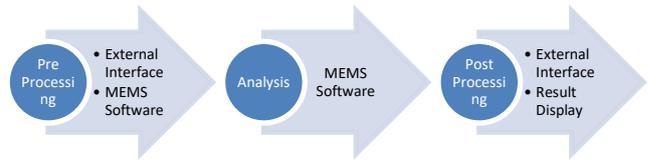


Fig 2. MEMS Simulation Phases

A. Available software for Preprocessing MEMS Simulations

MEMS software provides models for geometry creation. Sometimes due to complexity or ease of use, it appeals to use other software for creating geometry and then import in Software. Some commonly used software for creating geometry are MathCAD, AutoCAD, Vectorworks and Layout Editor.

B. Available software for MEMS Simulation

Some key software used for MEMS simulation are Ansys, COMSOL, Sugar, Coventor, and Intellisuite. Table 1 compares some features of four commonly used in MEMS Design Software. The software are compared with each other and not with any other software available in the market.

ANSYS

ANSYS stands for Analysis System and was founded in 1970 with its headquarters in Canonsburg[19], Pennsylvania. It is Product Life cycle management software that provides solutions for many mechanical problems such as structural analysis, heat transfer, fluid problems, acoustic problems, etc. Some of the products include 3D Design, Optical, Structures, Semiconductors, Fluids, Embedded software.

Some features are firstly it has GUI and Coded command interfaces. Secondly, it allows users to expand the structural solution to include explosion, drop test, penetration analysis, fatigues analysis. Thirdly it is capable of performing linear and non-linear analysis; fourthly it provides the ability to simulate coupled field behaviors. Lastly, it provides complex math operations, macros, branching and looping, and parameterization,

Ansys workbench workflow includes selecting the required system, material choosing, geometry creation or import geometry, Meshing, setting the boundary, and load conditions and lastly analysis and results. Biosensors [1], accelerometer [3], cantilever beam [18] are just some of the examples simulated in Ansys. Free student version for software is available on the website.

Software is widely used by researchers as well as industrialists some companies using the software are Bentley, Siemens, University of Liverpool, Hitech, HCL, Ford, SAIL, TVS, Whirlpool and many more.

INTELLISUITE

IntelliSense is founded in 1991 with headquarters in Boston[22]. The first version of Intellisuite was released in 1995. It provides end to end tool for MEMS process simulation applications and coupled field FEA. Users can use a top-down or Bottom-up approach for design. Intellisuite provides tools that can process simulation; mask layout, package and device analysis. Since all features such as design, simulation, fabrication, and testing are available in software, it becomes easy for design engineers to communicate on a common platform.

Major Modules provided are Design Suite(Blueprint, TapeOut, and CSViewer), Clean Room MEMS Analysis (3DBuilder, BioMEMS Suite (3DBuilder and Microfluidics Analysis) Fastfield ThermoElectroMechanical Module, and EDALinker), System and Synthesis(Synple, Hexpresso, and MEMSynth). Piezoelectric pressure sensor [16], Bio-MEMS[5], microactuator [2] are some examples simulated in Intellisuite.

Some features include a vast material library, allows users to perform Design rule check (DRC), fast and accurate results, parametric scripting and results can be exported to PowerPoint.

Some companies using the software are Hitachi, Nikon, Stanford University, Duke University, Apple, Honda, Hamamatsu and many more.

COMSOL Multiphysics

The COMSOL Group was founded in 1986 with its headquarters in Massachusetts [20]. It is general-purpose simulation software for modeling devices, designs, and processes in all engineering fields, scientific research, and manufacturing. It provides many products some of them are Electromagnetics Modules, MEMS Module Structural Mechanics & Acoustics Modules, Fluid Flow & Heat Transfer Modules, and Chemical Engineering Modules. It also provides several interfacing modules with other software (CAD, MATLAB). Some features are firstly material library is very vast and it allows users to change properties of materials if needed and the user can also define new material. Users can use the Matweb database and directly import material properties. Secondly, the user can view and define PDE anytime. Thirdly, it provides ready-made couplings between common physics and, the ability to handle CAD assemblies. Lastly, support for the multiphysics analysis of surface contact.

Comsol workflow consists of adding geometry, Defining Physics, Meshing and computing results. COMSOL support many file formats and output can be exported in Excel, images, and movies. Users can also export data to other software using interfacing links. Bimorph electrostatic actuated Cantilever beam[17], Capacitive Pressure Sensor[13], Bio-Sensor[6] are some example in COMSOL. Researchers and industrialists both use COMSOL widely. some companies using COMSOL are Fermilab, Duke university, Fujifilm, Siemens Healthineers, Huawei, NPL, Nokia Bell Labs and many more.

COVENTOR

Coventor was founded in 1996, with its headquarters in Raleigh, North Carolina[21]. The main products provided by COVENTOR are SEMulator3D and CoventorMP.

SEMulator3D provides the virtual fabrication environment, whereas CoventorMP includes Coventorware and MEMS+. Coventorware is widely used software in MEMS Design and device level simulation. It uses commercial solvers such as Abacus, Fluent, and Flow3D. Coventorware consists of four major modules namely Architect, Designer, Analyzer, and System Builder. Architect helps in the evaluation of MEMS behavior. Designer allows users to create the layout, masks, generate 3D solid models for solvers and define the fabrication process. Analyzer has a suite of solvers(electrostatic, mechanics, thermal, and many more) which allows users to analyze and verify MEMS Design. System builder prepares files so the user can generate output models or export the model into other software such as Synopsys, MEMS+, Cadence and MATLAB. Some features include extraction of files to make mask directly from the software and saving some FabCycles during development.

MEMS+ facilitate user to integrate MEMS Design with CMOS circuits and packaging. It helps the user to rapidly analyze MEMS and CMOS designs in Cadence(Circuit level), MATLAB and Simulink(System level). Gyroscope[4], MEMS comb structures [14], Micromechanical Switches for AC Power Handling[12] are some examples in Coventor.

MEMS foundries such as DALSA® and FAB® use SEMulator3D for Process development, Physical design verification, Customer support, and Failure analysis. Coventor is used by researchers as well as in industries. Some industries using the software are Texas Instruments, IBM, Sony, Fairchild Semiconductor, Toyota, Hyundai, Honeywell and many more.

MEMS PRO

MEMS Pro was founded in 2004, with North America Headquarters in Santa Clara, USA[25].

It is CAD tool for MEMS Design, and is a combination of MEMS and IC Design tools. It provides system-level design capability. It Features include easy creation, a schematic entry tool, layout verification, an analog, and mixed analog / digital circuit-level behavioral simulator, a design rule checking feature, generates netlist for verification, allow data sharing, allow automatic mask layout generation from an ANSYS and has powerful optimization algorithm. It allows simulation of a system containing MEMS and IC's, where MEMS components can be represented as equivalent circuits, tables of data or behavioral model. The software supports popular fabrication processes.

Software modules include MEMS Modeler, Layout Editing, MEMS Verification, 3D Solid Modeler and foundry modules. MEMS Modeler generates behavioral models. Layout editing includes a hierarchical and custom editor for MEMS Design. MEMS Verification modules are used for the Design Rule Check (DRC) used by the foundry. 3D Solid modeler creates a 3D view of the MEMS Device.

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Some Files supported are GDSII, CIF, EDIF, and DXF. Accelerometer[9], capacitive gyroscope[8] are some examples in MEMS Pro.

MEMS Solver

MEMS Solver is a simple analytical tool specifically designed for MEMS [23]. The software has a vast analytical model that represents the most commonly used MEMS. The user just needs to provide basic design and rest (meshing, boundary condition, etc.) is done by software. It provides device design and process design capabilities.

Software features include graphical representation of result, no programming skills are required and command-line input. There are five modules provides namely mechanics, sensing, actuation process, and data analysis.

SUGAR

It is an open-source simulation tool, based on nodal analysis techniques [24]. It can be used for simple designs and in initial phases of a new design. It is text-based programming and interfaces with MATLAB. Analysis features are limited to frequency and deflection analysis.

C. Available software for Postprocessing

MEMS software simulation results can further be used in system design where it is coupled with ICs, microcontrollers, display devices. Some common software used for postprocessing results are Matlab, Mathematica, MEMS+, Simulink, VHDL, Verilog or SPICE, Cadence, Tanner and many more. Users should explore the possibility of interfacing with the desired software as it will ease the process's design.

III. KEYPOINTS FOR SELECTING MEMS SOFTWARE

In final selection for FEA software we must acknowledge the following key points:

- All MEMS Simulation software have basic features, user needs to check the external interface to export geometry or material. Exporting design or material from external Interfaces allow the user to create complex geometry in familiar environment and work with desired material.
- Most software provides common physics for MEMS simulation. It's always good to check the physics models provided in the software. If the design uses multiphysics then the software should be able to support different physics at a time.
- The software should allow different element size mesh for different parts of the design. The local mesh is very useful in complex design where we want to study some particular areas in the design. Ex. there is fluid flowing in a pipe and we want to calculate pressure at bends.
- The software should produce accurate and flexible results as far as possible.
- The software should be easy to use and study. Among other things, software should have large examples and tutorials available.
- Result produced should be in the desired format if not then it should be in an easily interpretable format.
- MEMS are often combined with other Integrated circuit for operating in larger electronic circuits. It is advisable to check the external interfaces with other software as we sometimes need to take results from MEMS Simulation software and perform further simulations.
- Parametric Analysis is another useful feature as it allows designing engineer to change the values parameters automatically and re-perform simulations. It makes optimization more efficient and less hectic for the design engineer.
- If the user wants to fabricate the design then it's beneficial to start with software having virtual fabrication module

Table 1 Comparison table for MEMS Simulation software

FEATURE	COMSOL	ANSYS	Coventorware	INTELLISUITE
External Interface Software Links	Mimics, Excel, , Microsoft , Inventor , Solidworks, PTC Creo Elements, Solid Edge, Revit, AutoCAD, Design Module, ECAD,CATIA, MATLAB, HTML	Solidworks, Simulink, Excel , parasolid CAD, MATLAB,SAT CADDs	LayoutEditor, Simulink, Cadence, SPICE, MATLAB MEMS +	VHDL, Verilog or SPICE , ANSYS, Excel, Cadence, Mentor, Synopsys, Mathworks, Tanner , Agilent, Touchstone, Tecplot, SIMETRIX, SIMULINK
Supported File Formats	DWG, IPT, IAM, IGES,AVI,PNG, MP4, DXF and more [16]	ODB ,INP, CDB, RST, RMG, ASCII FILES, ,PATRAN PLOT3D and more[15]	GDSII, CIF, DXF, SAT, IGES, and STEP	IGES, DXF, ABAQUS, PATRAN , GDS II, ASCII, CSV, MEX, PLT TOUCHSTONE or bitmap and more[18]
User Friendly	√√	√	√√√	√√
Multiphysics Modelling	√√√	√	√√	√√
Simulation Time	√√	√√	√√√	√√√
System Integration	√	√√√	√√√	√√√

Ability To Design Own PDE	√	X	X	X
Geometry Portability	√	√	√	X
Virtual Fabrication Tool	X	X	√	√
Parametric Analyses	√	√	√	√

IV. RESULTS

All the discussed software are good for MEMS Analysis. COMSOL provides the user with the best CAD modeling, easy integration of multiple modules, virtual prototype and has large documentation in the form of user manuals, blogs, COMSOL user community, and webinars. But with COMSOL we find it painful to troubleshoot a numerical model and memory requirement for simulation is also large. Ansys is useful in expanding the structural solution to include explosion, drop test, penetration analysis, fatigues analysis and simulate non-linear problems too. Ansys has difficulty in defining material properties if they are a function of multiple dependent variables. Intellisuite provides the capability to use a top-down or Bottom-up approach for design which is one of the major advantages and it also provides the capability for real-time simulation. Intellisuite and Coventorware both provide virtual fabrication tools and have the ability to define circuit layout. Intellisuite is good for process simulation whereas Coventor and MEMSPro are good for system-level simulation.

V. CONCLUSION

This paper explores the functional and technical features of the software. There are other factors that contribute to choosing the particular software. One of the main factors is availability. Sometimes the user has access to some software as Industries and Universities already have it, so the user decides to use it. Other factors include ease of use, cost of the system, support levels, service availability, future use, etc. It is always best to manifest the software, make a requirement matrix and tick what is needed, rather than getting sidetracked by all features. For example, if you are a research scholar and only want simulation results then software supporting virtual fabrication is not needed and similarly, if you want to fabricate the design as an end product it is useful to select software that supports virtual fabrication and DRC example Coventor or Intellisuite.

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