COMSOL Multiphysics for Hi-tech Industry
MEMS Application Areas

Actuators and Sensors

Gyros and Accelerometers

Resonators

Piezoelectric and Piezoresistive Devices
MEMS Module Highlights

- User interfaces for
  - electrostatics
  - solid mechanics
  - electromagnetic-structure interactions
  - thermal-structure interactions
  - fluid-structure interactions
  - piezoelectricity
  - combinations of the above
- Advanced damping mechanisms
  - thin-film gas damping
  - anisotropic loss-factors for solid and piezo materials
  - anchor damping where perfectly matched layers (PMLs) provide state-of-the-art absorption of outgoing elastic energy
- Stationary and transient analysis, fully-coupled eigenfrequency, parametric, quasi-static, and frequency response analyses
- Lumped parameter extraction of capacitance, impedance, and admittance and connections to external electrical circuits via SPICE netlists
Green Energy Examples – Energy Harvesting

Mechanical Energy Harvesting

• Waves into Electrical Power
• Generate milliWatts to Watts

Excerpted from “Wave Energy Converter through Piezoelectric Polymers”, Zurkinden, Campanile, Martinelli  COMSOL Users Conference 2007 Grenoble
Prestressed Micromirror

This model shows the fundamentals of how to set up and solve lift-off of a prestressed plated micromirror that is controlled electrostatically. A parametric study reveals how much variations in the prestress affect the displacements.
The Batteries & Fuel Cells Module

- Spiral wound Li-ion battery
- Lead-acid battery electrode
- Planar fuel cell, counter current flow
- Water-cooled Li-ion battery pack
The Batteries and Fuel Cells Module

• Specialized tool:
  – Models and simulates all major types of battery and fuel cell applications

• Ease-of-use
  – Tailored functionality/interfaces for:
    • Primary, secondary and tertiary current density distribution
    • Porous and gas diffusion electrodes
    • Dilute and concentrated electrolytes

• Multiphysics
  – Flow, electric fields, and heat transfer with electrochemical reactions

Temperature distribution in a PEMFC equipped with passive self-breathing electrodes
Targeted Batteries and Fuel Cell Systems

- **Batteries:**
  - Lithium-ion
  - Nickel-metal hydride
  - Lead-acid
  - Nickel-cadmium

- **Fuel Cells:**
  - Proton exchange membrane, high and low temperature
  - Solid oxide
  - Molten carbonate
  - Direct methanol

Discharge-recharge cycle for a lithium-ion battery simulated with the new Lithium-ion battery interface.
Fuel Cells – Multiphysics by Nature

Fuel Cells in General

- Electro Chemistry
- Heat + Flow

Slice Plots of Velocity through Transparent Boundary Plot of Concentration in Fuel Cell Stack

Stress from Thermal & External Loading
Fuel Cell Electrochemistry

Solid Oxide Fuel Cell
- Electro Chemistry
- Convection & Diffusion
- Heat & Flow

Excerpted from “Modelling and Design of Solid Oxide Fuel Cell Anode”, Tseronis, Kookos, and Theodoropouls, COMSOL Conference 2006
Fuel savings of up to 15%.

GE plans to make use of the energy generated while dynamic breaking in their hybrid locomotives to achieve fuel savings of up to 15%. Michael Vallance of GE Global Research is simulating the sodium metal-chloride batteries that will drive GE’s hybrid locomotives to enable and even increase these savings.

Company: General Electric Global R&D
Industry: Transportation
Application: Hybrid Locomotives
Simulation: Electrochemistry, ion transport, heat transfer

http://www.comsol.com/stories/general_electric_modeling_train_batteries/
Biofuels

Enzymatic Biofuel Cell
• Chemical Energy to Electricity
• Nernst-Planck Analysis

Excerpted from “Simulation of C-MEMS Based Enzymatic Biofuel Cell”, Parikh, Penmatsa, Yang, and Wang  COMSOL Users Conference 2008
Situated on the east coast of Sicily, this innovative industrial demonstration plant uses Parabolic Trough Concentrating Solar Power (CSP) technology to generate electricity during sunny hours as well as under overcast conditions or at night.

Jointly developed by Italian utility ENEL and the Italian National Agency for New Technologies ENEA, it began operating in July 2010 and is named after the mathematician and engineer Archimedes who lived in the nearby town of Syracuse.

Archimede incorporates 30,000 square meters of reflective parabolic mirror surface, in the shape of troughs. The sun’s rays are concentrated onto long thin tubes, which together make up a receiver pipeline running along the inside of the curved surfaces and stretching for 5,400 meters.

This pipeline contains a heat transfer fluid made of 60% sodium nitrate and 40% potassium nitrate, commonly used as fertilizer.
Solar Thermal Collector

- Solar to Steam
Solar Energy

Spherical Photo Voltaic Cells
• Optimal Layout of Cells
• Missing Cells for Cu Leads

Electric Field of first order ensemble of SPVC

Excerpted from “Optimal Design of Spherical Photovoltaic Cells”, Keynote Address
Morega, Ordonez, Negoias, Morega & Hovsapian    COMSOL Users Conference 2006
Laser Heating

- Lasers are commonly used to achieve precision heating or welding. The beam often moves over the surface of the substrate.

- One difficulty with modeling a laser heat source is the fact that the beam is very narrow (nm-mm). Another is that the laser has a certain penetration depth which is important.

- The scenarios that can be investigated are:
  - Stationary laser with constant & pulsed power
  - Moving laser with constant & pulsed power
344 Papers on laser applications at www.comsol.com

- Propagation of a 3D Gaussian Beam Laser Pulse
- COMSOL Assisted Simulation of Laser Engraving
- Simulation of Laser-Material Interactions for Dynamic Transmission Electron Microscopy Experiments
- Modeling 2D and 3D of Hybrid Laser Nd:Yag - MIG Welding Processes
- Laser Welding of a Titanium Feed Through
- Laser Interstitial Thermo Therapy (LITT) for Prostate Cancer Animal Model: Numerical Simulation of Temperature and Damage Distribution
- Development of laser-driven micromachines using total internal reflection
- .....
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- **Laser Interstitial Thermo Therapy (LITT) for Prostate Cancer**...
  - Papers & Presentations. Laser Interstitial Thermo Therapy (LITT) for Prostate Cancer Animal Model: Numerical Simulation of Temperature and Damage Distribution...

- **Formation Of Porosities During Spot Laser Welding**: Case Of...
  - Papers & Presentations. More services...
  - Formation Of Porosities During Spot Laser Welding: Case Of Tantalum Joining...
Optics Examples

Luneburg lens

Stress-Optical Effects - with Generalized Plane Strain and in a Photonic Waveguide

Photonic Crystals and Band-gap Materials

Modeling of Negative Refractive Index

Fig. 1. COMSOL Multiphysics helps determine the modes of a given frequency of light within the optical core. With this analysis, designers can optimize the geometry to eliminate the effects of birefringence as well as find the modes with the best propagation properties. This image shows how periodic boundary conditions can approximate real-world effects.
Metamaterials

- The RF Module has applications for metamaterial and absorptive material design for RF, Microwave, and Optical frequencies.
- General solvers allow for microstructure simulations and also macroscopic simulations where negative values for refractive index, permittivity, and permeability is allowed.
- Anisotropic materials are supported.

Cloaking model by Steven A. Cummer and David Schurig - Duke University, Durham, NC
Electronics

Convection Cooling

Heat Transfer in a Surface-Mount Package for a Silicon Chip

Viscoplastic Creep in Solder Joints

Surface Resistor Thermo-Mechanical
Electrical Circuit Components
SPICE Import

Inductor in an Amplifier Circuit
ECAD Import: ODB++ file import

Mechanical deformation + RF simulation of PCB Microwave Low-Pass Filter

S-parameters, before and after mechanical deformation

PCB Planar Transformer: Self and Mutual Inductance Calculation
Connecting a 3D Electromagnetic Waves Model to an Electrical Circuit
Biomedical Applications

- Microwave heating of tissue
- Laser Interstitial Thermo Therapy (LITT) for Prostate Cancer
- Electrical Stimulation of Brain using a realistic 3D Human Head Model
- Fluid-Structure Interaction in a Network of Blood Vessels
Mixed Polymers Form Unique One-Piece Medical Implant

We then turned to simulation software to give us more insight into the process, and in the end it was only COMSOL Multiphysics that was up to the task. *DR. MARK YEOMAN, R&D DIRECTOR, CONTINUUM BLUE LTD*
Biomedical Engineering: Medrad (USA, PA) models diagnostic equipment and more

- Speed of delivery of a contrast material to the heart muscles
- Fluid-structure interaction in catheters so that they don’t damage blood vessel walls
- Magnetic shielding of an infra-red IC communication device from the magnetic fields arising from MRI equipment
- Injection of non-Newtonian fluids (blood cells) with high shear-rates through thin syringes

Figure: The Vanguard DX catheter allows for a very uniform distribution of contrast materials. Laser-drilled holes or slits force the contrast material to be transported radially from the catheter.
Simulating Energy-Tissue Interactions for Improved Patient Outcomes

- Electrosurgery is the application of high-frequency electric current to biological tissue as a means to cut through the tissue (vaporize) and/or stop bleeding (coagulate). These types of surgeries are performed using an electrosurgical generator and a hand piece that includes one or several electrodes.
- “The end result of a better understanding of the relationship between the application of energy and the desired surgical effect and the ability to clearly demonstrate that relationship through images and animations increases everyone’s understanding and comfort with new technologies and how they are best used in a surgical environment,” asserted Mr. Ward.

Covidien’s ForceTriad™ energy platform and a few of the associated electrosurgical devices that use it as an energy source.