Fluid Flow Modeling at SC Solutions

Multiphysics modeling: A versatile tool in the engineer's toolkit

The modeling team at SC Solutions has developed fluid flow models for a broad range of applications for more than two decades. These models have been developed primarily using the commercial finite element (FEM) modeling tool, COMSOL® Multiphysics, for which SC is a Certified Consultant.

SC's modeling methodology utilizes a hierarchy of models. Depending on the goal and scope of the effort, the models may be two-dimensional (2D) or three dimensional (3D), steady or time-dependent and encompass a wide range of flow regimes ranging from creeping to turbulent flows, and low-pressure flows. In almost all cases, the flow problems involve various multiphysics couplings such as buoyancy-driven flows (convective heat transfer), conjugate heat transfer, chemical species transport, flow coupled with phase change, and fluid-structure interaction.

Fluid flow models serve several goals:

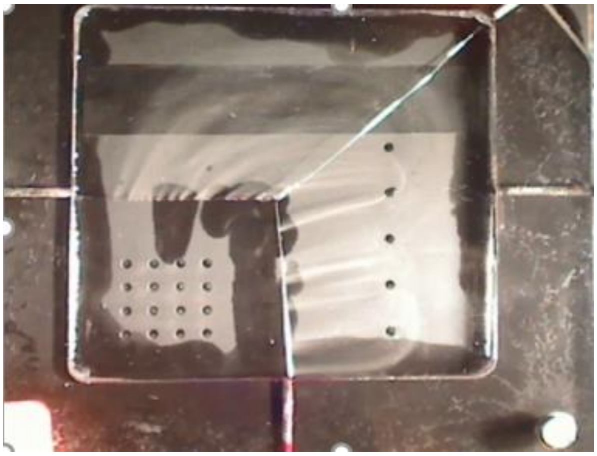
- *Modeling as a design tool*
  SC has used COMSOL Multiphysics to evaluate concept designs prior to cutting metal, minimizing design iterations and time to market for new product introductions.
- *Modeling for process optimization*
  The use of high-fidelity, experimentally- validated models provides a powerful virtual prototyping environment for evaluating and optimizing process performance of existing equipment.
- *Modeling for control*
  SC has developed low-order, fast models from the high-order FEM models for model-based control design. The fast execution speed of these low-order models makes them suitable for real-time control. Models have also been employed for virtual sensing by monitoring the performance of unmeasured process variables of interest.

Flow Through a Chamber Showerhead: Comparison with Experiments

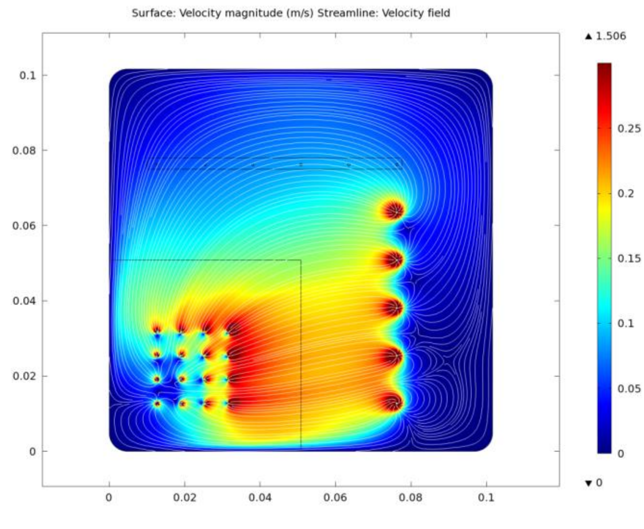
This example showcases the use of COMSOL for characterizing the flow through a showerhead of a semiconductor wafer processing chamber. Whenever feasible, we calibrate uncertain parameters in our models using experimental data and then validate the models using a different data set. Here, SC validated the flow model with in-house smoke visualization experiments.

The flow in in this example enters through a set of orifices on the lower left of the showerhead (see bottom left figure) and exits thought a column of orifices on the right. The streamlines captured in the flow visualization matches those predicted by the model simulation very well.

Experiment

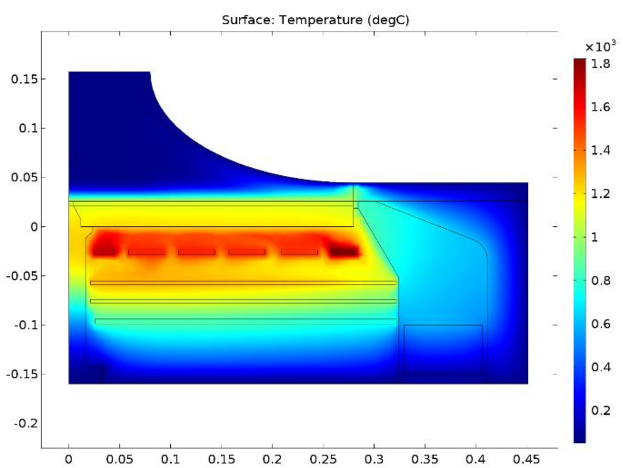


COMSOL model

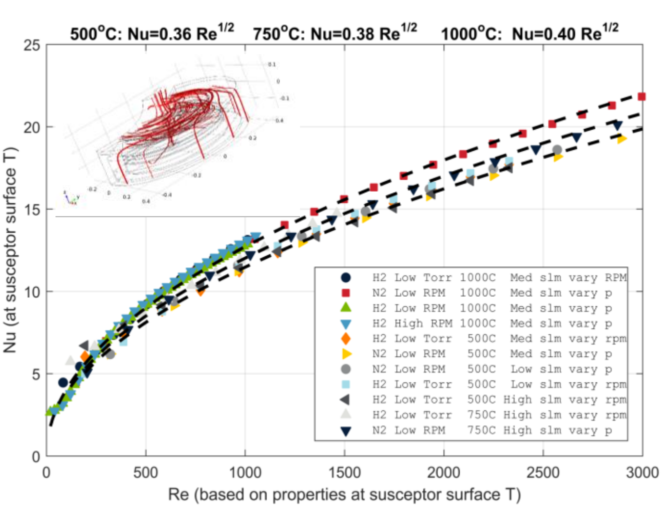


Flow Model of a Chemical Vapor Deposition (CVD) Chamber

SC has developed a non-linear flow and heat transfer FEM model of a metal-organic CVD reactor used for LED chip fabrication. Flow enters the chamber through a showerhead, and substrate rotation during the process generates a complicated 3-dimensional swirl flow. COMSOL enables coupling of the swirl flow to heat transfer simulations including chamber radiation. A snapshot of the simulated temperature profile in the chamber is shown in the figure below.

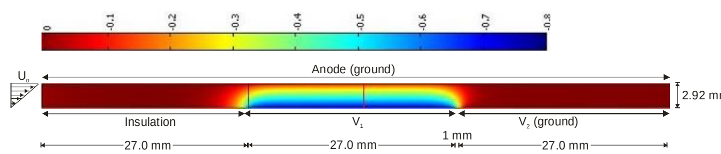


After conducting a series of simulations, we developed correlations for Nusselt number as a function of Reynolds number at three temperatures spanning the process temperature range as shown in the figure below. These correlations are useful for developing low-order models for real-time process simulations.

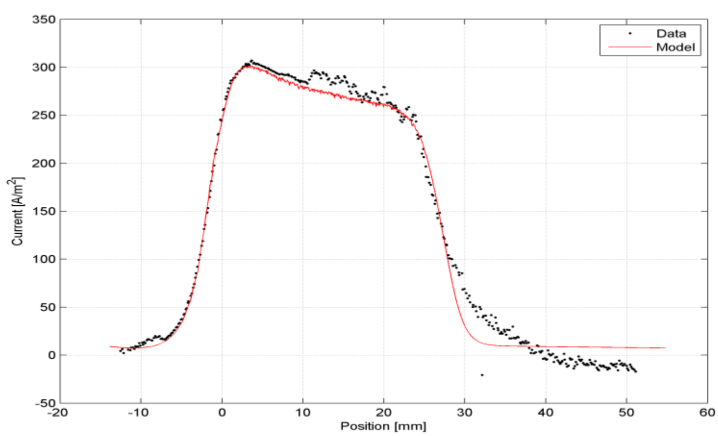


Flow in an Electrochemical-Mechanical Polishing (ECMP) Chamber

In this 2D model of flow, species transport, and electrochemistry in an ECMP chamber, the electrolyte enters from the left with a linear velocity profile (U), as shown in the figure below. Polishing occurs at the copper anode (top "wall") which is moving at velocity U0 with respect to the cathode on the pad (bottom "wall").



Simulation results for anode current matched experimental results very well and the comparison is shown in the figure below.



References:

[1] M. J. Begarney, and F. J. Campanale, Chemical Vapor Deposition Reactor, *US Patent 8,778,079*, 2014.

[2] J. L. Ebert, S. Ghosal, D. de Roover, and A. Emami-Naeini, "Experimental Validation of Model of Electro-Chemical-Mechanical Planarization (ECMP) of Copper," *Proc. 2012 COMSOL Conference*, Boston, October 3-5, 2012.

SC Solutions Inc., is a leading provider of modeling, controls, and optimization products for a wide range of applications. For further information please or visit our website shown below or contact us at (408) 617 4525.