Emcore Saves Hundreds of Thousands of Dollars in Testing Costs by Using CFD to Scale Up Patented Semiconductor Production Process

By Robert Walker, Director of Marketing
Pete Zawadzki , Laboratory Director
EMCORE Corp., Somerset, New Jersey

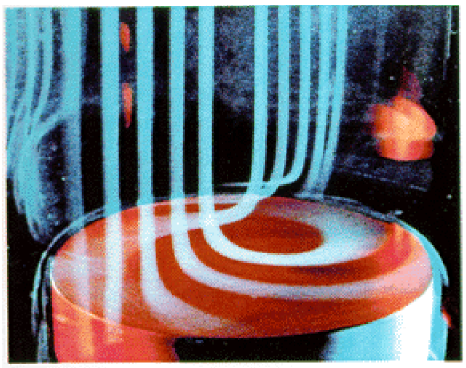
Computer Generated Flow Patterns in Rotating Disk System (THEORY). (Data courtesy of Sandia National Laboratories)

EMCORE Corp. has used computational fluid dynamics (CFD) analysis software to cut hundreds of thousands of dollars off the cost of scaling up its patented semiconductor production process. Critical to translating its TurboDisc® deposition process from small, R & D-size systems to production-size models is ensuring that material growth conditions within the system remain the same as the size of the chamber increases. Without the ability to simulate operational characteristics such as gas flow, the company would have to build and test many prototype machines. Testing one prototype costs hundreds of thousands of dollars and takes several months.

These costs are avoided by simulating the performance of larger equipment and using the results to determine the best operating conditions before the first prototype is built. EMCORE Corp. makes metal organic chemical vapor deposition (MOCVD) systems used in the manufacture of compound semiconductors. The company's proprietary TurboDisc deposition technology uses a unique high-speed rotating disc in a stainless steel chamber. Reactive gases decompose and deposit ultra-thin layers of compound semiconductor or advanced oxide materials on a substrate wafer.

Wafers grown by TurboDisc deposition allow for circuits and devices that are faster, have optoelectronic capabilities and possess properties superior to thosemanufactured using traditional deposition techniques. For example, EMCORE customers have used its systems to produce the highest-brightness InGaAlP LEDs, the lowestthreshold InGaAsP lasers, and the highest recorded solar cell efficiency.

EMCORE currently manufactures several models of TurboDisc systems for depositing III-V and II-VI materials, and thin film oxides, employing Metal Organic Chemical Vapor Deposition (MOCVD), Atomic Layer Epitaxy (ALE), and Chemical Vapor Deposition (CVD) technologies. EMCORE's systems range in price from $500,000 to $2.5 million. The unique aspect of all EMCORE systems is a vertically-oriented, stainless steel growth chamber with distributed reactant injection over the high-speed (around 1000 rpm) rotating disk. Viscous drag forces between the rotating disk's surface and the carrier gas stream create a unique pumping action in the TurboDisc system. Gases are forced to flow in a laminar manner down to the growth surface and then outward across the disk to be pumped from the reactor. This action creates sharp and uniform temperature and reactant concentration gradients at the disk's surface, resulting in a thin boundary layer that is very effective for uniform growth. In comparison, conventional chemical deposition systems don't use a rotating disk but simply cause the gas to flow horizontally through the chamber. As the gas flows further away from the inlet port, the amount of deposition decreases, making the compound thick on one part of the wafer and thin on the other. Having gas flow vertically and be pulled downward by the high-speed disk avoids that problem.

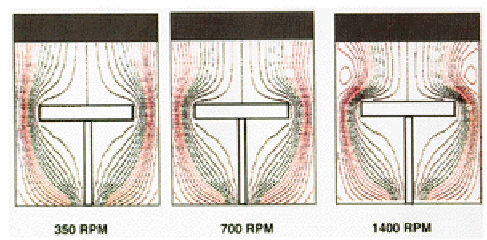


Smoke Flow Patterns in Rotating Disk System (EXPERIMENTAL).
(Data courtesy of Sandia National Laboratories)

Computer Generated Flow Patterns in Rotating Disk System (THEORY).

Central to the design of the TurboDisc system is that the results obtained can be scaled and utilized in any other TurboDisc unit from R & D through high volume production. The ability to "scale" a process to a larger system provides flexibility in process design and capacity enhancement for a lower per-wafer cost. Because EMCORE's entire family of systems has similar design specifications and features and operate identically, EMCORE customers can expand with additional systems without the need for new process development or retraining.This is an extremely important capability for companies and research facilities working with different growth processes.

The challenge in achieving similar design specifications for all sizes of systems is ensuring that the gas flow pattern is the same for all systems. When it is not, in a system that has gas recirculation above the disk, for instance, the desired sharp and uniform temperature and reactant concentration gradients will not occur. This results in an adverse affect on device performance. One way to determine if recirculation is occurring is to experimentally test prototypes. This was how the operational parameters for EMCORE's early, smaller TurboDisc systems were designed, but as mentioned earlier, this is an expensive approach, especially as the reactor size increases. Even after the expense of building the machine, just running some of the larger models could cost as much as several thousand dollars per hour. To minimize the amount of prototype testing needed as EMCORE scales its process up to larger and larger systems, the company used FLUENT CFD software from Fluent, Inc. of Lebanon, New Hampshire. This software, which uses a finite-volume procedure to solve the Navier-Stokes equations of fluid flow, allows engineers to simulate the gas flow patterns of new systems on the computer before building prototypes. They run FLUENT on a180 MHz Pentium PC under Windows NT.



TurboDisc Flow Patterns.

TurboDisc Flow Patterns

Emcore's system analysis proceedes in the following manner. The desirable growth conditions of the smaller systems, determined through experience, are plugged into equations provided by Sandia National Laboratory to calculate two values: the disk Reynolds number and the mixed convection parameter. To replicate these values in a larger system, engineers back-calculate to determine operating conditions for the new system, including disk size, rotation speed, chamber pressure, the diameter of the chamber relative to the diameter of disk, chamber height, distance from the disk to the gas inlet, and so on.

The disk Reynolds number and mixed convection parameters are somewhat imprecise guidelines, however. Also, sometimes when they are used to back-calculate operating conditions, the result is a value that is impossible to meet, such as a rotation speed that would destroy the machine. FLUENT software is used to verify that the design arrived at by back-calculating is feasible and will produce the right gas flow patterns for good growth conditions.

With FLUENT, the analysis can be set-up in as little as thirty minutes using a modern interactive graphical-user-interface. FLUENT then simulates the gas flow within the chamber and allows the designer to clearly visualize the gas flow distribution. Engineers can easily tell whether the gas is flowing as it should down into the chamber, out along the edge of the disk, and out the bottom of chamber -- rather than recirculating inside the chamber.

So far, CFD results have confirmed that the back-calculations were correct and that gas flowed as expected. No alterations to the designs were needed. With results showing a good gas flow pattern, the next step is to use FLUENT to look at how stable that pattern is under other operating conditions such as different pressures, different gas flows, different disk temperatures. The designer must make sure gas flow conditions are stable over a wide set of process conditions. Only then do they go in the lab and built a prototype. Using FLUENT in this way, they eliminate bad growth conditions in the new machine before spending any money on testing. In future development projects, CFD analysis may be used as a way to guide designs. When engineers see areas of recirculation, for instance, they will be able to go back and change the design, then run another analysis until the achieve the gas flow pattern they need. CFD software from Fluent, Inc. has been used by EMCORE for the past four years. The company's two newest systems, including the largest 420 mm system, were both developed with FLUENT. Nine 420 mm machines are currently being used by a single customer, Spectrolab Inc. of Sylmar, California, to produce solar cells for high earth orbit satellites. Several other systems are in use in other companies, both in the U.S.A. and overseas.

In addition to its role in scaling up the TurboDisc process, CFD is helping EMCORE in another way. Engineers are now developing different CFD models to explore how to grow different combinations of semiconductor materials with the TurboDisc process. For example, some materials require much higher growth temperatures than current systems provide. FLUENT is helping EMCORE ensure that its systems produce the right gas flow patterns for a variety of growth conditions, saving hundreds of thousands of dollars.