Switching Fiber-Optic Cir
MICROSCOPIC

Advanced computational fluid dynamics modeling software plays a critical role in the development of a revolutionary photonic switching platform.

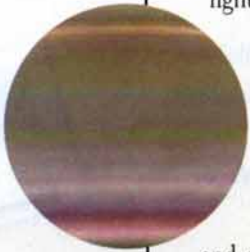
John Uebbing, Agilent Technologies

Fiber-optic cable has provided dramatic increases in data communications throughput, and there's a growing demand for technology that will make it possible to switch large volumes of data without converting the switching signal from optical to electronic and back. In the mid-1990s, Agilent Laboratories (when it was part of Hewlett-Packard Labs) realized the importance of an all-optical circuit switch and started a research program to develop a compact, scalable switch fabric that had minimal impact on the optical signal. The research team capitalized on two established technologies—inkjets and planar light wave circuits—to build a switch that routes optical beams from one path to another without having to convert the switching signal.

To work, the photonic switching platform is placed at the intersection of three fiber-optic ribbons. When a light signal comes in through a fiber, it can cross the planar light-wave circuit unimpeded via the straight-through waveguide. But if the signal must be redirected to a different optical fiber, inkjet technology inserts a bubble into the cross point of the two waveguide paths, altering its optical properties and reflecting the signal down the path to the output fiber. The bubbles can be formed and removed in <5 ms, all without the use of mirrors or mechanical moving parts (see Figure 1, page XX).

The switch operates by blowing bubbles in a fluid that is index matched to the array of crossed optical waveguides. The bubbles are formed by evaporation induced by electrical heaters on the device substrate. The fluid fills an array of microtrenches located at the cross points of the waveguides. Total internal reflection from the bubble wall causes light to be switched from one waveguide to another.

The problem is that the acceptance angle, or numerical aperture, of the optical waveguides is low. If the vertical reflecting wall of the bubble is not perpendicular to the axis of the waveguide, the light will not be properly reflected into the output waveguide, and there will be signal loss.



Dimples Impact Performance

Testing was performed on early prototypes, showing the effects of heater power and ambient pressure on optical reflection characteristics and bubble shape and size. The tests showed that the reflected optical signal vs. heater power curve not did not meet the requirements needed for effective optical switching and that there were instabilities in the reflected light signals.

When the computer simulations showed that there were dimples forming on each side of the bubble (see Figure 2, page XX), it dawned on the researchers that the dim-

The switch operates by blowing bubbles in a fluid that is i

cuits with BUBBLES

SIMULATION SOFTWARE

ples might be the cause of the humps on the power curve and the reason the reflected signal was so unstable. The team's ability to take physical measurements with sensors did not extend to the scale of the MEMS device. The most they could do was use special optics to take photomicrographs (see Figure 1). The pictures couldn't show the dimple directly because it was thin on a wavelength scale.

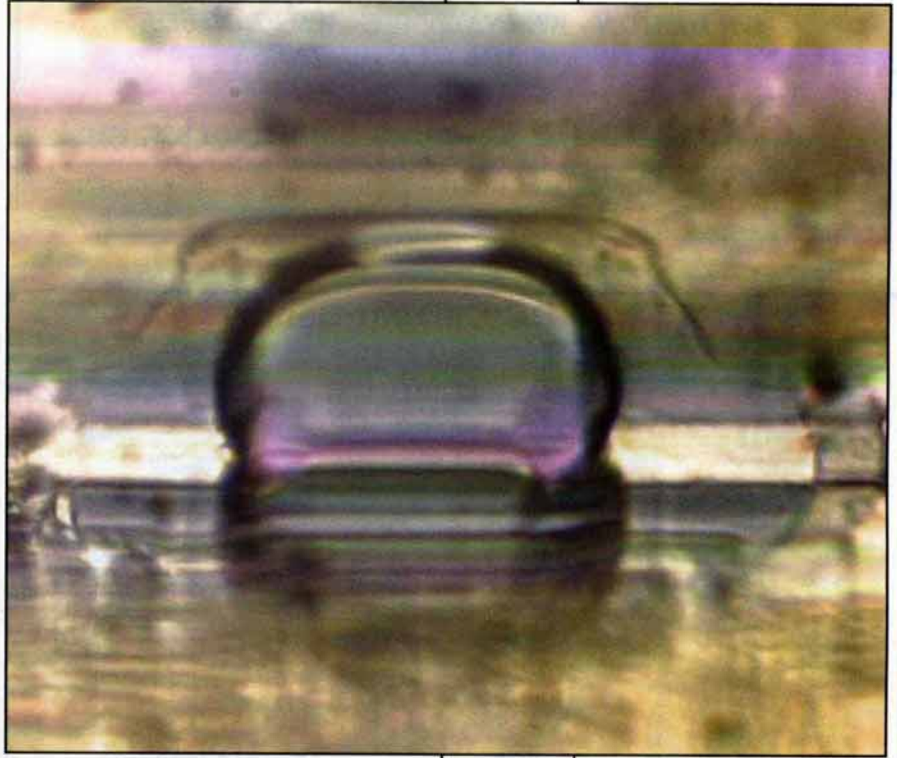


Figure 1. The Agilent photonic switching platform inserts a bubble into the cross point of two waveguide paths to redirect a light signal to the correct path. The bubbles are formed by evaporation induced by electrical heaters on the device substrate. The bubbles can be formed and removed in <5 ms without the use of mirrors or mechanical moving parts.

Simulating the Bubble

Initially, the researchers considered several alternatives for simulating the operation of the bubble. The team had been using various analytical models to investigate bubble formation, but they didn't show any problems with the bubbles. It seemed the models were too simple to capture the problem. A college professor was hired to write custom software, but this project was going to take considerable time.

In the meantime, Agilent's researchers began looking for commercial software that could handle the complicated physics of the problem. Unfortunately, most of the packages they looked at didn't have a bubble model that would solve the problem without extensive modification. However, a company by the name of Flow Science said its software, Flow-3D, could handle the problem (see the sidebar, page XX).

Flow Science's new homogeneous bubble model assumes uniform bubble pressure and temperature, which is a good approximation of reality. One of the key issues is the modeling of the contact line, where the liquid, vapor, and solid come together. The new model balances all of these forces and fluxes in the computational cell.

Simulations using Flow-3D showed the dimples that proved so important in explaining the experiments. The simulation and experiment also showed that the bubbles oscillated at 35 kHz, but researchers had no idea why. Simple calculations showed that it was just a simple spring mass or a trenched version of the classic bubble radial oscilla-

ndex matched to the array of crossed optical waveguides.

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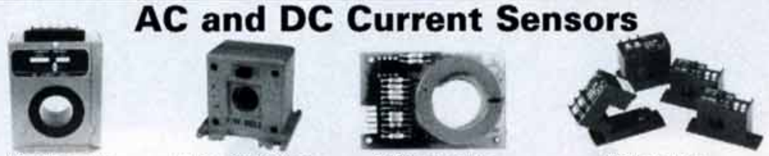

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IHA-100	100	5	dc to 50
IHA-150	150	5	dc to 50
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IA-0250	250	10	dc only
IA-0500	500	10	dc only
IA-1000	1000	10	dc only
IA-2000	2000	10	dc only
IA-3000	3000	10	dc only
IF-0100	100	10	dc to 1
IF-0250	250	10	dc to 1
IF-0500	500	10	dc to 1
IF-1000	1000	10	dc to 1
IF-2000	2000	10	dc to 1
IF-3000	3000	10	dc to 1
NT-5	15	2.5	dc to 100
NT-15	45	2.5	dc to 100
NT-25	75	2.5	dc to 100
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CLN-500	500	100	dc to 150
CLN-1000	1000	200	dc to 100

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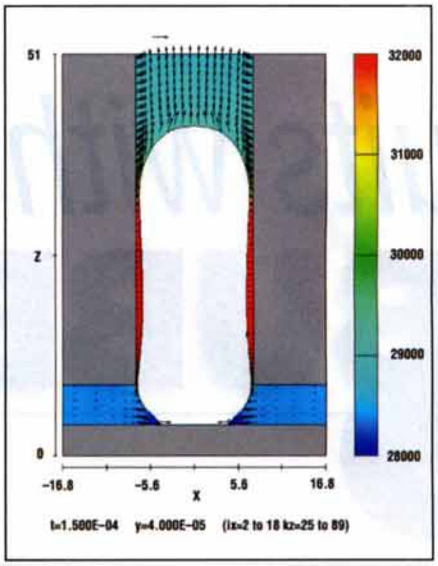

Figure 2. This 2D computational fluid dynamics simulation shows how the dimple is formed when condensing fluid piles up on the wall of the bubble. The fluid tries to escape through the thin film of liquid on the wall of the trench and the resulting pressure difference deforms the bubble. The simulation used Flow Science's new homogeneous bubble model, which assumes a uniform bubble pressure and temperature.

tion. This unexpected correlation with reality gave the team confidence in the results of the simulation.

The simulation results went beyond what Agilent could measure in the tests by showing the flow velocity, pressure, and temperature at every point in the problem domain. With these results, the researchers were able to determine what was happening: The dimple was caused by capillarity. The condensing fluid piled up on the wall of the bubble and tried to escape through the thin film of liquid on the wall of the trench. To push liquid through such a layer required significant pressure difference. The high pressure in the center of the bubble wall caused the bubble to form a dimple.

Solving the Problem

Understanding how the dimples are formed suggests two methods of correcting the shape of the bubbles to provide stable signals. The first is to extend the bubble heater under the glass sidewall of the trench. Heat flows up the wall of the microtrench and dries out its surface. Simulations with Flow-3D showed a stable dry wall that would give stable switched signals. Basic physics suggests that if the bubble temperature is less than the wall temperature the wall will be dry. Flow-3D simulations confirmed this expectation. ▶

Flow-3D

Tom Jensen, Flow Science, Inc.

Because computational fluid dynamics (CFD) software uses many different kinds of physical approximations and numerical techniques, the selection of a suitable package can be difficult. Some CFD programs are designed to deal with a particular type of flow problem, while others are general-purpose solvers. As a general-purpose solver, Flow-3D, from Flow Science, Inc., offers a variety of physical models for the investigation of the dynamic behavior of liquids and gases in a broad assortment of applications. The program is based on the fundamental laws of mass, momentum, and energy conservation, and so it can address a wide range of flow processes.

Flow-3D is based on a discrete Navier-Stokes scheme, using a finite difference (finite volume) approach. The software's fractional area/volume representation (FAVOR) method captures geometries in a fixed grid of rectangular control elements (i.e., a structured grid). This allows complex geometries to be treated without the stair-step effect (see Figure 3). The mesh is generated independent of the specification of the geometry.

Flow-3D specializes in the simulation of free-surface flows, especially for problems with discontinuous and rapidly varied flows. The software tracks free surfaces using the volume-of-fluid technique. Flow-3D is typically used to solve time-dependent (transient) problems, and solutions can be performed in one, two, or three dimensions. Users typically don't choose the software to solve steady-state fluidics problems, though such results can be computed as the limit of a time transient.

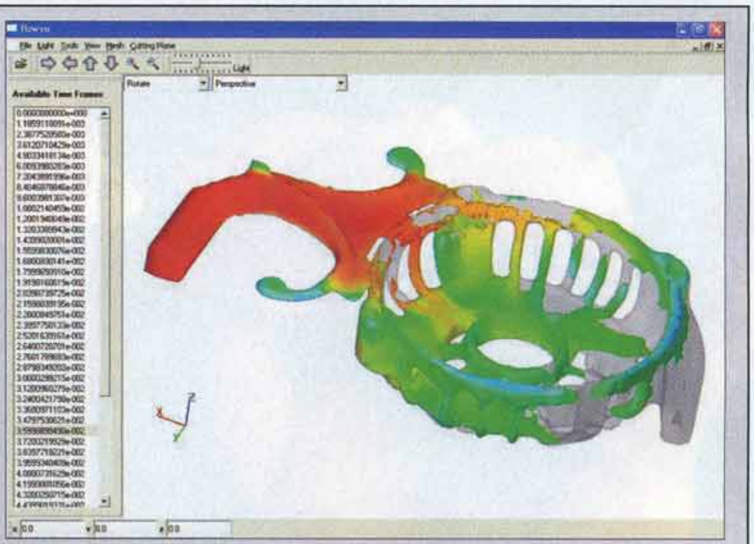

Figure 3. Shown here is a simulation of a high-pressure die casting of an alternator. Flow-3D uses the volume-of-fluid method to track free fluid surfaces, and it's especially useful for problems involving discontinuous flows, where the surface breaks up and then coalesces again. With the fractional area/volume representation (FAVOR) technique, the geometry is easily and smoothly represented without stairsteps.

Flow-3D consists of a suite of programs that includes a preprocessor, solver, postprocessor, and an OpenGL-based graphical display program.

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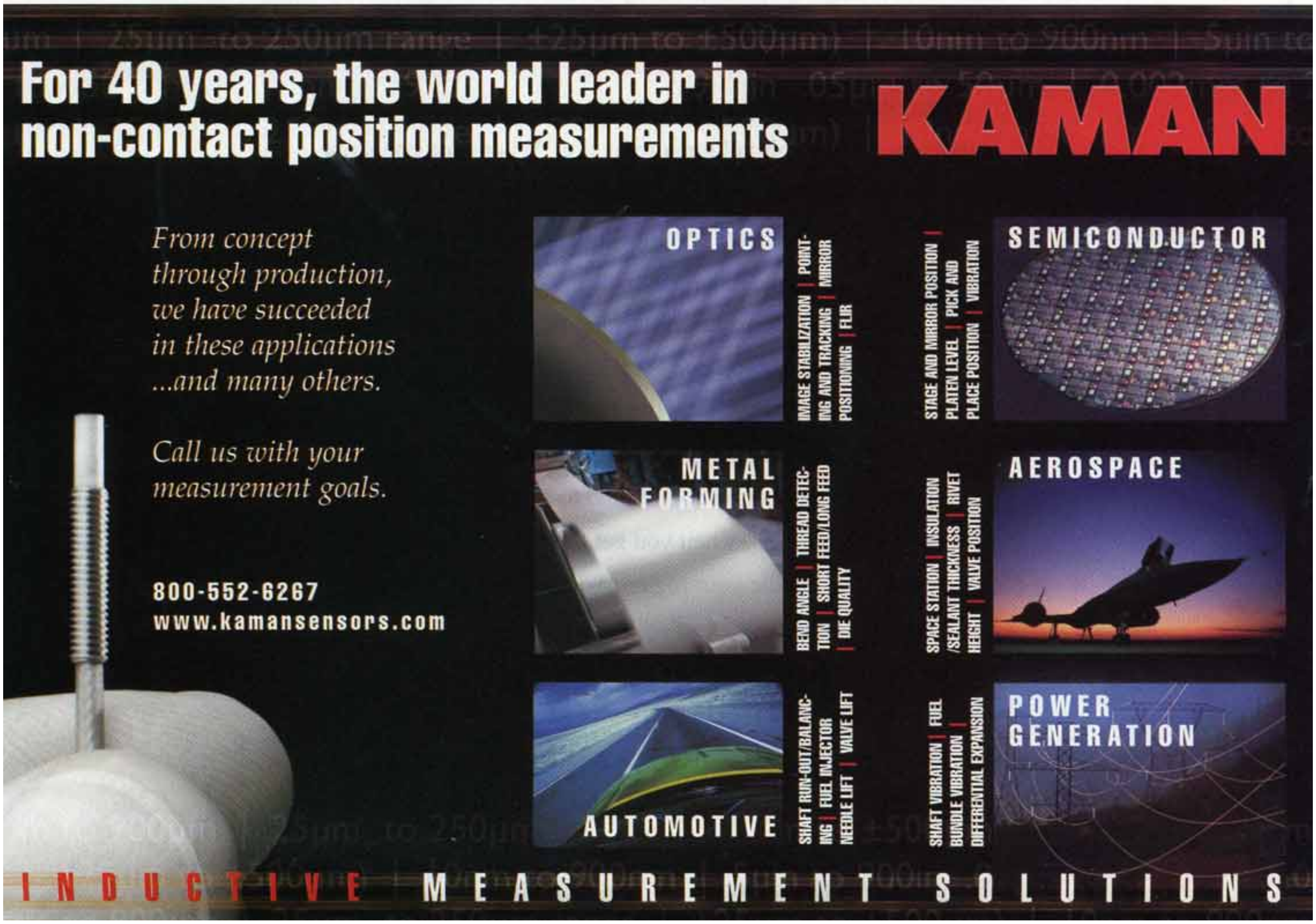

The second method—also verified by Flow-3D—is to make a static bubble in the microtrench. These bubbles exist if the device temperature is hotter than the pressure-setting reservoir temperature. The device temperature creates enough pressure to push the bubble into the corners of the trench, but not enough to blow the bubble out through the gap between the waveguide array and the heater substrate. Static bubbles can be turned off with a nearby "crusher" bubble, which temporarily generates enough overpressure to cause the static bubble to collapse. The crusher bubble itself is in a smaller trench, so surface tension forces are enough to make it collapse after it's done its work. Flow-3D simulations were also used to show the switch operation in this mode. ■

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