Micro resolution

A project to reduce inkjet printheads to the MEMS scale calls for a detailed profile of the ink.

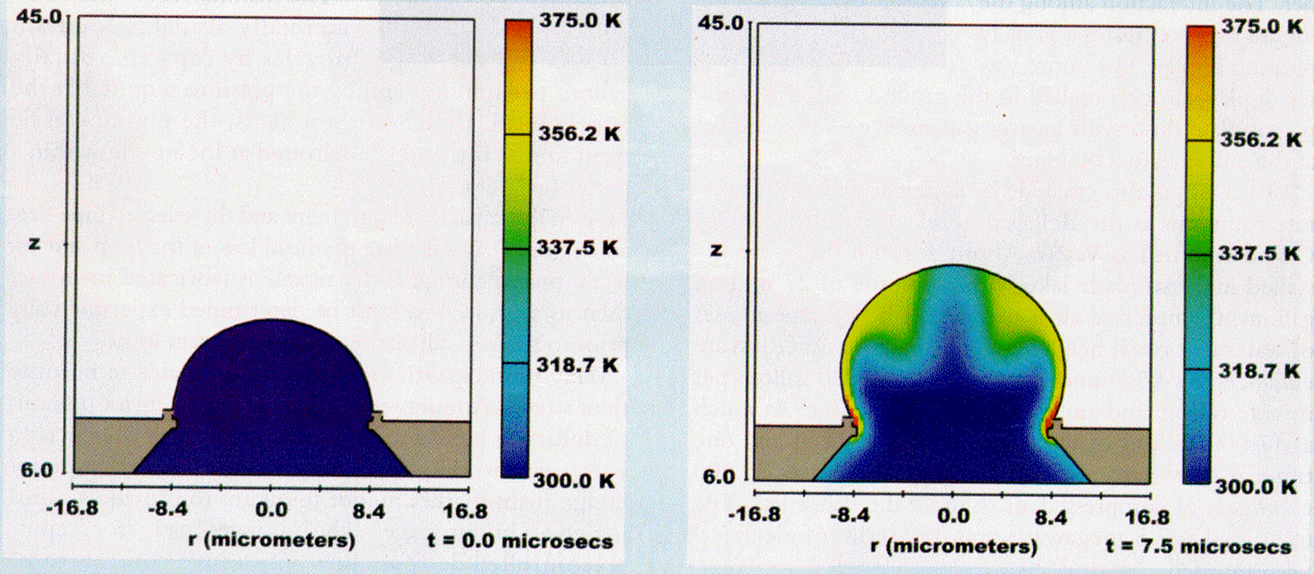
RESEARCHERS AT EASTMAN KODAK CO. are working toward a new generation of inkjet printheads that are based on microelectromechanical technology. The prize is that the MEMS scale has the potential to advance the quality of inkjet images by permitting larger and denser arrays of smaller ink orifices, to increase resolution and printing speed.

In addition, the company expects that economies of scale of MEMS manufacturing will make printers more affordable by decreasing production costs.

The company is involved in several areas of research related to inkjet printers. One area is work that is directed at improving printhead performance.

Kodak researchers are studying drop formation by MEMS structures and are using computational fluid dynamics analysis to compare various possible designs. According to one of the lead researchers, CFD is helping development proceed far faster than it would if the project relied on physical prototypes and also is providing information that real-world testing can't obtain.

"In addition to letting us visualize these microfluidic phenomena that can't be seen in a test situation, the main benefit of CFD is that it lets us quickly explore many design alternatives," said Christopher Delametter, senior research analyst in the Integrated Materials and Microsystems Laboratory at Eastman Kodak. "In this way, simulation is significantly reducing the time required to



A computer simulation by Kodak predicts the temperature contours of an ink drop as it emerges from a MEMS-scale printhead. The temperature gradients

This article was prepared by staff writers in collaboration with outside contributors.

make MEMS a commercially viable type of printhead."

Eastman Kodak, based in Rochester, N.Y., markets traditional photography and other imaging products. Its annual sales are about $14 billion. The company's research and development activities involve more than 5,000 engineers and scientists who work at Kodak laboratories in the United States, England, France, Japan, China, and Australia. Although Kodak is best known for products related to photography, the company also offers inkjet printers and media.

PIEZO OR HEAT

Currently, inkjet printheads use one of two approaches for ejecting ink. One uses piezoelectric channels filled with ink. The printer applies a voltage across each channel, which deforms to squeeze out the ink. But limitations in the manufacturing process make it difficult to increase the size of the orifice array.

"This type of inkjet printer is popular for home use, but it needs larger arrays to be fast enough for use in an office," Delametter said.

The other approach to ejecting ink from the cartridge uses thermal bubble jet technology. This type of printhead heats ink with a resistive heater to create a vapor bubble. As the bubble grows, it pushes ink out of the orifice. The limitation here is that the process requires a lot of energy to vaporize the ink.

Because the printer must deal with the waste heat, it is difficult to increase the size of the arrays. Also, unlike the piezoelectric method that does an accurate job of positioning ink, thermal bubble jet technology isn't as precise, so the printer must include ways to compensate.

Delametter and his colleagues are developing printhead technology that has the potential to improve image quality and printing speed by replacing conventional printheads with MEMS.

"The MEMS structures we are developing will control the motion of ink by exploiting its surface properties," Delametter explained. "Heating a fluid meniscus nonuniformly induces a gradient in surface tension. This produces a tangential force, called a Marangoni force, on the liquid free surface. Whenever fluid dimensions are less than 10 microns, thermocapillary-driven forces can separate discrete droplets from the main fluid body and also propel them rapidly through space."

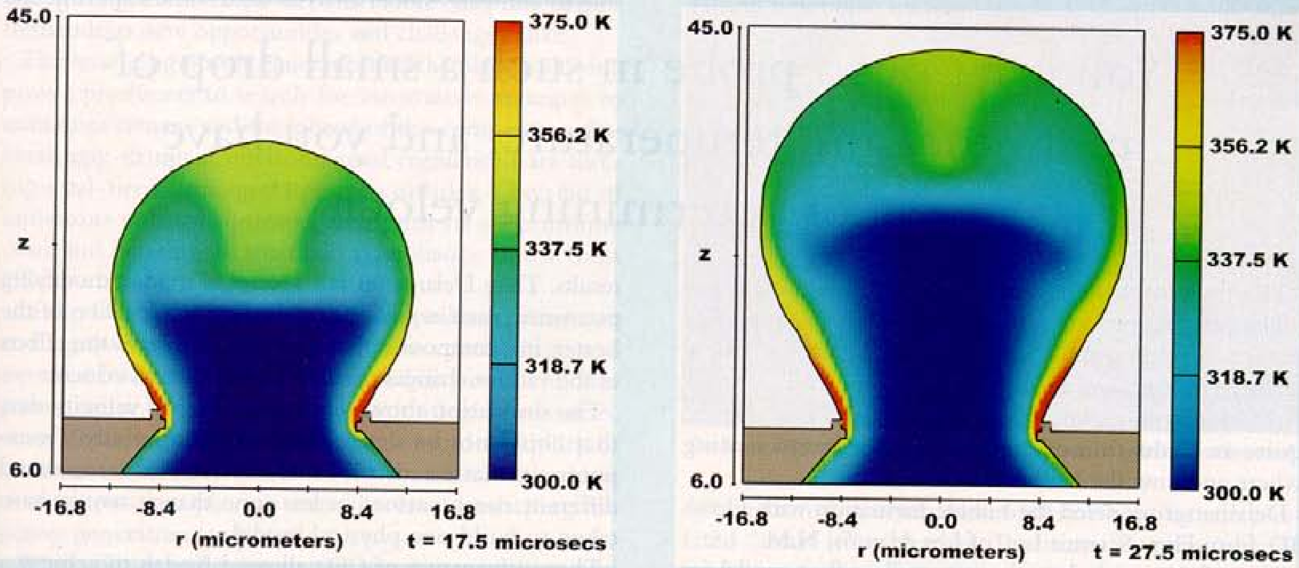
This represents a MEMS approach to creating and controlling ink drops because the device could be created through the VLSI semiconductor manufacturing process. "MEMS printheads would have the same low production cost as that of the bubble jet printheads," Delametter added. "Yet they would produce less heat, so it would be possible to increase the size of the printhead arrays."

To make MEMS technology viable for commercial use, Kodak researchers must design a printhead that produces very small drops (smaller than 2 picoliters) at frequencies faster than 50 kHz, thereby enabling high-speed printing with photographic quality. This requires a thorough understanding of a number of microfluidic phenomena, including drop creation via thermocapillary-driven forces.

Many design variables influence thermocapillary flow, including the size of the orifice, the size of the heater, whether the heater is embedded or sits on the surface, the best thermal and structural properties of materials for the ink, and the body of the MEMS. In the past, when physical testing was the only option for evaluating fluidic performance, it would have taken a prohibitively long time to understand and optimize all these variables.

Building a single prototype printhead takes months, and with so many variables involved, Kodak would have needed many prototypes. "If we had to develop this technology using the experimental approach, it would take years," Delametter said.

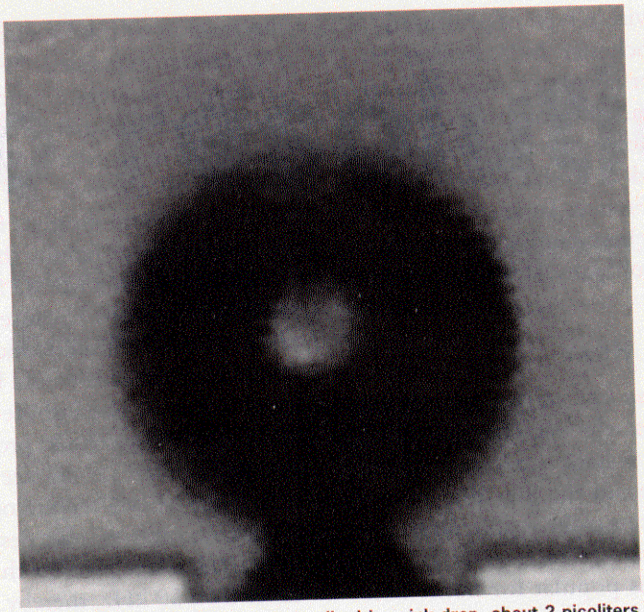
Another drawback to the experimental approach is that it is very difficult to view bubble formation in devices this



s a result of energy applied to a resistive poly-silicon ring heater element on top of the single crystal silicon-based device.

small. "The scale of microfluidics makes it impossible to collect all the data we would need," Delametter added. "For example, you can't put a probe in such a small drop of ink to measure temperature, and you have no way of determining velocity."

Delametter and his colleagues are studying the behavior of the droplets by simulating the operation of the printhead on the computer using CFD. "By utilizing simulation, we decrease development time tremendously," Delametter said. "It also helps us better understand the underlying mechanisms. We can turn some forces off, others on, and really dissect the system to understand its behavior."



A microphotograph shows a thermally driven ink drop, about 2 picoliters in volume, formed by a prototype of a MEMS print head at Kodak.

CFD involves the solution of the governing equations for fluid flow, heat transfer, and chemistry at several thousand discrete points on a computational grid in the flow domain. The use of CFD enables engineers to obtain solutions for problems with complex geometries and boundary conditions. The CFD analysis yields values for fluid velocity and fluid temperature throughout the solution domain.

The biggest challenge in using CFD to simulate the inkjet printing process is keeping track of the drop's free surface. Modeling problems such as Delametter's, where surface tension plays an important role, require accurate resolution and tracking of fluid surfaces. They also require an evaluation of surface curvatures and sensing where and how fluid adheres to solids.

Delametter modeled the bubble formation with Flow-3D, from Flow Science Inc. of Los Alamos, N.M.

The software includes a thermocapillary flow model for predicting Marangoni forces. It provides algorithms that track sharp liquid interfaces through arbitrary deformations and apply the correct normal and tangential stress boundary conditions.

According to Delametter, the hardware for the simulations varied, but generally they ran on generic PCs with a half-gigabyte of RAM and 500-MHz processors.

Delametter began the CFD analysis by defining the geometry of the device, which was fairly simple, consisting of an orifice, a taper back to a large open channel that holds the ink, an ink reservoir, a heater on the structure of silicon, and contacts for electrical connections. Besides the orifice and the area surrounding it, the analysis domain included part of the ink reservoir at one limit and, at the other, extended beyond the orifice by about 100 micrometers into free space, to let the ink drop detach from the bulk of the fluid.

Conditions included a pressure boundary representing backpressure on the ink reservoir and a continuative boundary where the fluid flows out of the domain.

Most simulations are axisymmetric, with approximately 50,000 cells. "That's a very small number compared to some CFD analysis being done today, but it's sufficient for this simple geometry," Delametter said. The grid is rectangular, with the conforming properties of a body-fitted grid.

Before Delametter became involved in the printhead project, developers had made prototypes of some designs. "I got into the program late," he said. "If I'd been there, we would have modeled first."

Since the project had prototypes, the design team was able to compare model analysis with some experimental results. Then Delametter ran a series of models modifying parameters such as orifice size, the size and location of the heater, ink composition, and so on, to observe the effects of the various changes on drop formation and velocity.

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The simulation showed temperature and velocity data that could not be determined experimentally. Computer simulation also let Delametter evaluate several different combinations in less time than it would have taken to build one physical model.

These advantages of CFD allowed Kodak to achieve a workable MEMS printhead in a reasonable amount of time. "Without simulation, it would have taken years to get to the point where we understood this technology and had a working device," Delametter said.

Now the company believes it needs to improve velocity to get the kind of performance needed to make a commercial product. Simulation is making that process faster, too.

"With CFD simulation, the company has been able to understand the mechanisms of how MEMS can form ink drops, optimize a MEMS printhead design, and bring it toward a commercial application," Delametter said. ■