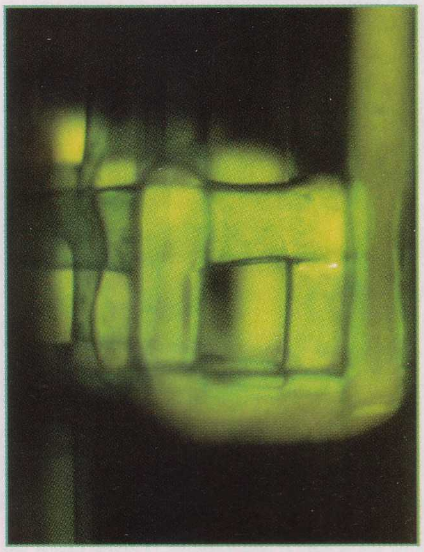
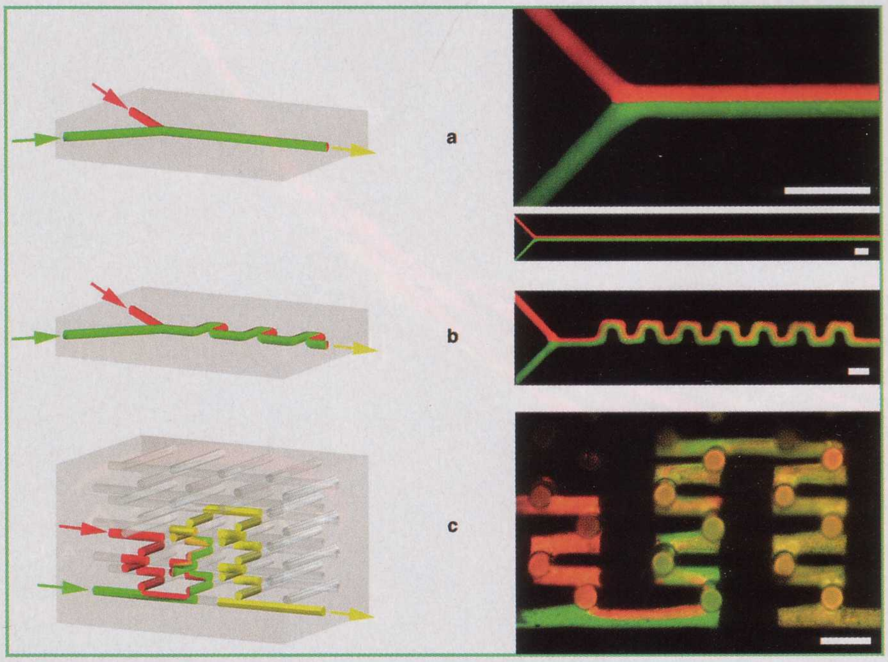
Scientists achieve 3-D plumbing on a chip

Using special ink, heat, epoxy and UV-cured resins, researchers have developed a method for creating three-dimensional plumbing on a millimeter-size chip. Although in its infancy, the method is inexpensive, straightforward and may provide a leap ahead for lab-on-a-chip and sensor applications.

In theory, the lab-on-a-chip platform can miniaturize chemical processes such as drug discovery. Such an application means less reagent use, cleanup and preparation, not to mention the ability to automate the entire process. In reality, one of the main challenges to achieving an effective lab-on-a-chip application has been the fluid flow systems on which it depends. Until now, most plumbers for this application relied on soft lithography or photolithography to create their pipes. But these methods can only create relatively small pipes that can only be two-dimensional, meaning that they run in only one plane of the chip's structure. When fluid dynamics are added to this picture, the result is a piping system that does not twist and turn enough to mix fluids efficiently in a short space.



Researchers at the University of Illinois have developed a new method for fabricating 3-D plumbing in a polymer resin block. The plumbing provides superior fluid mixing compared with conventionally created 2-D chips. Courtesy of Daniel Therriault.



To test the usefulness of a new method for making 3-D fluid channels, researchers at the University of Illinois compared the mixing capabilities of standard 2-D fluid channels with a 3-D channel. They introduced red and green fluorescent dye streams and watched how quickly they became a single yellow stream. Reprinted from** Nature Materials **with permission from researchers.

Rather than subtracting material using photolithography, researchers Daniel Therriault, Scott R. White and Jennifer A. Lewis at the University of Illinois at Urbana-Champaign relied on a paraffin-based organic ink. The idea is simple: Map out a three-dimensional network of tiny pipes with the wax, seal it in a hard resin and then melt out the wax to leave the pipes in place. The process itself is slightly more complicated.

They start with a porous Teflon substrate mounted on an X-Y movable stage. Above the stage a special robotic syringe deposits paraffin-based ink that is specifically tailored to hold its shape during the process. The syringe is mounted on a Z-axis movable stage so that it can deposit layer upon layer of material to build the structure vertically.

Currently, the researchers must lay down the ink in a continuous filament so that the structure they build looks like many lattices, one on top of another, with each staggered so that the pipes of one layer are offset 0.5 mm from the layer above or below. The deposition moves at 15 mm/s, meaning that it takes about three minutes to build 16 layers.

Build the chip

To create the chip, the scientists cooled the lattice stack using dry ice and infiltrated the lattice with a liquid resin and curing agent from Shell Chemicals in Houston. The porous Teflon substrate allowed air to escape as the resin was added and allowed for the chip to be removed after it had cured. After curing the resin for 24 hours, they heated it to 60 °C for two hours. This melted the paraffin ink, which was suctioned off, leaving an entire network of piping.

At this point, they sealed off parts of the piping that they didn't want to use in the plumbing structure. To do this, they filled the pipes with a photocurable resin and laid down a photomask prepared by a high-resolution printer. They exposed the resin to 360-nm UV radiation from a 100-W UV lamp, focused through an Olympus epifluorescent microscope with a 2× objective. In this particular series of experiments, they created a variety of piped towers.

To test the effects of the new method on fluid dynamics, the group conducted a simple test comparing the ability of its 3-D device and two conventional 2-D structures to mix equal amounts of red and green fluorescent dyes to produce yellow. A fully mixed stream would be completely yellow, while partially mixed streams would show varying degrees of unmixed red and green. The chip achieved a fully mixed stream in a horizontal distance far shorter than either of the conventional structures.

From here the researchers plan to explore different polymer resins, inks and UV curing methods, such as two-photon excitation, that could allow them to make more arbitrary plumbing structures. In 2001, the group reported developing a self-healing polymer that might function in such a system. The polymer contains small microcapsules of a "healing agent," explained White. "Cracks open up the microcapsules and the healing agent is released into the material; [it] undergoes polymerization and provides a means to recover mechanical properties. A microvascular network of channels in 3-D could be used to store and transport the healing agent in a next generation of self-healing materials. The microvascular system could serve the same purpose as the circulatory system in the human body — a means to distribute the necessary chemicals for healing throughout." □

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