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EVEN FLOW BUILDS MICROSTRUCTURES

New technique holds promise of simple, inexpensive microfabrication

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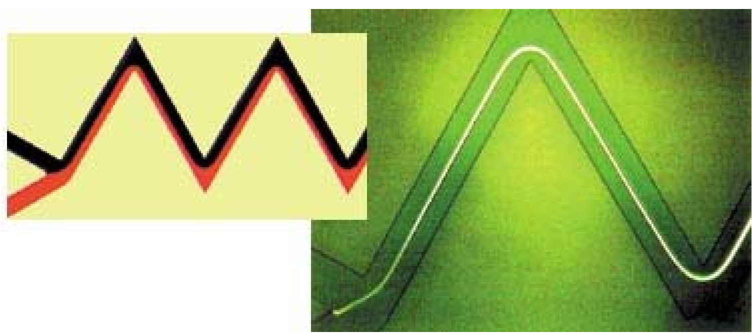
Gentle motions of reactive fluids flowing through capillaries form the basis of a new microfabrication procedure that offers great simplicity compared with other methods. The new method, which may be applied to materials that aren't amenable to other fabrication techniques, has been used with high precision to build micrometer-sized electrode systems and other devices [*Science*, **285,** 83 (1999)].



Streams of colored fluids (inset) zigzag side-by-side over centimeter lengths through capillaries with micrometer-sized diameters while maintaining laminar flow; diffusional mixing occurs strictly at the liquid-liquid interface. A tiny silver wire (above) is formed from an ionic silver solution and a reducing agent. [Courtesy of Harvard University]

The procedure was developed by Harvard University chemistry professor George M. Whitesides and postdoctoral associates Paul J. A. Kenis and Rustem F. Ismagilov.

By selecting conditions that promote a mild and nonturbulent type of mass transport known as laminar flow, the Harvard researchers carry out chemical reactions strictly at the interface between streams of solutions flowing side-by-side through minuscule channels or at the interface of tiny reagent streams and capillary walls. These reactions leave in their wake lines of metal atoms or other products that can serve as microelectronic devices.

"It's a really clever combination of a physical process with chemistry," remarks University of Chicago assistant chemistry professor Milan Mrksich. "Others have used laminar flow of several parallel fluids to mix reagents and deliver reagents, but here they've plugged in some real chemistry to make interesting structures."

Stanford University associate professor of electrical engineering Gregory T. A. Kovacs expects that "the study will stimulate the thinking of a broad cross section of scientists and engineers and provide a tantalizing introduction to microfluidics."

Kovacs points out that "basic microfluidic effects, while not intuitive at the garden-hose level of flow, occur often in nature." He offers fluid flows in rocks, blood vessels, and insects as examples. "This work takes advantage of a well-known phenomenon in microfluidics--the tendency for flows to be laminar--and actually does something useful with it," he adds.

To make the type of minuscule flow apparatus used in this study, the Harvard team seals polydimethylsiloxane (PDMS) membranes with channels molded into their surfaces against flat surfaces such as a glass slide or a PDMS block. Then by introducing reagent fluids through Y- or T-shaped junctions, the group generates parallel streams of smoothly flowing liquids that can react with each other at a liquid-liquid interface via limited diffusion of one reagent stream into another. Reactions between streams can be used to deposit solid products at the site of an interface, whereas reactions between fluids and channel walls can be used to deposit material or etch material from a capillary wall.

In one demonstration of the new procedure, the Harvard chemists flowed a solution of silver ions alongside a reducing agent through a zigzagging capillary. The solutions negotiated the sharp turns admirably--maintaining laminar flow throughout the centimeter-length journey. Unused reagents exited the channels, leaving behind a continuous micrometer-scale silver wire.

In another experiment, Whitesides and coworkers deposited a thin polymeric product by flowing oppositely charged polymer solutions through a tiny channel. The technique was also used to deposit arrays of single crystals and to effect multiple reactions in a single capillary simultaneously.

Demonstrating that complex structures may be fashioned using the new method, the team constructed a three-microelectrode assembly inside a 200-μm-wide rectangular channel and tested the microscopic device using cyclic voltammetry.

And earlier this year, the authors of the current study, together with other Harvard researchers, used the laminar flow patterning process in biological applications. In that investigation, the group patterned cell culture substrates and media and carried out patterned cell deposition [*Proc. Natl. Acad. Sci.,* **96,** 5545 (1999)].

Researchers in microfluidics originally relied upon technology and materials used in silicon microprocessing, Whitesides remarks. But recognizing those methods as too expensive and complicated to apply to many problems, scientists now turn to fabrication in plastics using less expensive and simpler methods like micromolding, embossing, and printing, he says.

Although laminar flow patterning offers simplicity and may be used with plastics and other materials, the method has its weaknesses, Whitesides points out. For example, the technique requires each device to be modified individually--making it a serial fabrication method. But parallel fabrication procedures are needed to produce large numbers of devices quickly and efficiently, he notes.

"My belief is that there will be a whole range of new methods for microfabrication developed in the next years as new areas of microtechnology emerge," Whitesides says. "Laminar flow patterning will be one useful new technique, but microtechnology is so large that there is enormous room for invention."

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