



## Manufacturing & Prototyping

### **Microfabrication of a High-Throughput Nanochannel Delivery/Filtration System**

*Lyndon B. Johnson Space Center, Houston, Texas*

A microfabrication process is proposed to produce a nanopore membrane for continuous passive drug release to maintain constant drug concentrations in the patient's blood throughout the delivery period. Based on silicon microfabrication technology, the dimensions of the nanochannel area, as well as microchannel area, can be precisely controlled, thus providing a steady, constant drug release rate within an extended time period. The multilayered nanochannel structures extend the limit of release rate range of a single-layer nanochannel system, and allow a wide range of pre-defined porosity to achieve any arbitrary drug release rate using any preferred nanochannel size. This membrane system could also be applied to molecular filtration or isola-

tion. In this case, the nanochannel length can be reduced to the nanofabrication limit, i.e., 10s of nm.

The nanochannel delivery system membrane is composed of a sandwich of a thin top layer, the horizontal nanochannels, and a thicker bottom wafer. The thin top layer houses an array of microchannels that offers the inlet port for diffusing molecules. It also works as a lid for the nanochannels by providing the channels a top surface. The nanochannels are fabricated by a sacrificial layer technique that obtains smooth surfaces and precisely controlled dimensions. The structure of this nanopore membrane is optimized to yield high mechanical strength and high throughput.

*This work was done by Mauro Ferrari, Xuewu Liu, Alessandro Grattoni, Daniel Fine, Sharath Hosali, Randi Goodall, Ryan Medema, and Lee Hudson of the University of Texas Health Science Center for Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

*Office of Technology Management  
The University of Texas Health Science  
Center*

*7000 Fannin Street, Suite 720  
Houston, TX 77030*

*Refer to MSC-24488-1, volume and number of this NASA Tech Briefs issue, and the page number.*

### **Improved Design and Fabrication of Hydrated-Salt Pills**

**Salt pills for adiabatic-demagnetization refrigerators could be mass-produced.**

*Goddard Space Flight Center, Greenbelt, Maryland*

A high-performance design, and fabrication and growth processes to implement the design, have been devised for encapsulating a hydrated salt in a container that both protects the salt and provides thermal conductance between the salt and the environment surrounding the container. The unitary salt/container structure is known in the art as a salt pill. In the original application of the present design and processes, the salt is, more specifically, a hydrated paramagnetic salt, for use as a refrigerant in a very-low-temperature adiabatic-demagnetization refrigerator (ADR). The design and process can also be applied, with modifications, to other hydrated salts.

Hydrated paramagnetic salts have long been used in ADRs because they have the desired magnetic properties at low temperatures. They also have some properties, disadvantageous for ADRs, that dictate the kind of enclosures in which they must be housed:

- Being hydrated, they lose water if exposed to less than 100-percent relative humidity. Because any dehydration compromises their magnetic properties, salts used in ADRs must be sealed in hermetic containers.
- Because they have relatively poor thermal conductivities in the temperature range of interest (<0.1 K), integral thermal buses are needed as means of efficiently transferring heat to and from the salts during refrigeration cycles. A thermal bus is typically made from a high-thermal-conductivity metal (such as copper or gold), and the salt is configured to make intimate thermal contact with the metal. Commonly in current practice (and in the present design), the thermal bus includes a matrix of wires or rods, and the salt is grown onto this matrix. The density and spacing of the conductors depend on the heat fluxes that must be accommodated during operation.

Because the salt is hydrated, it must be grown from solution onto the matrix, in a container that, immediately after growth, must be hermetically sealed to complete the salt pill. In the present design and fabrication process, the thermal bus is initially fabricated in two pieces: (1) a unitary piece comprising a square array of parallel copper fingers protruding from a copper disk, and (2) a copper cap that can be bolted into thermal contact with an external object. The disk-and-fingers piece is made from a single copper rod by using automated electrical-discharge machining (EDM) to create the gaps between the rods. Prior to EDM, the bolt holes (for subsequent connection to other parts of the ADR) and two access holes (for use in growing the magnetic salt) are machined into the copper rod.

In a single brazing operation, the two copper pieces constituting the thermal bus are joined together, two stainless-steel weldment rings are joined to the

copper (one at each end), and two stainless-steel collars surrounding the access holes are joined to the copper. After brazing, an outer stainless-steel containment tube is welded to the weldment rings. At this point, the salt pill is hermetically sealed except for the collared openings, which are to be welded shut after the salt is grown.

The size and spacing of the copper fingers are set to provide very high thermal conductance to the salt while minimizing complications caused by surface-tension forces on the salt solution during growth of the salt. The salt is grown by use of a continuous-counterflow technique in which saturated solution is pumped into,

and depleted solution is withdrawn from, the salt pill in such a way that crystallites are first nucleated at the bottom, and then salt crystals grow from the bottom upward in a controlled manner until the entire container is filled with salt. The salt solution is circulated by a dual peristaltic pump, using tubes of different sizes for supply and return so that the flow capability for return exceeds that for supply: This is key to ensuring that the saturated solution occupies only a thin layer above the growing salt, ensuring that salt grows only by extending itself rather than by nucleation at random locations throughout the salt pill. Growing the salt in this way ensures that regard-

less of the configuration and thermal conductance of the thermal bus, there is no premature formation of salt in the upper volume of the salt pill. If allowed to occur, such premature formation could trap pockets of solution.

This salt-growth process can yield a high fill fraction (>98 percent). The process can be automated at a high growth rate. The fabrication and salt-growth processes are suitable for mass production of salt pills for ADRs.

*This work was done by Peter J. Shirron, Michael J. DiPirro, and Edgar R. Canavan of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-14873-1*

## Monolithic Flexure Pre-Stressed Ultrasonic Horns

**Flexures are used rather than stress bolts, allowing one to apply pre-load to the piezoelectric material.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

High-power ultrasonic actuators are generally assembled with a horn, backing, stress bolt, piezoelectric rings, and electrodes. The manufacturing process is complex, expensive, difficult, and time-consuming. The internal stress bolt needs to be insulated and presents a potential internal discharge point, which can decrease actuator life. Also, the introduction of a center hole for the bolt causes many failures, reducing the throughput of the manufactured actuators.

A new design has been developed for producing ultrasonic horn actuators. This design consists of using flexures rather than stress bolts, allowing one to apply pre-load to the piezoelectric material. It also allows one to manufacture them from a single material/plate, rapid prototype them, or make an array in a plate or 3D structure. The actuator is easily assembled, and application of pre-stress greater than 25 MPa was demonstrated.

The horn consists of external flexures that eliminate the need for the conventional stress bolt internal to the

piezoelectric, and reduces the related complexity. The stress bolts are required in existing horns to provide pre-stress on piezoelectric stacks when driven at high power levels. In addition, the manufacturing process benefits from the amenability to produce horn structures with internal cavities. The removal of the pre-stress bolt removes a potential internal electric discharge point in the actuator. In addition, it significantly reduces the chances of mechanical failure in the piezoelectric stacks that result from the hole surface in conventional piezoelectric actuators. The novel features of this disclosure are:

1. A design that can be manufactured from a single piece of metal using EDM, precision machining, or rapid prototyping.
2. Increased electromechanical coupling of the horn actuator.
3. Higher energy density.
4. A monolithic structure of a horn that consists of an external flexure or flex-

ures that can be used to pre-stress a solid piezoelectric structure rather than a bolt, which requires a through hole in the piezoelectric material.

5. A flexure system with low stiffness that accommodates mechanical creep with minor reduction in pre-stress.

*This work was done by Stewart Sherrit, Xiaohu Bao, Mircea Badescu, and Yoseph Bar-Cohen of Caltech, and Phillip Grant Allen of Cal Poly Pomona for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

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*Innovative Technology Assets Management  
JPL  
Mail Stop 202-233  
4800 Oak Grove Drive  
Pasadena, CA 91109-8099  
E-mail: iaoffice@jpl.nasa.gov  
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