

The figure shows a prototype assembly of conformal tanks. Each tank was fabricated by (1) copper plating a wax tank mandrel to form a liner and (2) wrapping and curing layers of graphite/epoxy composite to form a shell supporting the liner. In this case, the conformal tank surfaces are flat

ones where they come in contact with the adjacent tanks. A band of fibers around the outside binds the tanks together tightly in the assembly, which has a quasi-toroidal shape. For proper functioning, it would be necessary to maintain equal pressure in all the tanks.

*This work was done by Tom DeLay of Marshall Space Flight Center.*

*This invention is owned by NASA, and a patent application has been filed. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at [sammy.a.nabors@nasa.gov](mailto:sammy.a.nabors@nasa.gov). Refer to MFS-32015-1.*

## Microfluidic Pumps Containing Teflon® AF Diaphragms

**Operational temperature ranges have been extended to lower and higher limits.**

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Microfluidic pumps and valves based on pneumatically actuated diaphragms made of Teflon® AF polymers are being developed for incorporation into laboratory-on-a-chip devices that must perform well over temperature ranges wider than those of prior diaphragm-based microfluidic pumps and valves. Other potential applications include implanted biomedical microfluidic devices, wherein the biocompatibility of Teflon® AF polymers would be highly advantageous. These pumps and valves have been demonstrated to function stably after cycling through temperatures from  $-125$  to  $120$  °C.

These pumps and valves are intended to be successors to similar prior pumps and valves containing diaphragms made of polydimethylsiloxane (PDMS) [commonly known as silicone rubber]. The PDMS-containing valves are designed to function stably only within the temperature range from  $5$  to  $80$  °C. Undesirably, PDMS membranes are somewhat porous and retain water. PDMS is especially unsuitable for use at temperatures below  $0$  °C because the formation of ice crystals increases porosity and introduces microshear.

"Teflon® AF" is the trade name of family of fluoropolymers that are amorphous (in the sense of lacking crystalline structure). These polymers are less permeable and more thermally stable, relative to PDMS. These polymers are similar to other fluoropolymers in their mechanical and optical properties, in

being highly resistant to attack by many chemicals, and in retaining their desirable properties over wide temperature ranges. However, unlike other fluoropolymers, these are soluble in selected solvents; as such, they are amenable to spin coating to form membranes.

A typical microfluidic device of the type to which the present development applies includes one or more rigid glass substrate layers containing fluid-handling channels and chambers. Each pump or valve includes a polymer membrane diaphragm bonded to a glass layer or sandwiched between two glass layers, with one or more circular cutout(s) in each such glass layer to accommodate motion of the diaphragm and flows of fluids. The development effort thus far has included experiments to determine optimum combinations of ingredients and process conditions to form Teflon® AF membranes and incorporate them into pumps as diaphragms. It was found that structurally robust Teflon® AF 1600 membranes of acceptably high quality, about  $50$   $\mu\text{m}$  thick, can be formed by means of a spin-coating process repeated at least five times and that adequate adhesion of the membranes to glass substrates could be ensured by coating the membrane-anchoring areas of the substrates by vapor deposition of chromium to a thickness of  $50$  Å. Chromium was removed from valve seats and other nearby substrate areas to which moving portions of diaphragms were required not to adhere.

Pumps fabricated according to the guidance provided by the experiments have been operated for more than 240 hours without delamination of membranes from substrates or any other failures. Diaphragms and valve seats of various sizes and shapes have been tested; the combination of circular diaphragms of 2 mm diameter with hemispherical valve seats was found to yield the best overall performance. Various combinations of opening and closing actuation pressures were also tested; a combination of 6 psi (41 kPa) closing pressure and  $-12$  psi ( $-83$  kPa) opening pressure was found to generate the highest rate of flow while preventing formation of bubbles in the pumped liquid.

Temperature-cycling tests have also been performed. The first test involved warming the pumps to  $50$  °C followed by cooling the pumps to  $-25$  °C for 30 minutes. Next, the pumps were cooled to  $-80$  °C and held there for 48 hours. Finally, the pumps were cycled from  $-125$  to  $120$  °C four times over 24 hours. After each thermal cycle, pumping characteristics were measured. Interestingly, flow rates were found to be slightly increased after temperature cycling. No detrimental effects were noted after any of the temperature tests.

*This work was done by Peter Willis, Victor White, Frank Grunthaler and Mike Ikeda of Caltech and Richard A. Mathies of the University of California, Berkeley, for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-44482*