



## Gas-Tolerant Device Senses Electrical Conductivity of Liquid

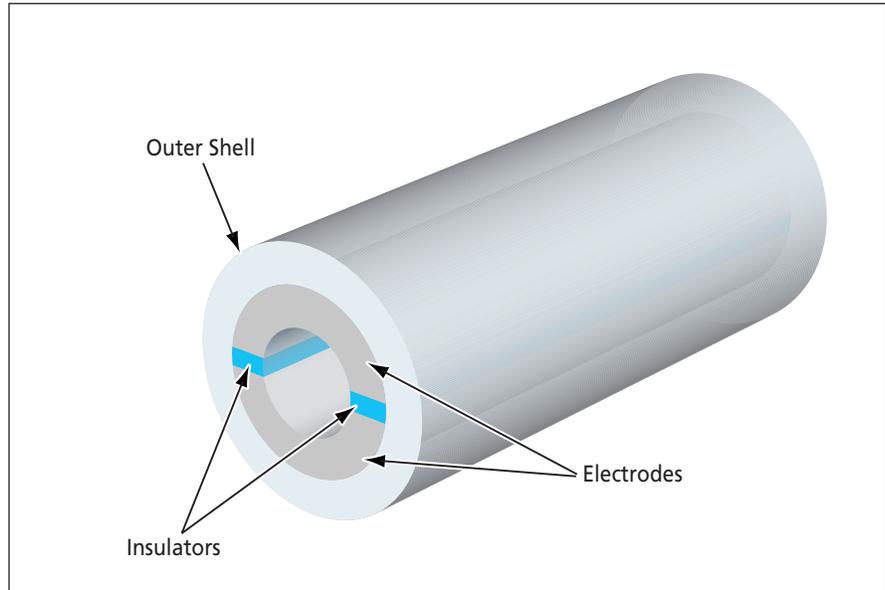
**Bubbles are not trapped in this device.**

*Marshall Space Flight Center, Alabama*

The figure depicts a device for measuring the electrical conductivity of a flowing liquid. Unlike prior such devices, this one does not trap gas bubbles entrained in the liquid.

Usually, the electrical conductivity of a liquid is measured by use of two electrodes immersed in the liquid. A typical prior device based on this concept contains large cavities that can trap gas. Any gas present between or near the electrodes causes a significant offset in the conductivity reading and, if the gas becomes trapped, then the offset persists.

Extensive tests on two-phase (liquid/gas) flow have shown that in the case of liquid flowing along a section of tubing, gas entrained in the liquid is not trapped in the section as long as the inner wall of the section is smooth and continuous, and the section is the narrowest tubing section along the flow path. The design of the device is based on the foregoing observation: The electrodes and the insulators separating the electrodes constitute adjacent parts of the walls of a tube. The bore of the tube is machined to make the wall smooth and to provide a straight flow path from the inlet to the outlet. The diameter of the electrode/insulator tube assembly is less than the diameter



A **Straight Tube With a Smooth Inner Wall** is formed by an assembly of electrodes and insulators in a hollow cylindrical configuration. The electrical conductivity of a liquid flowing along the tube is measured by use of the electrodes.

of the inlet or outlet tubing. An outer shell contains the electrodes and insulators and constitutes a leak and pressure barrier. Any gas bubble flowing through this device causes only a momentary conductivity offset that is filtered out by software used to process the conductivity readings.

*This work was done by Edward W. O'Connor of Hamilton Sundstrand for Marshall Space Flight Center. For further information, contact Chris Flynn, Hamilton Sundstrand Company New Technology Representative, at [chris.flynn@hs.utc.com](mailto:chris.flynn@hs.utc.com). Refer to MSC-31931.*

## Nanoactuators Based on Electrostatic Forces on Dielectrics

**Large force-to-mass ratios could be achieved at the nanoscale.**

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

Nanoactuators of a proposed type would exploit the forces exerted by electric fields on dielectric materials. As used here, "nanoactuators" includes motors, manipulators, and other active mechanisms that have dimensions of the order of nanometers and/or are designed to manipulate objects that have dimensions of the order of nanometers.

The underlying physical principle can be described most simply in terms of the

example of a square parallel-plate capacitor in which a square dielectric plate is inserted part way into the gap between the electrode plates (see Figure 1). Using the conventional approximate equations for the properties of a parallel-plate capacitor, it can readily be shown that the electrostatic field pulls the dielectric slab toward a central position in the gap with a force,  $F$ , given by

$$F = V^2(\epsilon_1 - \epsilon_2)a/2d,$$

where  $V$  is the potential applied between the electrode plates,  $\epsilon_1$  is the permittivity of the dielectric slab,  $\epsilon_2$  is the permittivity of air,  $a$  is the length of an electrode plate, and  $d$  is the thickness of the gap between the plates.

Typically, the force is small from our macroscopic human perspective. The above equation shows that the force depends on the ratio between the capacitor dimensions but does not depend on

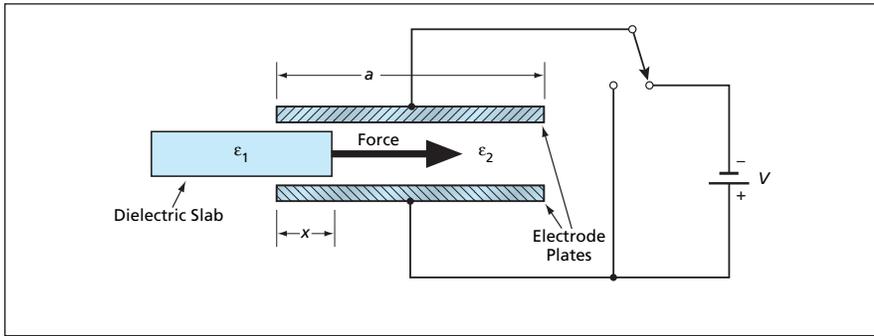


Figure 1. In a **Parallel-Plate Capacitor**, the electric field pulls a partially inserted dielectric slab further into the gap.

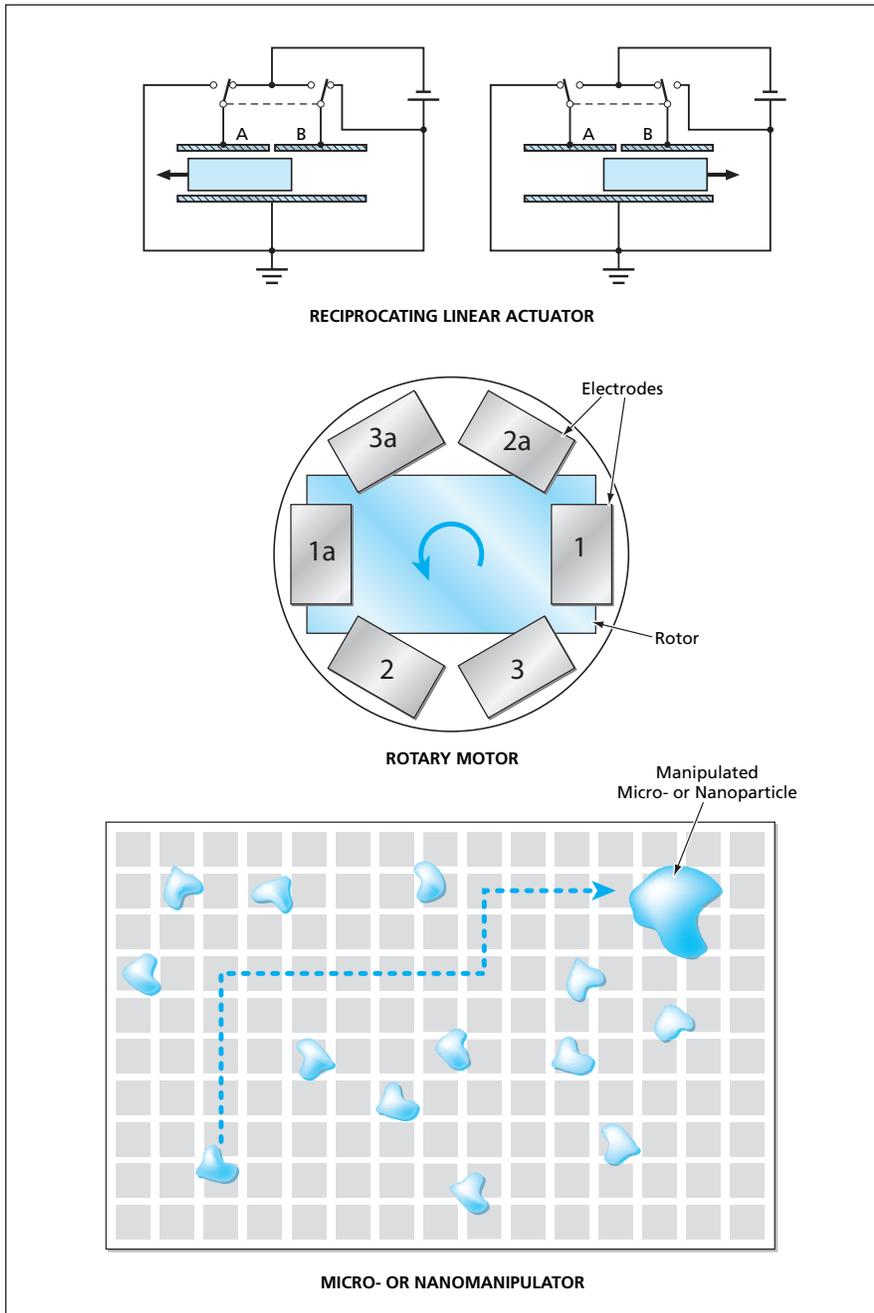


Figure 2. **These Three Devices** are examples of nanoactuators that would exploit the principle illustrated in Figure 1.

the size. In other words, the force remains the same if the capacitor and the dielectric slab are shrunk to nanometer dimensions. At the same time, the masses of all components are proportional to third power of their linear dimensions. Therefore the force-to-mass ratio (and, consequently, the acceleration that can be imparted to the dielectric slab) is much larger at the nanoscale than at the macroscopic scale. The proposed actuators would exploit this effect.

The upper part of Figure 2 depicts a simple linear actuator based on a parallel-plate capacitor similar to Figure 1. In this case, the upper electrode plate would be split into two parts (A and B) and the dielectric slab would be slightly longer than plate A or B. The actuator would be operated in a cycle. During the first half cycle, plate B would be grounded and plate A would be charged to a potential,  $V$ , with respect to the lower plate, causing the dielectric slab to be pulled under plate A. During the second half cycle, plate A would be grounded and plate B would be charged to potential  $V$ , causing the dielectric slab to be pulled under plate B. The back-and-forth motion caused by alternation of the voltages on plates A and B could be used to drive a nanopump, for example.

A rotary motor, shown in the middle part of Figure 2, could include a dielectric rotor sandwiched between a top and a bottom plate containing multiple electrodes arranged symmetrically in a circle. Voltages would be applied sequentially to electrode pairs 1 and 1a, then 2 and 2a, then 3 and 3a in order to attract the dielectric rotor to sequential positions between the electrode pairs.

A micro- or nanomanipulator, shown at the bottom of Figure 2, could include lower and upper plates covered by rectangular grids of electrodes — in effect, a rectangular array of nanocapacitors. A dielectric or quasi-dielectric micro- or nanoparticle (a bacterium, virus, or molecule for example) could be moved from an initial position on the grid to a final position on the grid by applying a potential sequentially to the pairs of electrodes along a path between the initial and final positions.

*This work was done by Yu Wang of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-30747*