Ring-Resonator/Sol-Gel Interferometric Immunosensor

Light would make multiple passes through the sensing volume.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed biosensing system would be based on a combination of (1) a sensing volume containing antibodies immobilized in a sol-gel matrix and (2) an optical interferometer having a ring resonator configuration. The antibodies

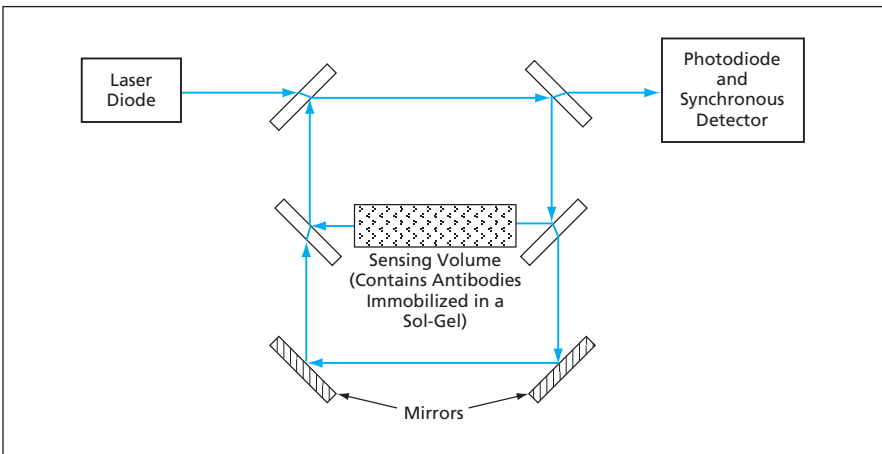tration of the antigen species of interest.

The basic principle of using interferometry to detect antibody-antigen binding is not new in itself. However, the prior implementation of this principle has involved the use of a Mach-

ferometer configuration, there would be two interferometer arms with coupled optical paths. One of the optical paths would pass through the sensing volume; the other optical path would not pass through the sensing volume (see figure). Interference between light beams in the two interferometer arms would be characterized by a phase difference proportional to the change in the index of refraction of the sensing volume. The phase difference would result in a change in the interferometer output intensity measured by use of a photodiode. A synchronous detector could be used to increase sensitivity.

The ring resonator/interferometer could be built by use of traditional bulk optical components or fabricated as a unit by standard silicon-fabrication techniques. Inasmuch as a sol-gel precursor can be poured into a mold, an etched recess in a planar waveguide or other structures could be used as the sensing volume.

A **Ring Resonator/Interferometer** would include a sensing volume on one of its optical paths. Binding of antigens to antibodies would cause a change in the index of refraction of the sensing volume leading to a change in the photodiode output.

would be specific to an antigen species that one seeks to detect. The binding of the antigens to the immobilized antibodies would change the index of refraction of the sensing volume, which would be mounted in one of the interferometer arms. The interferometer would measure the change in the index of refraction, thereby indirectly measuring the concen-

Zehnder interferometer, which affords only a single pass of light through the sensing volume. In the ring resonator of the proposed system, light would make multiple passes through the sensing volume, affording greater interaction length and, hence, greater antibody-detection sensitivity.

In one proposed ring-resonator/inter-

This work was done by Gregory Bearman and David Cohen of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Management Office–JPL. Refer to NPO-30807.

Compact Fuel-Cell System Would Consume Neat Methanol

Size, mass, and parasitic power consumption would be reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

In a proposed direct methanol fuel-cell electric-power-generating system, the fuel cells would consume neat methanol, in contradistinction to the dilute aqueous methanol solutions consumed in prior direct methanol fuel-cell systems. The design concept of the proposed fuel-cell system takes advantage of (1) electro-osmotic drag and diffusion

processes to manage the flows of hydrogen and water between the anode and the cathode and (2) evaporative cooling for regulating temperature. The design concept provides for supplying enough water to the anodes to enable the use of neat methanol while ensuring conservation of water for the whole fuel-cell system. By rendering unnecessary some of the auxil-

iary components and subsystems needed in other direct methanol fuel-cell systems for redistributing water, diluting methanol, and regulating temperature, this fuel-cell design would make it possible to construct a more compact, less massive, more energy-efficient fuel-cell system.

In a typical prior direct methanol fuel-cell system, neat methanol is stored in a
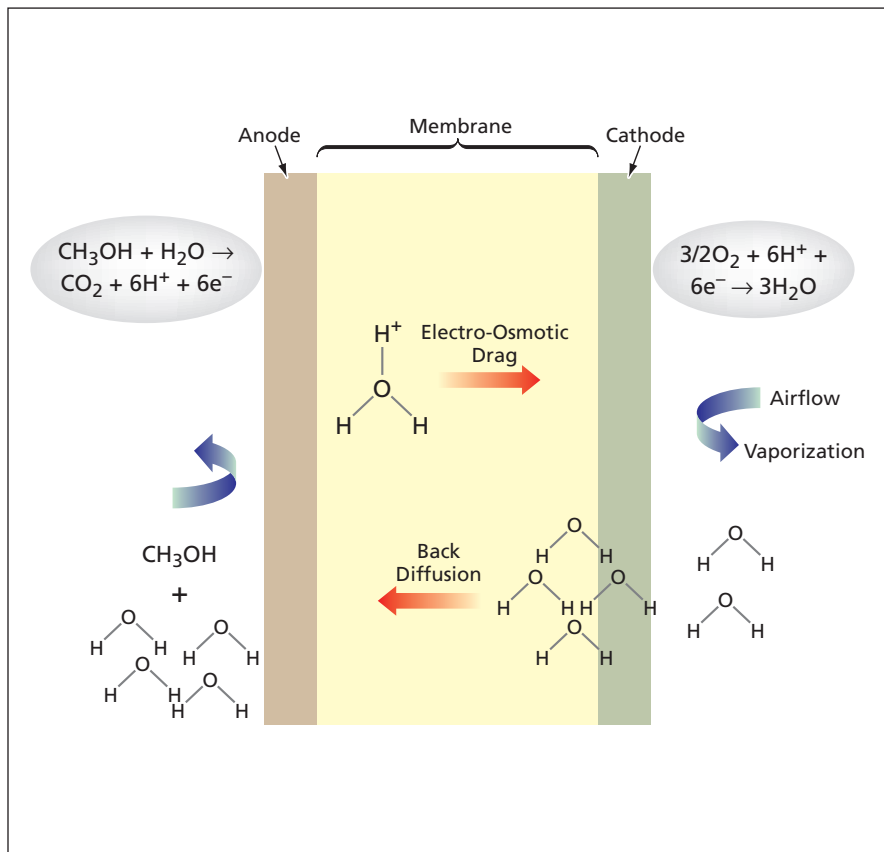
The **Transport Processes** involved in the operation of a direct methanol fuel cell figure prominently in the proposed design.

container and then diluted with water to a concentration between 2 and 3 percent before it is introduced into the fuel-cell stack. Water for dilution is gathered from the cathode side of the fuel-cell stack. The fuel solution is recirculated, the fuel solution entering the anodes is monitored by use of a methanol sensor, and, in response to the sensor reading, methanol is added to the solution as needed to maintain the required concentration. The collection of water, the dilution of methanol, the control of concentration, and the circulation of the fuel solution entail the use of several pumps and control subsystems, and substantial electrical energy is consumed in operating the pumps and control subsystems. These auxiliary components and subsystems typically contribute about half of the overall volume and mass and at least half of the parasitic energy consumption of the system.

The figure schematically depicts the transport processes involved in the operation of a direct methanol fuel cell (whether of prior or proposed design). Methanol is oxidized to protons and carbon dioxide at the anode, and oxygen is reduced to water at the cathode. As protons migrate from the anode to the cathode through a proton-con-

ducting mebrane that is part of a membrane/electrode assembly, water is transported along with them by electro-osmotic drag: in other words, water molecules associated with the protons are dragged along with the protons. Air flowing over the cathode evaporates some of the water. However, some of the water tends to diffuse back toward the anode because the concentration of water at the cathode exceeds the concentration of water in the methanol-water solution at the anode (this diffusion is hereafter denoted "back diffusion"). Water is consumed at the anode by the oxidation of methanol, and water is produced at the cathode by reduction of oxygen.

The rate of consumption of water at the anode is proportional to the electric-current density. The rate of electro-osmotic drag of water from the anode to the cathode is determined by the electric-current density and a drag coefficient that amounts to about 3 molecules of water per proton. The rate of production of water in the chemical reaction at the cathode is also proportional to the electric-current density. The rate of flow of air over the cathode, the temperature of the cell, and the absolute humidity of

the air at that temperature determine the rate of evaporation. The gradient of concentration of water between the anode and the cathode and the diffusion coefficient of water in the membrane/electrode composite determine the rate of back diffusion.

In a fuel cell of prior design, the rate of back diffusion is insufficient, necessitating the use of pumps to return water from the cathode to the anode side. The proposed fuel-cell design concept provides for enhancement of the rate of back diffusion through enhancement of the gradient of concentration of water between the anode and the cathode, thereby eliminating the need for the pumps and controls heretofore needed for this purpose.

The enhancement of the gradient of concentration of water would be effected, nearly independently of the electric-current density, through appropriate choice of the concentration of methanol, the porosity of the electrodes, the thickness of the membrane, the operating temperature, and the stoichiometric rate of flow of air. For any given set of values of these parameters, there would be an electric-current density at which water balance would be achieved. Therefore, a membrane/electrode assembly capable of supporting any desired value of electric-current density and maintaining water balance could be designed for use in a fuel cell without need for pumps or other components for dilution or for redistribution of water.

An important consideration in the design concept is that an uncontrolled excess of neat methanol at the anode would cause swelling of the membrane. Therefore, the rate of delivery of methanol must be such that only a small quantity of methanol reaches the anode and that the entire quantity of delivered methanol be utilized within the anode, so that no appreciable quantity of neat methanol can reach the surface of the membrane. The full utilization of methanol could be achieved if the anode structure were made sufficiently porous and thick: such a structure would ensure that the residence time for methanol was adequate for complete consumption of ethanol within the anode structure. The porous anode structure would contain enough proton-conducting polymer material to form conducting paths for protons and water molecules, yet would have enough tortuosity to afford sufficient residence time. The anode structure would include layers having various proton-conducting-polymer contents so

that the desired level of utilization could be achieved. The design choice of thickness and porosity of the anode would depend on the planned rate of delivery of methanol and on whether the methanol were to be delivered directly in purely liquid form, delivered directly in aerosol form, or delivered in purely liquid form through a diffusion barrier.

The design must provide for removal of excess heat. In a fuel cell of prior design, one can utilize the circulation of the dilute fuel solution to remove heat on the anode side and evaporative cooling on the cathode side. In the absence of fuel-solution circulation in the proposed design and without further modification, only evaporative cooling would be available. Under most conditions, evaporative cooling alone may not suffice, so that it may be necessary to add cooling fins to the fuel-cell stack.