on the electron source side and the desired higher pressure in the sample-exchange chamber. In the original intended application of the MEMSA, the PLAs would be four platinum disks containing apertures of ≈0.5-mm diameter, chosen to maintain a pressure between 5 and 7 torr (about 0.67 to 0.93 kPa) of residual Martian atmospheric gas comprising primarily CO_2.

The MEMSA is expected to be capable of imaging at a spatial resolution of 40 nm or finer without EDX, or imaging at somewhat coarser resolution (of the order of 200 nm) with EDX in the energy range from 100 to 20 keV. The coarsening of resolution in the case of EDX would be a consequence of the need to use higher electron current. The maximum power demand of the MEMSA during operation has been estimated to be ≈5 W.

This work was done by Harish Manohara, Gregory Bearman, Susanne Douglas, Michael Bronikowski, Eduardo Urgiles, and Robert Kowalczyk, of Caltech and Charles Bryson of Apperati, Inc. for NASA's Jet Propulsion Laboratory.

Nanowire Electron Scattering Spectroscopy

Multiple chemical compounds could be sensed, without the need to chemically functionalize nanowires.

NASA's Jet Propulsion Laboratory, Pasadena, California

Nanowire electron scattering spectroscopy (NESS) has been proposed as the basis of a class of ultra-small, ultra-low-power sensors that could be used to detect and identify chemical compounds present in extremely small quantities. State-of-the-art nanowire chemical sensors have already been demonstrated to be capable of detecting a variety of compounds in femtomolar quantities. However, to date, chemically specific sensing of molecules using these sensors has required the use of chemically functionalized nanowires with receptors tailored to individual molecules of interest. While potentially effective, this functionalization requires labor-intensive treatment of many nanowires to sense a broad spectrum of molecules. In contrast, NESS would eliminate the need for chemical functionalization of nanowires and would enable the use of the same sensor to detect and identify multiple compounds.

NESS is analogous to Raman spectroscopy, the main difference being that in NESS, one would utilize inelastic scattering of electrons instead of photons to determine molecular vibrational energy levels. More specifically, in NESS, one would exploit inelastic scattering of electrons by low-lying vibrational quantum states of molecules attached to a nanowire or nanotube (see figure). The energy of the electrons is set by the voltage bias applied across the nanowire. When the electron energies correspond to particular molecular vibrational levels, enhanced electronic scattering will lead to a change in the differential conductance (dI/dV, where I is current and V is voltage) at that voltage. Thus changes in the conductance provide a direct readout of molecular vibrational energies, to enable spectroscopic identification of the attached molecules.

To realize a practical chemical sensor based on NESS, one would need a narrow-energy-band electron source, efficient coupling between the electrons and the molecules of interest, and the narrow vibrational bands in the molecules of interest. A carbon nanotube (CNT) provides a nearly ideal structure for satisfying the electron-source and coupling requirements for the following reasons: Even at room temperature, the energy bands in one dimensional carbon nanotubes are narrow, and low-energy electrons travel ballistically over distances of the order of a micron, so that injected electrons can have a nearly uniform kinetic energy. Because single-walled CNTs are essentially all "surface," there is strong coupling between electrons and molecules on their surfaces.

Other than CNTs, nanowires of silicon and perhaps other materials may yield usable NESS signals, though the signals are expected to be smaller than those from CNT-based sensors. One might need non-CNT nanowire NESS sensors to detect molecules that do not readily bind to CNTs.

In order to simplify the interpretation of a complex spectrum from a mixture of compounds, a NESS-based sensor could be integrated with a microfluidic
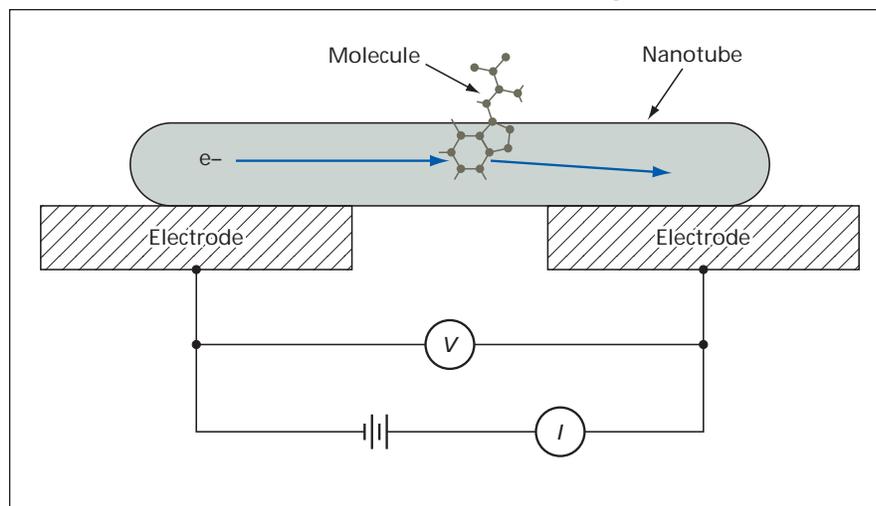
Inelastic Scattering of Electrons by molecules on the surface of a nanotube would affect the current-versus-voltage characteristic of the nanotube.

separation column. The column would enable separation and concentration of individual species, which would then be detected and identified at the column outlet by use of NESS.

This work was done by Brian Hunt, Michael Bronikowsky, Eric Wong, Paul Von Allmen, and Fabiano Oyafuso of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

Electron-Spin Filters Would Offer Spin Polarization >1
Net spin flux could be generated with little net electric current.

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A proposal has been made to develop devices that would generate spin-polarized electron currents characterized by polarization ratios having magnitudes in excess of 1. Heretofore, such devices (denoted, variously, as spin injectors, spin polarizers, and spin filters) have typically offered polarization ratios having magnitudes in the approximate range of 0.01 to 0.1. The proposed devices could be useful as efficient sources of spin-polarized electron currents for research on spintronics and development of practical spintronic devices.

The polarization ratio in question — denoted the current spin polarization — is a standard measure of efficiency of a spin-polarizing device. It is defined in terms of current densities along a given coordinate axis, by means of the following equation:

$$P_J = (J\uparrow - J\downarrow) / (J\uparrow + J\downarrow),$$

where $J\uparrow$ is current density of electrons in the "up" spin state and $J\downarrow$ is the current density of electrons in the "down" spin state. If $J\uparrow$ and $J\downarrow$ can be made to have opposite signs — in other words, if electrons in opposite spin states can be made to move in opposite directions — then, as desired, it is possible to obtain $|P_J|>1$. By making $|P_J|>1$, one would make it possible to obtain a net spin flux with little net electric current.

A spin-polarizing device according to the proposal would be based largely on the same principles as those of the devices described in "Electron-Spin Filters Based on the Rashba Effect" (NPO-30635), *NASA Tech Briefs*, Vol. 28, No. 10 (October 2004), page 58. To recapitulate: The Rashba effect is an energy splitting, of what would otherwise be degenerate quantum states, caused by a spin-orbit interaction in conjunction with interfacial electric fields in an asymmetrical semiconductor heterostructure. The magnitude of the energy split
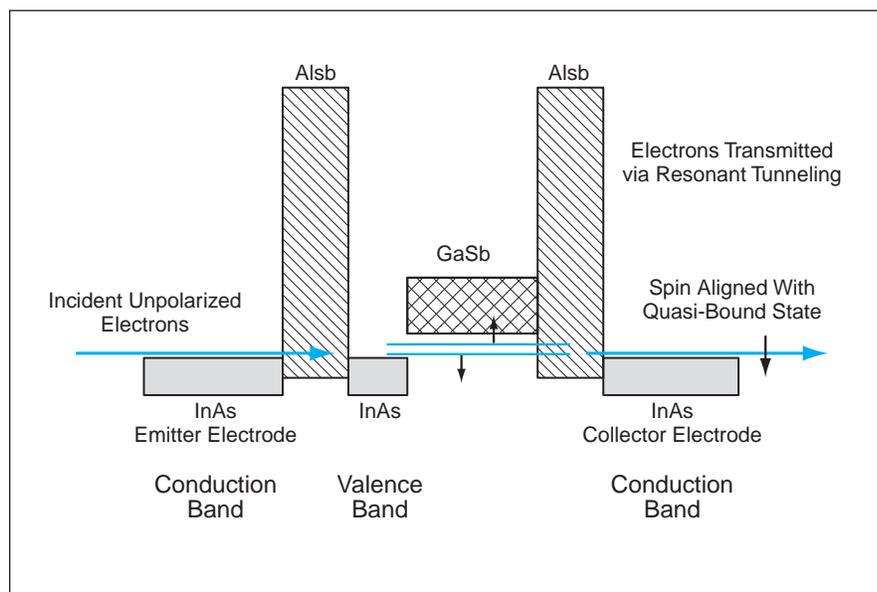
Electron-Energy-Band Alignments depicted here schematically are those of a proposed InAs/GaSb/AlSb a-RITD device for achieving current spin polarization >1. The shaded and cross-hatched regions represent bandgaps.

is proportional to the electron wave number. Theoretically, electron-energy states would be split by the Rashba effect, and spin-polarized currents would be extracted by resonant quantum-mechanical tunneling. Accordingly, a spin-polarizing device based on these principles would be denoted an asymmetric resonant interband (or intraband, as the case may be) tunneling diode [a-RITD].

One possible structure of a device according to the present proposal would be similar to the a-RITD structure described previously: The device would comprise an asymmetric composite InAs-GaSb well, sandwiched between AlSb barriers and degenerately-n-doped InAs emitter and collector electrodes (see figure). Unpolarized electrons from the conduction band of the InAs emitter electrode would tunnel through one AlSb barrier and travel

through an asymmetric InAs-GaSb quantum well, where Rashba spin splitting would occur; they would then tunnel through the other AlSb barrier into the conduction band of the InAs collector electrode. The device would be operated in an intraband-tunneling regime, in which no bias would be applied through the thickness of the stack of layers. A lateral electric (an electric field parallel to the planes of the layers) would be applied to emitter layer. With appropriately chosen thicknesses of layers and an appropriate value of the applied lateral electric field, it should be possible to achieve $|P_J|>1$.

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