Electron-Spin Filters Based on the Rashba Effect

Filters would be made from nonmagnetic semiconductors and operated without applied magnetic fields.

NASA's Jet Propulsion Laboratory, Pasadena, California

Semiconductor electron-spin filters of a proposed type would be based on the Rashba effect, which is described briefly below. Electron-spin filters — more precisely, sources of spin-polarized electron currents — have been sought for research on, and development of, the emerging technological discipline of spintronics (spin-based electronics). There have been a number of successful demonstrations of injection of spin-polarized electrons from diluted magnetic semiconductors and from ferromagnetic metals into nonmagnetic semiconductors. In contrast, a device according to the proposal would be made from nonmagnetic semiconductor materials and would function without an applied magnetic field.

The Rashba effect, named after one of its discoverers, is an energy splitting, of what would otherwise be degenerate quantum states, caused by a spin-orbit interaction in conjunction with a structural-inversion asymmetry in the presence of interfacial electric fields in a semiconductor heterostructure. The magnitude of the energy split is proportional to the electron wave number. The present proposal evolved from recent theoretical studies that suggested the possibility of devices in which electron energy states would be split by the Rashba effect and spin-polarized currents would be extracted by resonant quantum-mechanical tunneling. Accordingly, a device according to the proposal would be denoted an asymmetric resonant interband tunneling diode [a-RITD]. An a-RITD could be implemented in a variety of forms, the form favored in the proposal being a double-barrier heterostructure containing an asymmetric quantum well.

It is envisioned that a-RITDs would be designed and fabricated in the InAs/GaSb/AlSb material system for several reasons: Heterostructures in this material system are strong candidates for pronounced Rashba spin splitting because InAs and GaSb exhibit large spin-orbit interactions and because both InAs and GaSb would be available for the construction of highly asymmetric quantum wells. This mate-rial system affords a variety of energy-band alignments that can be exploited to obtain resonant tunneling and other desired effects. The no-common-atom InAs/GaSb and InAs/AlSb interfaces would present opportunities for engineering interface potentials for optimizing Rashba spin splitting.

More specifically, a device of this type would comprise an asymmetric composite InAs-GaSb well, sandwiched between AlSb barriers and InAs electrodes. Unpolarized electrons from the conduction band of an InAs emitter electrode would tunnel rapidly through one AlSb barrier and 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 an InAs collector electrode. With appropriately chosen
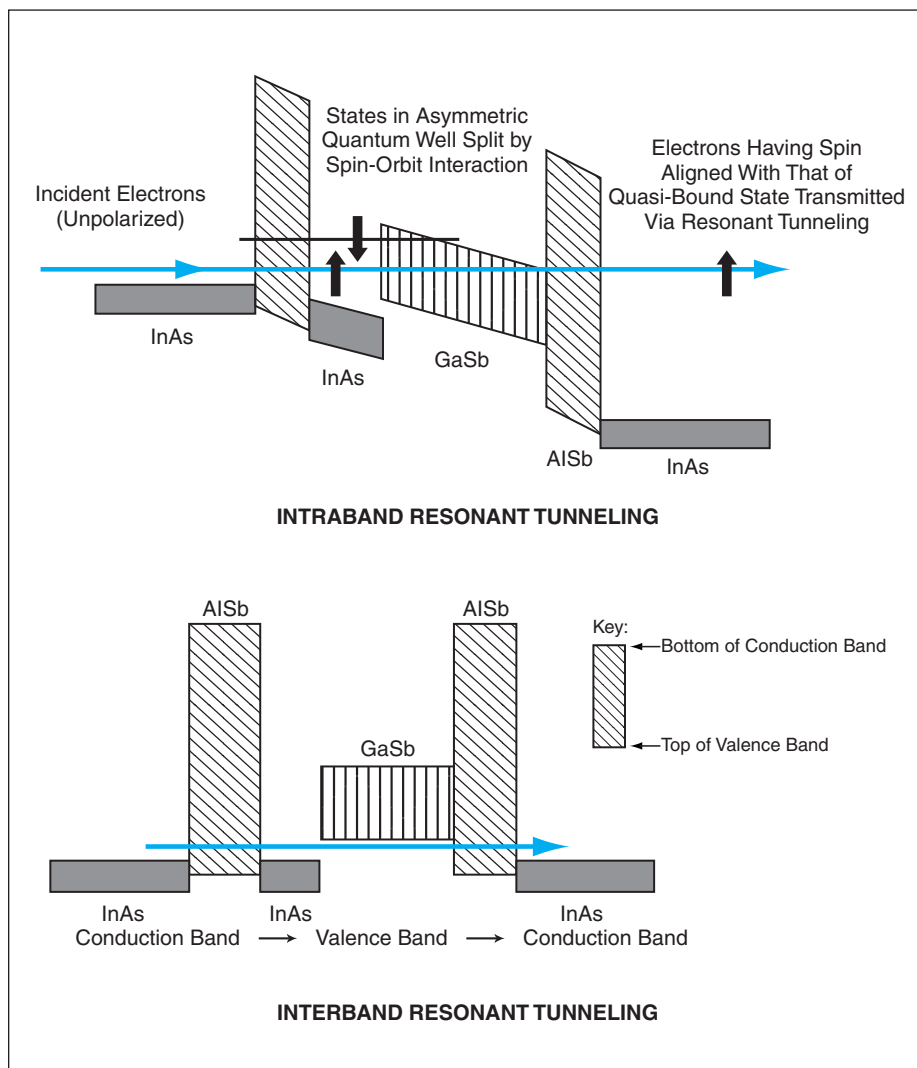
Electron-Energy-Band Alignments and two tunneling schemes of proposed InAs/GaSb/AlSb a-RITD devices are depicted here schematically. The shaded and cross-hatched regions represent bandgaps.

thicknesses of layers, this device could be made to operate in either of two regimes (see figure):

- Under low bias, in a resonant-interband-tunneling regime, in which electrons would traverse valence subband states in GaSb or
- Under moderate bias, in an intraband-resonant-tunneling regime, in which electrons would traverse conduction subband states in InAs. Computational simulations have led to an expectation that the interband regime would yield better performance.

This work was done by David Z.-Y. Ting, Xavier Cartoixà, and Thomas C. McGill of Caltech; Jeong S. Moon, David H. Chow, and Joel N. Schulman of HRL Laboratories, LLC; and Darryl L. Smith of Los Alamos National Laboratory for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

In accordance with Public Law 96-517, the contractor has elected to retain title to this

Diffusion-Cooled Tantalum Hot-Electron Bolometer Mixers

Lower TCs should translate to lower noise and lower required local-oscillator power.

NASA's Jet Propulsion Laboratory, Pasadena, California

A batch of experimental diffusion-cooled hot-electron bolometers (HEBs), suitable for use as mixers having input frequencies in the terahertz range and output frequencies up to about a gigahertz, exploit the superconducting/normal-conducting transition in a thin strip of tantalum. The design and operation of these HEB mixers are based on mostly the same principles as those of a prior HEB mixer that exploited the superconducting/normal-conducting transition in a thin strip of niobium and that was described in "Diffusion-Cooled Hot-Electron Bolometer Mixer" (NPO-19719), *NASA Tech Briefs*, Vol. 21, No. 1 (January 1997), page 12a.

One reason for now choosing tantalum instead of niobium arises from the fact that the superconducting-transition temperature (T_C) of tantalum lies between 2 and 3 K, while that of niobium lies between 6 and 7 K. Theoretically, the input mixer noise of a superconducting HEB is proportional to T_C and the power demand on the local oscillator that supplies one of the input signals to the mixer is proportional to T_C^2. The lower noise and power demand associated with the lower T_C of tantalum could make tantalum HEBs more attractive, relative to niobium HEBs, in applications in which there are requirements to minimize noise and/or to provide mixers that can function well using the weak signals generated by typical solid-state local oscillators. Of course, to reach the required lower T_C, it is necessary to use more complex cryogenic equipment. Fortunately, such equipment (e.g., helium-3 cryostats) is commercially available.

In order to make a practical tantalum HEB, it is necessary to overcome a challenge posed by the fact that thin films of tantalum tend to contain grains of two different crystalline phases. The presence of the two phases would be unacceptable in a practical device because (1) the additional electron scattering at the grain boundaries would tend to suppress the diffusion-cooling mechanism, and (2) the different T_Cs of the two phases would lead to broadening of the transition.

The present HEB mixers contain tantalum microbridges having lengths of 100 to 400 nm, widths of 100 to 200 nm, and thicknesses of 10 nm. The bridges were made from a 10-nm-thick film of tantalum deposited by sputtering onto a 1.5-nm-thick seed layer of niobium on a silicon wafer. The niobium seed layer was used to promote the growth of one of the two crystalline phases (the α phase) to ensure the required crystalline purity and thereby keep the superconducting transition (see figure) as sharp as possible.

The results of microwave impedance tests of one of the experimental tantalum HEBs have been interpreted as signifying that the 3-dB roll-off frequency for mixer conversion efficiency can be expected to be about 1 GHz, neglecting the effect of electrothermal feedback. End effects are small enough (as illustrated by the smallness of the "foot" of the resistance-versus-temperature curve in the figure) that it should be possible to use devices as short as 100 nm and possibly even shorter. Inas-
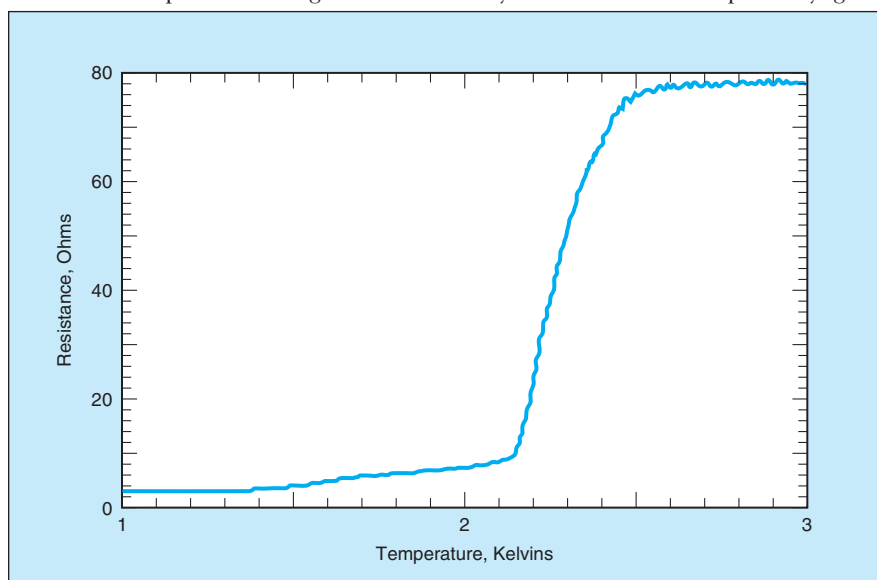
DC Resistance of an HEB was measured as a function of temperature from below to above T_C. Except for the lower T_C, this plot is similar to the resistance-vs.-temperature plots of niobium HEBs. The nonzero-resistance "foot" of this plot is an effect of normally conductive gold contact pads at the ends of the device.