



Resonant Tunneling Spin Pump

Electrons in opposite spin states would flow in opposite directions across a spin filter.

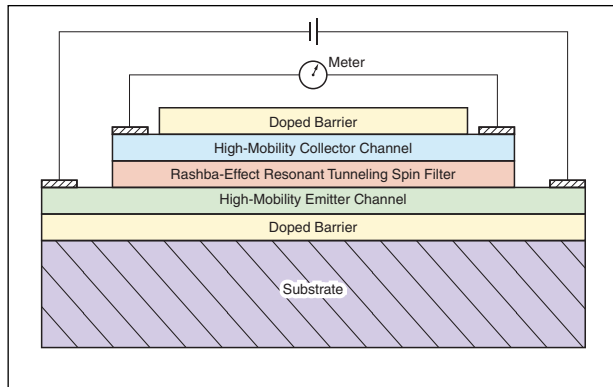
NASA's Jet Propulsion Laboratory, Pasadena, California

The resonant tunneling spin pump is a proposed semiconductor device that would generate spin-polarized electron currents. The resonant tunneling spin pump would be a purely electrical device in the sense that it would not contain any magnetic material and would not rely on an applied magnetic field. Also, unlike prior sources of spin-polarized electron currents, the proposed device would not depend on a source of circularly polarized light.

The resonant tunneling spin pump would have some features in common with other, similarly named devices, including resonant tunneling spin filters described in a previous NASA Tech Briefs article: "Electron-Spin Filters Based on the Rashba Effect" (NPO-30635), Vol. 28, No. 10 (October 2004), page 58.

To recapitulate: Proposed semiconductor electron-spin filters would exploit the Rashba effect, which can induce energy splitting in 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. Theoretical studies have 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.



In the Resonant Tunneling Spin Pump, the lateral electric field applied to the emitter channel would induce a lateral current in the collector channel and spin-polarized currents across the spin filter.

The resonant tunneling spin pump (see figure) would include a spin filter between two reservoirs of initially unpolarized electrons. Like the devices of the cited prior article, the resonant tunneling spin pump would be designed and fabri-

cated in the InAs/GaSb/AlSb material system. One reservoir would be a high-mobility InAs emitter channel and the other a high-mobility InAs collector channel. The spin filter would comprise an InAs/GaSb/AlSb asymmetric resonant tunneling structure.

The application of a lateral electric field in the emitter channel would cause current of one spin state to flow from the emitter channel to the collector channel and a current of the opposite spin state to flow from the collector channel to the emitter channel, thereby inducing spin polarization in both reservoirs. This mode of operation would differ somewhat from that of a spin filter: In a spin filter, component currents containing spins of both states would flow from the emitter to the collector and spin polarization in the collector would be achieved by choosing the design and the operating conditions of the device

to make one of the spin component currents larger than the other.

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). NPO-30885

Enhancing Spin Filters by Use of Bulk Inversion Asymmetry

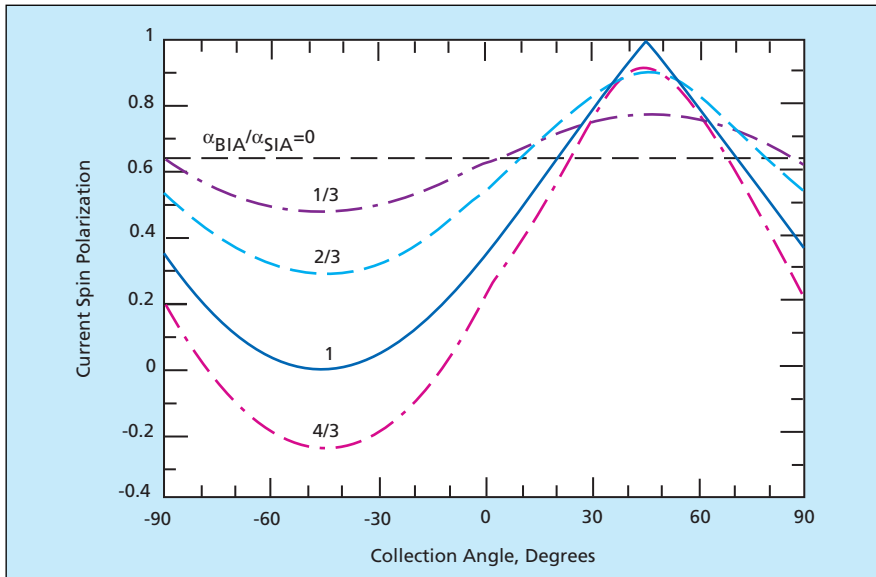
Current spin polarization could be maximized through appropriate choice of collection angle.

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Theoretical calculations have shown that the degrees of spin polarization in proposed nonmagnetic semiconductor resonant tunneling spin filters could be increased through exploitation of bulk inversion asymmetry (BIA). These enhancements would be effected through suitable orientation of spin collectors (or spin-polarization-inducing lateral electric fields), as described below.

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-transport electronics). Proposed nonmagnetic semiconductor electron-spin filters were described in a prior NASA Tech Briefs article: "Electron-Spin Filters Based on the Rashba Effect" (NPO-30635), Vol. 28, No. 10 (October 2004),

page 58. To recapitulate: The proposed spin filters were to be based on the Rashba effect, which 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 (SIA) in the presence of interfacial electric fields in a semiconductor heterostructure. The magnitude of the energy split is proportional to the electron wave num-



Current Spin Polarization was computed as a function of collection angle for different values of the ratio between the BIA and SIA coefficients ($\alpha_{\text{BIA}}/\alpha_{\text{SIA}}$), under the simplifying assumption of perfect sub-band filtering.

ber. In a spin filter, the spin-polarized currents produced by the Rashba effect would be extracted by quantum-mechanical resonant tunneling.

The origin of the enhancement now proposed lies in recognition that not only

the SIA but also bulk inversion asymmetry (BIA) contributes to the spin-dependent energy splitting. The conceptual device structure on which the proposal is based is a spin-filtering resonant tunneling heterostructure, grown along the [001] direc-

tion (the z axis), that includes an asymmetric quantum well. The physics of this structure was represented by a simplified two-band, spin-dependent Hamiltonian model. This model was chosen because although it is only approximate, its simplicity facilitates understanding of how BIA could be utilized to enhance spin filtering.

The theoretical calculations were performed using this model. It was found that when only SIA is taken into account, the theoretical upper limit of current spin polarization for a Rashba-effect resonant tunneling spin filter with a one-sided spin collector can be expected to be $2/\pi$ (about 63.7 percent), independent of the direction of the collector. When BIA was taken into account along with SIA, it was found that current spin polarization could be changed from the SIA-only value by varying the collection angle: in particular, the greatest and least polarization values were found to occur in the [110] and $[1\bar{1}0]$ directions, representing collection angles of $+45^\circ$ and -45° , respectively.

This work was done by David Ting and Xavier Cartoixa of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-40210

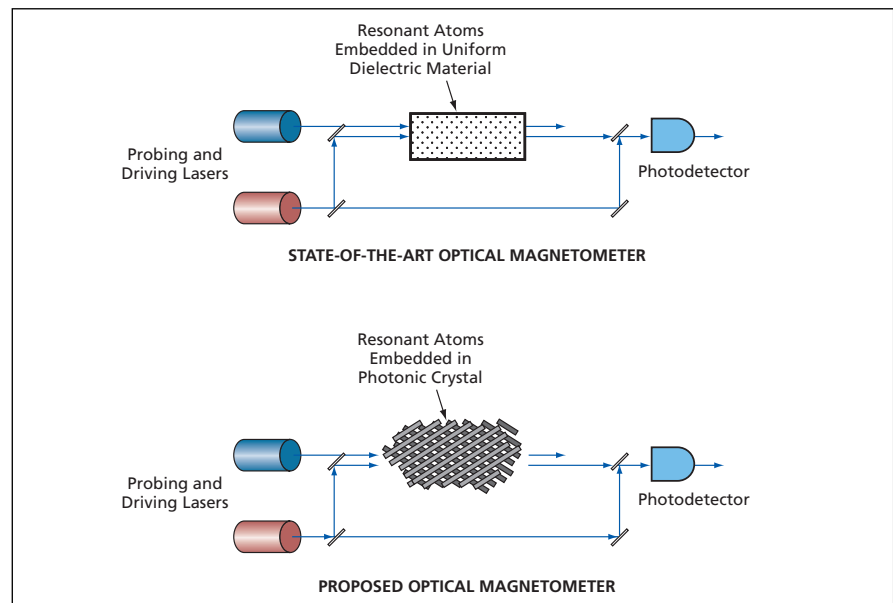
Optical Magnetometer Incorporating Photonic Crystals

Sensitivity would be increased by orders of magnitude.

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According to a proposal, photonic crystals would be used to greatly increase the sensitivities of optical magnetometers that are already regarded as ultrasensitive. The proposal applies, more specifically, to a state-of-the-art type of quantum coherent magnetometer that exploits the electromagnetically-induced-transparency (EIT) method for determining a small change in a magnetic field indirectly via measurement of the shift, induced by that change, in the hyperfine levels of resonant atoms exposed to the field.

One of the key components of a magnetometer of this type is a collection of the aforesaid resonant atoms, which have an energy spectrum that is sensitive to any variation in magnetic field. These atoms are placed in a cell, wherein they are irradiated with light from a quantum source (see figure), such that the interactions between the light and the atoms produce a beam of coherent or entangled photons suitable for use in determining the magnetic



An **Optical EIT Magnetometer** according to the proposal would be based on the same measurement principle as that of a state-of-the-art optical EIT magnetometer, but the resonant atoms would be embedded in a photonic crystal such that the variation in the index of refraction with magnetic field would be greatly increased.