Nonmagnetic Resonant Tunneling Spin Devices

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We report device concepts for creating spin polarized current sources without external magnetic fields, using nonmagnetic semiconductor resonant tunneling structures. These devices contain asymmetric quantum wells where quantized states are spin-split by the Rashba effect [1], and achieve spin filtering by exploiting the phenomenon that the spin of a resonantly transmitted electron aligns with that of the quasibound state traversed [2,3]. Achieving significant spin filtering using this approach is difficult because of the intrinsic properties of the spin-split quantum well states: the $\mathbf{k}_{\parallel}$-dependent spin splitting is typically small and vanishes at the zone center; states with opposite $\mathbf{k}_{\parallel}$ within a given spin-split subband have opposite spins so that there is no net spin when averaged over the subband. We have developed effective strategies for overcoming these challenges, and proposed a number of new concepts for designing heterostructure based spin devices. We will present modeling results on:

(1) ***BIA (Bulk Inversion Asymmetry) Enhanced Resonant Tunneling Spin Filter***. We present a resonant tunneling spin filter [3] containing a composite quantum well with optimized Rashba coefficients. We then show a simple method for enhancing spin filtering efficiency by properly combining the BIA and the SIA (structural inversion asymmetry) effects.

(2) ***Resonant Spin Lifetime Transistor Devices.*** The consideration of the interaction of BIA and the SIA effects have led us to the concept of a variant of the Datta-Das transistor [4] in which the switching action is accomplished by electrically controlling the spin lifetimes of electrons in the channel. The device can be the basis for a non-volatile memory.

(3) ***Resonant Interband Tunneling Spin Filter*** [5]. The interband design exploits large valence band spin-orbit interaction to provide strong spin selectivity, without suffering from fast hole spin relaxation. Spin filtering efficiency is also enhanced by the reduction of tunneling through quasibound states near the zone center. The asymmetric resonant tunneling diode (aRITD) improves spin-filtering efficiency significantly (current spin polarization exceeding 60%) over the resonant intraband tunneling diode.

(4) ***Bi-Directional Spin Pump***. In the spin filters we try to overcome the challenges presented by the spin configurations in Rashba-effect quantum wells. The spin pump, on the other hand, is designed specifically to take advantage of the Rashba spin configuration. The bi-directional spin pump can generate significant levels of spin current with very little net electrical current across the tunnel structure, a condition characterized by a greater-than-unity current spin polarization.

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As a specific example, in Fig. 1 we illustrate the concept of a bi-directional spin pump. The device structure consists of an asymmetric composite InAs-GaSb well, surrounded by AlSb barriers and high mobility InAs emitter and collector channels. Electrons can tunnel between InAs electrodes via the GaSb valence subband states. We do not intentionally bias the spin pump along the growth (z) direction. Instead we apply a small lateral E-field in the emitter region only. The application of an in-plane E-field displaces the emitter Fermi surface. As depicted in Fig. 1, the displacement creates an excess of carriers on the $+k_x$ side, which can tunnel to the collector, and a deficit of carriers on the $-k_x$ side, which becomes available to receive electrons tunneling from the collector. The structure is designed such that resonantly transmitted electrons on the $+k_x$ and $-k_x$ sides will be spin polarized along the $-y$ and $+y$ directions, respectively. The net result is a forward (emitter to collector) electron current with $-y$ spin polarization, and a backward current with $+y$ spin polarization.

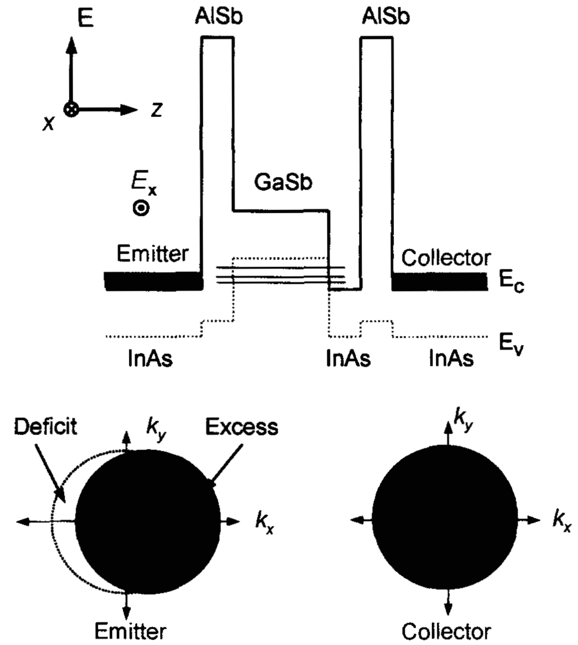

Figure 1. Schematic energy band diagram of an asymmetric resonant interband tunneling structure used for the bi-directional spin pump. The bottom illustrates the emitter and collector carrier populations in momentum space.

Figure 2 shows the computed spin-dependent current densities and current spin polarization as functions of the lateral E-field for a resonant tunneling spin pump. The electrode carrier densities are selected to reach hh1 resonant tunneling conditions. It shows substantial spin up and spin down (defined with respect to the y-axis) current flows in opposite directions for modest values of lateral E-field. Since in bi-directional spin pumping the spin polarized current density components J_{+y} and J_{-y} are opposite in sign, $P_J = (J_{+y} - J_{-y})/(J_{+y} + J_{-y})$, the current spin polarization, can attain values greater than 1. Physically, this means that we could obtain a sizeable spin current with very little net electrical current across the tunnel structure.

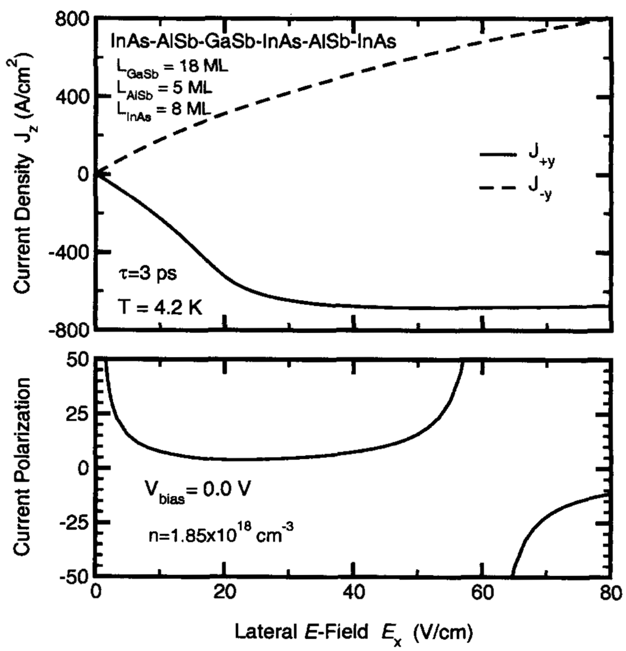

Figure 2. Spin polarized current density components and current spin polarization as functions of lateral E-filed for the bi-directional spin pump.