Draa ft 4rt4My3 1t,2 10f.4Ffo1sf4ubmf 4t 4n f4Pbmnhb4Reefs 4vm1tL4b4 abLt f 1s4 Pfmrt bt 4tt f0 tL4F1rif

A recent Letter [1] proposed a nonmagnetic triple-barrier resonant tunneling diode (RTD) as a spin filter. The device uses a novel spin-blockade mechanism to increase the separation between the positions of spin-split resonant tunneling peaks, and significantly improves upon the spin-filtering performance of the double-barrier RTD [2]. The work reported calculated current spin polarization values in excess of 99.9% at the peak positions in I-V curves. However, it should be noted that the polarization in the Letter is defined with respect to "counter-clockwise" (ccw) and "clockwise" (cw) current density components [1]. Here we show that using a more conventional definition, we obtain a theoretical upper limit of 63.7% on the current spin polarization for the proposed device geometry.

Quasibound state spin splitting in resonant tunneling heterostructures occurs when structural inversion asymmetry (SIA) is present. This in combination with the fact that the spin of a resonantly transmitted electron aligns with that of the quasibound state traversed [2, 3] form the basis for spin filtering in non-magnetic heterostructures. However, before net current spin polarization (with respect to a fixed axis, in the conventional sense) is obtained, we must contend with the complexity of quasibound state spin directions. As illustrated in Fig. 1, the direction of a quasibound state spin is perpendicular to both the growth direction and the in-plane wave vector $p_{\|}$ [4]. Within a given spin-split subband, states at $+p_{\|}$ and $-p_{\|}$ have opposite spins. In a typical RTD, incident electrons come from a reservoir in local thermal equilibrium, occupying $+p_{\|}$ and $-p_{\|}$ states with equal probability. Therefore the ensemble of transmitted electrons yields no net spin polarization. Thus, while we could use spin blockade to achieve excellent discrimination between the current density components associated with the ccw and the cw spin-split quasibound states, denoted $I_{\uparrow}$ and $I_{\downarrow}$, we cannot obtain net spin polarization along any fixed axis in these current components.

To achieve current spin polarization, one must create an anisotropy in the lateral momentum distribution of electrons undergoing resonant tunneling. Voskoboynikov, Lin, and Lee proposed the application of a small in-plane electric field in the source region of the RTD to shift the incident electron distribution towards, say, the positive k_x side in k-space [2]. The Letter [1] proposed an alternative device geometry where the collector is placed on the $+x$ (right) side, intended to collect transmitted states with positive k_x (right-going) only. For the purposes of this discussion, we assume the feasibility of such an idealized collector. Then, as can be surmised from Fig. 1, the right-going portions of $I_{\uparrow}$ and $I_{\downarrow}$, denoted by $I_{\uparrow}^{R}$ and $I_{\downarrow}^{R}$, respectively, have net spin polarizations along the y-axis (only). Accordingly, we should analyze the spin polarization of the transmitted current with respect to the y-axis. We decompose $I^R_\uparrow$ and $I^R_\downarrow$ into components which are spin-aligned along the $+y$ and $-y$ directions as $I^R_\uparrow = I^R_{+y,\uparrow} + I^R_{-y,\uparrow}$ and $I^R_\downarrow = I^R_{+y,\downarrow} + I^R_{-y,\downarrow}$. These components can be recombined to yield right-going currents polarized along the y-axis as $I^R_{+y} = I^R_{+y,\uparrow} + I^R_{+y,\downarrow}$ and $I^R_{-y} = I^R_{-y,\uparrow} + I^R_{-y,\downarrow}$.

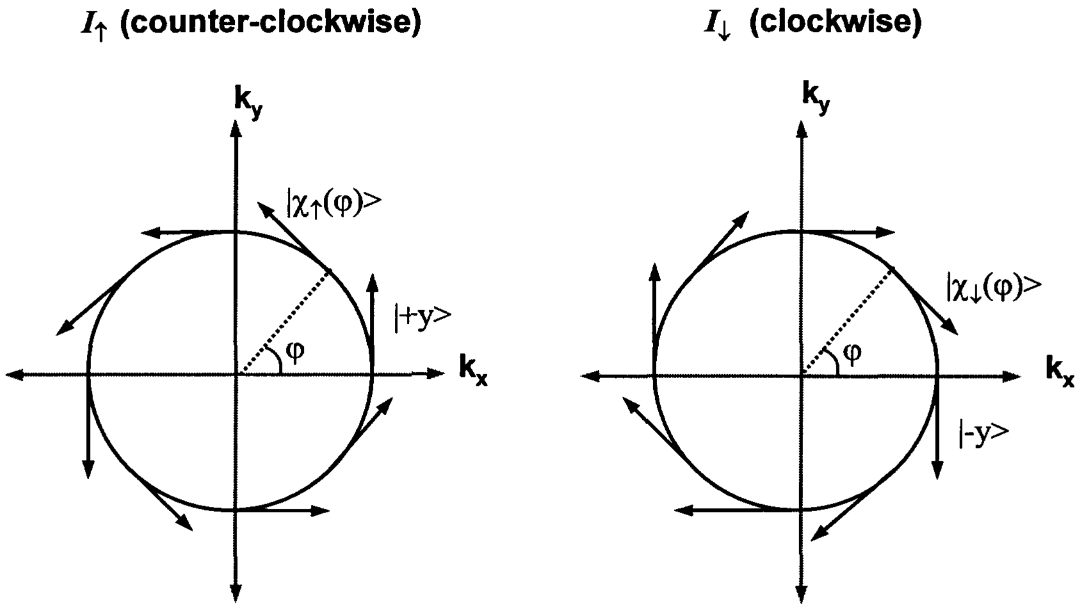

Fig. 1. Schematic illustration showing quasibound state spin directions for two spin-split subbands on a constant $k_{||}$ contour. The right and left sides of the figure shows spin-split quasibound states which contribute to the clockwise and counter-clockwise components of the current density, $I_\uparrow$ and $I_\downarrow$, respectively, as defined in Ref. [1].

To relate the $\uparrow$ and $\downarrow$ (ccw and cw) current components to the $+y$ and $-y$ current components, we note that a resonantly transmitted electron has the same spin as the quasibound state traversed. Let $|\chi_{\uparrow,\downarrow}(\varphi)>$ be the spinors associated with quasibound states with the wave vector $p_{||}$ along the direction specified by the azimuthal angle φ (see Fig. 1). They can be decomposed into spinors along the y-axis, $|+y>\equiv|\chi_\uparrow(\varphi=0)>$ and $|-y>\equiv|\chi_\downarrow(\varphi=0)>$. In general, a transmitted electron with the spinor $|\chi_{\uparrow,\downarrow}(\varphi)>$ can be found in either the $|+y>$ or the $|-y>$ spin state. The probabilities are given by $|<\pm y|\chi_\uparrow(\varphi)>|^2=[1\pm\cos(\varphi)]/2$ and $|<\pm y|\chi_\downarrow(\varphi)>|^2=[1\mp\cos(\varphi)]/2$. In computing the right-going current densities, we need to sum over all states with $k_{||}<k_F$ and $-\pi/2<\varphi<\pi/2$. Assuming as in

Ref. [1] that transmission coefficients do not depend on the direction of $p_{\|}$ (isotropic approximation), integration over the desired range of φ yields $I^R_{\pm y,\uparrow} = f(\pm,\uparrow)I^R_\uparrow$ and $I^R_{\pm y,\downarrow} = f(\pm,\downarrow)I^R_\downarrow$, where

$$f(\pm,\uparrow) = \int_{-\pi/2}^{\pi/2} |<\pm y\,|\,\chi_\uparrow(\varphi)>|^2 d\varphi = (1/2) \pm (1/\pi) \tag{1a}$$

and

$$f(\pm,\downarrow) = \int_{-\pi/2}^{\pi/2} |<\pm y\,|\,\chi_\downarrow(\varphi)>|^2 d\varphi = (1/2) \mp (1/\pi)\,. \tag{1b}$$

The analysis above allows us to relate the current densities spin-polarized along $+y$ and $-y$ to the unpolarized ccw and cw current densities in a simple manner:

$$I^R_{\pm y} = f(\pm,\uparrow)I^R_\uparrow + f(\pm,\downarrow)I^R_\downarrow = [f(\pm,\uparrow)I_\uparrow + f(\pm,\downarrow)I_\downarrow]/2\,. \tag{2}$$

Using $I^R_{\pm y}$, we can define current spin polarization (with respect to the y-axis) as $P^R_y = |I^R_{+y} - I^R_{-y}|/|I^R_{+y} + I^R_{-y}|$. In an ideal case where we could have complete discrimination between $I_\uparrow$ and $I_\downarrow$, we obtain a limiting value of $P^R_y = 2/\pi \approx 63.7\%$. The novel spin-blockade mechanism proposed in the Letter [1] offers a very effective means for achieving strong discrimination, and attaining a high degree of spin polarization.

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