An effective carrier compensation under spin injection to ambipolar conductor with intrinsically different hole and electron densities

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In our previous study [1], we have found the presence of two modes of spin currents namely parallel ($\mathbf{J}_{\mathrm{P}}$) and anti-parallel ($\mathbf{J}_{\mathrm{AP}}$) spin currents under simultaneous injection of hole and electron spins to ambipolar conductor with intrinsically different hole and electron densities. $\mathbf{J}_{\mathrm{P}}$ and $\mathbf{J}_{\mathrm{AP}}$ can be expressed as

$$\mathbf{J}_{\boldsymbol{P}} = \frac{\hbar}{2e}\left[\sigma_{\uparrow}^{(h)} + \sigma_{\downarrow}^{(h)} - \frac{1+\Phi}{1-\Phi}\left(\sigma_{\uparrow}^{(e)} + \sigma_{\downarrow}^{(e)}\right)\right] \times \left(-\frac{1}{e}\right) \mathrm{grad}\,\Delta\mu_{\mathrm{p}} \qquad (\Phi \neq \pm 1)\,, \qquad (1)$$

$$\mathbf{J}_{\boldsymbol{AP}} = \frac{\hbar}{2e}\left[\sigma_{\uparrow}^{(h)} + \sigma_{\downarrow}^{(h)} + \frac{1+\Phi}{1-\Phi}\left(\sigma_{\uparrow}^{(e)} + \sigma_{\downarrow}^{(e)}\right)\right] \times \left(-\frac{1}{e}\right) \mathrm{grad}\,\Delta\mu_{\mathrm{Ap}} \qquad (\Phi \neq \pm 1)\,, \qquad (2)$$

where Φ is the charge polarization defined by $\Phi = \left(n^{(h)} - n^{(e)}\right) / \left(n^{(h)} + n^{(e)}\right)$. We also calculated the entropy production rate of ambipolar conductors as [1]

$$\frac{\partial S}{\partial t} + \mathrm{div}\left(\frac{\mathbf{J}_Q}{T}\right) = \mathbf{J}_Q.\mathrm{grad}\left(\frac{1}{T}\right) - \frac{1}{T}\mathbf{J}_C.\mathrm{grad}\,\mathrm{V} + \frac{8\Phi}{(1-\Phi)T\tau_s}\left(\Delta\mu_0^{(h)}\right)^2\left(N^{(h)} - \frac{1+\Phi}{1-\Phi}N^{(e)}\right)\left[\exp\left(-\frac{2x}{l_{AP}}\right) - \exp\left(-\frac{2x}{l_P}\right)\right], \qquad (3)$$

where $N^{(h/e)} = \left(N_{\uparrow}^{(h/e)} N_{\downarrow}^{(h/e)}\right) / \left(N_{\uparrow}^{(h/e)} + N_{\downarrow}^{(h/e)}\right)$ is the density of states of hole and electron at the Fermi level. If we assume the Fermi energy for hole and electron is equal, then the free electron model appears as the density of states of electrons and holes at the Fermi level is proportional to the density of electron and hole, respectively. By applying this model in entropy production rate equation yields spin current term zero in Eq. (3), implying that spin current in ambipolar conductor has no contribution in entropy production. Thus, spin injection in ambipolar conductors produces dissipationless spin current which makes its spin diffusion length for both parallel and anti-parallel spin current larger. On the other hand, the derivation of the Hall resistivity under simultaneous injection of hole and electron spin currents requires drift current terms in addition to diffusion terms because the drift term is essential for the measurement of Spin Hall effect in real experiment [2]. After proper addition of the drift current term in the equations (1) and (2) gives the resonant Hall effect condition i.e. $1 + Py_{\mathrm{AP}} = 0$, where P is the spin polarization $\left(\frac{n_\alpha^{(h)} - n_\beta^{(e)}}{n_\alpha^{(h)} + n_\beta^{(e)}}\right)$ and y_{AP} is the phenomenological parameter as the ratio of effective electric field to the electric field of anti-parallel spin current $\left({\Delta E_y^{AP}}/{E_y}\right)$ in transverse direction. The resonant Hall effect condition reveals that the Hall resistivity $\left(\rho_{yx}\right)$ is strongly influenced by the spin splitting chemical potential $\left(\Delta\mu_{\mathrm{Ap}}\right)$ of antiparallel spin current in ambipolar conductors.

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