Long carrier lifetime by Rashba splitting

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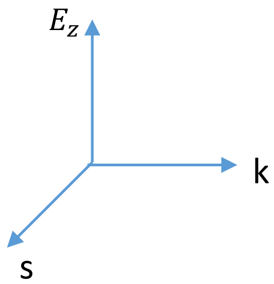
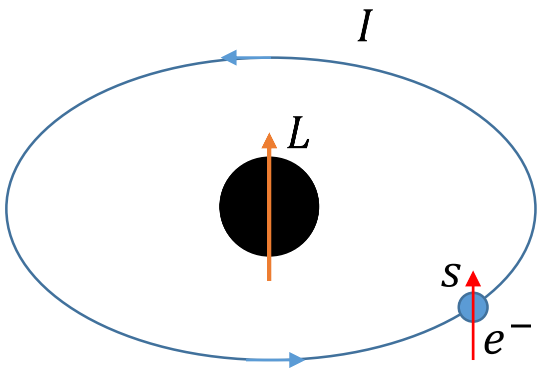
2018-11-02

Rashba spin-orbit coupling

SOC in E field



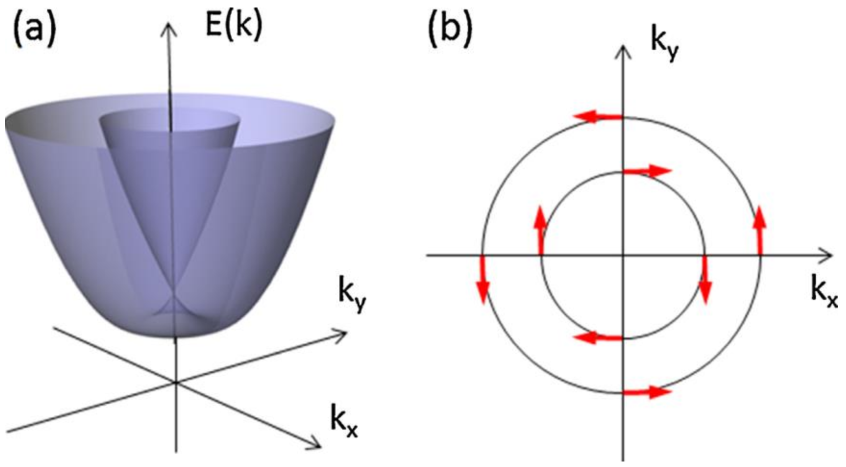
Local SOC



$$B = IA$$

Free electron model

$$E(k) = \frac{\hbar^2 k^2}{2m_e}$$



$$B = -\frac{v \times E}{c^2}$$

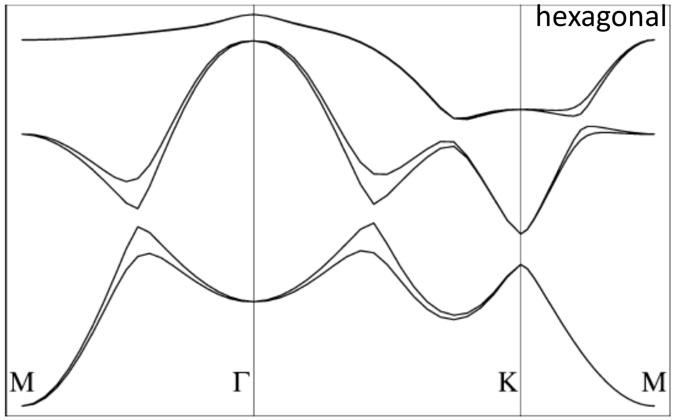
$$H_{SOC} = \alpha(\sigma \times p) \cdot \hat{z}, \alpha = \frac{g\mu_B E_0}{2mc^2}$$

$$\Delta E_{\uparrow\downarrow} = \alpha k_\perp$$

Tight binding model

$$E(k) = \varepsilon - J_0 - \sum_{neighbor} J(R_s) e^{-ik\cdot R_s}$$

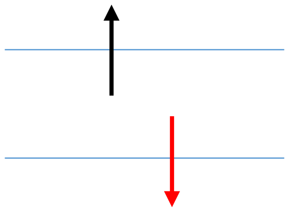
p orbitals of 2D hexagonal lattice



$$H_{SOC} = \frac{\alpha}{2}\begin{pmatrix} 0 & -i & 0 & 0 & 0 & 1 \\ i & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & -1 & i & 0 \\ 0 & 0 & -1 & 0 & i & 0 \\ 0 & 0 & -i & -i & 0 & 0 \\ 1 & i & 0 & 0 & 0 & 0 \end{pmatrix}.$$

L. Petersen., Surface science 459 (2000) 49-56

Intersystem crossing (spin flip rate)



$$H_{soc} = \alpha^2 \sum_{\mu}^{N} \sum_{i}^{n} \frac{Z_\mu}{r_{i\mu}^3} (\overrightarrow{L_i} \cdot \overrightarrow{S_i})$$

- Fermi golden rule $w = \frac{2\pi}{\hbar} |\langle B, n_r(k) + 1 | H_I | A, n_r(k) \rangle|^2 \delta(E_A - E_B - \hbar\omega_k)$

- Frank-Condon vibrational model

$$w = \frac{2\pi}{\hbar} |\langle \psi^3 | H_{soc} | \psi^1 \rangle|^2 \frac{1}{\sqrt{4\pi\lambda RT}} \exp\left(-\frac{(\Delta E + \lambda)^2}{4\lambda RT}\right), \lambda\ is\ Marcus\ reorganization\ energy$$

So to get larger transition rate, we need larger spin-orbit coupling and smaller energy splitting.

$$\langle \psi^3 | H_{soc} | \psi^1 \rangle = \alpha^2 \sum_{\mu}^{N} \sum_{i}^{n} \frac{Z_\mu}{r_{\mu i}^3} \left\langle \varphi^3 \middle| \overrightarrow{L_i} \middle| \varphi^1 \right\rangle \left\langle \begin{matrix} |++\rangle \\ |--\rangle \\ \frac{1}{\sqrt{2}}(|+-\rangle + |-+\rangle) \end{matrix} \middle| \overrightarrow{S_i} \middle| \frac{1}{\sqrt{2}}(|+-\rangle - |-+\rangle) \right\rangle$$

Long carrier lifetime due to Rashba splitting

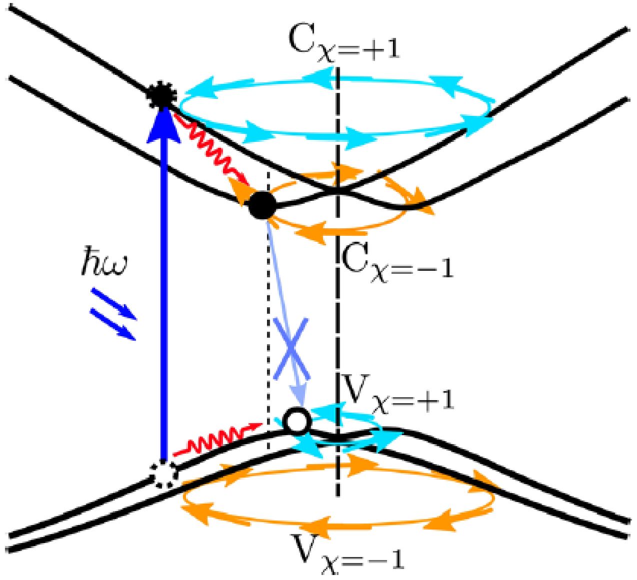
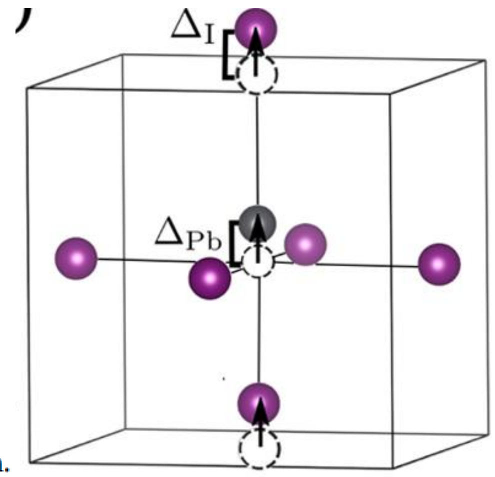
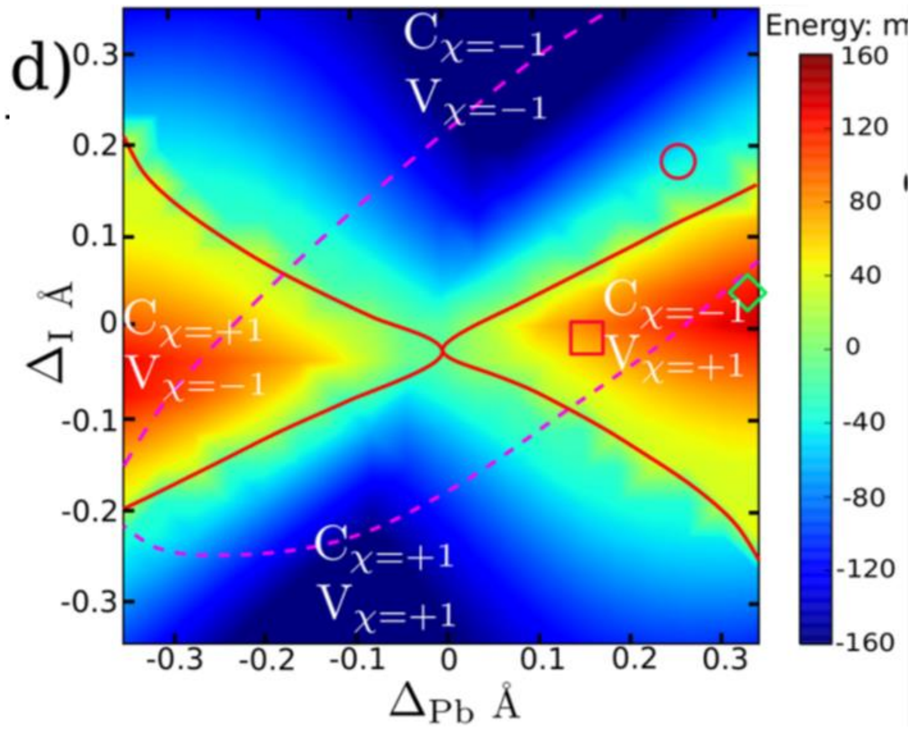


Figure 1. Diagram of Rashba bands and the electron transport path. The cyan and orange arrows indicate the directions of the spins. The spin texture χ indicates spin vortex direction with its signs characterizing spin rotation in "clockwise" ($\chi = -1$) and "counter-clockwise" ($\chi = +1$). After absorbing the photons, the excited electrons on conduction bands $C_{\chi=+1}$ and $C_{\chi=-1}$ will quickly relax to $C_{\chi=-1}$ band minimum due to the inelastic phonon scattering. Similarly, the holes will quickly relax to the $V_{\chi=+1}$ band maximum. However, the radiative recombination of $C_{\chi=-1} \rightarrow V_{\chi=+1}$ is a spin-forbidden process due to the opposite spin states they have. Moreover, the minimum of $C_{\chi=-1}$ band and the maximum of $V_{\chi=+1}$ band are located in different positions in the Brillouin Zone. This creates an indirect band gap for recombination, which further slows down the recombination process.





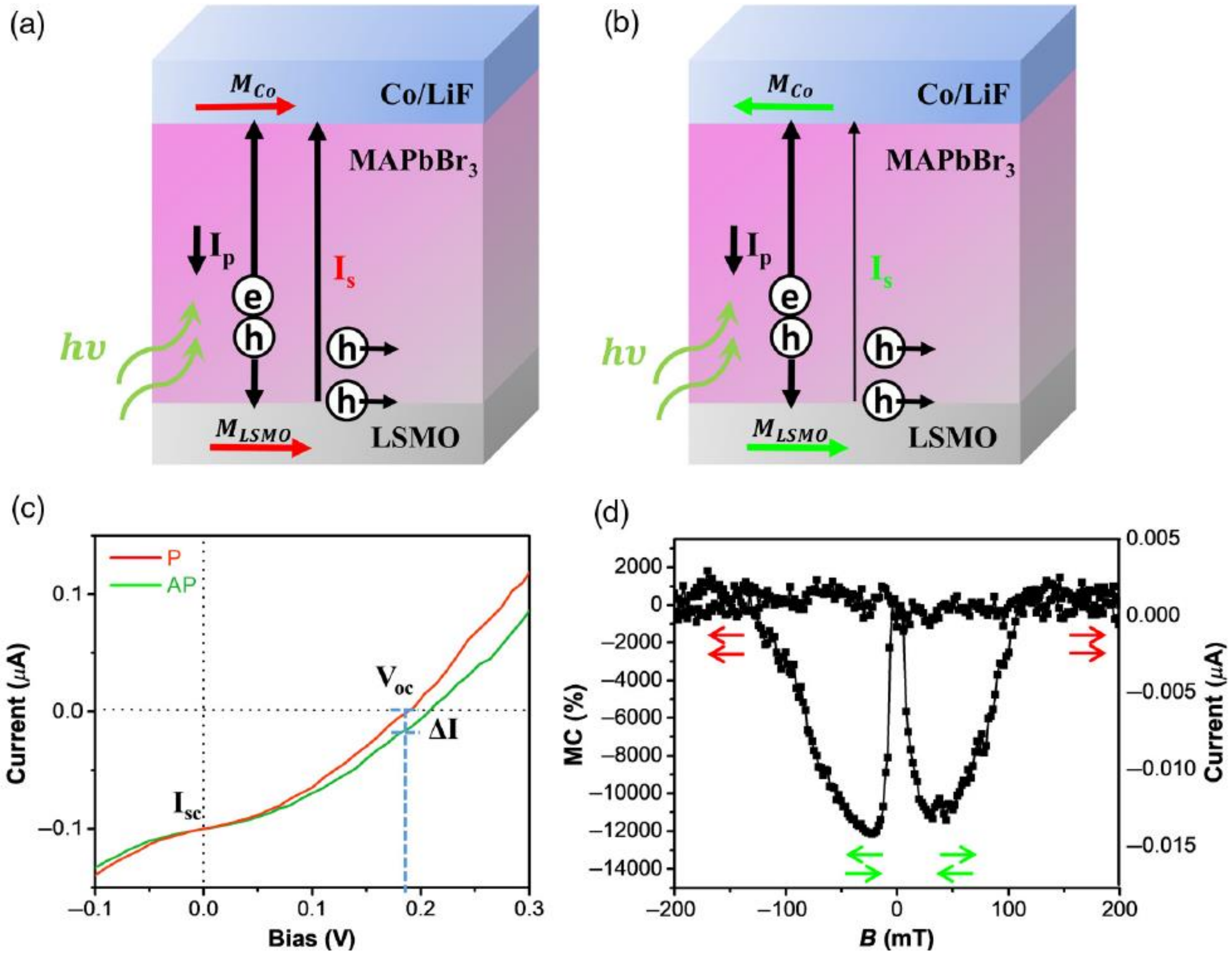
Displacement in Pb and I can change the Rashba splitting

Fan Zheng, Nano lett. 2015, 15, 7794-7800

Large MR due to long lifetime carrier

Parallel $I_p = -I_s$

Anti-Parallel $I_p \neq -I_s$



J. Wang., Journal of Photonics for energy

DOI: 10.1117/1.JPE.8.032207