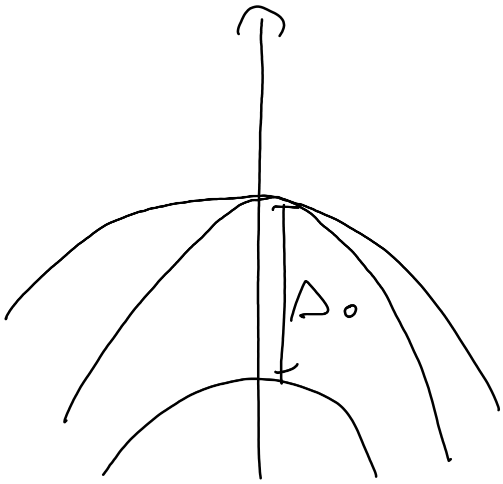
# Optical spin orientation

venerdì 8 novembre 2024 08:59




$P \rightarrow l = 1$

$H_{SO} = \lambda \vec{L} \cdot \vec{S}$

$H_{SO} = \lambda \frac{\hbar^2}{2} \left( J(J+1) - l(l+1 \right.$

$J^2, \; L^2, \; S^2 \rightarrow J_z$

$\quad\;\; / \;\; 1 \; / \;\; \frac{1}{2}$

$m, \; S_z \rightarrow$ ~~GOOD Q NUMBER~~

$J \rightarrow \frac{3}{2}$

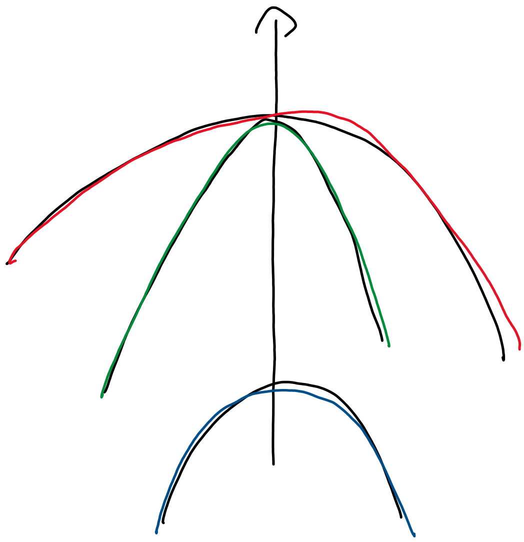
$J \rightarrow \frac{1}{2}$

$\vec{L} \cdot \vec{S} = L_x S_x + L_y S_y + L_z S_z \quad \leftarrow S_z \quad \leftarrow L_z$

$J \quad \frac{3}{2} \rightarrow \pm \frac{3}{2} \; J_z$

$\quad\quad\; \frac{3}{2} \rightarrow \pm \frac{1}{2} \; J_z$

$\frac{1}{2} \rightarrow \pm \frac{1}{2} J_z$



| | $J$ | $J_z$ |
|---|---|---|
| HH | $\frac{3}{2}$ | $\pm \frac{3}{2}$ |
| LH | $\frac{3}{2}$ | $\pm \frac{1}{2}$ |
| SO | $\frac{1}{2}$ | $\pm \frac{1}{2}$ |

## Selection rules for interband transitions

The relevant matrix element is:

$$\boldsymbol{p}_{\text{if}} = -i\hbar \int \psi^*_{\mathbf{k}_f \ell'} \, \nabla \psi_{\mathbf{k}_i \ell} \, d^3 r$$

$$\begin{aligned} |i\rangle &= \psi_{\mathbf{k}_i \ell} \\ &= e^{i\mathbf{k}_i \cdot \mathbf{r}} u_{\mathbf{k}_i \ell} \\ |f\rangle &= \psi_{\mathbf{k}_f \ell'} \\ &= e^{i\mathbf{k}_f \cdot \mathbf{r}} u_{\mathbf{k}_f \ell'} \end{aligned}$$

HH↑ , LH↑

S↑

$$\boldsymbol{p}_{\text{if}} = \hbar \boldsymbol{k}_i \int \psi^*_{\mathbf{k}_f \ell'} \, \psi_{\mathbf{k}_i \ell} \, d^3 r - i\hbar \int u^*_{\mathbf{k}_f \ell'} \, (\nabla u_{\mathbf{k}_i \ell}) \, e^{i(\mathbf{k}_i - \mathbf{k}_f)\cdot \mathbf{r}} \, d^3 r$$

Zero since Bloch states are orthogonal



## Selection rules for interband transitions

- Conduction band:

$$u_{c0} = |s\rangle$$

where $|s\rangle$ is a spherically symmetric state.

- Valence band:

Heavy hole states: $|3/2, 3/2\rangle = \frac{-1}{\sqrt{2}} (|p_x\rangle + i|p_y\rangle) \uparrow$

$|3/2, -3/2\rangle = \frac{1}{\sqrt{2}} (|p_x\rangle - i|p_y\rangle) \downarrow$

Light hole states: $|3/2, 1/2\rangle = \frac{-1}{\sqrt{6}} [(|p_x\rangle + i|p_y\rangle) \downarrow - 2|p_z\rangle \uparrow]$

$|3/2, -1/2\rangle = \frac{1}{\sqrt{6}} [(|p_x\rangle - i|p_y\rangle) \uparrow + 2|p_z\rangle > \downarrow]$

From symmetry we see that *only* the matrix elements of the form

$$-\hbar\langle s|\frac{\partial}{\partial x}|p_x\rangle = -\hbar\langle s|\frac{\partial}{\partial y}|p_y\rangle = -\hbar\langle s|\frac{\partial}{\partial z}|p_z\rangle = p_{cv}$$

are different from zero.

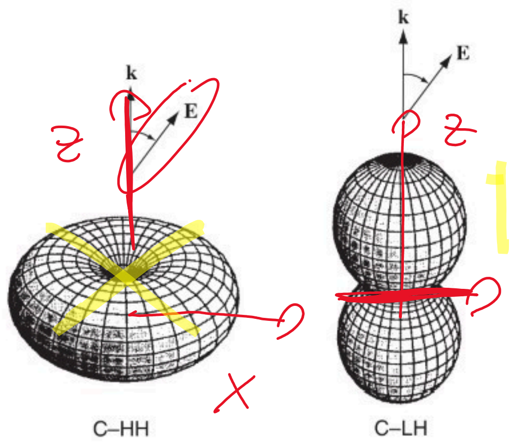


## Selection rules for interband transitions

| | VB HH → CB S | VB LH → CB S | |
|---|---|---|---|
| X pol | $\hbar^2\left|\langle s\|\frac{\partial}{\partial x}\|HH\rangle\right|^2 = \frac{1}{2}p_{cv}^2$ | $\hbar^2\left|\langle s\|\frac{\partial}{\partial x}\|LH\rangle\right|^2 = \frac{1}{6}p_{cv}^2$ | $\frac{1}{2} + \frac{1}{6}$ |
| Y pol | $\hbar^2\left|\langle s\|\frac{\partial}{\partial y}\|HH\rangle\right|^2 = \frac{1}{2}p_{cv}^2$ | $\hbar^2\left|\langle s\|\frac{\partial}{\partial y}\|LH\rangle\right|^2 = \frac{1}{6}p_{cv}^2$ | $\frac{2}{3}$ |
| Z pol | 0 | $\hbar^2\left|\langle s\|\frac{\partial}{\partial y}\|LH\rangle\right|^2 = \frac{2}{3}p_{cv}^2$ | $\frac{2}{3}$ P |



## Optical matrix element for HH and LH



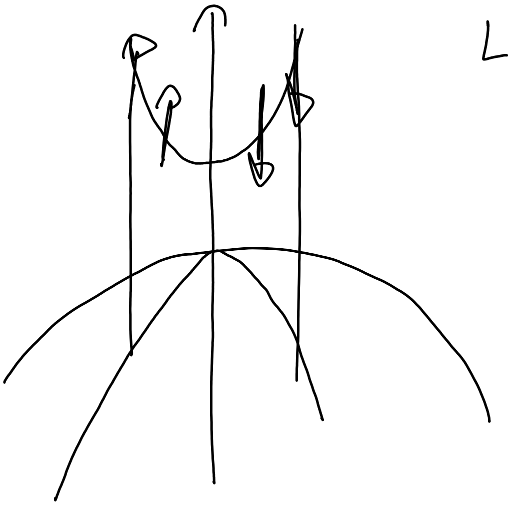

HH states can be excited only by x,y polarized light

LH states can be excited by x,y and (predominantly) z polarized light

**FIGURE A10.2:** Dependence of the transition strength, $|M_T|^2$, on angle between the electron's $k$-vector and the incident electric field vector, **E**, for C–HH and C–LH transitions

(C–SO transitions are independent of angle). For C–HH transitions, $|M_T|^2$ is zero when $\mathbf{E} \parallel \mathbf{k}$ and becomes a maximum of $\frac{1}{2} \times |M|^2$ when $\mathbf{E} \perp \mathbf{k}$. For C–LH transitions, when $\mathbf{E} \parallel \mathbf{k}$, $|M_T|^2$ has a peak value of $\frac{2}{3} \times |M|^2$ and is reduced to $\frac{1}{6} \times |M|^2$ when $\mathbf{E} \perp \mathbf{k}$.





LINEARLY POL LIGHT

HH↑ S↑ HH↓ S↓

LH↑ S↑ LH↓ S↓

LH↓ S↑ LH↓ S↑

Circularly polarized light

$$\vec{e} = \vec{e}_x \pm i\vec{e}_y \quad \to \sigma^+ \text{ CLOCKWISE} \quad \to \sigma^- \text{ ANTICLOCKWISE}$$

↑ LIGHT POL

HH↑ → S↑ $\sigma^+$ — $\vec{e} = \vec{e}_x + \underline{i\vec{e}_y}$

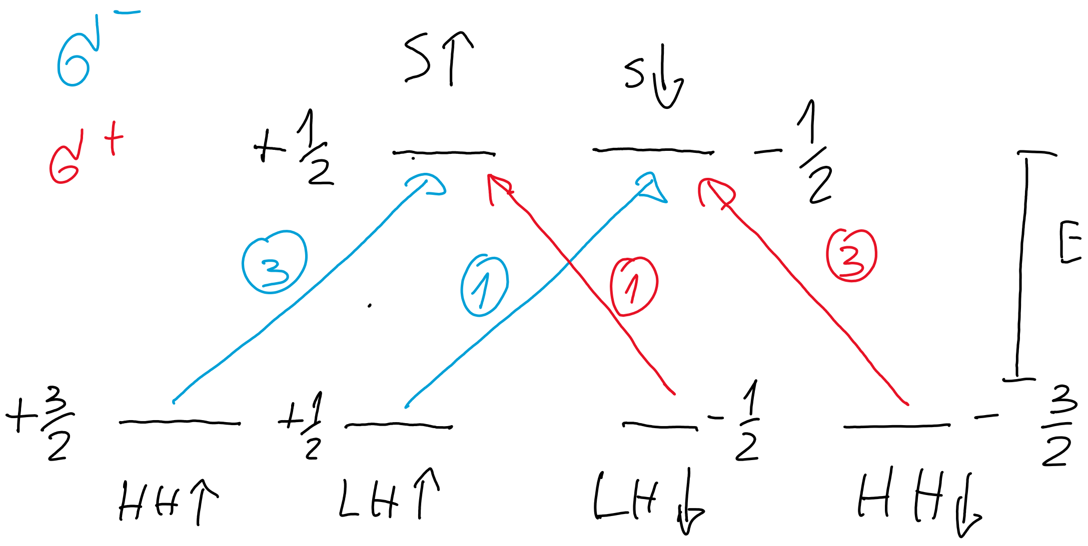
$$-i\hbar \left\langle -\frac{1}{\sqrt{2}}(P_x + iP_y)\uparrow \right| \frac{\partial}{\partial x} + i\frac{\partial}{\partial y} \left| S\uparrow \right\rangle =$$

$$-\frac{1}{\sqrt{2}} P_{cv} - \frac{1}{\sqrt{2}}(-1) P_{cv} = \emptyset$$

VIOLATING OF ANGULAR MOMENTUM

$$+\frac{3}{2}\hbar + \hbar \neq \frac{1}{2}\hbar \quad \to \sigma^-$$

$HH\uparrow \;\; +\frac{3}{2}\hbar - \hbar = \frac{1}{2}\hbar \qquad LH\uparrow \;\; \frac{1}{2}\hbar - \hbar = -\frac{1}{2}$




$P = \frac{3\uparrow -}{3+}$

$= \frac{1}{2} =$

$\sigma^-$ $HH\uparrow \to S\uparrow \qquad \sigma^-$

$$-i\hbar \langle -\frac{1}{\sqrt{2}}(P_x + iP_y)\uparrow | \frac{\partial}{\partial x} - i\frac{\partial}{\partial y} | S\uparrow \rangle =$$

$$-\frac{1}{\sqrt{2}}P_{cv} - \frac{1}{\sqrt{2}}P_{cv} = -\frac{2}{\sqrt{2}}P_{cv}.$$

$$|\langle f| e^{l}\cdot\vec{p} | i\rangle|^2 = 2P_{cv}^2$$

$LH\uparrow - S\downarrow$

$\frac{3}{2}, \frac{1}{2}$

$$-i\hbar \langle -\frac{1}{\sqrt{6}}[(P_x + iP_y)\downarrow - 2P_z\uparrow] | \frac{\partial}{\partial x} - i\frac{\partial}{\partial y} | S\downarrow$$

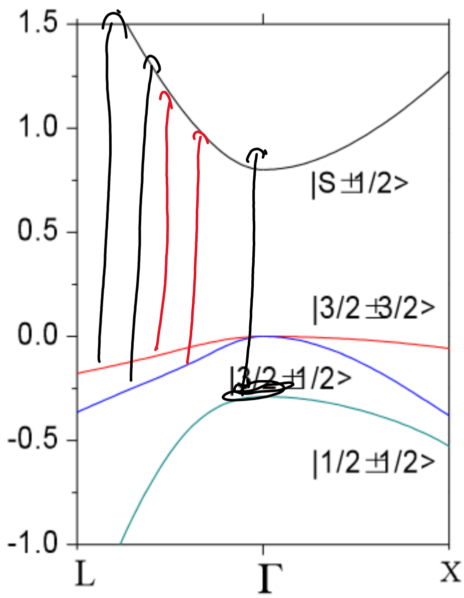
$$= -\frac{1}{\sqrt{6}}P_{cv} - \frac{1}{\sqrt{6}}P_{cv} = -\frac{2}{\sqrt{6}}P_{cv}$$

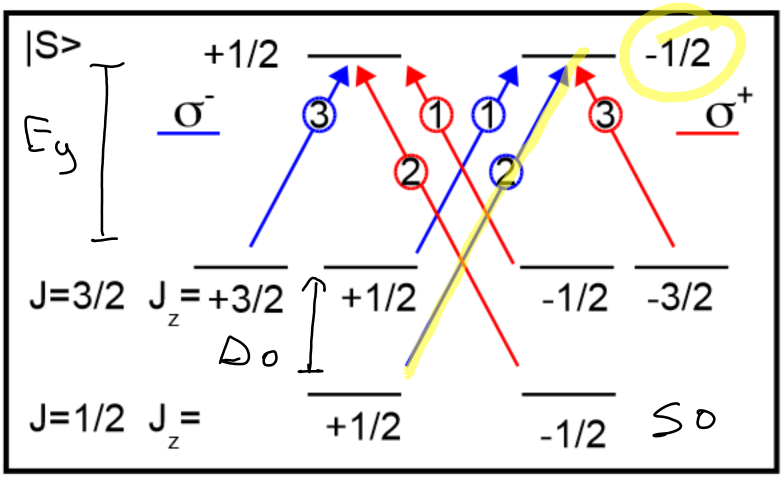
$| - \quad |^2 \quad 2P^2$

$|S \quad >|$ = $3$ 'cv

$$\frac{HH\uparrow \to S\uparrow}{LH\uparrow \to S\downarrow} = \frac{2P_{cv}^2}{\frac{2}{3}P_{cv}^2} = 3$$

## Optical Spin Orientation




$$P = \frac{n_\uparrow - n_\downarrow}{n_\uparrow + n_\downarrow}$$

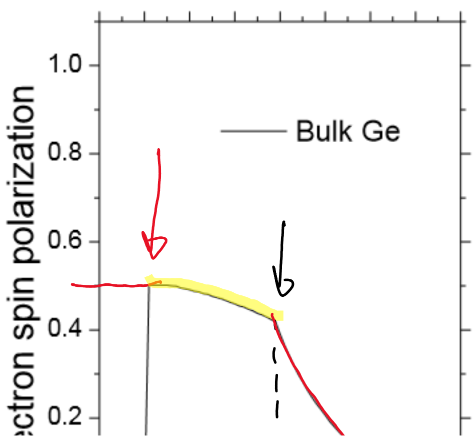
$\sigma^-$ excitation

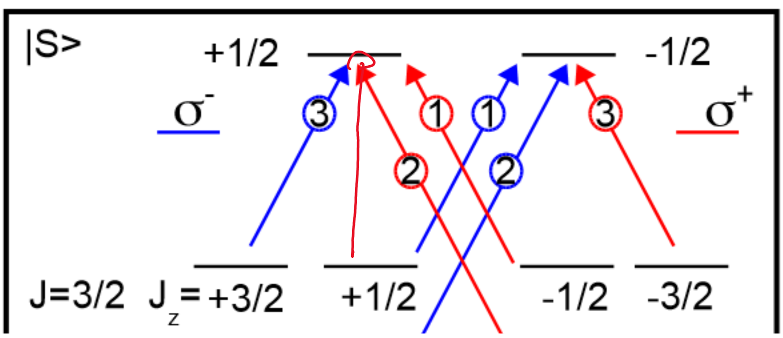
at $\Gamma$

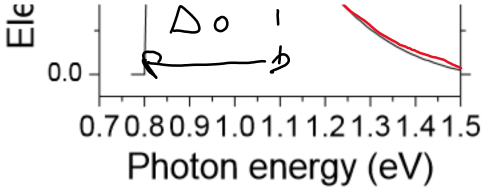
$$P = 0.5$$

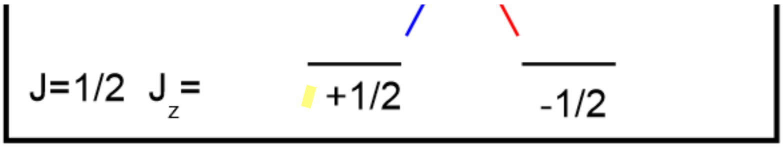


## Optical Spin Orientation






$$P = \frac{n_\uparrow - n_\downarrow}{n_\uparrow + n_\downarrow}$$

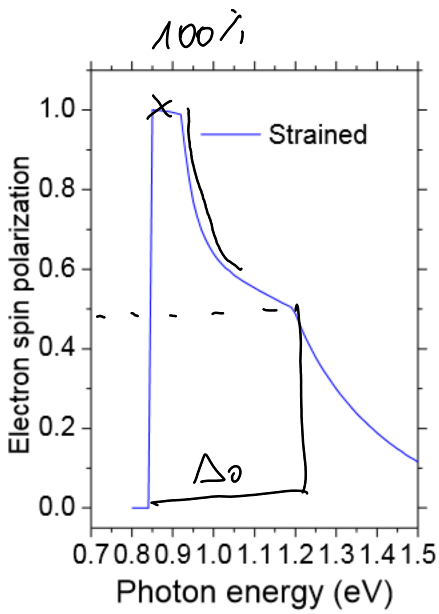
$\sigma^-$ excitation

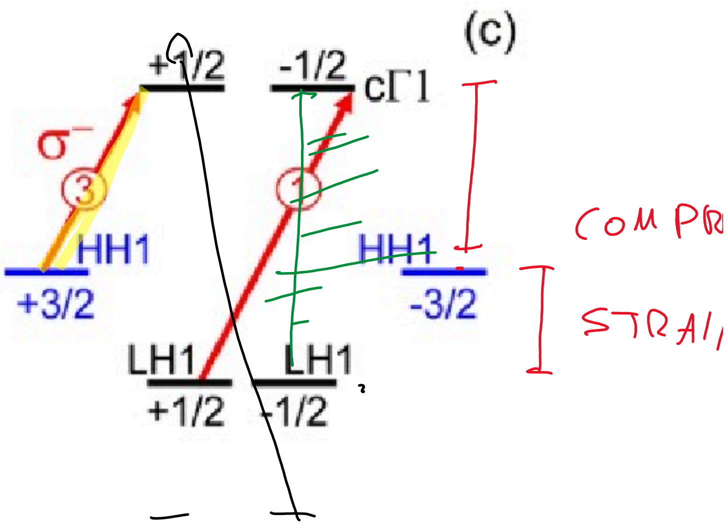
at $\Gamma$

$$P = 0.5$$



## Optical Spin Orientation




$$P = \frac{n_\uparrow - n_\downarrow}{n_\uparrow + n_\downarrow}$$

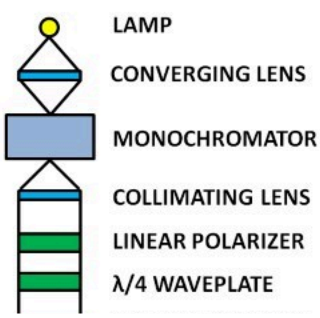
$\sigma^-$ excitation

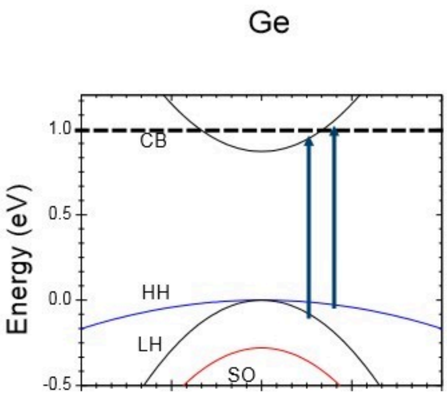
at $\Gamma$

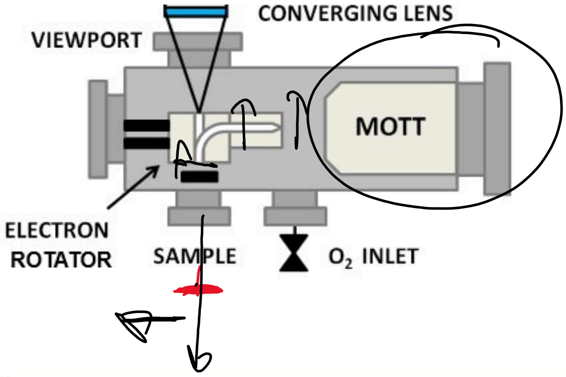
$$P = 1$$

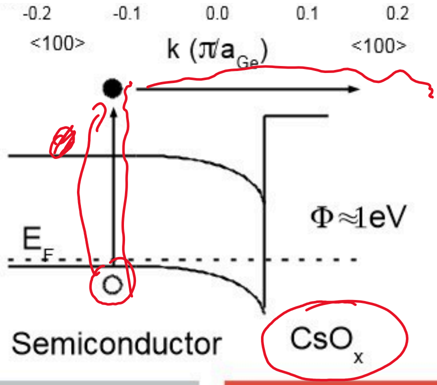


## Optical Spin Orientation: spin polarized photoemission

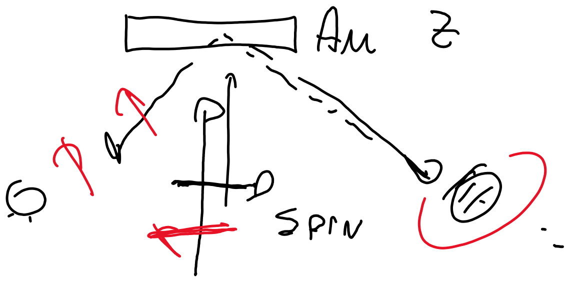


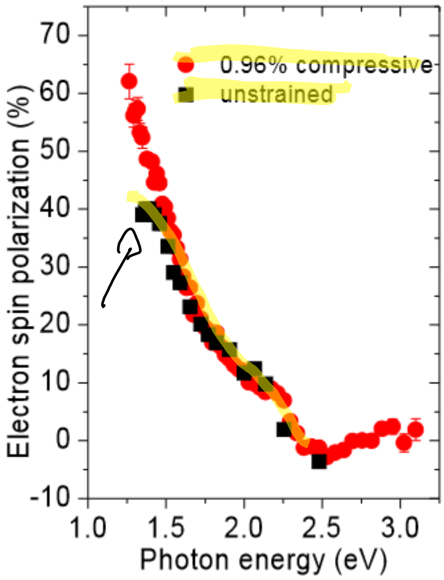


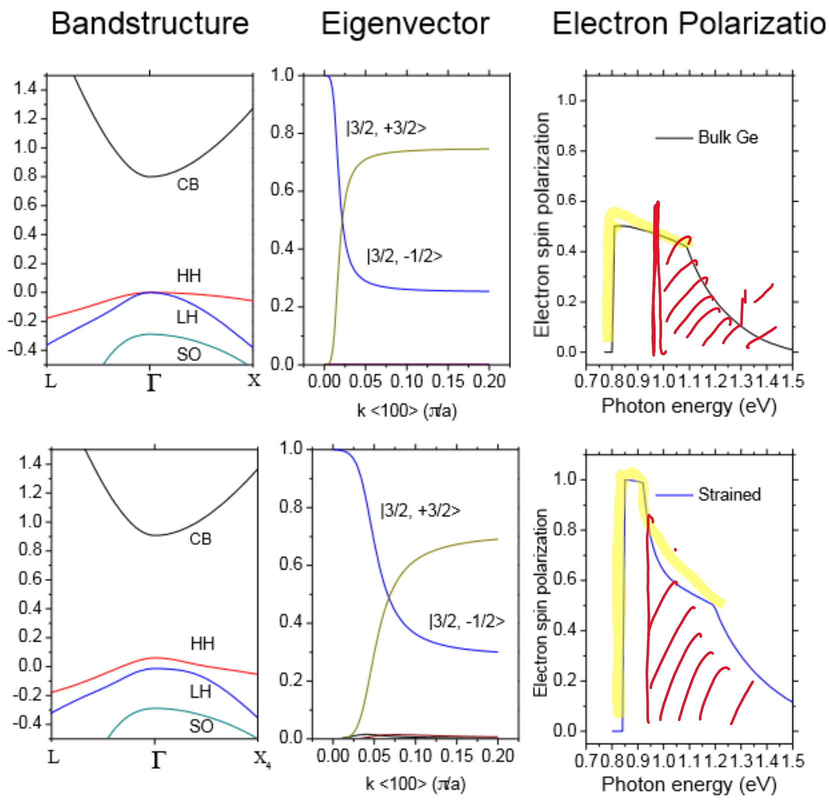





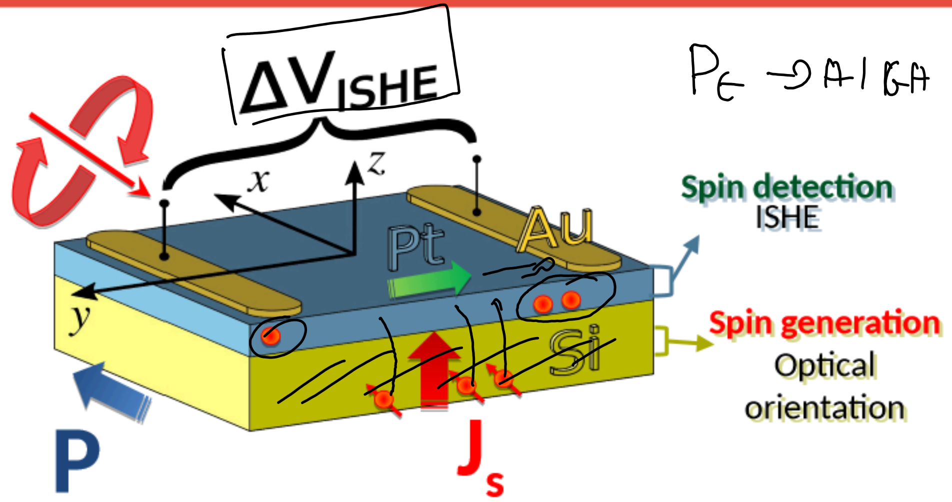

# Optical Spin Orientation: spin polarized photoemission



# Photo induced ~~inverse spin Hall effect~~

Pt → AlGaAs




$$\Delta V_{ISHE} \propto \gamma_{Pt} \, | \, J_s \times P \, |$$

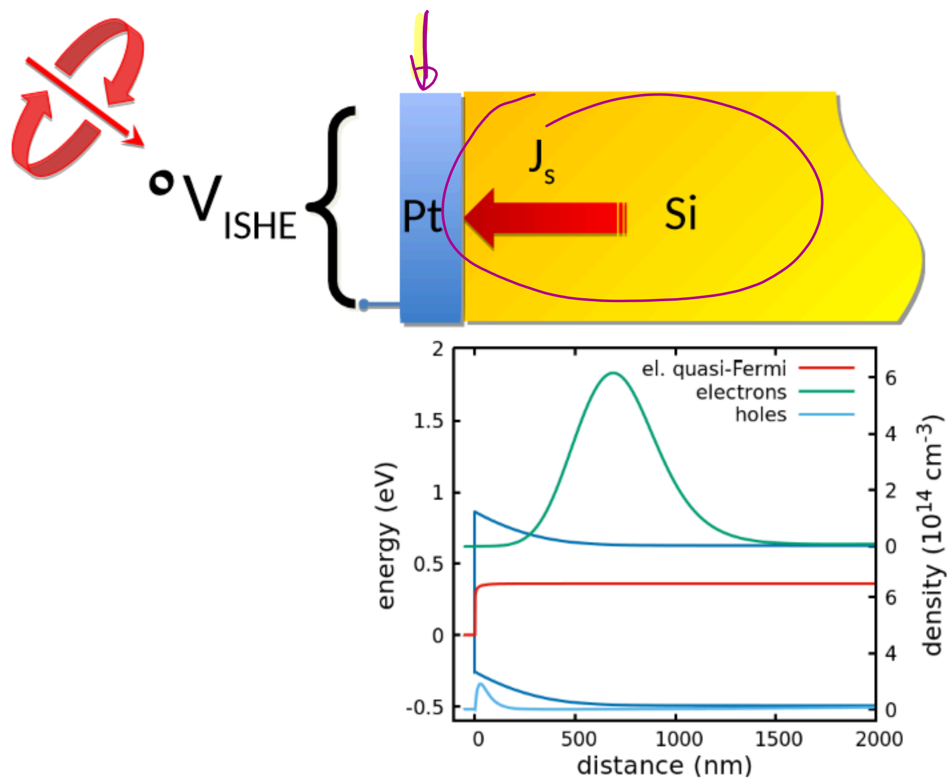
Spin-to-charge conversion

Spin current

Spin polarization



# Photo induced inverse spin Hall effect



## Charge drift-diffusion equations

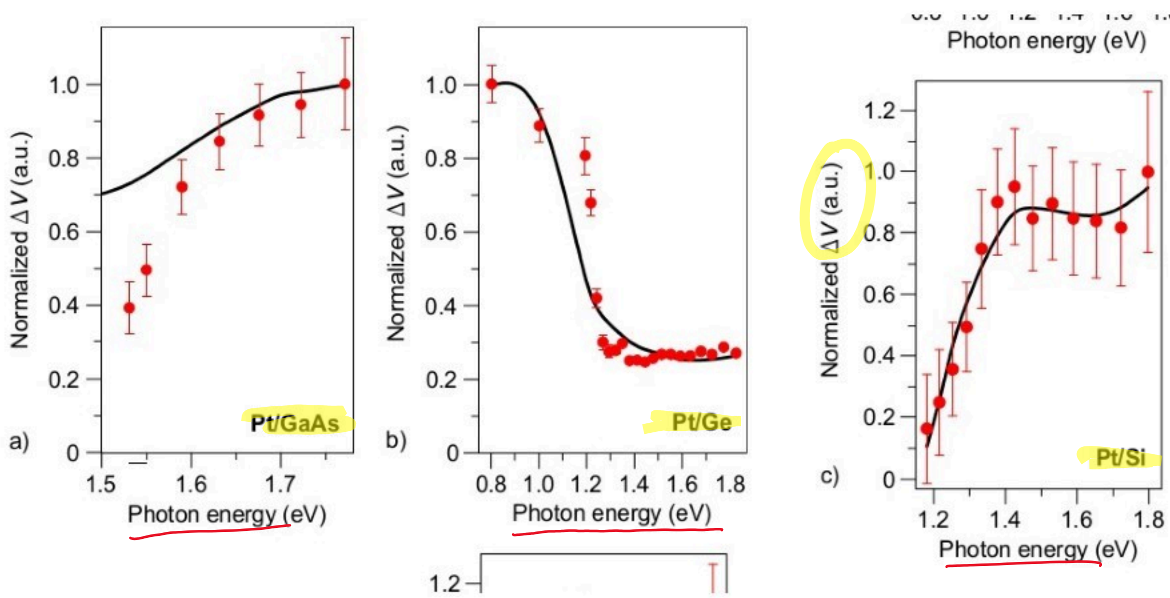
| Current eq. | Continuity eq. | Poisson |
|---|---|---|
| $J_n = -D_n \frac{\partial n}{\partial x} + \mu_n n E$ | $\frac{\partial J_n}{\partial x} = SRH + \Phi_0 \alpha e^{-\alpha x}$ | $\frac{\partial E}{\partial x} = \frac{q}{\epsilon}(p + N_d - n)$ |
| $J_p = -D_p \frac{\partial p}{\partial x} + \mu_p p E$ | $\frac{\partial J_p}{\partial x} = SRH + \Phi_0 \alpha e^{-\alpha x}$ | $SRH = w(x)(n_i^2 - np)$ |

## Spin drift-diffusion equations

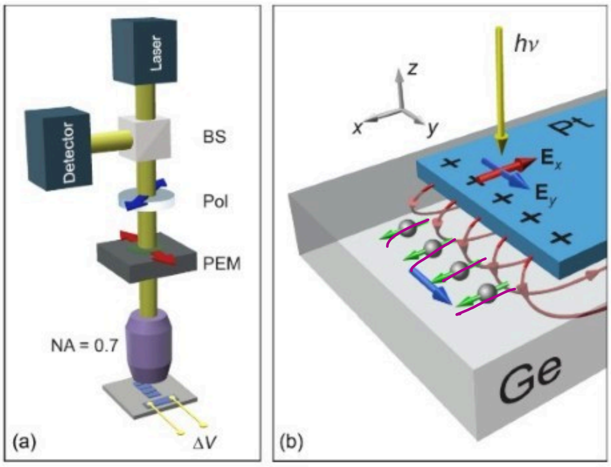
| Definitions | Current eq. | Continuity eq. |
|---|---|---|
| $s = n_+ - n_-$ <br> $J_s = J_{n+} - J_{n-}$ | $J_s = -D_n \frac{\partial s}{\partial x} - \mu_n s E$ | $\frac{\partial J_s}{\partial x} = \frac{-s}{\tau_s} - w(sp) + P\Phi_0 \alpha e^{-\alpha x}$ |

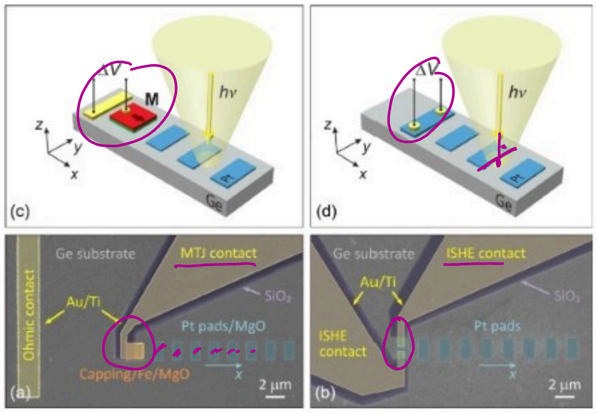






# Imaging spin diffusion






# Imaging spin diffusion