Modeling of a Spin-Coherent Photon Transmitter/Receiver System

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SPINS Review

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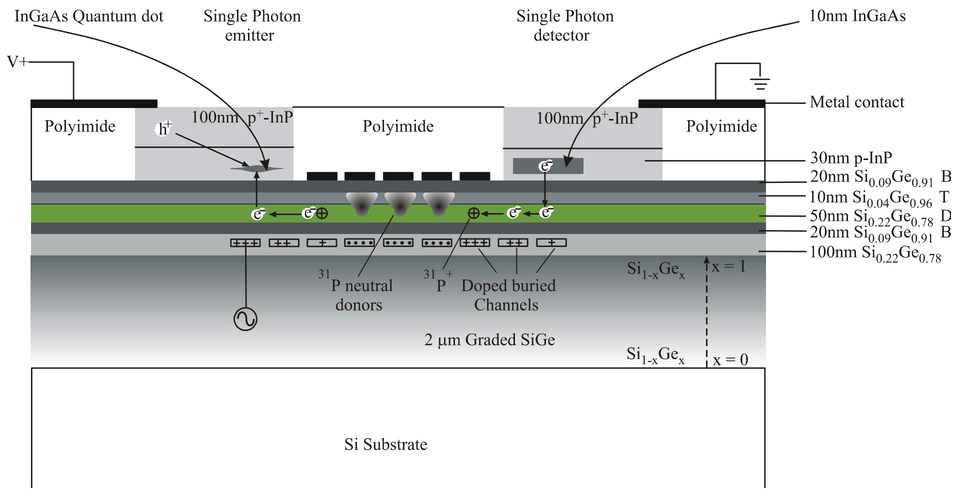
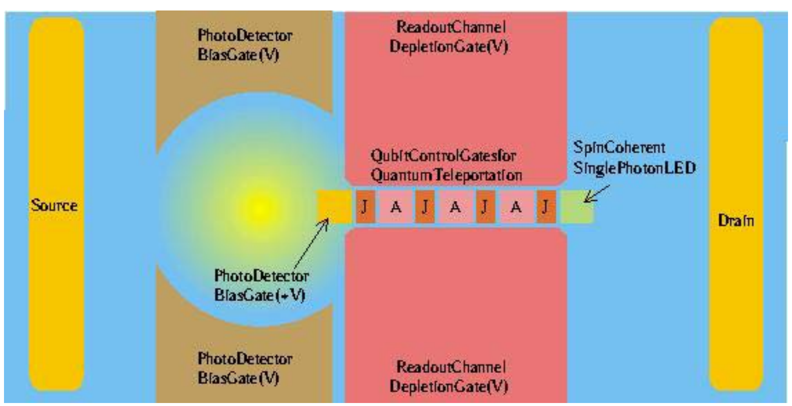
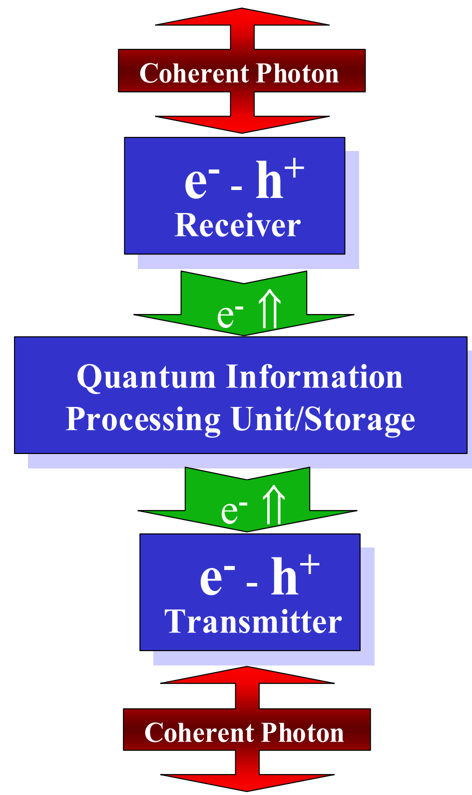
Overview

Conceptual diagram of the quantum transmitter/receiver and IPU







From Yablonovitch et al.

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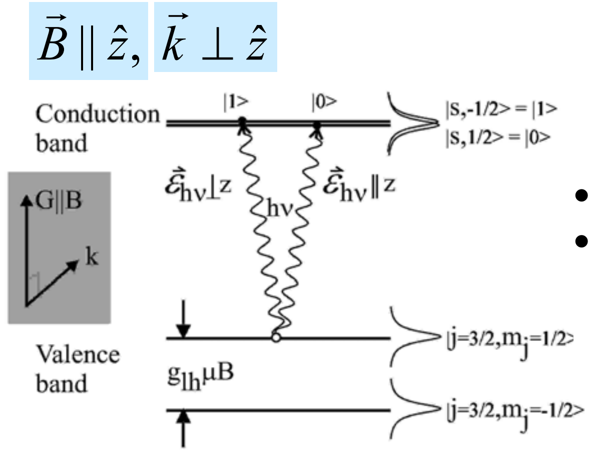
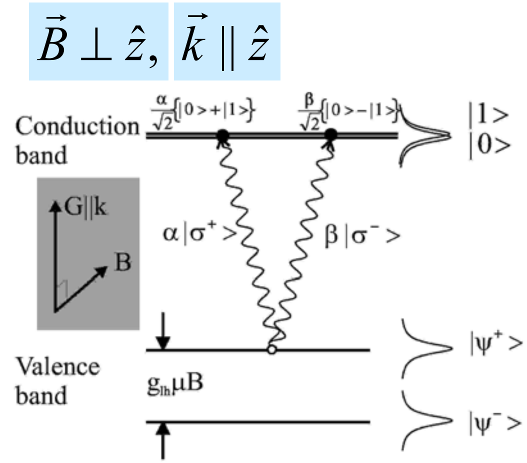
Receiver Design – Selection Rule

Desired conditions

- E-h transitions for both electron spin states should be within the photon bandwidth. => small g_C
- Only a single hole state should be involved. => $|g_H \mu_B B| >> \Gamma_{photon}$
- Both electron spin states should couple to a single lowest-energy hole state. => proper selection rules
- E_g ~ 1.3 – 1.55 μm



- HH not possible
- Unbalanced conversion strength to |1> & |0>



- $g_{HH,\perp} \cong 0$
- Balanced conversion

From Vrijen & Yablonovitch

=> LH should be the lowest with $|g_{LH}|$ >> $|g_C|$ (strained QW)

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Receiver Design – g Factor Calculation

Multiband Hamiltonian with $\vec{B}$

$$H \cong H(\vec{k}) + \frac{1}{c}\left\{ \vec{A} \cdot \frac{\partial H}{\partial \vec{k}} \right\} + \delta H_B$$

$$\vec{A} = \left(B_y z, \quad -B_x z, \quad 0 \right)$$ for in-plane field

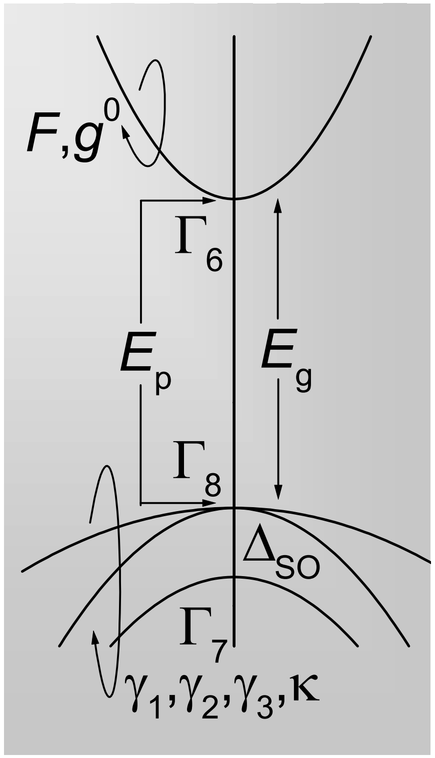
Zeeman contribution to the 2×2 Hamiltonian (s =↑ or ↓)

$$\delta H_{ss'} \equiv \frac{1}{2}\mu_B \sigma_{\alpha,ss'} g_{\alpha\beta} B_\beta = \frac{1}{c}\left\langle s \middle| \vec{A} \cdot \frac{\partial H}{\partial \vec{k}} \middle| s' \right\rangle + \left\langle s \middle| \delta H_B \middle| s' \right\rangle$$

$$\delta H_B = \left(\quad \right) \cdot \vec{B}$$

$$\Rightarrow \frac{\mu_B}{2} \sigma \left(g_0 + \Delta g_{remote} \right) B$$ for CB

$8 \times 8 \; \vec{k} \cdot \vec{p}$ model



QW LH and CB wavefunctions at $k_x = k_y = 0$

$$\left| \uparrow \right\rangle = u(z)\left| s \uparrow \right\rangle + v(z)\left| LH \uparrow \right\rangle + w(z)\left| SO \uparrow \right\rangle$$

$$\left| \downarrow \right\rangle = u(z)\left| s \uparrow \right\rangle + v(z)\left| LH \uparrow \right\rangle - w(z)\left| SO \downarrow \right\rangle$$

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Receiver Design – g Factor Calculation

In-plane LH g factor

$$g_{LH,\perp} = g_{imp} + g_{exp}$$

$$g_{imp} = 4\int z\left[\frac{3}{\sqrt{2}}\gamma_3\left(w^* v' - v^* w'\right) + \frac{E_p}{3(E_g - E)}\left(v^* v' - \frac{1}{\sqrt{2}} v^* w' + \sqrt{2} w^* v' - w^* w'\right)\right] dz$$

$$g_{exp} = 4\int \left[\frac{1}{2}|u|^2 - \kappa |v|^2 + \left(\kappa + \frac{1}{2}\right)|w|^2 - \frac{1}{\sqrt{2}}(\kappa + 1)\left(v^* w + w^* v\right)\right] dz$$

In-plane conduction electron g factor

$$g_{c,\perp} = g_{imp} + g_{exp}$$

$$g_{imp} = -4\int dz \quad Dz\frac{d|u|^2}{dz}, \quad D = -\frac{E_p}{2}\frac{\Delta_{SO}}{3}\left(E + E_g\right)^{-1}\left(E + E_g + \Delta_{SO}\right)^{-1}$$

$$g_{exp} = g_0 + \Delta g_{remote}$$

Strain

$$\varepsilon_\perp = \varepsilon_{xx} = \varepsilon_{yy} = a_{sub} / a_0 - 1$$

$$\varepsilon_\parallel = \varepsilon_{zz} = -\left(2C_{12} / C_{11}\right)\varepsilon_\perp$$

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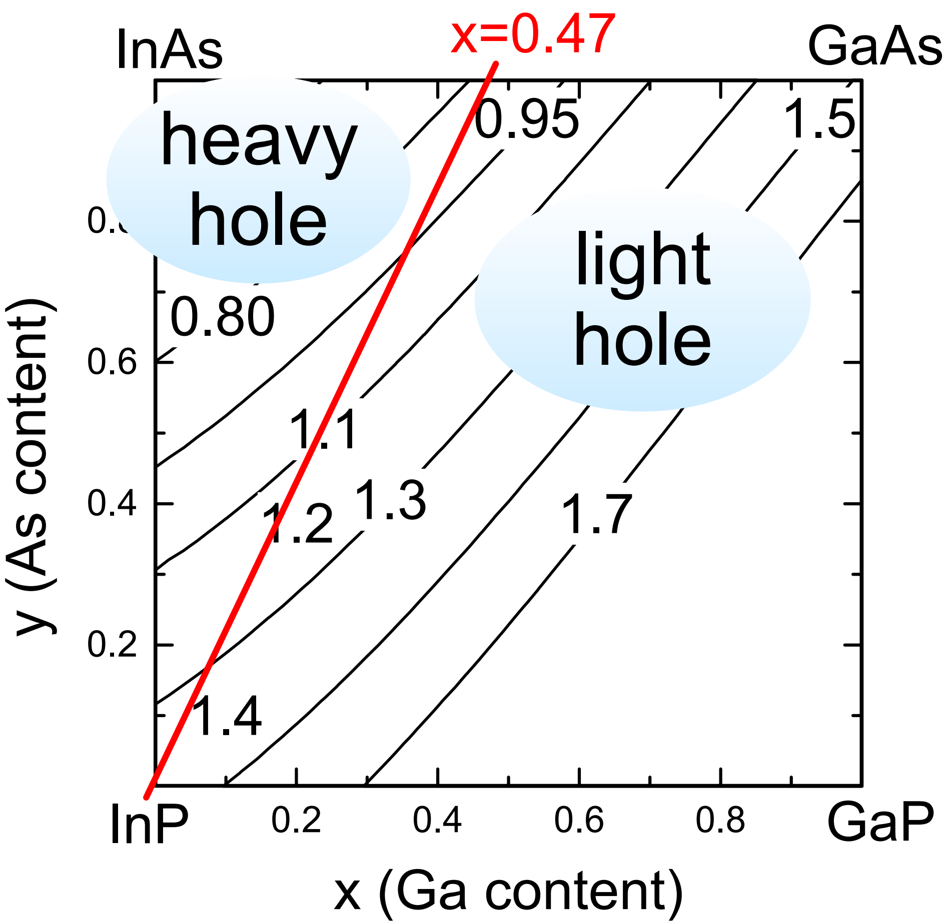
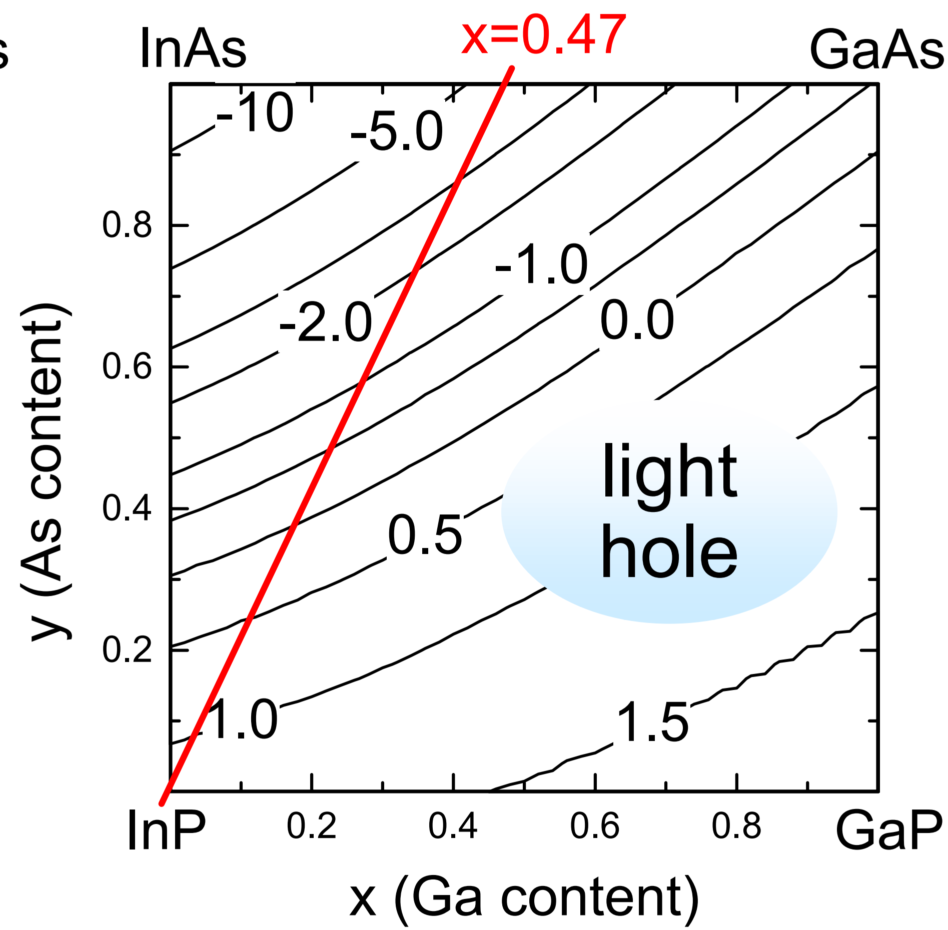
Receiver Design – Bulk $In_{1-x}Ga_xAs_yP_{1-y}$ Properties

Band gap



Electron g factor



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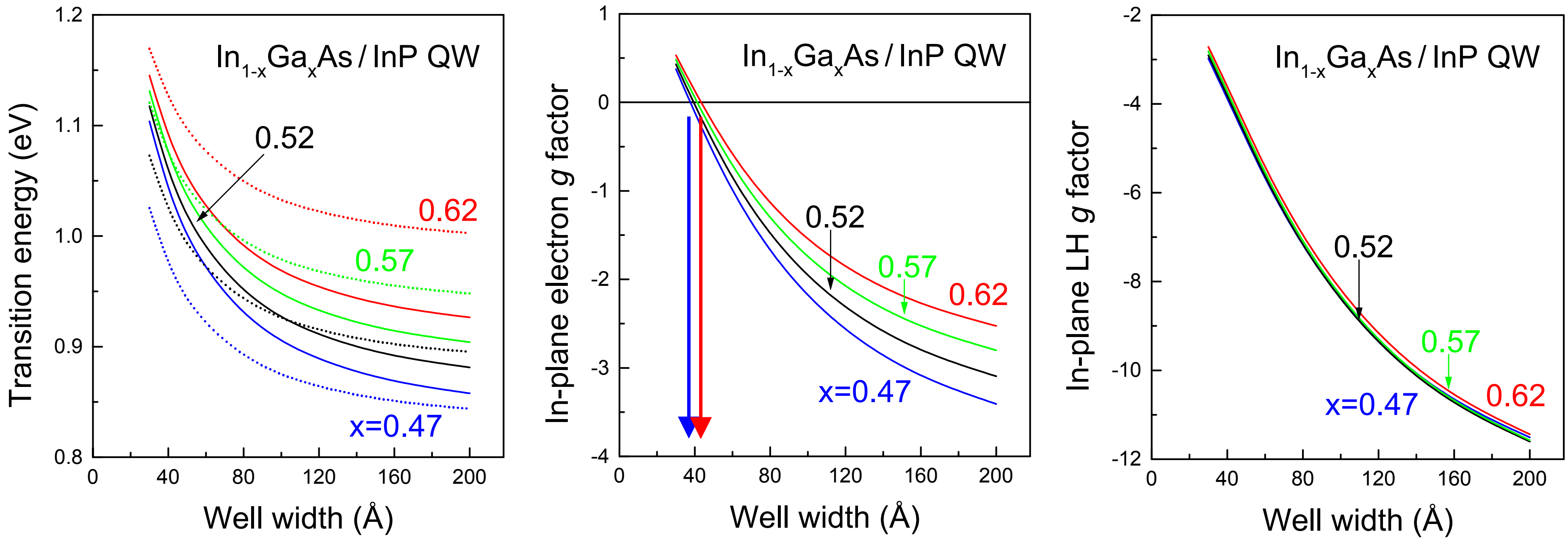
Receiver Design – $In_{1-x}Ga_xAs/InP$ QW

Transition energies (solid: e-lh; dotted: e-hh) | Electron g factor | LH g factor



=> 43Å $In_{0.38}Ga_{0.62}As/InP$ QW

- Negligible in-plane electron g factor $g_{c,\perp} \cong 0$
- Large in-plane light hole g factor $g_{LH,\perp} \cong -3.8$
- Principal transition $E_{el}-E_{lh}=1.075$eV, very moderate strain $\varepsilon_{xx}=1\%$

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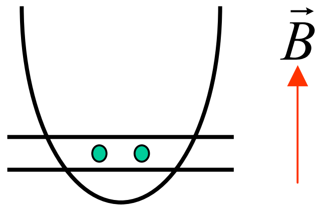
Single Spin Detector – Two Interacting Electrons in a QD

Toy model



- Two interacting 2D electrons in a quadratic confining potential
- $\vec{B} \perp$ 2D plane
- $H = H_1 + H_2 + \frac{e^2}{\varepsilon r}$

$$H_i = \frac{1}{2m^*}\left[\vec{P}_i + \frac{e}{c}\vec{A}(\vec{r}_i)\right]^2 + \frac{1}{2}m^*\omega^2 r_i^2 + \frac{g\mu_B}{2}\vec{B}\cdot\vec{\sigma}_i$$

$\Rightarrow$ Calculate the eigenstates through numerical diagonalization.

(from PRB47, 2244, 1993)

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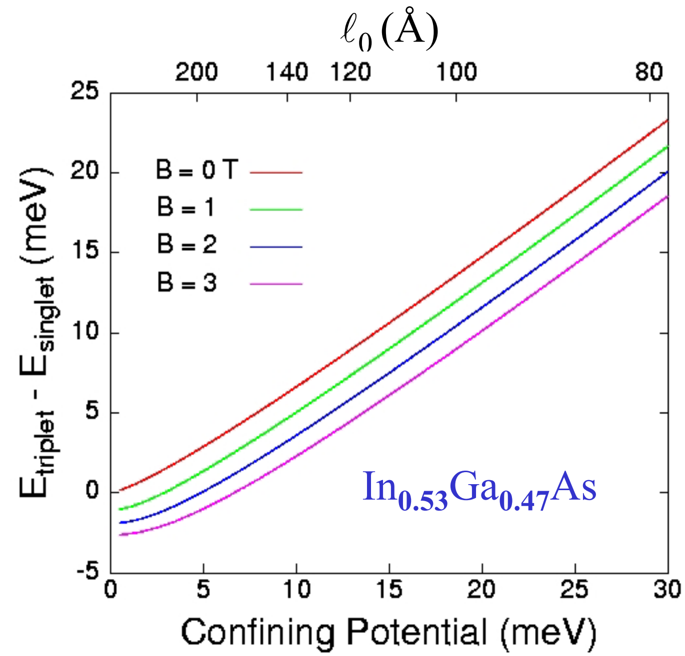
Triplet-singlet splitting



- $l_0 = (\hbar / m^*\omega)^{1/2}$; half-width of prob. density
- $E_T - E_S$~10meV with l_0~10nm

=> Large enough for detection

What happens when **B** is in-plane?

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