Analytical view on decoherence effects in coupled electrostatic qubits in tight-binding model

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Wannier qubit in the chain of coupled q-dots

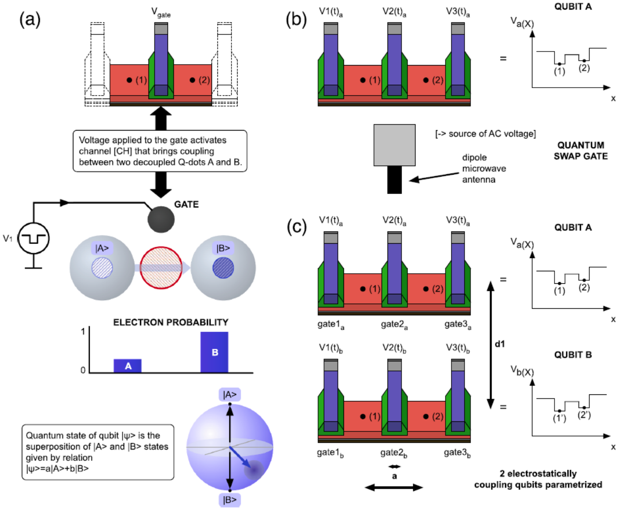


Figure: Basic concept of Wannier (position-based qubit) as from [Cryogenics 2020, Pomorski et al.].

Philosophy of anticorrelation in single electron devices

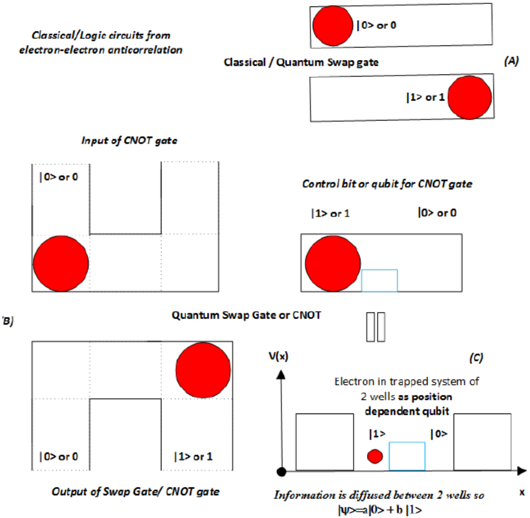
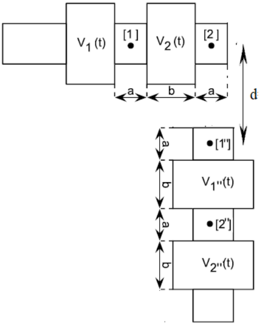
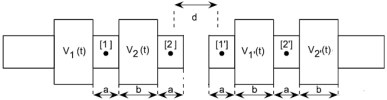
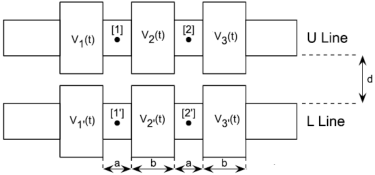


Figure: Principle of anticorrelation as by [Spie 2019, Pomorski et al.]

Different topologies of interacting qubits







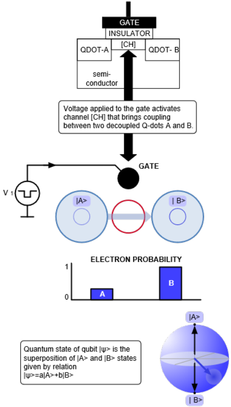
Physics of single electrostatic qubit

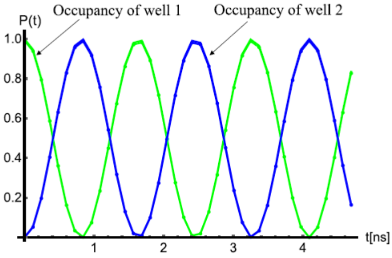
The tight-binding Hamiltonian of this system is given as

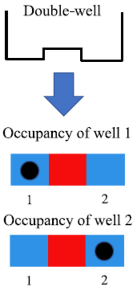
$$\hat{H}(t)_{[x=(x_1,x_2)]} = \begin{pmatrix} E_{p1}(t) & t_{s12}(t) = |t_{s12}|e^{+i\alpha(t)} \\ t_{s12}^{\dagger}(t) = |t_{s12}|e^{-i\alpha(t)} & E_{p2}(t) \end{pmatrix} =$$

$$E_{p1}(t)\,|x_1\rangle\langle x_1| + E_{p2}(t)\,|x_2\rangle\langle x_2| + t_{s12}(t)\,|x_1\rangle\langle x_2| + t_{s21}(t)\,|x_2\rangle\langle x_1|$$

$$= (E_1(t)\,|E_1\rangle_t\,\langle E_1|_t + E_2(t)\,|E_2\rangle\langle E_2|)_{[E=(E_1,E_2)]}. \quad (1)$$







Physics of 2 interacting qubits

$$
\begin{aligned}
\hat{H} = (t_{s21}(t)\,|2\rangle\langle 1| + t_{s12}(t)\,|1\rangle\langle 2|)\hat{I}_b) + \\
+(\hat{I}_a(t_{s2'1'}(t)\,|2'\rangle\langle 1'| + t_{s1'2'}(t)\,|2'\rangle\langle 1'|) + \\
+(E_{p1}(t)\,|1\rangle\langle 1| + E_{p2}(t)\,|2\rangle\langle 2|)\hat{I}_b + \\
\hat{I}_a(E_{p1'}(t)\,|1'\rangle\langle 1'| + E_{p2'}(t)\,|2'\rangle\langle 2'|) + \\
+\frac{q^2}{d_{11'}}\,|1,1'\rangle\langle 1,1'| + \frac{q^2}{d_{22'}}\,|2,2'\rangle\langle 2,2'| + \\
\frac{q^2}{d_{12'}}\,|1,2'\rangle\langle 1,2'| + \frac{q^2}{d_{21'}}\,|2,1'\rangle\langle 2,1'| = \\
H_{kinetic1} + H_{pot1} + H_{kinetic2} + H_{pot2} + H_{A-B}
\end{aligned}
\tag{2}
$$

described by parameters $E_{p1}(t)$,$E_{p2}(t)$,$E_{p1'}(t)$,$E_{p2'}(t)$, $t_{s12}(t)$, $t_{s1'2'}(t)$ and distances between nodes k and l': $d_{11'}$,$d_{22'}$,$d_{21'}$,$d_{12'}$. In such case q-state of the system is given as

$$
\begin{aligned}
|\psi\rangle_t = \gamma_1(t)\,|1,0\rangle_U\,|1,0\rangle_L + \gamma_2(t)\,|1,0\rangle_U\,|0,1\rangle_L + \\
+\gamma_3(t)\,|0,1\rangle_U\,|1,0\rangle_L + \gamma_4(t)\,|0,1\rangle_U\,|0,1\rangle_L ,
\end{aligned}
$$

$$\left|E_g,t\right\rangle_n = \frac{(\frac{(E_{p2}(t)-E_{p1}(t))}{2}+\sqrt{\frac{(E_{p2}(t)-E_{p1}(t))^2}{2}+|t_{s12}(t)|^2})e^{-i\alpha(t)}\left|x_1\right\rangle - |t_{s12}(t)|\left|x_2\right\rangle)}{\sqrt{|t_{s12}(t)|^2+(\frac{(E_{p2}(t)-E_{p1}(t))}{2}+\sqrt{\frac{(E_{p2}(t)-E_{p1}(t))^2}{2}+|t_{s12}(t)|^2})^2}} = a(t)\left|x_1\right\rangle_n + b(t)\left|x_2\right\rangle_n,$$

$$\left|E_e,t\right\rangle_n = \frac{(-\frac{(E_{p2}(t)-E_{p1}(t))}{2}+\sqrt{\frac{(E_{p2}(t)-E_{p1}(t))^2}{2}+|t_{s12}(t)|^2})e^{+i\alpha(t)}\left|x_1\right\rangle + |t_{s12}(t)|\left|x_2\right\rangle)}{\sqrt{|t_{s12}(t)|^2+(-\frac{(E_{p2}(t)-E_{p1}(t))}{2}+\sqrt{\frac{(E_{p2}(t)-E_{p1}(t))^2}{2}+|t_{s12}(t)|^2})^2}} = c(t)\left|x_1\right\rangle_n + d(t)\left|x_2\right\rangle_n, \quad (4)$$

$$a(t) = \frac{((\frac{E_{p2}(t)-E_{p1}(t)}{2})+\sqrt{(\frac{E_{p2}(t)-E_{p1}(t)}{2})^2+|t_{s12}(t)|^2})e^{-i\alpha(t)}}{\sqrt{|t_{s12}(t)|^2+(\frac{(E_{p2}(t)-E_{p1}(t))}{2}+\sqrt{\frac{(E_{p2}(t)-E_{p1}(t))^2}{2}+|t_{s12}(t)|^2})^2}}, \quad (5)$$

$$b(t) = \frac{-|t_s(t)|}{\sqrt{|t_s(t)|^2+(\frac{(E_{p2}(t)-E_{p1}(t))}{2}+\sqrt{\frac{(E_{p2}(t)-E_{p1}(t))^2}{2}+|t_{s12}(t)|^2})^2}}, \quad (6)$$

$$c(t) = \frac{-(\frac{E_{p2}(t)-E_{p1}(t)}{2})+\sqrt{(\frac{E_{p2}(t)-E_{p1}(t)}{2})^2+|t_s(t)|^2})e^{+i\alpha(t)}}{\sqrt{|t_s|^2+(-(E_{p2}(t)-E_{p1}(t))+\sqrt{\frac{(E_{p2}(t)-E_{p1}(t))^2}{2}+|t_{s12}(t)|^2})^2}}, \quad (7)$$

$$d(t) = \frac{+|t_s(t)|}{\sqrt{|t_s|^2+(-\frac{(E_{p2}(t)-E_{p1}(t))}{2}+\sqrt{\frac{(E_{p2}(t)-E_{p1}(t))^2}{2}+|t_{s12}(t)|^2})^2}}, \quad (8)$$

We start from spectral decomposition of operator $|x_1\rangle|x_{1'}\rangle\frac{q^2}{d(1,1')}\langle x_1|\langle x_{1'}|$ into eigenergy represenation of qubits A and B and we obtain ,

$$\left(|x_1\rangle|x_{1'}\rangle\frac{q^2}{d(1,1')}\langle x_1|\langle x_{1'}|\right)_{a_A(t),c_A(t),a_B(t),c_B(t)} =$$

$$(|E_{1a}><E_{1a}|+|E_{2a}><E_{2a}|)(|E_{1b}><E_{1b}|+|E_{2b}><E_{2b}|)(|x_1>|x_{1'}>\frac{q^2}{d(1,1')}<x_1|<x_{1'}|)\times$$

$$\times(|E_{1a}><E_{1a}|+|E_{2a}><E_{2a}|)(|E_{1b}><E_{1b}|+|E_{2b}><E_{2b}|)=$$

$$=\frac{q^2}{d(1,1')}(|E_{1a}><E_{1a}||x_1>+|E_{2a}><E_{2a}||x_1>)(|E_{1b}><E_{1b}||x_{1'}>+|E_{2b}><E_{2b}||x_{1'}>)\times$$

$$\times(<x_1||E_{1a}><E_{1a}|+<x_1||E_{2a}><E_{2a}|)(<x_{1'}||E_{1b}><E_{1b}|+<x_{1'}||E_{2b}><E_{2b}|)=$$

$$=\frac{q^2}{d(1,1')}(|E_{1a}>a_A(t)^*+|E_{2a}>c_A(t)^*)(|E_{1b}>a_B(t)^*+|E_{2b}>c_B(t)^*)\times$$

$$\times(a_A(t)<E_{1a}|+c_A(t)<E_{2a}|)(a_B(t)<E_{1b}|+c_B(t)<E_{2b}|)=$$

$$=\frac{q^2}{d(1,1')}(||E_{1a},E_{1b}\rangle a_B(t)^*a_A(t)^*+|E_{1a},E_{2b}\rangle a_A(t)^*c_B(t)^*+|E_{2a},E_{1b}\rangle c_A(t)^*a_B(t)^*+|E_{2a},E_{2b}\rangle c_A(t)^*c_B(t)^*)\times$$

$$(\langle E_{1a},E_{1b}|a_B(t)a_A(t)+\langle E_{1a},E_{2b}|a_A(t)c_B(t)+\langle E_{2a},E_{1b}|c_A(t)a_B(t)+\langle E_{2a},E_{2b}|c_A(t)c_B(t))=$$

$$=\Bigg[\frac{q^2}{d(1,1')}(|E_{1a},E_{1b}\rangle\langle E_{1a},E_{1b}||a_B(t)|^2|a_A(t)|^2+|E_{1a},E_{2b}\rangle\langle E_{1a},E_{2b}||a_B(t)|^2|c_A(t)|^2+$$

$$+|E_{2a},E_{1b}\rangle\langle E_{2a},E_{1b}||c_B(t)|^2|a_A(t)|^2+|E_{2a},E_{2b}\rangle\langle E_{2a},E_{2b}||c_B(t)|^2|c_A(t)|^2)\Bigg]_{r1}+$$

$$\Bigg[\frac{q^2}{d(1,1')}(|E_{1a},E_{1b}\rangle\langle E_{1a},E_{2b}||a_A(t)|^2c_B(t)a_B^*(t)+|E_{1a},E_{2b}\rangle\langle E_{1a},E_{1b}||a_A(t)|^2c_B^*(t)a_B(t)+$$

$$+|E_{2a},E_{1b}\rangle\langle E_{2a},E_{2b}||c_A(t)|^2c_B(t)a_B^*(t)+|E_{2a},E_{2b}\rangle\langle E_{2a},E_{1b}||c_A(t)|^2c_B^*(t)a_B(t))\Bigg]_{r2}+$$

Literature

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