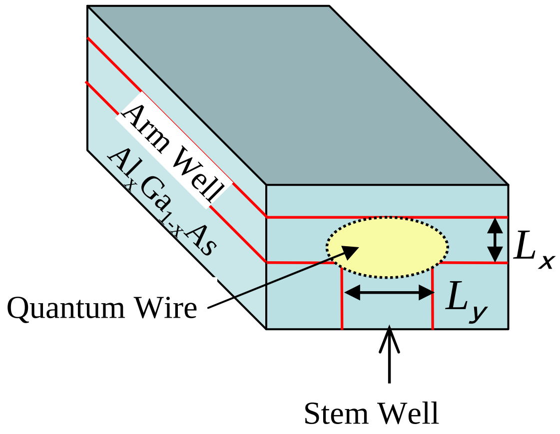
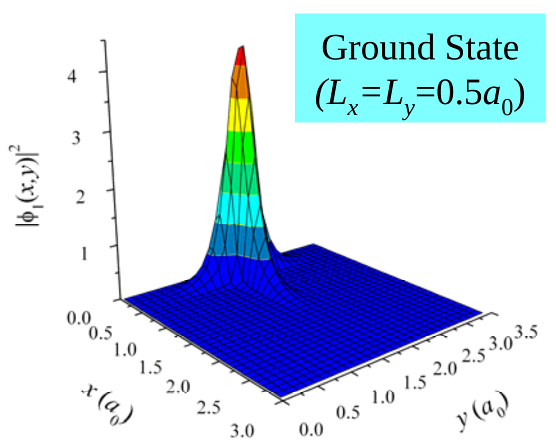
Coulomb Potentials in T-Shaped Quantum Wires

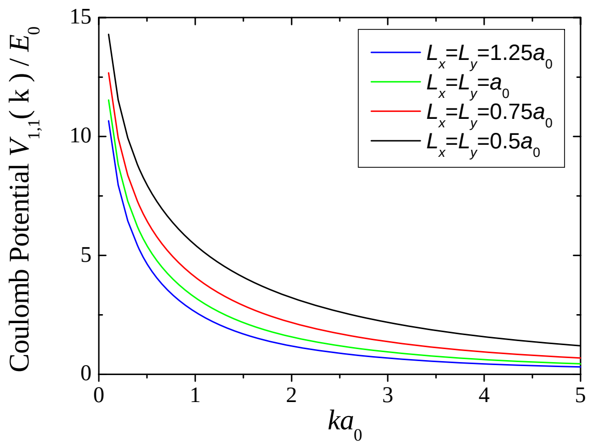


Confinement Potential

$$U(x,y)=\begin{cases}0 & \text{arm/stem well}\\ +\infty & \text{barriel material}\end{cases}$$



$$V_{i,j}(k)=\frac{2e^2}{\varepsilon_0}\iint dx_1dy_1\iint dx_2dy_2\left|\phi_i(x_1,y_1)\right|^2K_0\left(k\sqrt{(x_1-x_2)^2+(y_1-y_2)^2}\right)\left|\phi_j(x_2,y_2)\right|^2$$



Long wavelength limit
$ka_0 << 1$ ⇨ $V_{i,j}(k)\rightarrow-\frac{2e^2}{\varepsilon_0}\ln(|k|)$

Short wavelength limit
$ka_0 >> 1$ ⇨ $V_{i,j}(k)\rightarrow\begin{cases}\text{2D} & \propto k^{-1}\\ \text{3D} & \propto k^{-2}\end{cases}$

Coulomb interaction enhanced by quantum confinement

Numerical Calculation Improvement

$$\Gamma(k) = 1 + \frac{1}{2\pi d_{cv}} \int_{-\infty}^{+\infty} dk' \chi^0(k') V_s(|k-k'|) \Gamma(k')$$

$$\chi_k^0 = -d_{cv} \frac{1 - f_{e,k} - f_{h,k}}{\hbar\omega + i\gamma - E_{e,k} - E_{h,k}}$$

The Γ integral equation is solved by matrix inversion based on discrete sum of right side of the equation.

(1) New quadrature rule is adopted to solve the Γ integral equation.
The logarithmic singularity is removed smoothly.

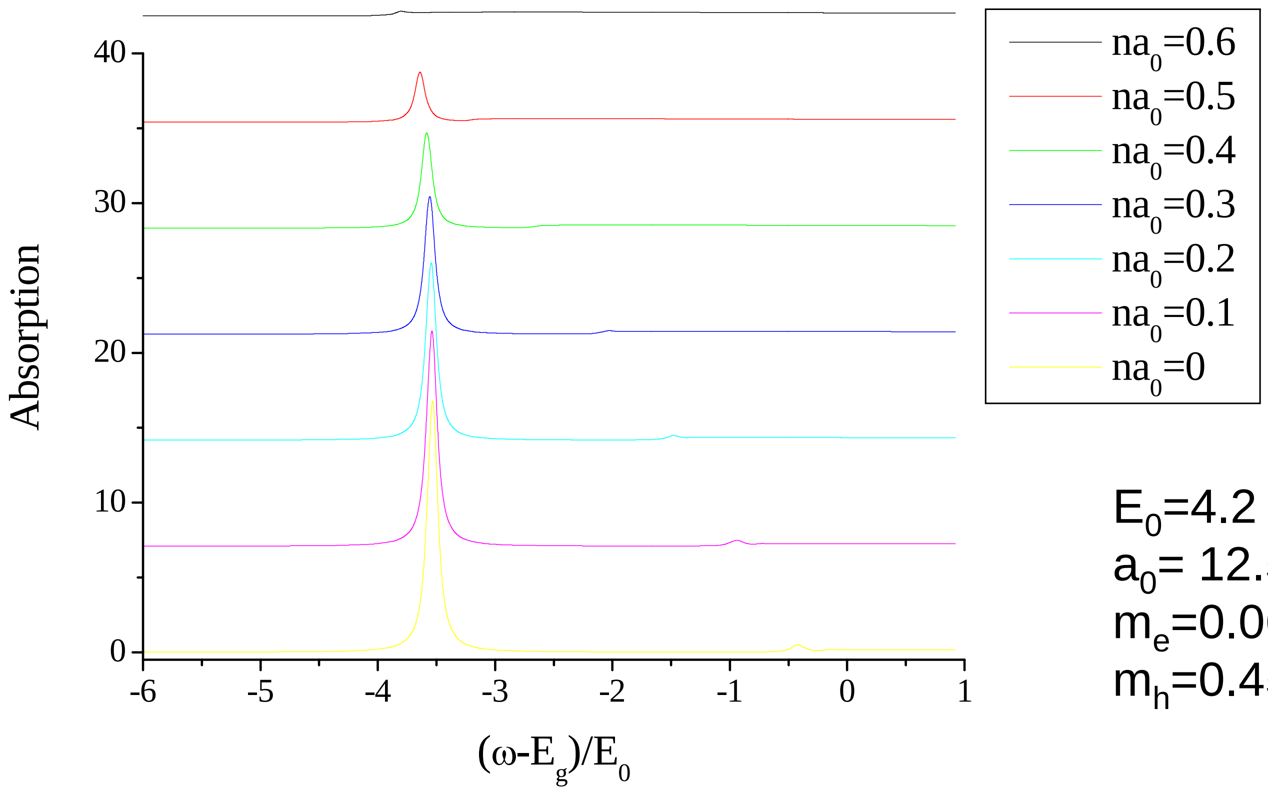
(2) Singular value decomposition shows that the matrix is in quite good condition without any singularity.

(3) Different summation precision and cutoff of K are checked.
All show quite stable results. (little alteration even doubling number the points, see Fig. 4)

Absorption Vs. Carrier Density (low)

T=80K γ=0.05E_0

L_x=L_y=0.5a0



E_0=4.2 meV
a_0= 12.5nm
m_e=0.0665
m_h=0.457

Fig.1

Absorption Vs. Carrier Density (high)

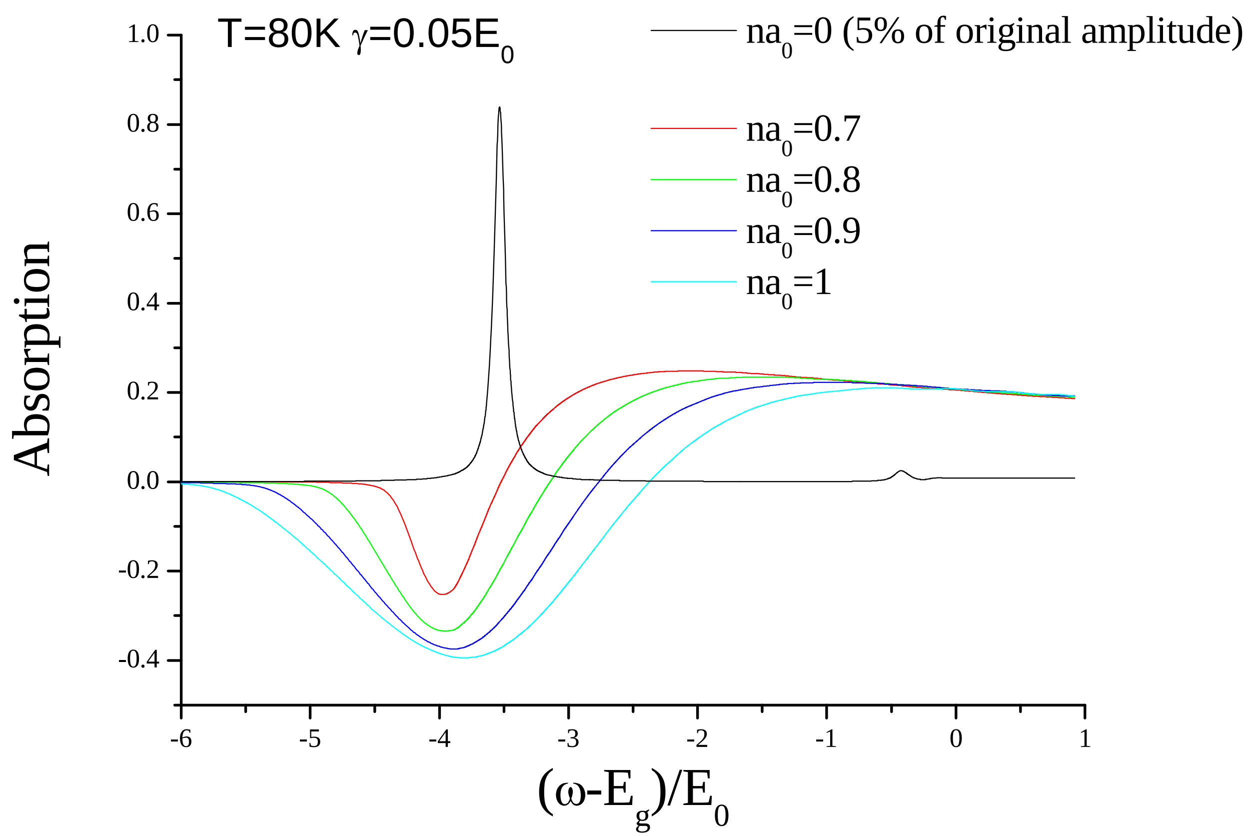


Fig. 2

Absorption Vs. Temperature

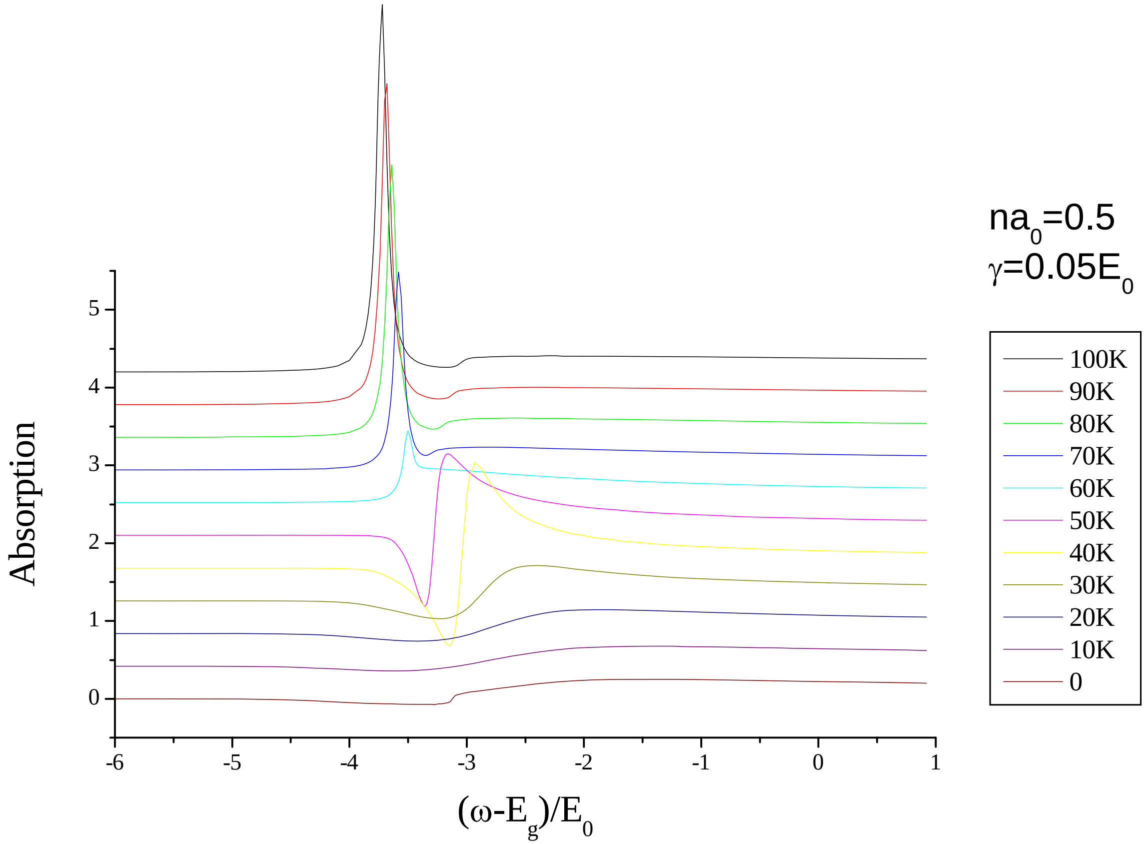


Fig. 3

Abnormal behaviors in temperature dependence (not due to numerical error, see next figure)

Possible reason

(1) The damping parameter γ is the same for all temperature (phonon scattering should increase as T increases).

(2) Simple HF theory fails (actually the resonant behaviors are very sensitive to self-energy, which is under estimated in HF approx.)

Numerical Precision Check

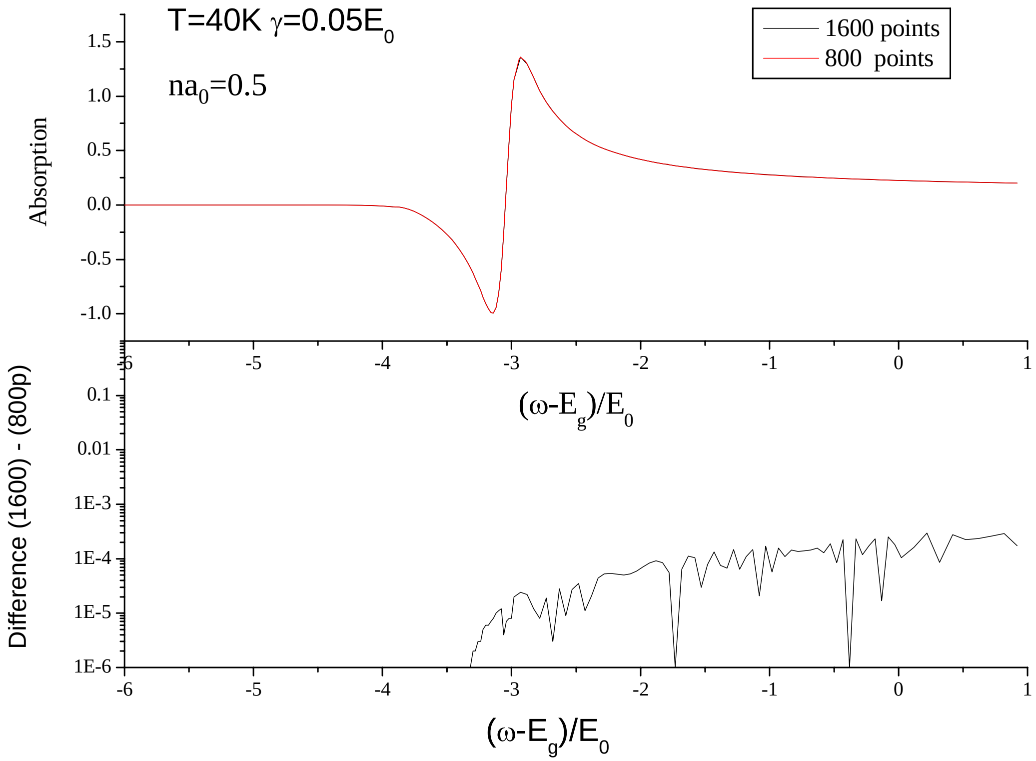


Fig.4

Fig. 4 shows results with 800 and 1600 point of k (momentum). Because they are too close, the difference is shown in the lower panel. The maximum difference is less than 10^{-4}. Thus the resonant behavior in T=50K does not come from the numerical error.

What is the next?

(1) Further investigation on absorption and gain spectra with finite confinement potential of T-shaped wires and realistic parameters.

(2) Proper treatment of screening (Poisson's equation in T-shaped geometry)

(3) Electron correlation (DCT theory).

(4) Coupling of electron and photon, Collective spontaneous emission.