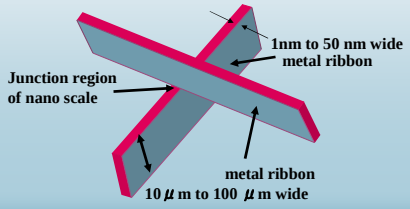
The Quasi-Particle Energy Spectrum of Electron Gas in Quantum Structures

Kenji Kondo
Research Institute for Electronic Science
Hokkaido University

Our Purpose is to investigate nano-scale physics and combine top-down systems and bottom-up systems in nano-space.

↓

Proposal of new structures which could bridge a gap between both systems.



Quantum Cross Structure[1)]

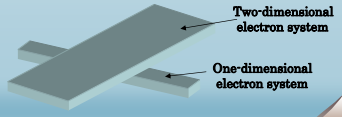
(1) A.Ishibashi and K.Kondo,Proc.The5thRIES-Hokudai Symposium on Advanced Nanoscience 2003.p44

Junction region can have different dimensional electron systems

according to metal ribbon width.

Interaction between different dimensional electron systems.

- One-dimensional electron system to one-dimensional one.
- Two-dimensional electron system to one-dimensional one.
- Two-dimensional electron system to two-dimensional one. And so on.



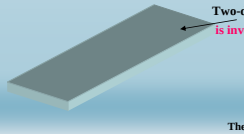
We'd like to know the properties of these new structures.

↓

We have to know each dimensional electron systems' energy spectrum.

↓

We focus on two-dimensional electron gas in nano-space firstly.



The Calculation of Energy Spectrum of Two-Dimensional Electron Gas using GW approximation.

- We need to solve the Hedin's equations in order to calculate the quasi-particle energy.
- We approximate the vertex function to be delta-function this time. That is GW approximation.

The Feynman Graphs that we take into consideration.

Free particle Green's function $G^0(\boldsymbol{p}, i\omega_n) =$

Bare coulomb potential $v(\boldsymbol{q}) =$

Dressed Green's function $G(\boldsymbol{p}, i\omega_n) =$

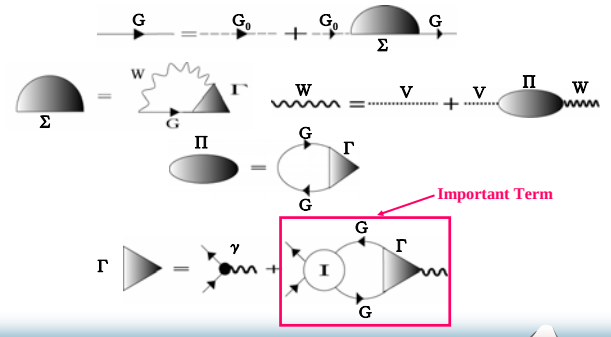
Screened coulomb potential $W(\boldsymbol{q}, i\omega_l) =$

Self energy $\Sigma(\boldsymbol{p}, i\omega_n) =$

Polarization function $\Pi(\boldsymbol{q}, i\omega_l) =$

Vertex function $\Gamma_0(p; p+q) =$

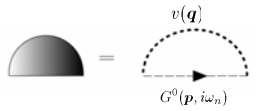
The Feynman Graph's representation of Hedin's Equations



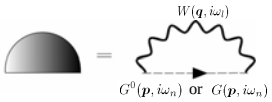
All of the equations we should consider are as follows.

$$
\begin{aligned}
G^0(\boldsymbol{p}, i\omega_n) &= [i\omega_n - \epsilon(\boldsymbol{p}) + \mu]^{-1} \\
G(\boldsymbol{p}, i\omega_n) &= 1/[G^0(\boldsymbol{p}, \omega_n)^{-1} - \Sigma(\boldsymbol{p}, i\omega_n)] \\
\Sigma(\boldsymbol{p}, i\omega_n) &= -\int \frac{d^2\boldsymbol{q}'}{(2\pi)^2} \sum_{\omega_l} W(\boldsymbol{q}, i\omega_l) G(\boldsymbol{p}+\boldsymbol{q}, i\omega_n + \omega_l)) \Gamma_0(\boldsymbol{p}, i\omega_n; \boldsymbol{p}+\boldsymbol{q}, i\omega_n + i\omega_l) \\
\Pi(\boldsymbol{q}, i\omega_l) &= T \int \frac{d^2\boldsymbol{p}}{(2\pi)^2} \sum_{\omega_n} G(\boldsymbol{p}, i\omega_n) G(\boldsymbol{p}+\boldsymbol{q}, i\omega_n + i\omega_l) \Gamma_0(\boldsymbol{p}, i\omega_n; \boldsymbol{p}+\boldsymbol{q}, i\omega_n + i\omega_l) \\
\Gamma_\nu(p; p+q) &= \gamma_\nu(p; p+q) + T \int \frac{d^2\boldsymbol{p}'}{(2\pi)^2} \sum_{\omega_n'} \tilde{I}(p, p+q; p', p'+q) G(p') G(p'+q) \Gamma_\nu(p', p'+q) \\
&\quad \text{where } p = (\boldsymbol{p}, i\omega_n), p+q = (\boldsymbol{p}+\boldsymbol{q}, i\omega_n + i\omega_l) \text{ is used.} \\
\epsilon(\boldsymbol{q}, i\omega_l) &= 1 - V(\boldsymbol{q}) \Pi(\boldsymbol{q}, i\omega_l) \\
W(\boldsymbol{q}, i\omega_l) &= V(\boldsymbol{q}) / \epsilon(\boldsymbol{q}, i\omega_l)
\end{aligned}
$$

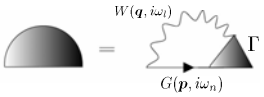
HF approximation:

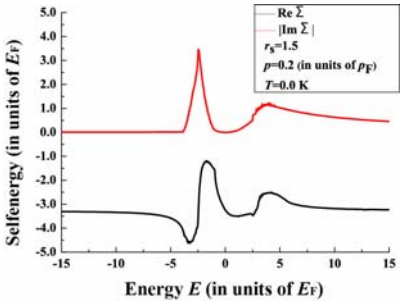


GW approximation
(frequency-dependent HFA):

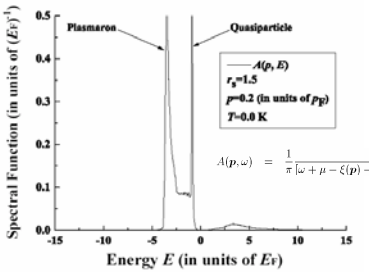


GW Γ approximation:





The energy dependence of electron self-energy



$$A(\boldsymbol{p}, \omega) = \frac{1}{\pi} \frac{|Im\Sigma(\boldsymbol{p}, \omega)|}{[\omega + \mu - \xi(\boldsymbol{p}) - Re\Sigma(\boldsymbol{p}, \omega)]^2 + [Im\Sigma(\boldsymbol{p}, \omega)]^2}$$

The energy dependence of spectral function

Conclusion and To Do in the near future.

- We have proposed new structures which could bridge a gap between top-down systems and bottom-up systems.
- We have calculated the quasi-particle energy in two-dimensional electron gas.
- In order to improve this calculation, we are going to calculate the energy spectrum using GW Γ approximations.
- We'd like to calculate the energy spectrum between different dimensional electron systems.

Acknowledgement

I'd like to thank Prof. Takada for fruitful discussion about the calculation of GW and GW Γ method.