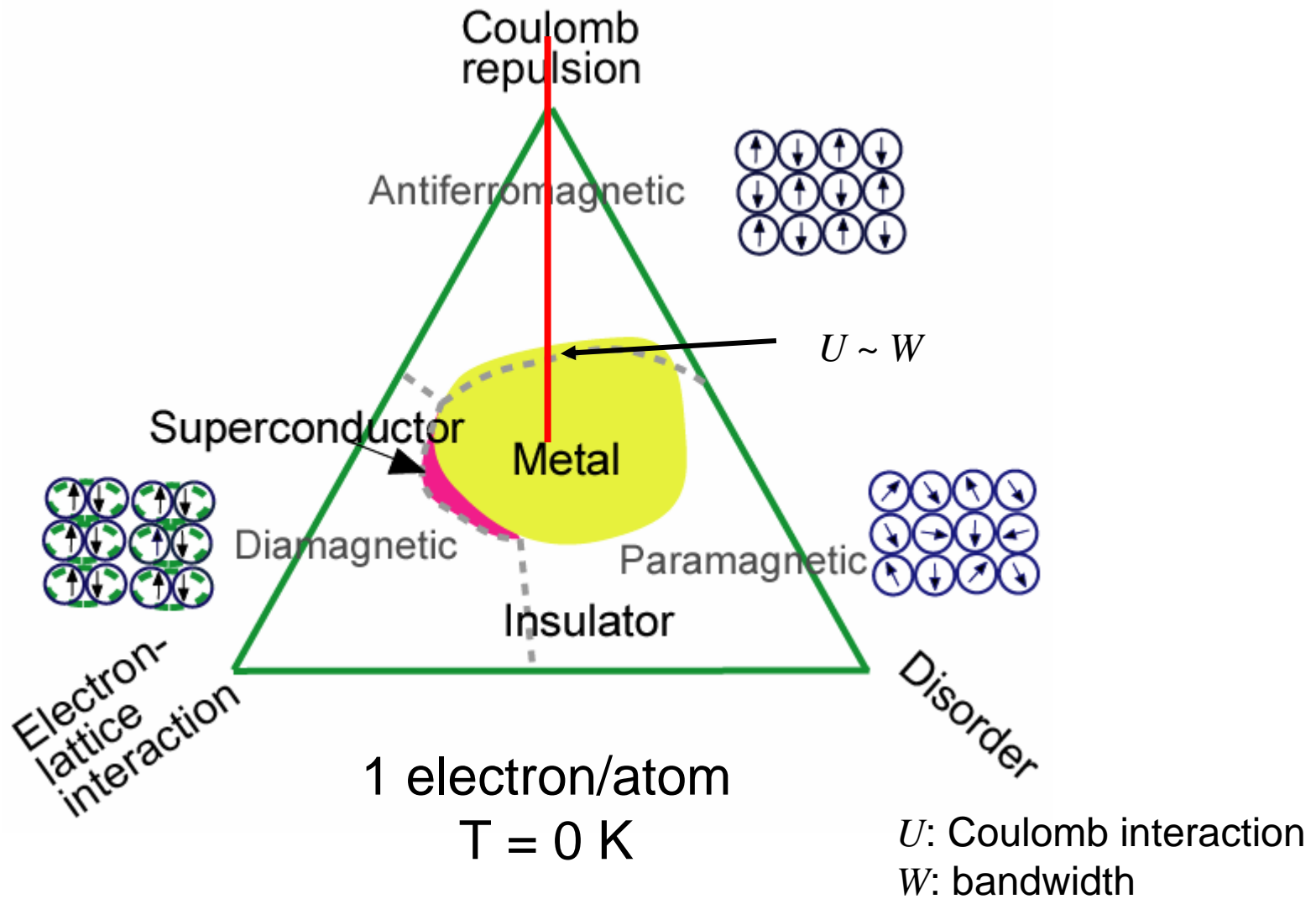
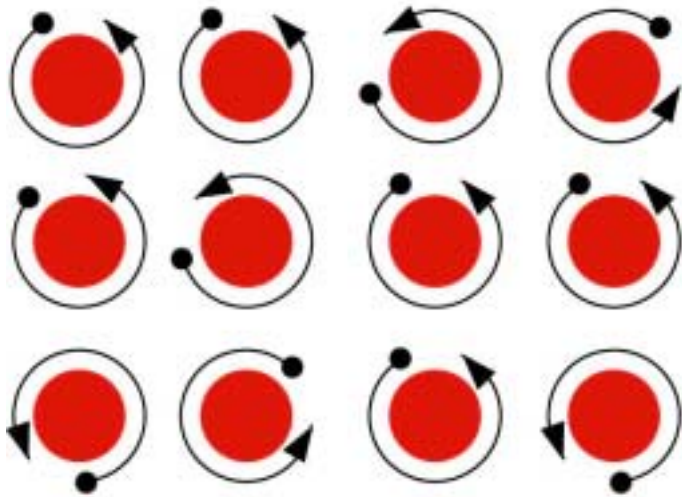


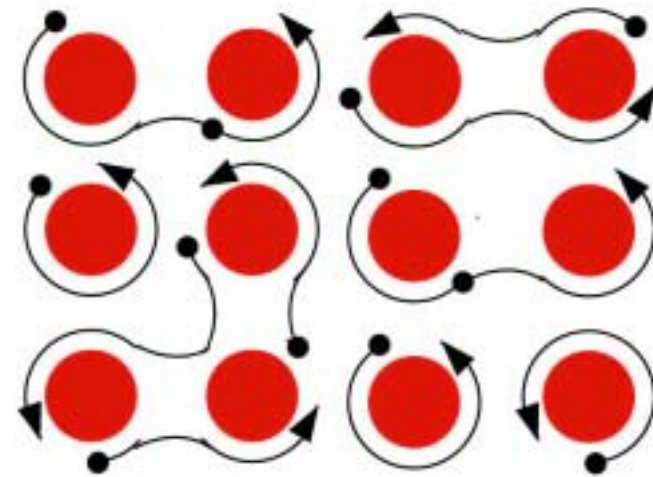
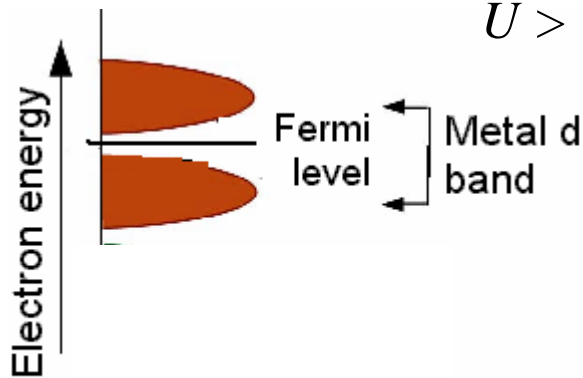
強相関電子系の相図



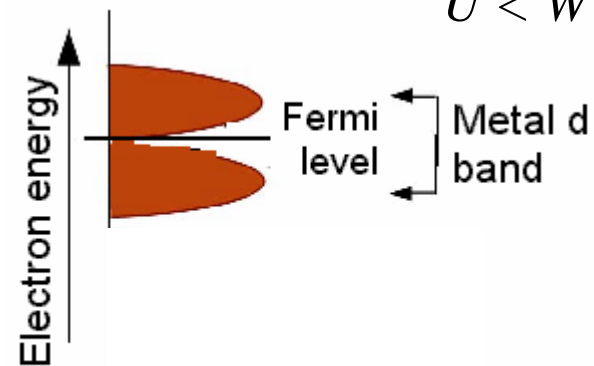
モット・ギャップの開閉による金属-絶縁体転移



$$U > W$$

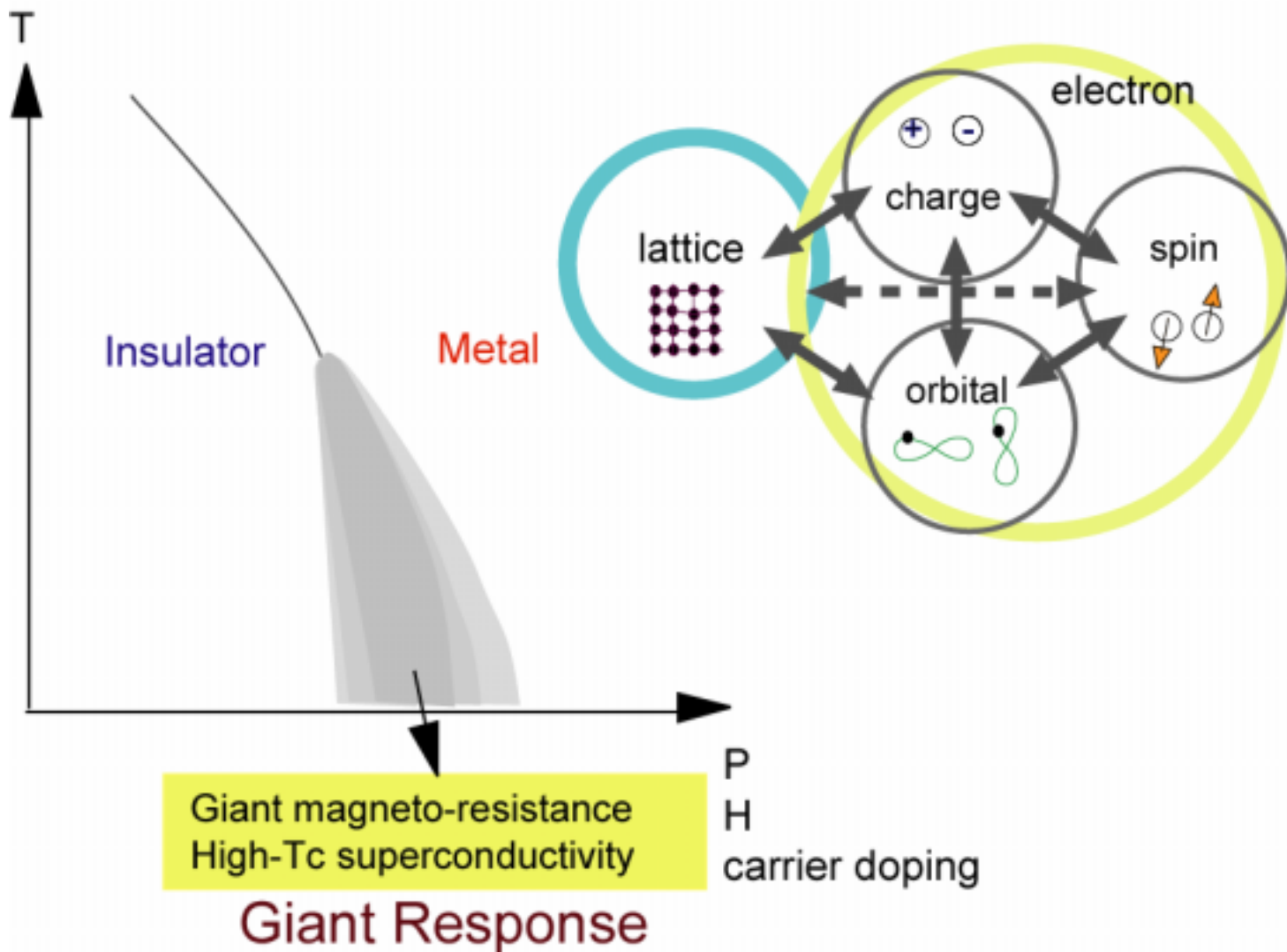


$$U < W$$



U : Coulomb interaction
 W : bandwidth

強相関係におけるスピン, 電荷, 軌道, 格子の結合

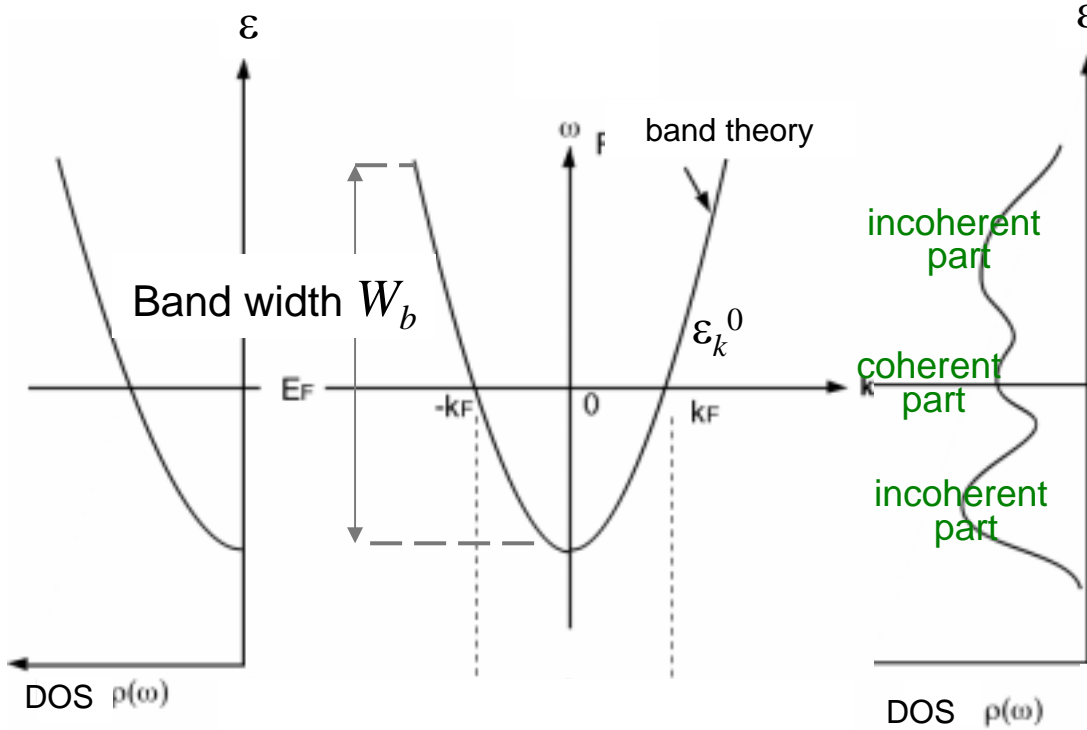


バンド電子に対する電子相関効果

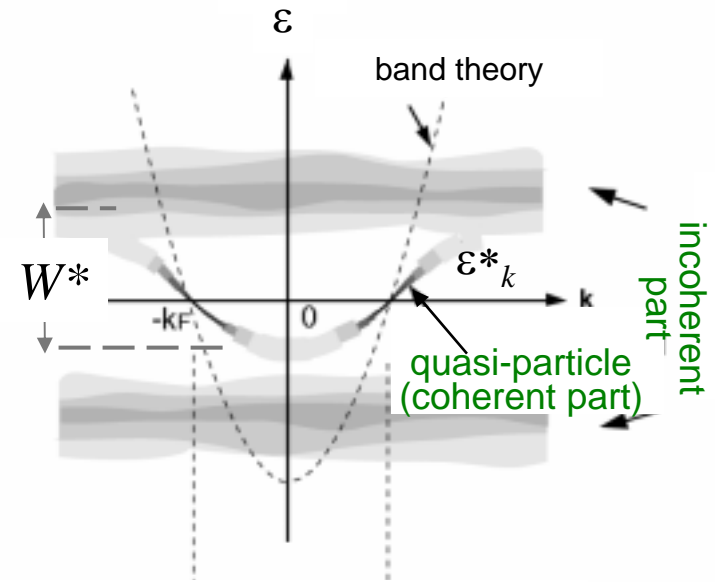
Band theory



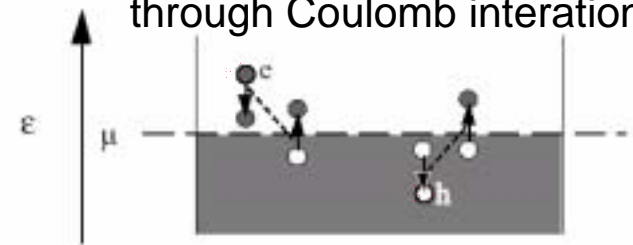
+ Electron correlation



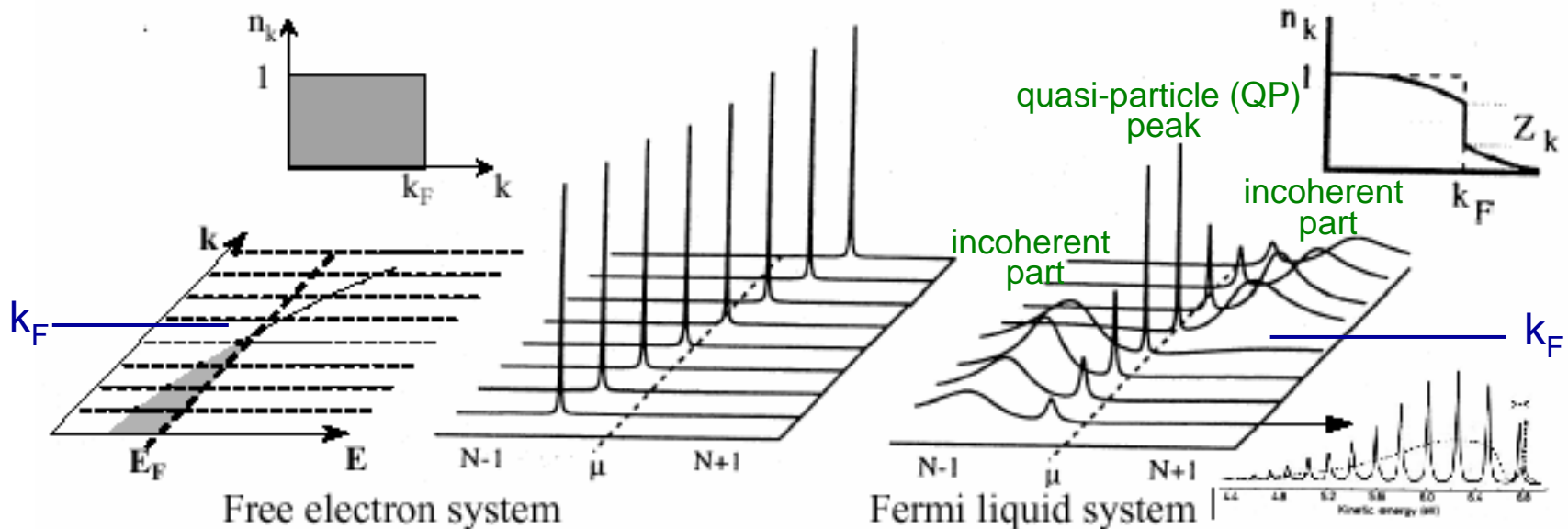
k_F : Fermi momentum



Electron-electron scattering through Coulomb interaction



バンド電子に対する電子相関効果 - スペクトル関数 -



Fermi surface k_F is defined by

- * Discontinuity in n_k
- * E_F crossing of infinitely sharp QP peak

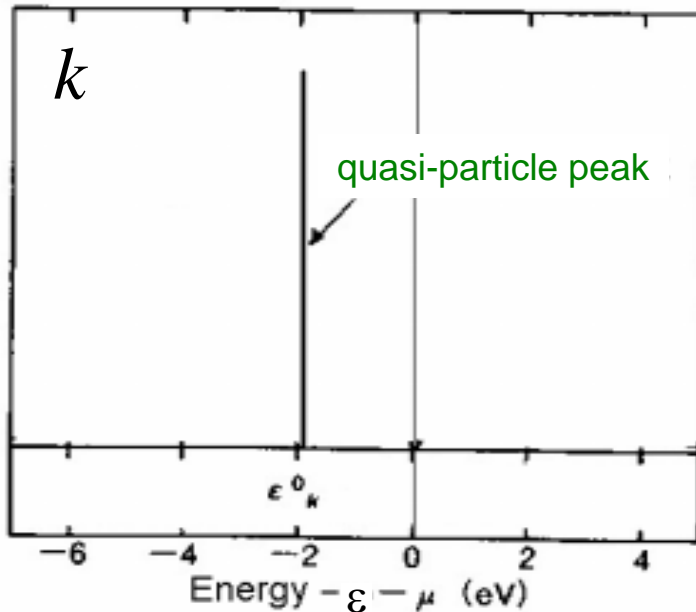
バンド電子に対する電子相関効果 - スペクトル関数 -

Band theory

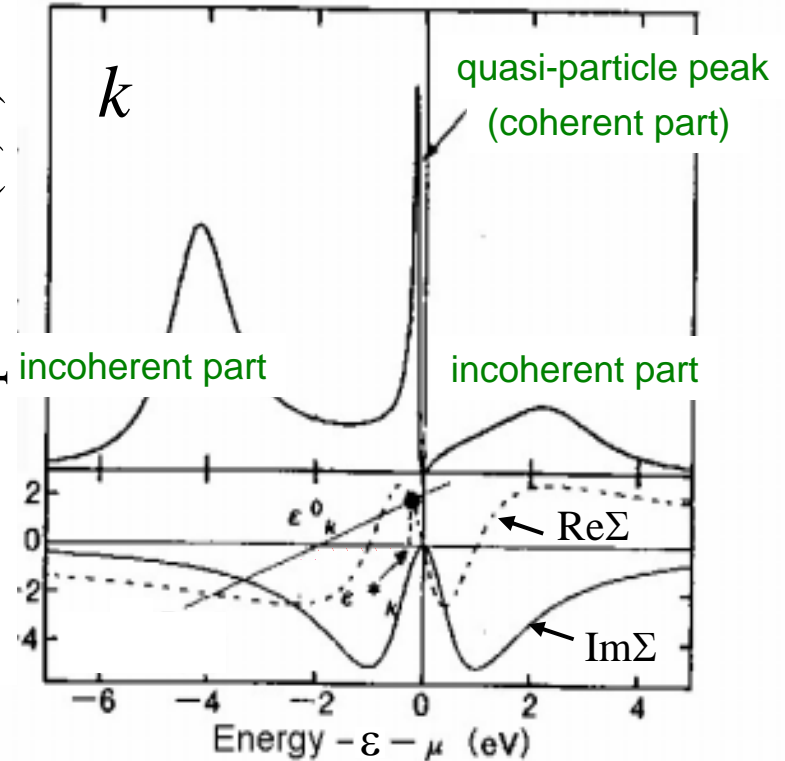


+ Electron correlation

ARPES spectra $A(\mathbf{k}, \omega)$



ARPES spectra $A(\mathbf{k}, \omega)$



Self energy: $\Sigma(\mathbf{k}, \varepsilon) = \text{Re } \Sigma(\mathbf{k}, \varepsilon) + \text{Im } \Sigma(\mathbf{k}, \varepsilon)$

$\text{Re}\Sigma(\mathbf{k}, \varepsilon) \rightarrow$ energy shift, $\partial \text{Re}\Sigma / \partial \varepsilon \sim m^*/m_b$

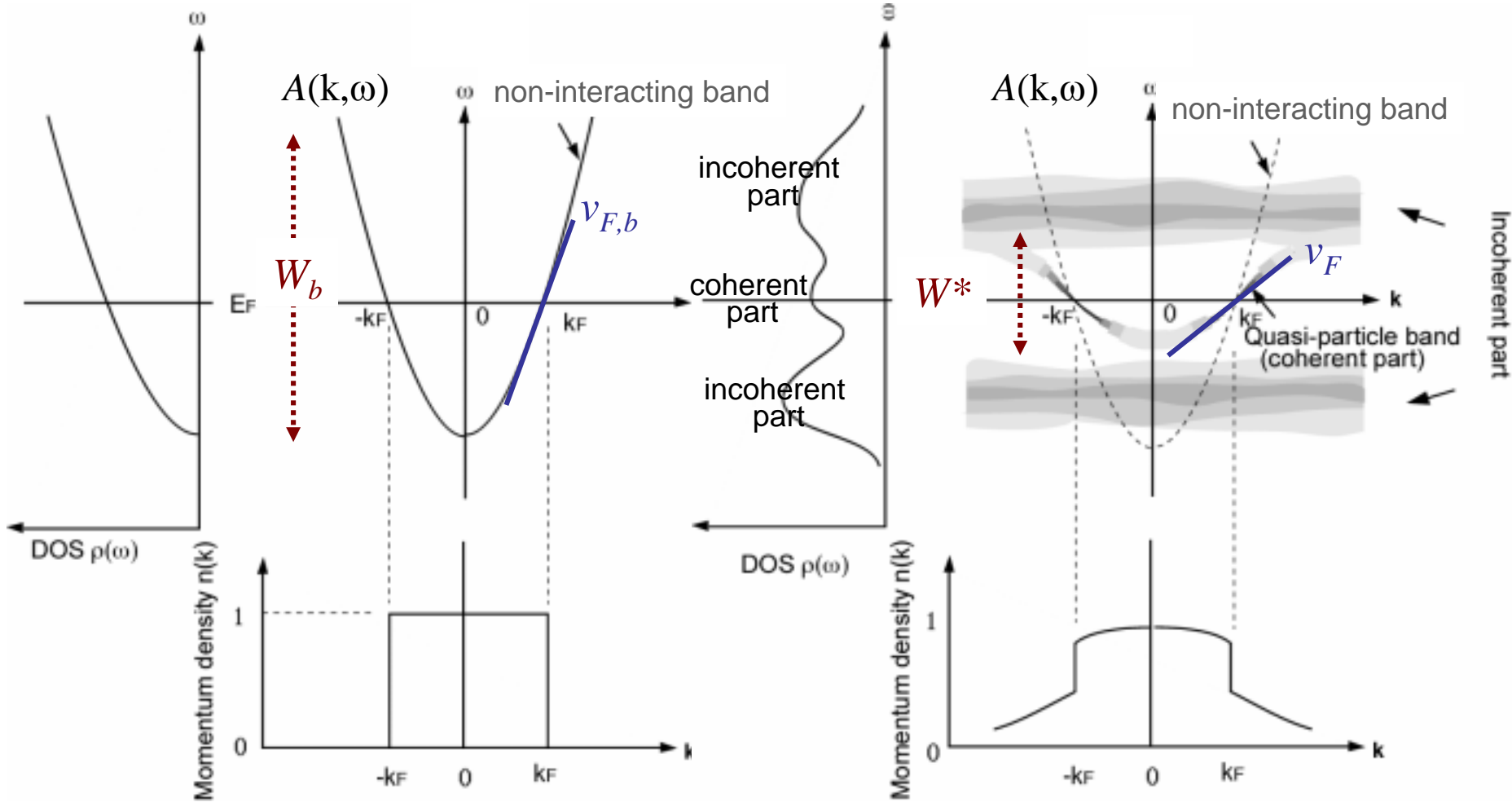
\updownarrow Kramers-Kronig relation

$-\text{Im}\Sigma(\mathbf{k}, \varepsilon) \rightarrow$ lifetime broadening

バンド電子に対する電子相関効果 - 運動量分布関数 -

without electron correlation

with electron correlation



$$m^*/m_b \sim W_b/W^* \sim v_{F,b}/v_F > 1: \text{mass renormalization}$$

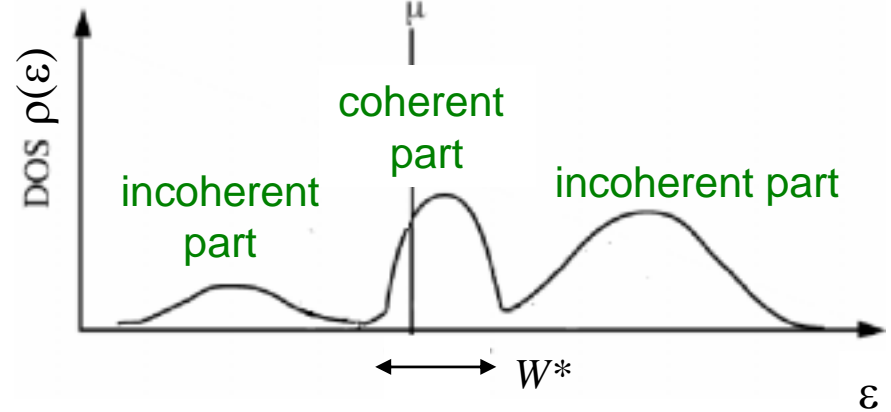
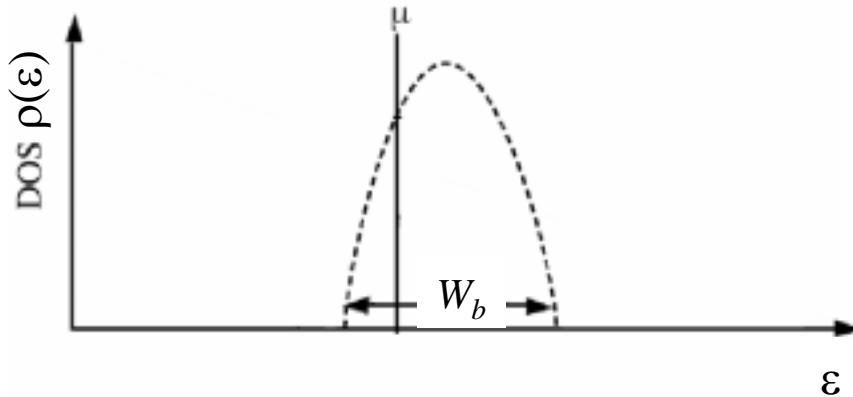
bandwidth Fermi velocity (m_b : band mass,)

バンド電子に対する電子相関効果

Band theory



+ Electron correlation



Heat capacity

$$C = \underbrace{\gamma T}_{\text{electron}} + \underbrace{\beta T^3}_{\text{phonon}}$$

Electronic specific heat coefficient γ

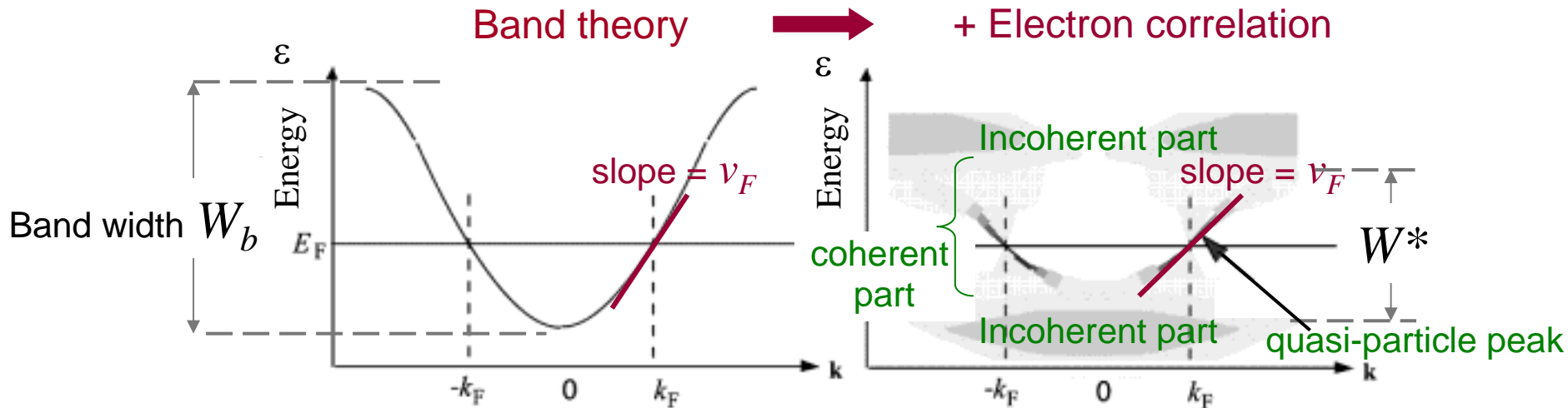
N^* : quasi-particle density
 m^* : effective mass

m_b



$$\gamma \propto N^*(\mu) \propto \frac{1}{W^*} \propto m^*$$

電子系の物理量 - 電子比熱



Heat capacity

$$C = \underbrace{\gamma T}_{\text{electron}} + \underbrace{\beta T^3}_{\text{phonon}}$$

Electronic specific heat coefficient γ

$$m_b \longrightarrow \gamma \propto N^*(\mu) \propto \int \frac{1}{v_F} dS = \left\langle \frac{1}{v_F} \right\rangle_{\text{FS}} \propto \frac{1}{W^*} \propto m^*$$

$\langle \dots \rangle_{\text{FS}}$: average over Fermi surface

k_F : Fermi momentum

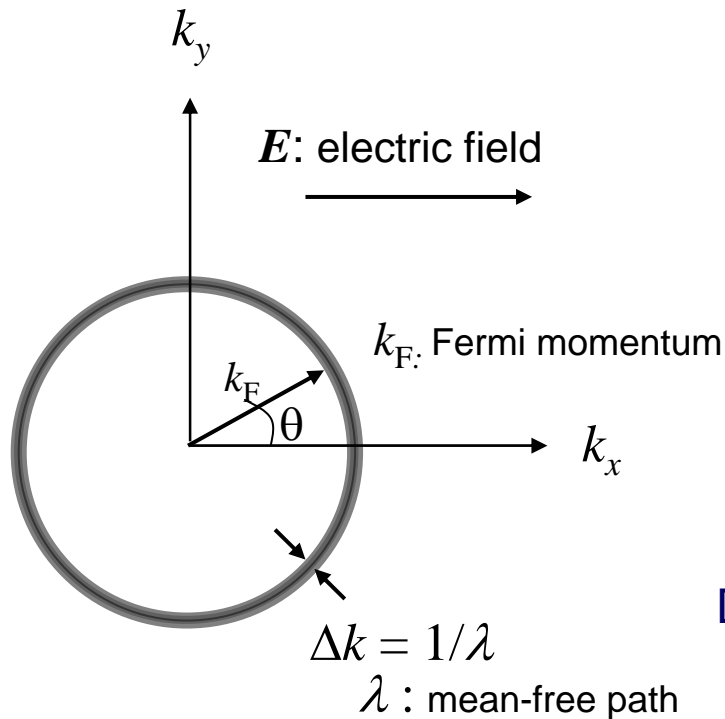
$v_F = \hbar k_F / m^*$: Fermi velocity

N^* : quasi-particle density

m^* : effective mass

電子系の物理量 - 電気伝導度

Fermi surface



Boltzmann formula for electrical conductivity

$$\begin{aligned}\sigma &\propto e^2 \int_{\text{FS}} \tau v_x \cos \theta dS \\ &= ne^2 \langle 2 \cos^2 \theta / k_F \Delta k \rangle_{\text{FS}}\end{aligned}$$

$\langle \dots \rangle_{\text{FS}}$: average over Fermi surface

n : carrier density

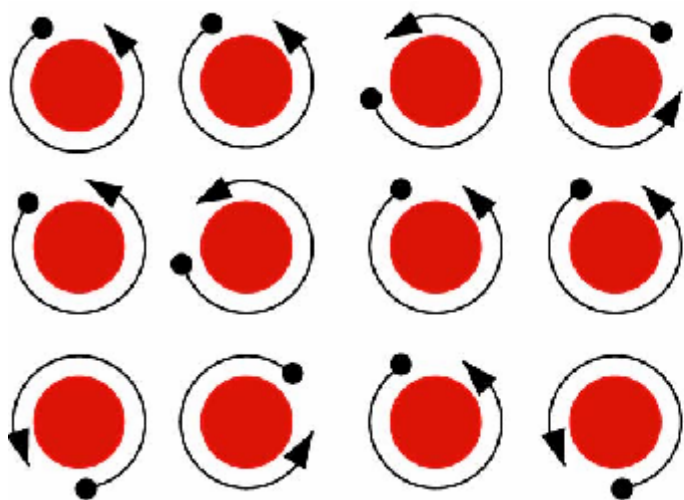
τ : scattering time

Drude formula for electrical conductivity

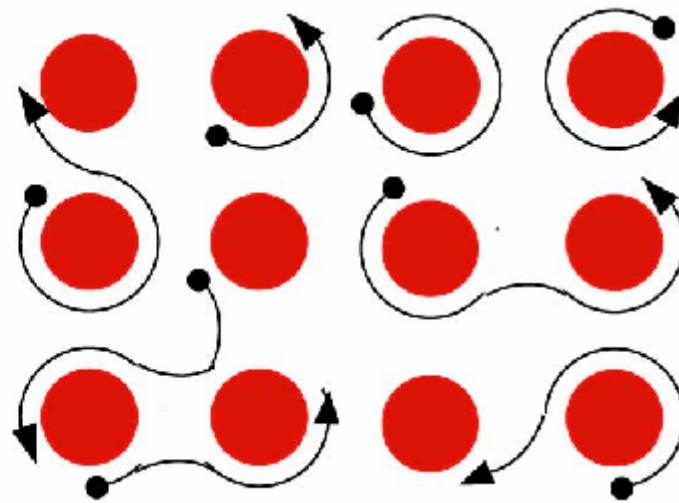
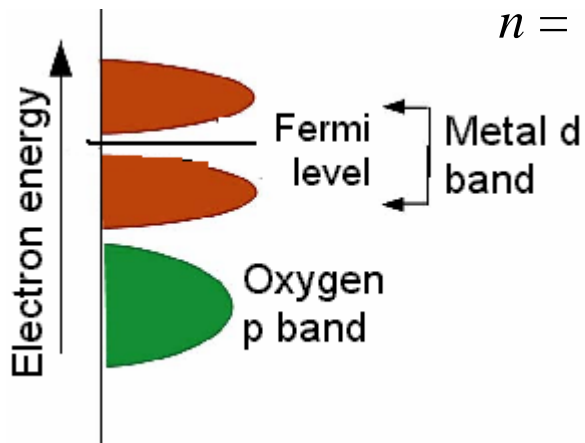
$$\sigma = \frac{ne^2\tau}{m^*} = \frac{e^2 k_F}{\hbar \Delta k}$$

m^* : effective mass

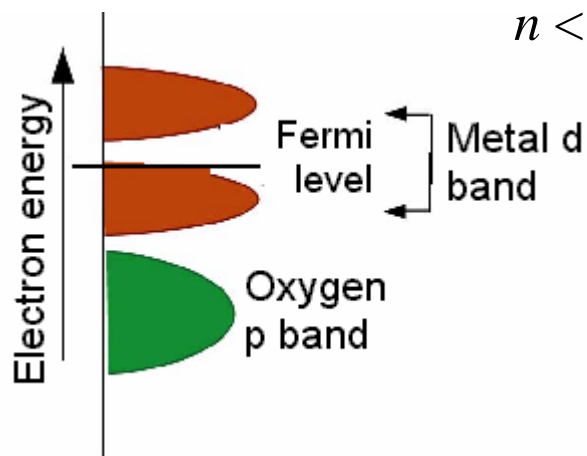
キャリア注入(フィリング制御)による 金属-絶縁体転移



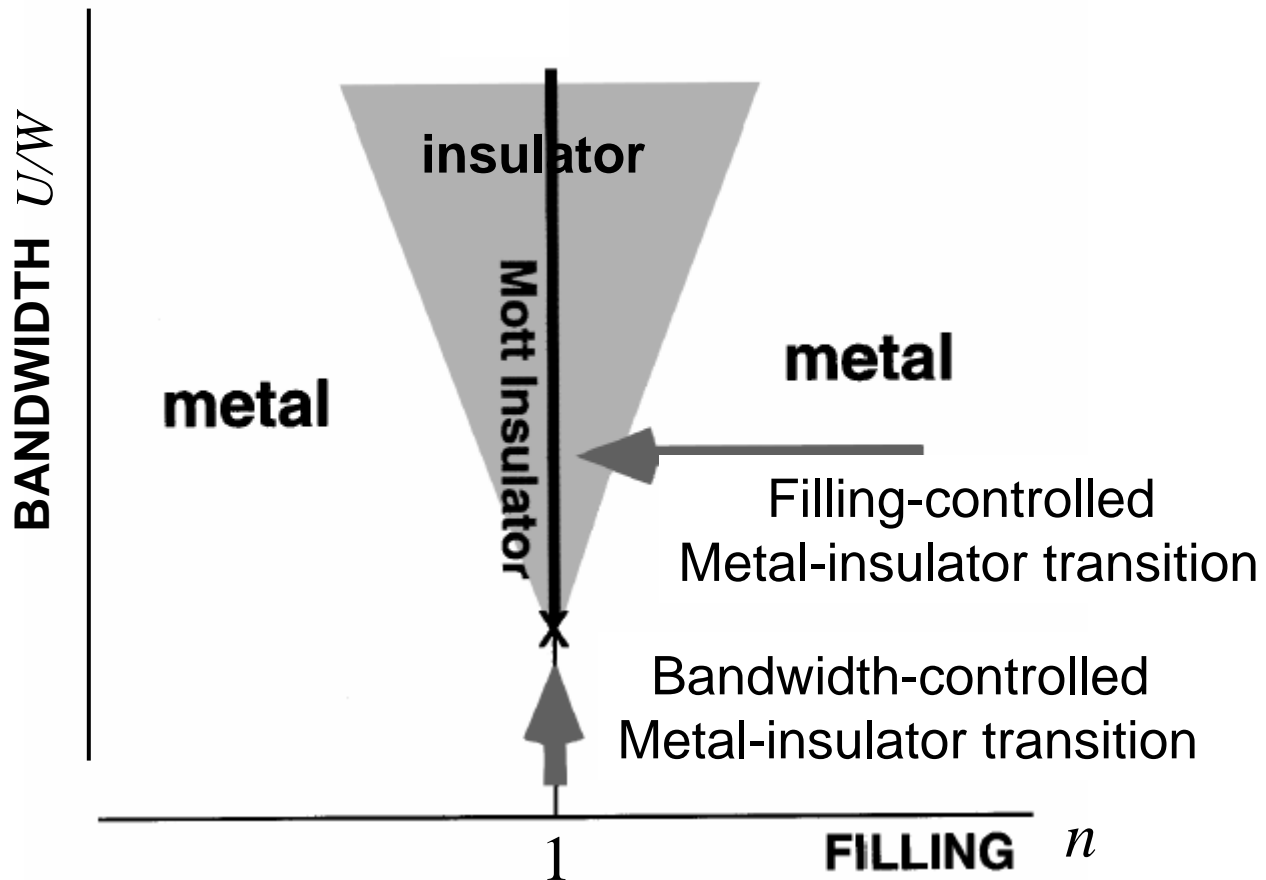
$n = 1$



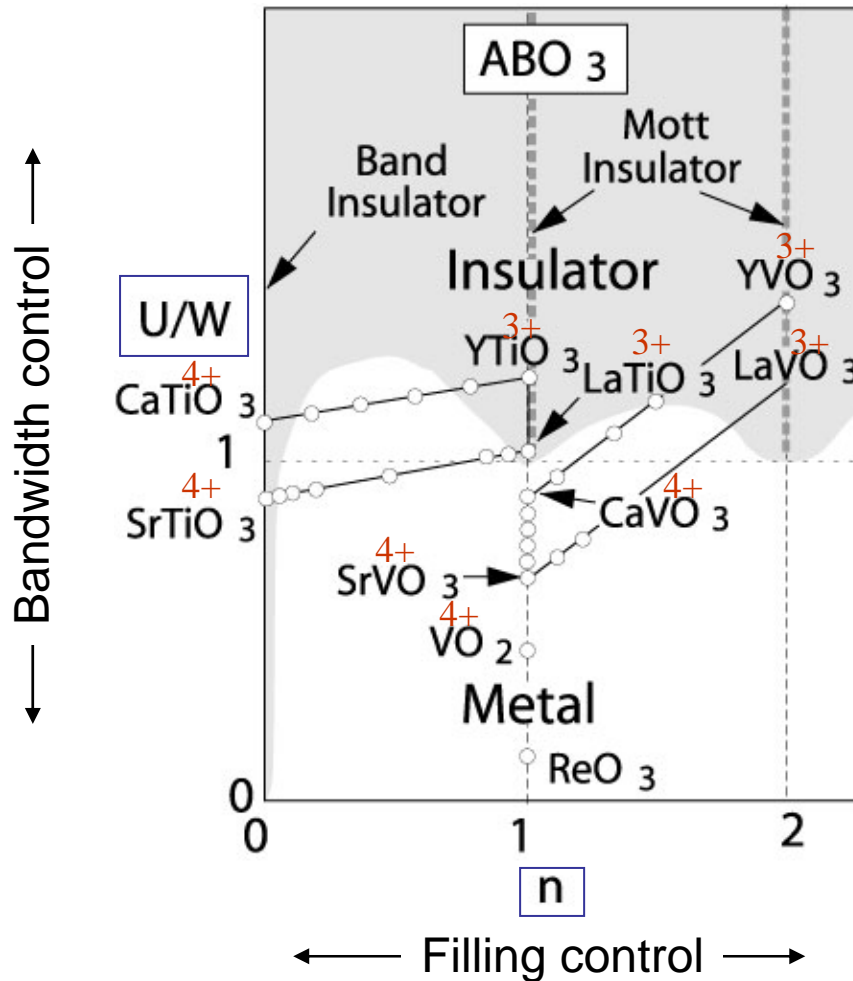
$n < 1$



バンド幅制御 vs フィリング制御金属-絶縁体転移



バンド幅制御 vs フィリング制御 金属-絶縁体転移



Ti³⁺ (d¹)
Ti⁴⁺ (d⁰)
V⁴⁺ (d¹)
V³⁺ (d²)