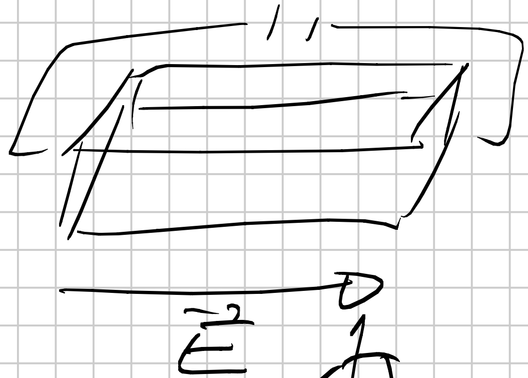
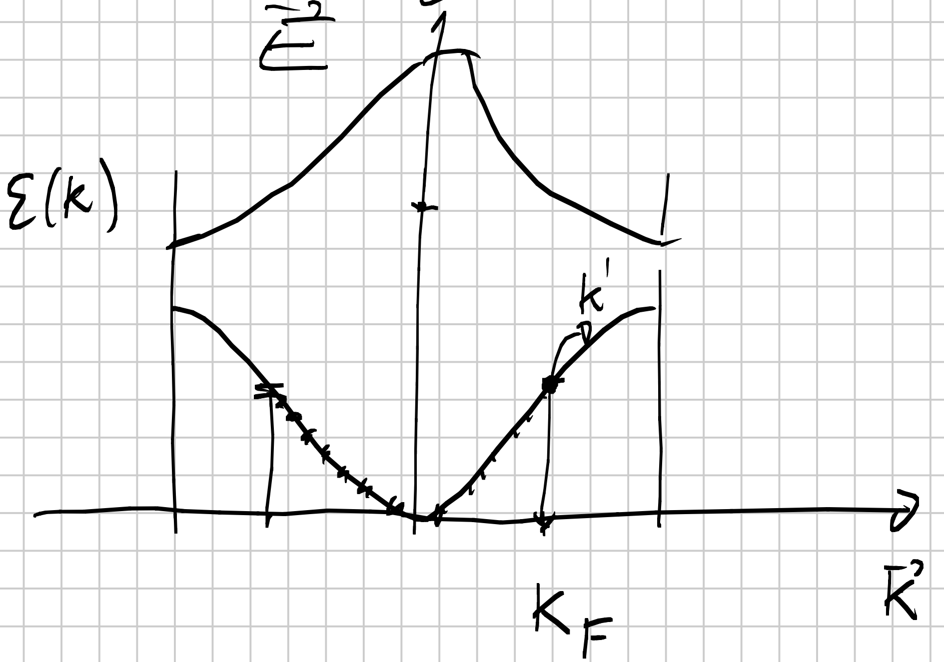
LECTURE # 24

Note Title 12/1/2008

TRANSPORT PROPERTIES



→ MEASURE A CURRENT



FORCE ON ONE ELECTRON:

$$\vec{F} = -e\vec{E}$$

CRYSTAL MOMENTUM WILL CHANGE

$$\hbar \vec{K}_F \sim \vec{P}_F$$

$$\frac{\Delta \vec{P}}{\Delta t} = -e\vec{E}$$

PHONONS → ELECTRON - LATTICE SCATTERING.

ELECTRON ACCELERATION OCCURS ONLY BETWEEN TWO ELECTRON - PHONON SCATTERING EVENTS

$$\Delta \vec{P}_{AVERAGE} = \vec{F} \cdot \tau \qquad \Delta P_{AVER} = \langle \Delta p \rangle$$

τ = RELAXATION TIME = AVERAGE DELAY BETWEEN TWO ELECTRON - PHONON SCATTERING EVENTS

$$\langle V_i \rangle = 0 \qquad \vec{E} = E\hat{x}$$

$$m\langle V_f - V_i \rangle = m\langle V_f \rangle = -eE \cdot \tau$$

CURRENT DENSITY

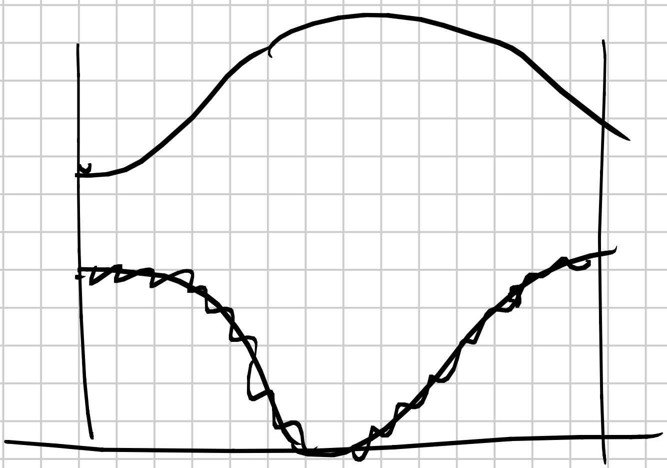
$$\vec{J} = -en\langle \vec{V}_f \rangle = \frac{ne^2\tau}{m} \vec{E}$$

$$\vec{J} = \sigma \vec{E}$$

σ CONDUCTIVITY

$$\sigma = \frac{n e^2 \tau}{m}$$ (DRUDE CONDUCTIVITY)

$$\frac{1}{\sigma} = \rho$$ → RESISTIVITY (OHM - CM)



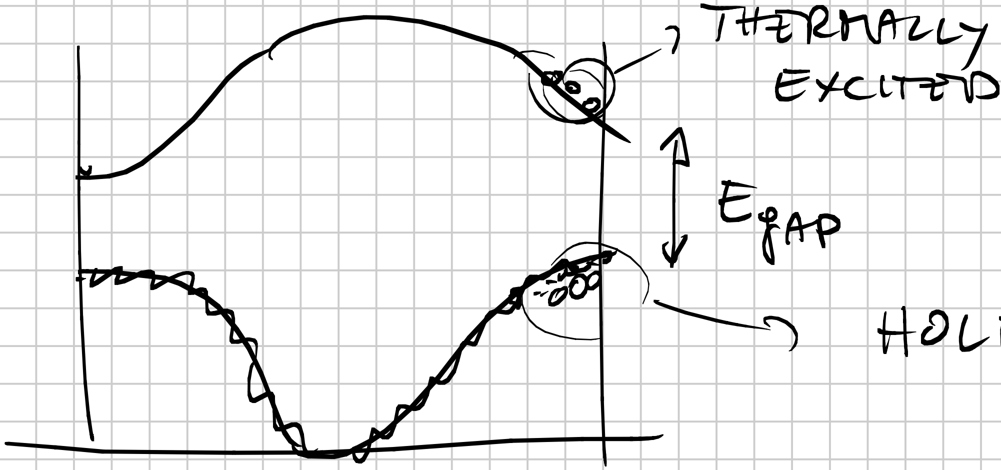
BAND COMPLETELY FILLED

AT $T = 0$

NO $\Delta \vec{p}$ POSSIBLE

$\Rightarrow$ $\vec{J} = 0$ (INSULATOR CASE)

AT FINITE TEMPERATURE



$K_B T \sim E_{gap}$

SEMICONDUCTOR

① METALS

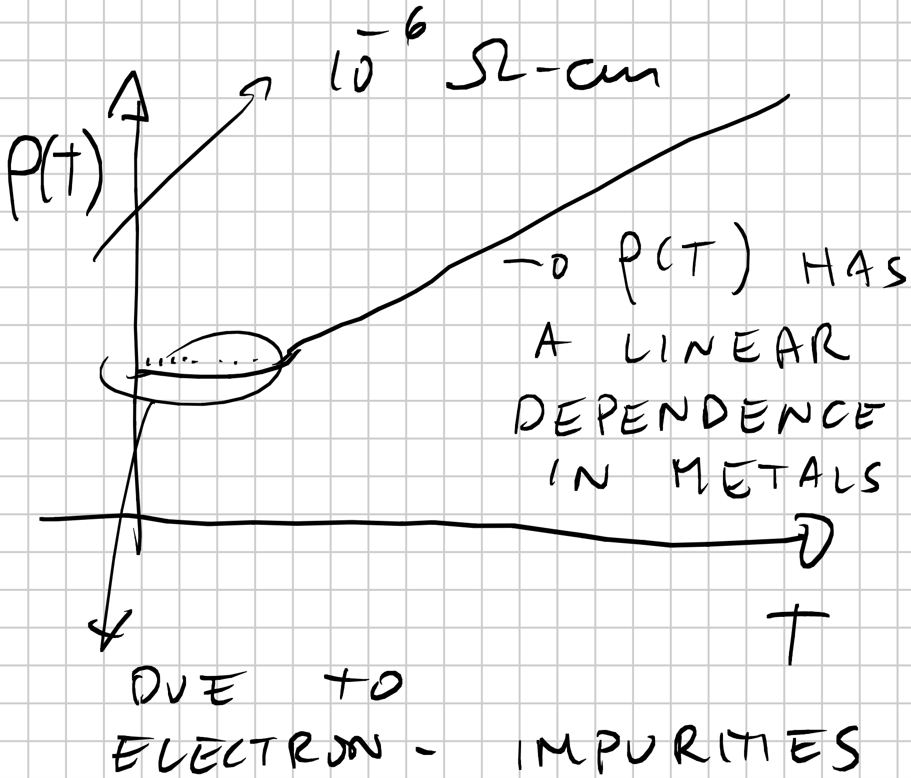
FERMI SURFACE

PARTIALLY FILLED BAND

$$\rho = \frac{1}{\sigma} \sim 10^{-6} \ \Omega\text{-cm}$$

HOW DOES ρ DEPEND ON TEMPERATURE?

$$\rho \sim \frac{m}{n e^2} \cdot \frac{1}{\tau}$$



$\frac{1}{\tau} \propto$ PROBABILITY OF SCATTERING WITH PHONONS

$\frac{1}{\tau}$ PROPORTIONAL TO DENSITY OF PHONONS

DENSITY OF PHONONS $\propto T$ (IN 3D)

② SEMICONDUCTOR CASE

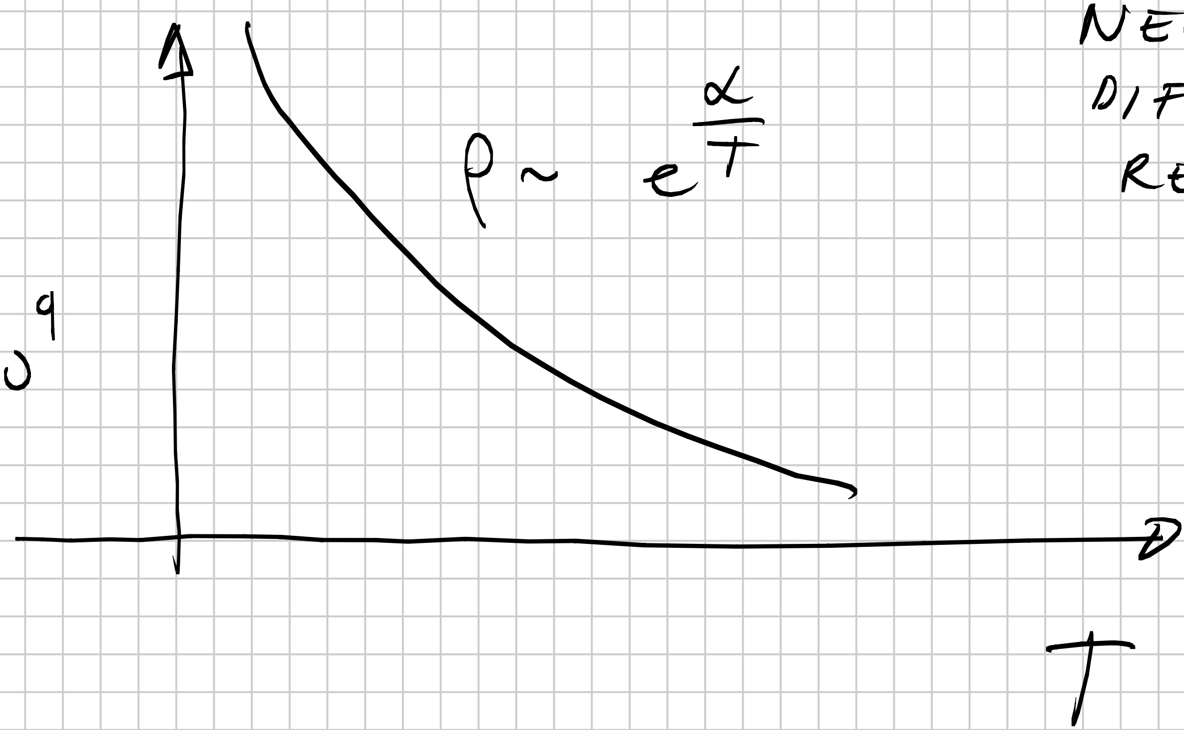
$$\sigma \sim \frac{n(T)\, e^2 \tau}{m} \sim \frac{n_0\, e^{-\frac{E_g}{2k_BT}}\, e^2\, \tau(T)}{m}$$

$$\rho = \frac{1}{\sigma}$$

$\rho(T)$

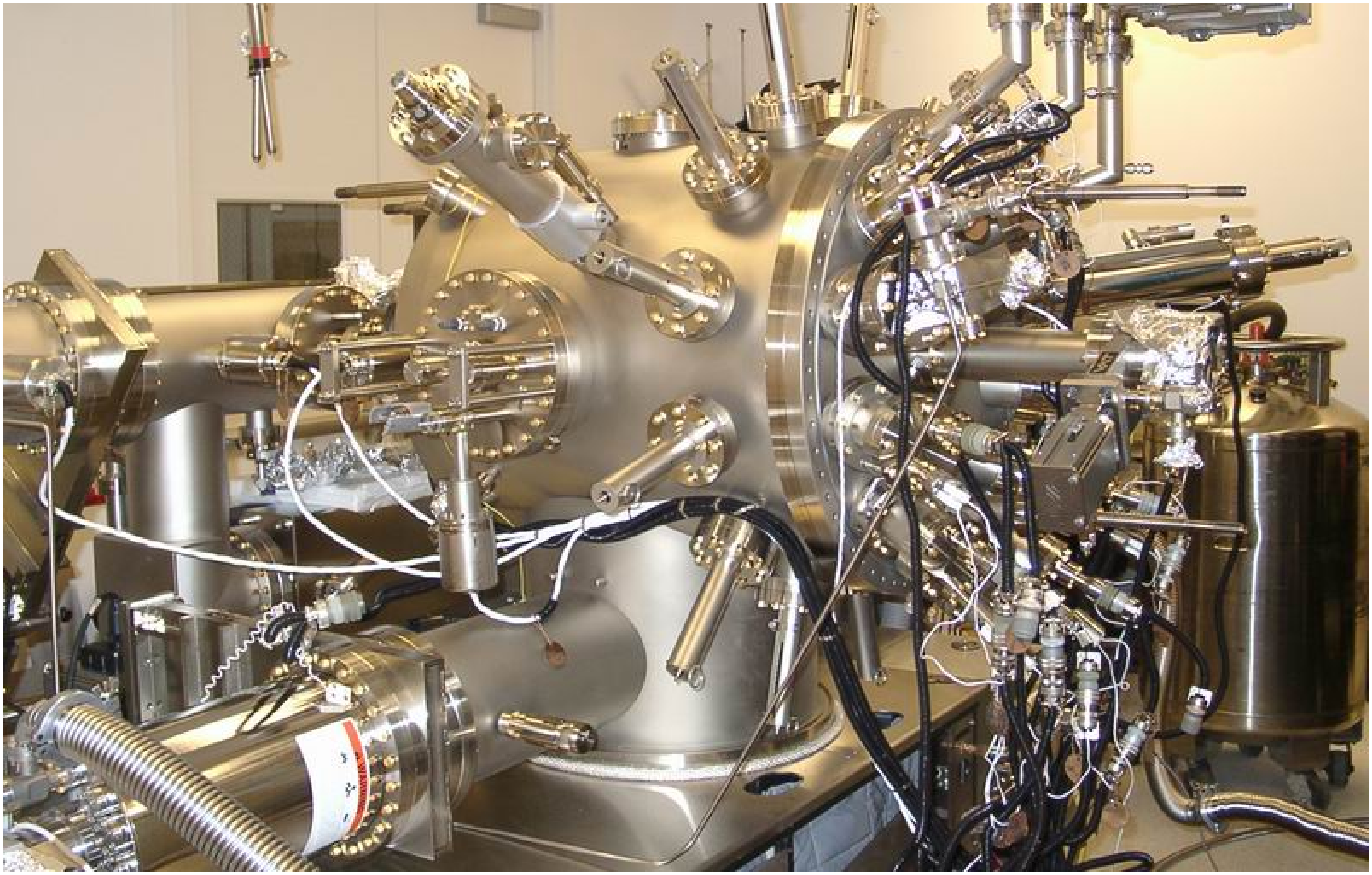
$10^{-3} \sim 10^{9}$

Ω-cm

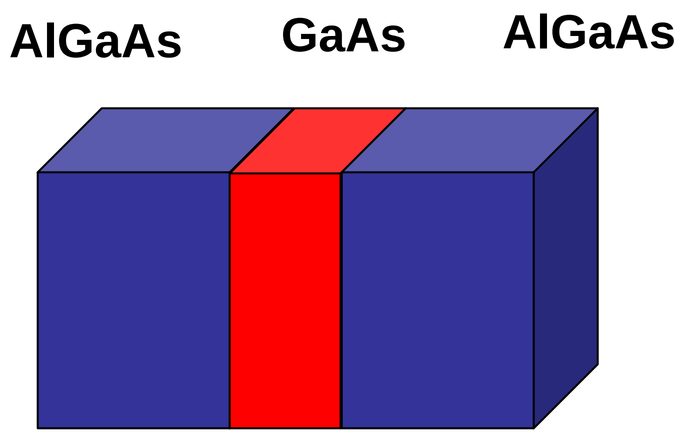


NEGATIVE DIFFERENTIAL RESISTIVITY

MOLECULAR BEAM EPITAXY

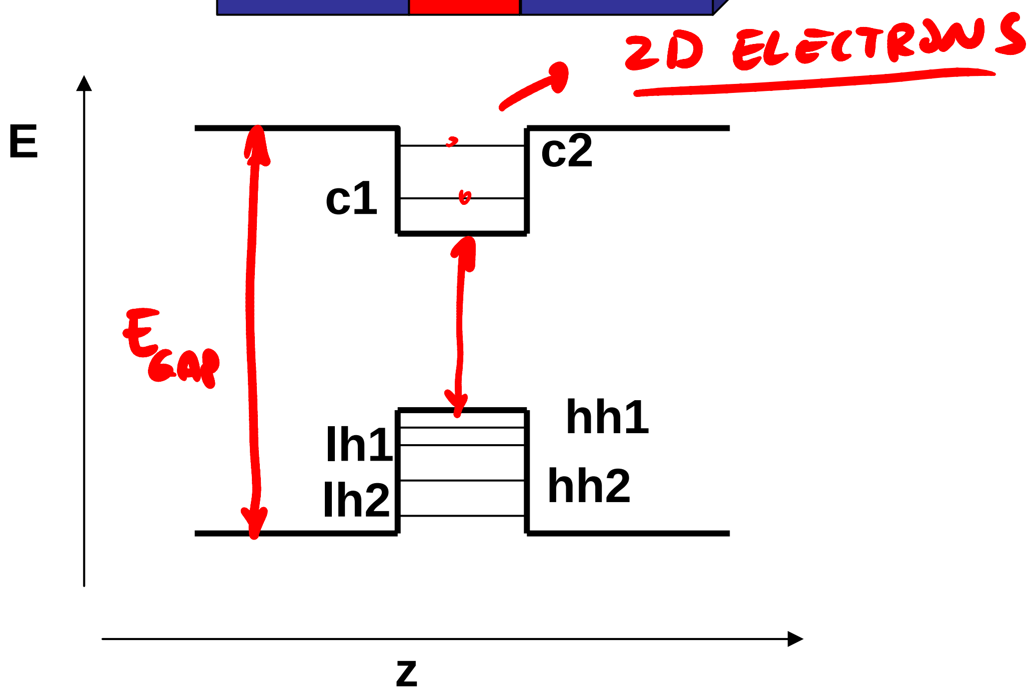


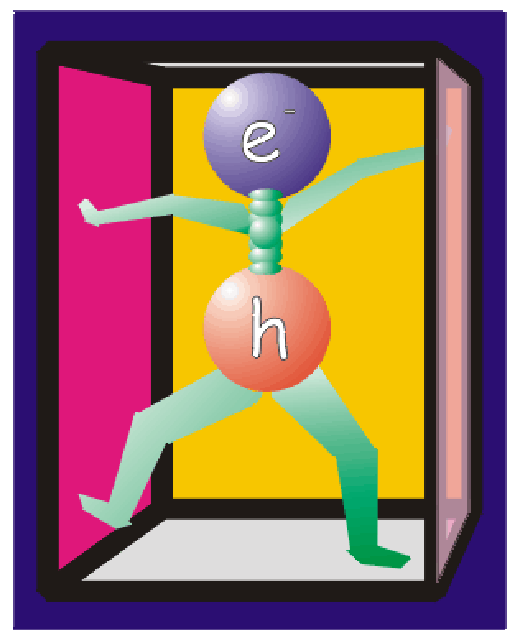
Excitons confined in a quantum well

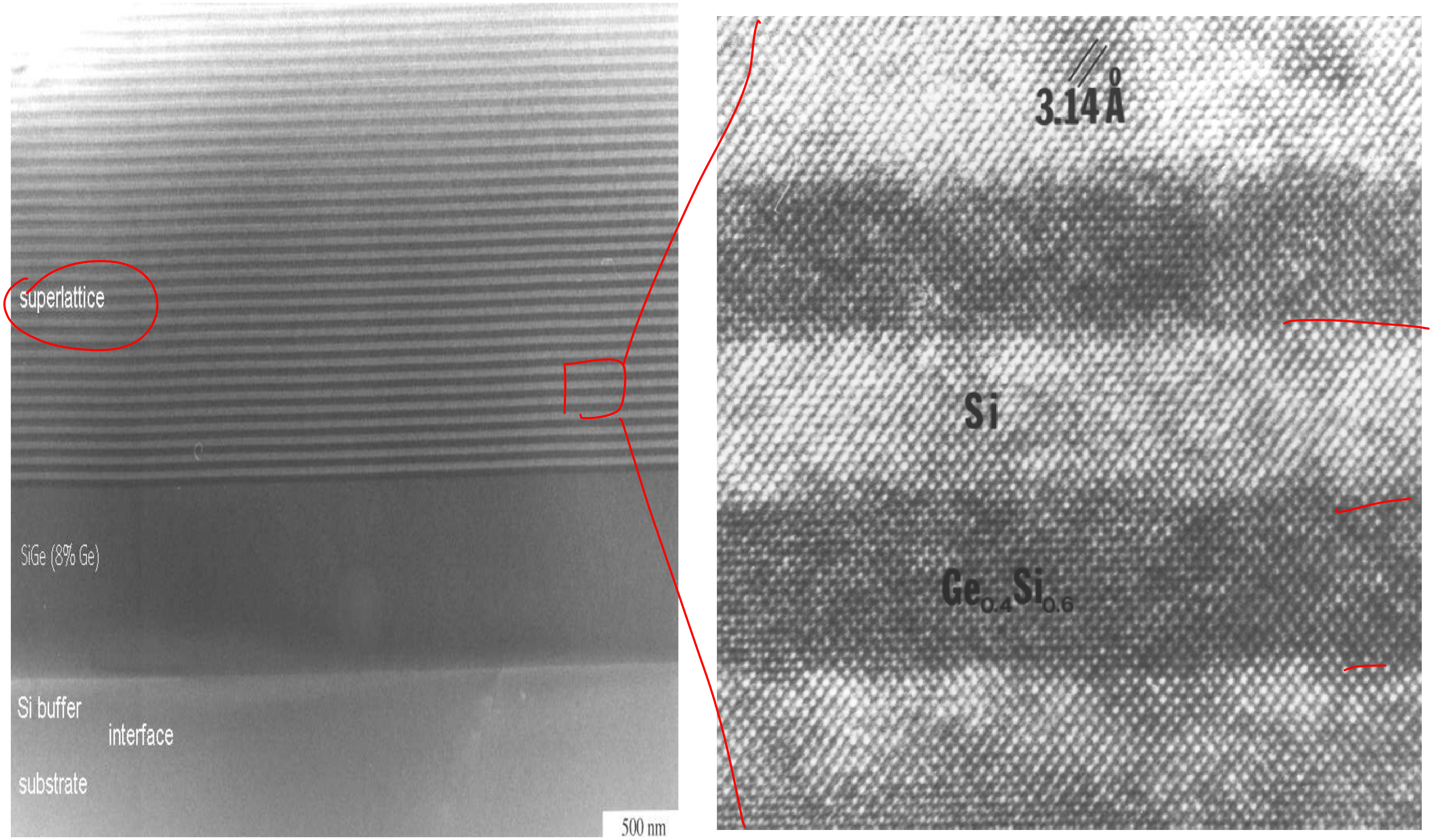


Growth direction [001]

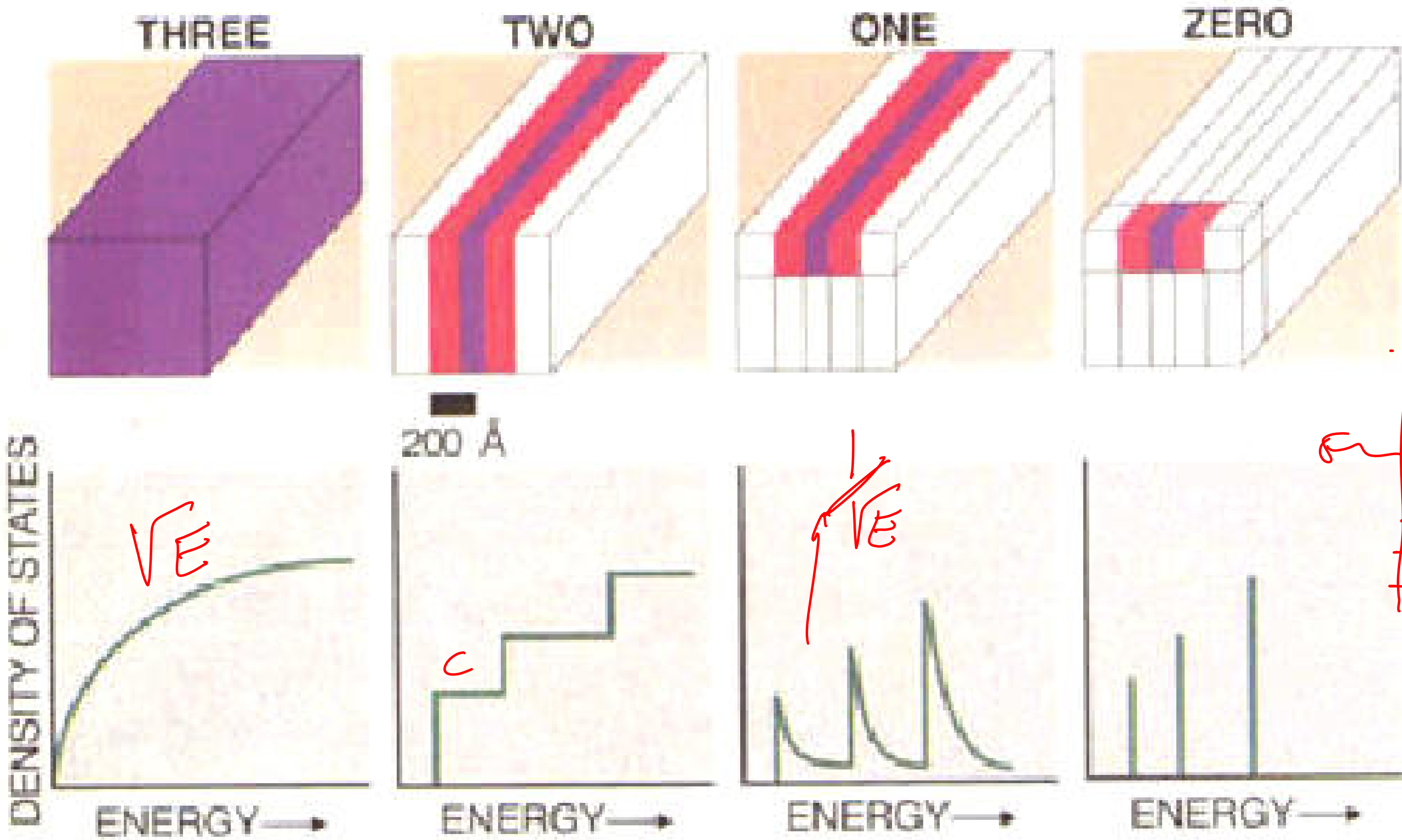
Propagation allowed only in the in-plane direction

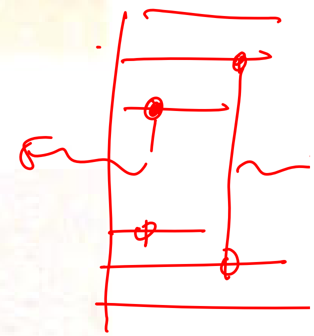





superlattice
SiGe (8% Ge)
Si buffer
interface
substrate
500 nm
3.14 Å
Si
Ge0.4Si0.6

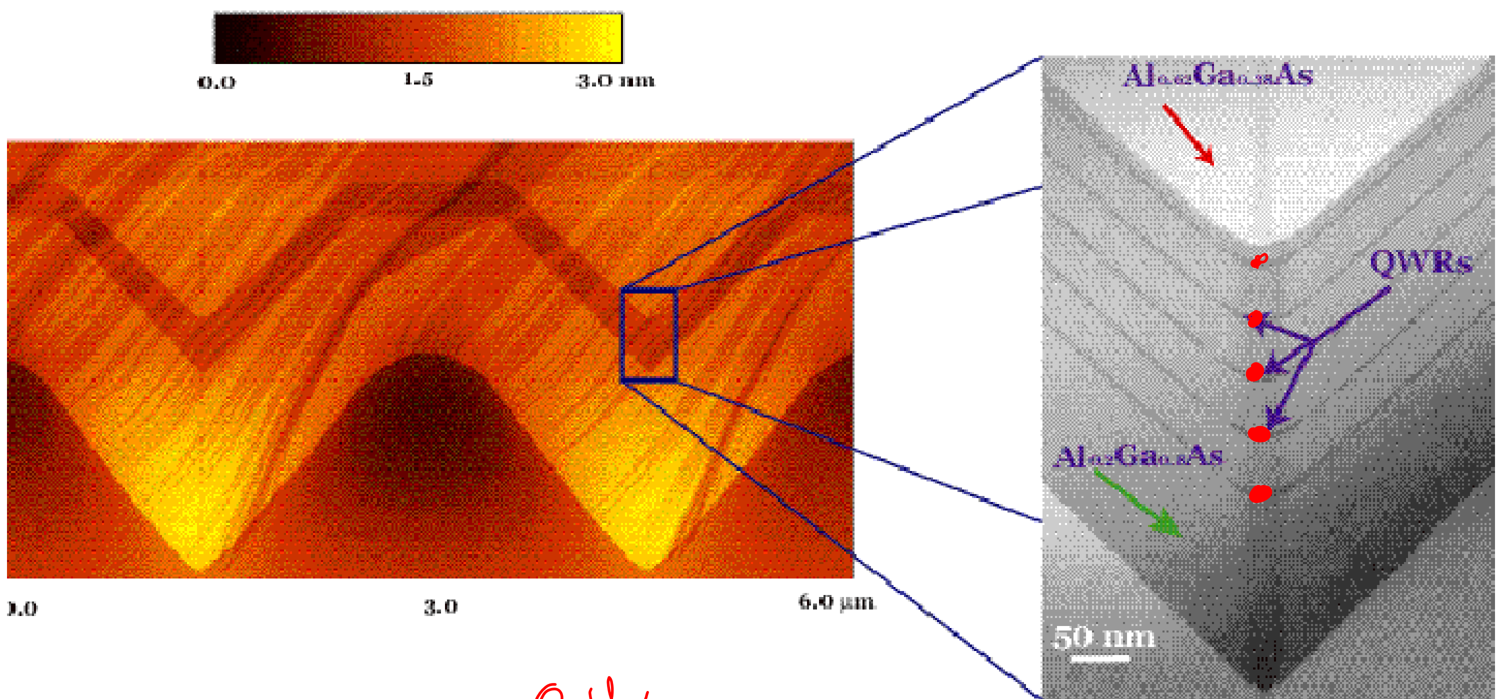
BULK | QW | Q WIRE | Q DOT

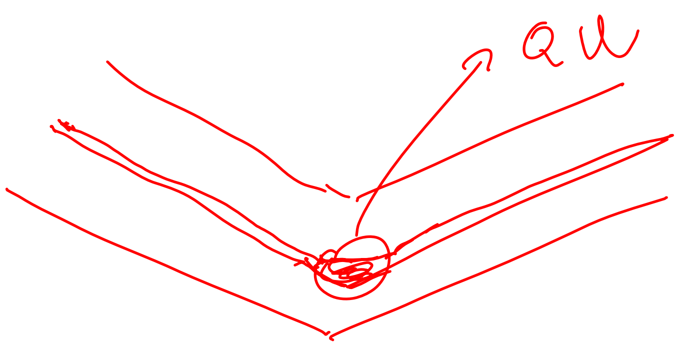


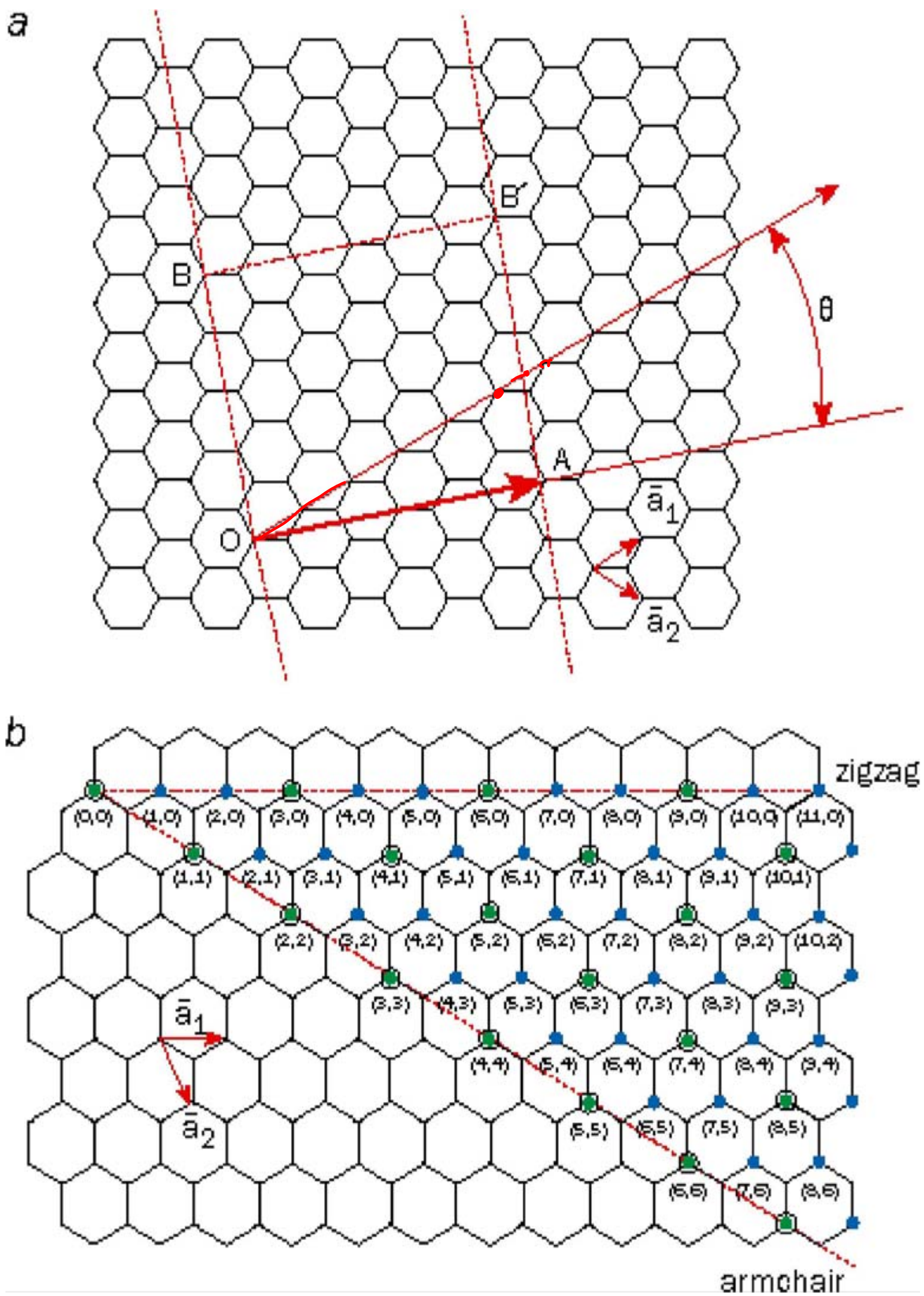


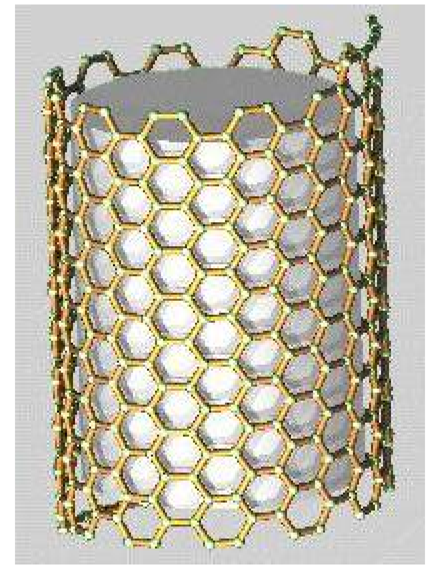
$$g(E) = \int \frac{d^3k}{(2\pi)^3}\, \delta\left(E - \frac{\hbar^2 k^2}{2m}\right) \qquad g(E) = c \qquad g(E) = \sum \delta(E - E_n)$$

V-GROOVED QWIRES







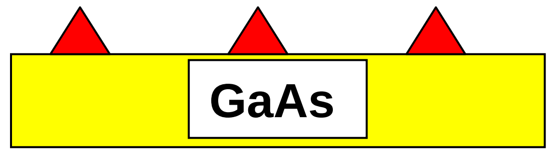


GRAPHITE

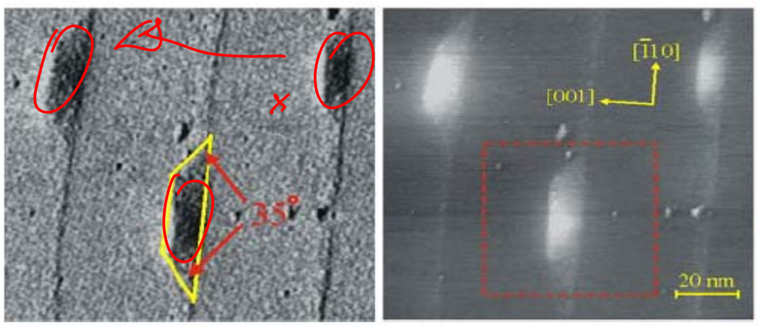
GRAPHENE
SINGLE 2D PLANE

MOLECULAR
ELECTRONICS

Quantum Dots are artificial atoms made of semiconductor materials



Self-assembled quantum dots

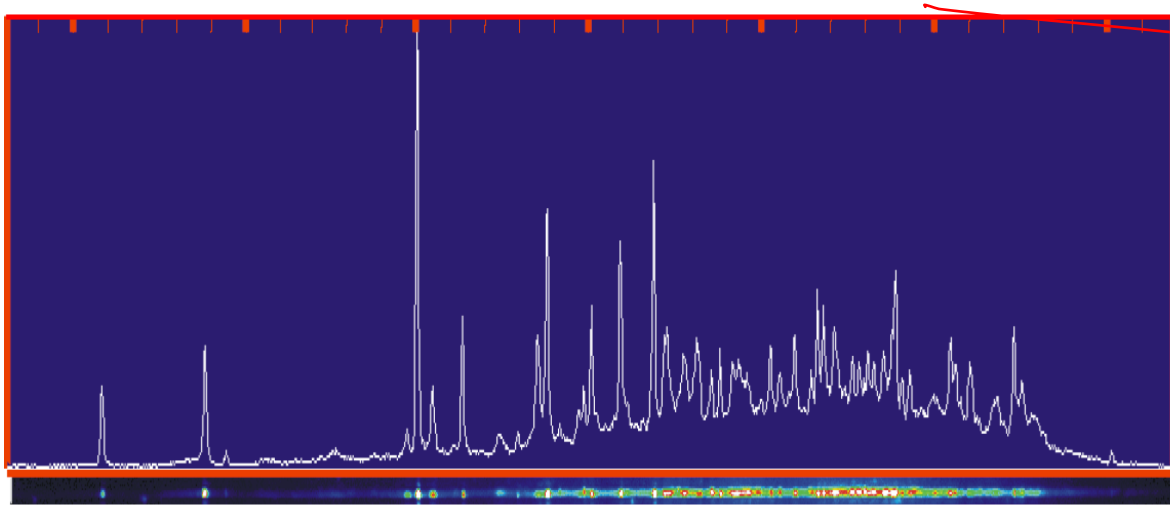


1 nm=0.000000001 m

Atom

Quantum Dot

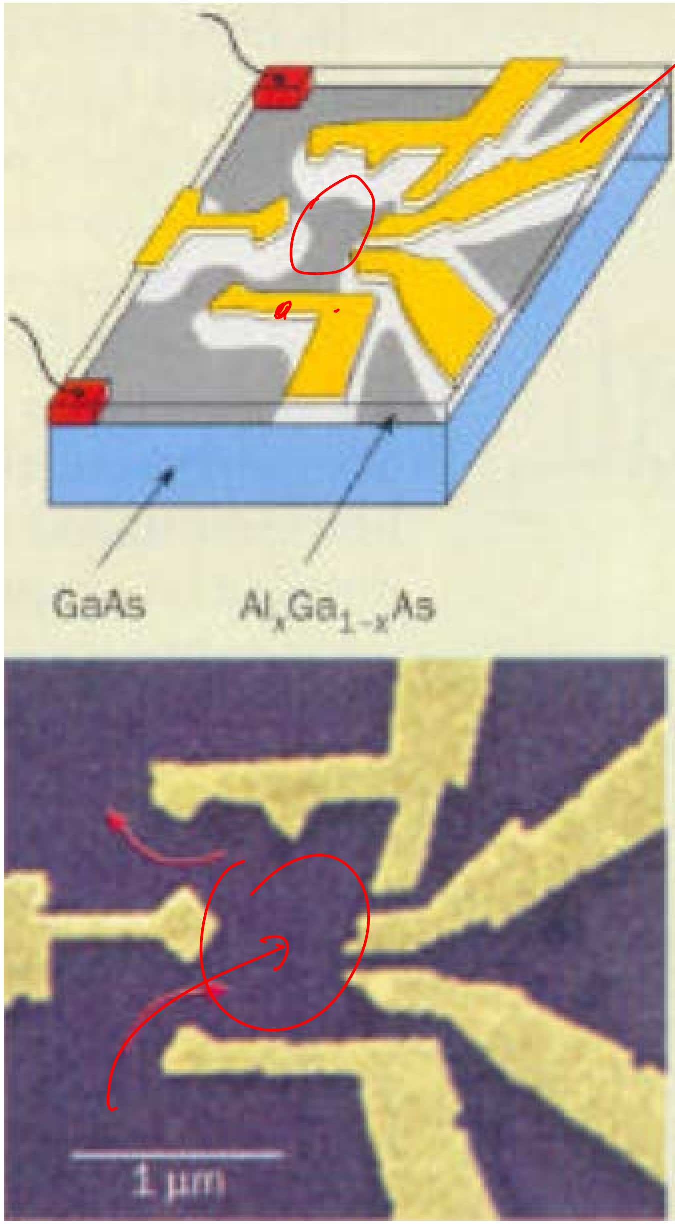
1 inch

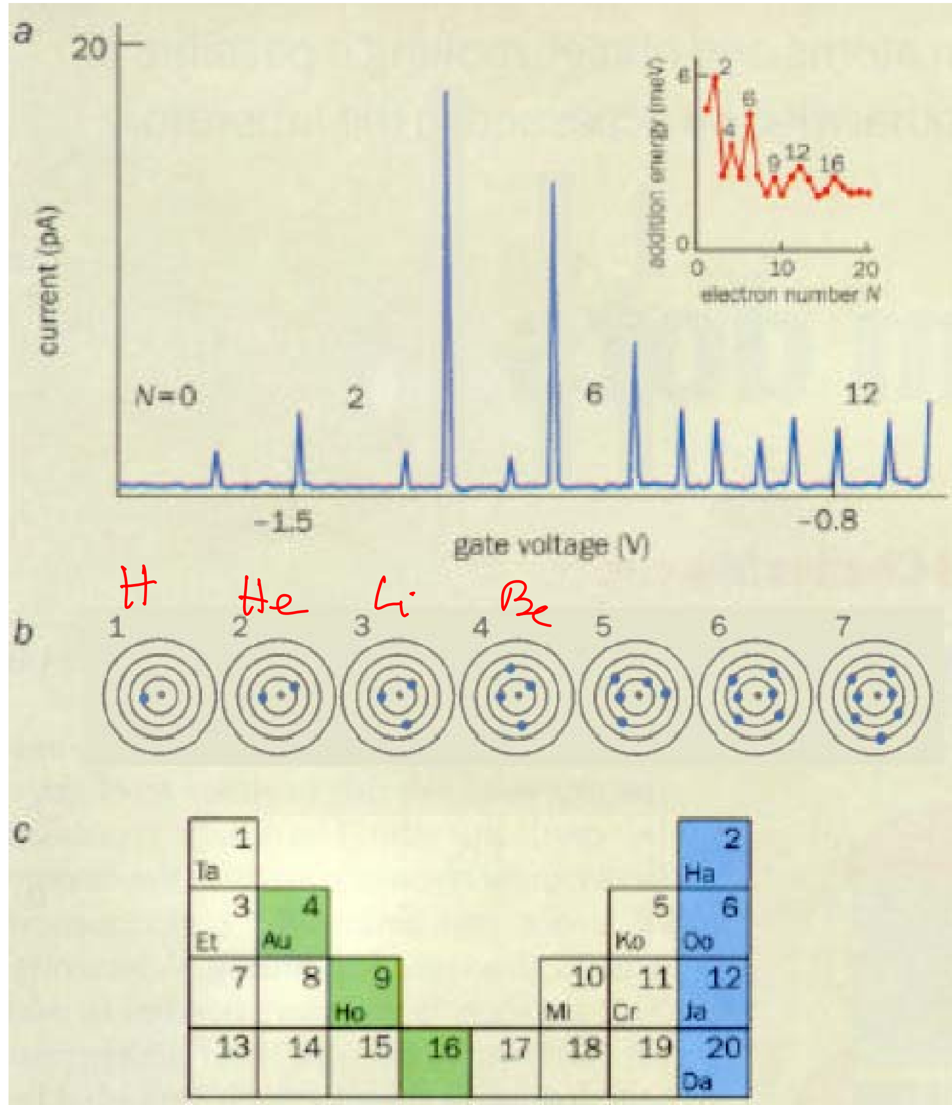


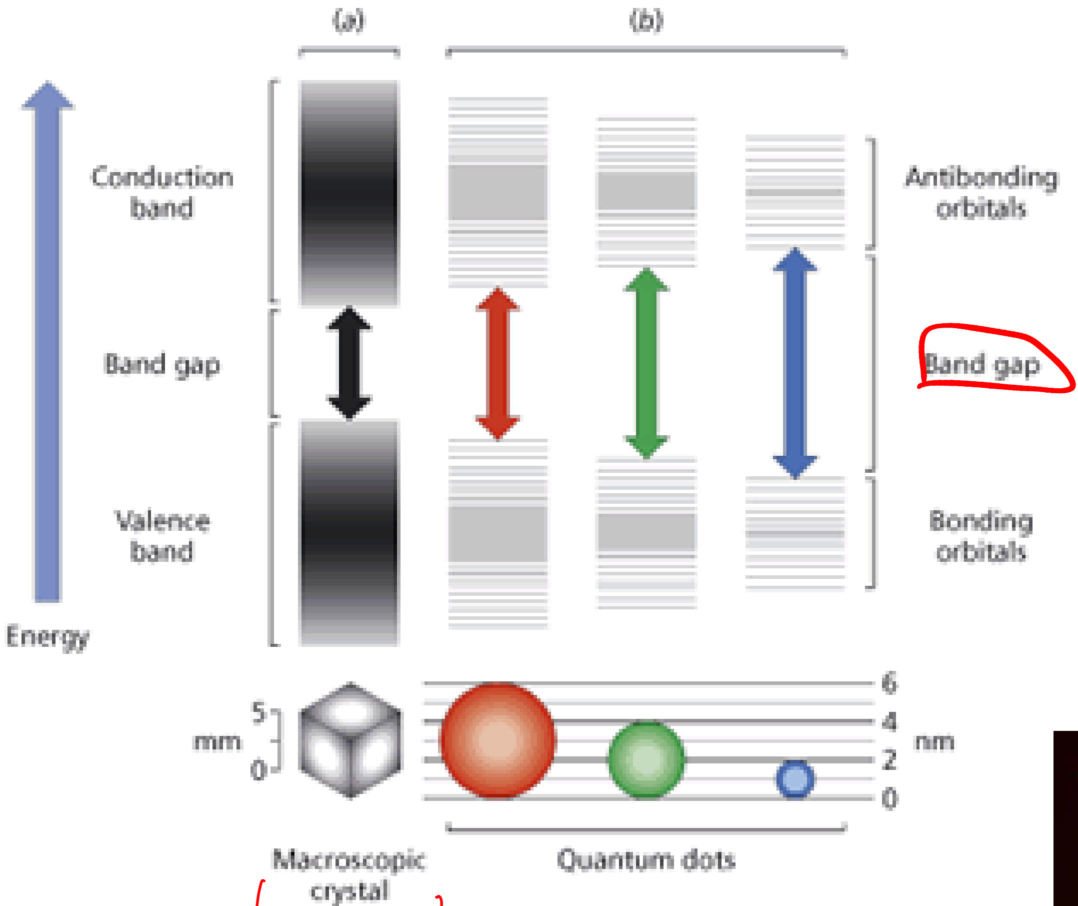
Emission spectrum like in atoms

Dr. Shih Lab, Phys. Dept. UT

METAL GATES


GaAs
$Al_xGa_{1-x}As$
1 µm


a
20
current (pA)
N=0
2
6
12
-1.5
-0.8
gate voltage (V)
addition energy (meV)
electron number N
b
1 2 3 4 5 6 7
H He Li Be
c
1 Ta
2 Ha
3 Et
4 Au
5 Ko
6 Do
7 8
9 Ho
10 Mi
11 Cr
12 Ja
13 14 15 16 17 18 19
20 Da


(a)
(b)
Conduction band
Band gap
Valence band
Energy
Antibonding orbitals
Band gap
Bonding orbitals
mm
5
0
6
4
2
0
nm
Macroscopic crystal
Quantum dots

II - VI