Semiconductor Materials

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材料工学科 Department of Materials Science

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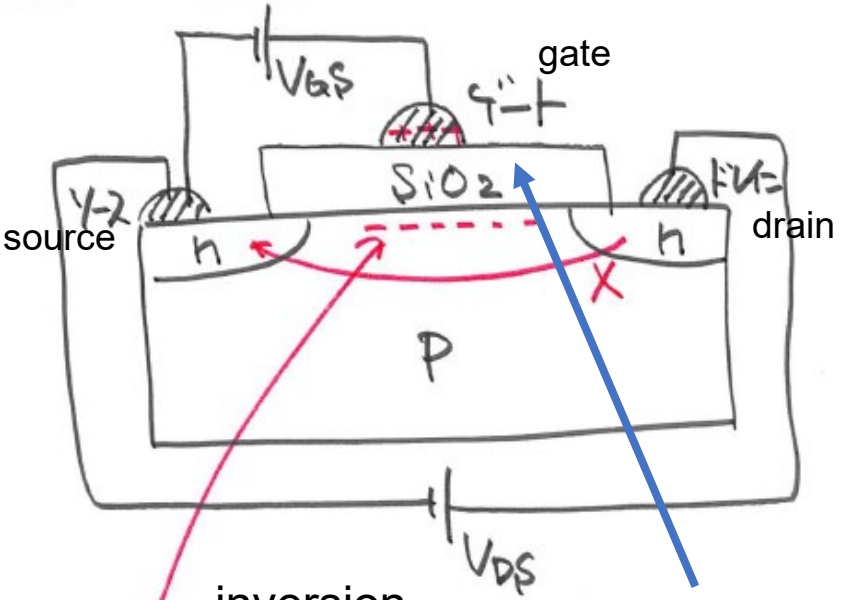
電界効果トランジスタ.

MOS FET.

Metal Oxide Semiconductor Field Effect Transistor.



増幅 amplification

スイッチ. switch

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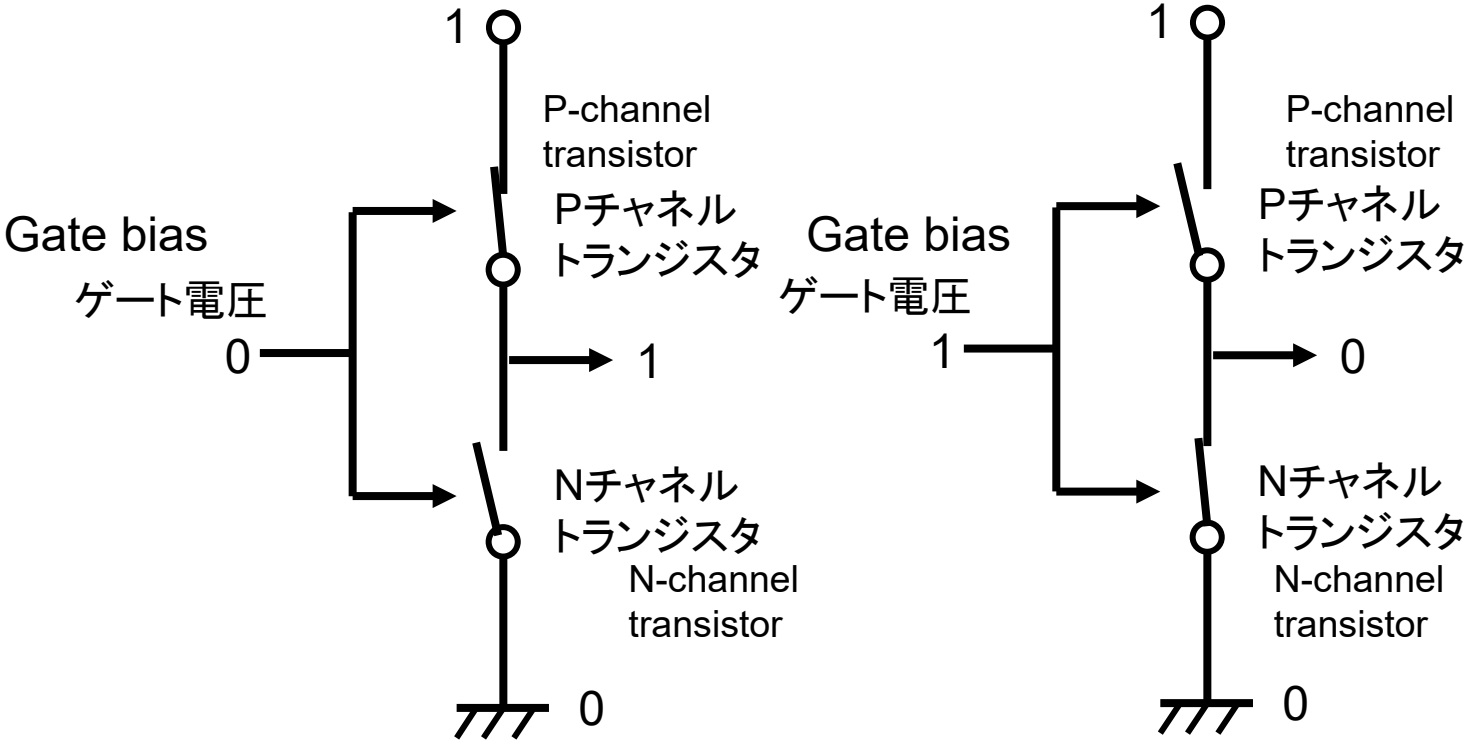
Logic circuit

- 論理回路(CPU)
- メモリ Memory device
- ディスプレイ. Display device

N-channel transistor

NOT 回路
NOT circuit (inverter)



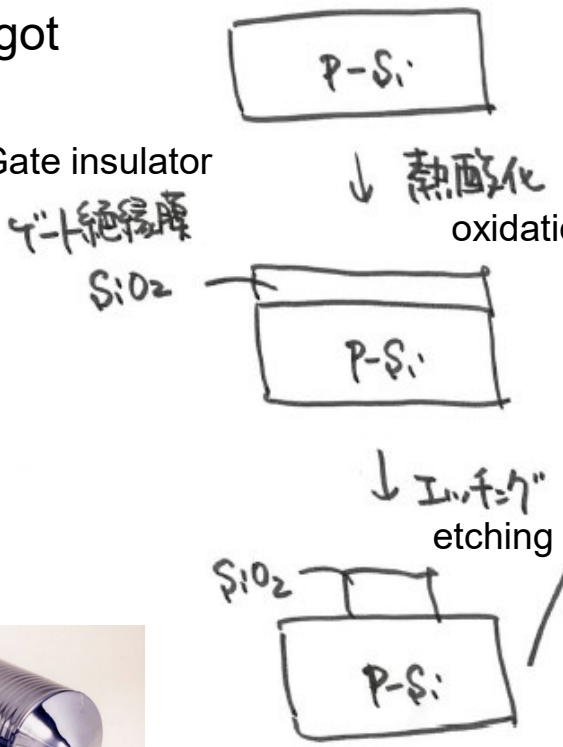
AND, OR circuits

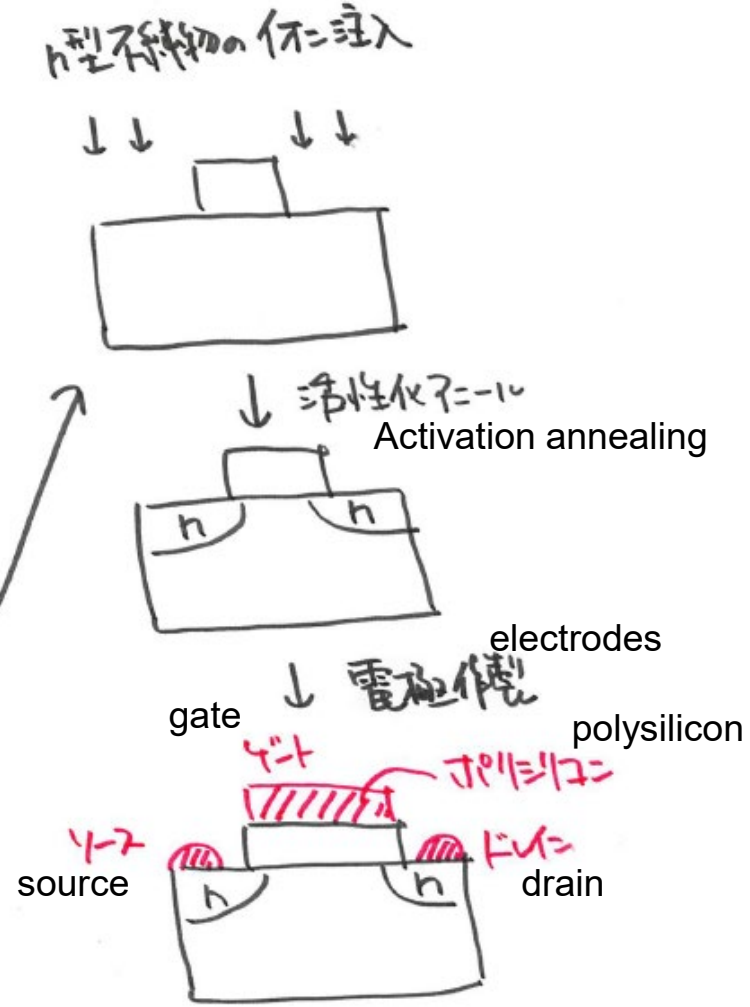
AND, OR回路も作製可能 → 論理回路、メモリ

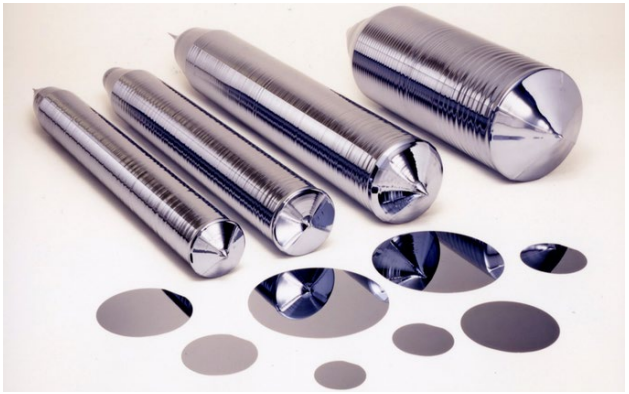
Logic circuit, memory device

Fabrication of MOSFET on a Si wafer

トランジスタの作製プロセス







日本経済新聞 2021/3/22

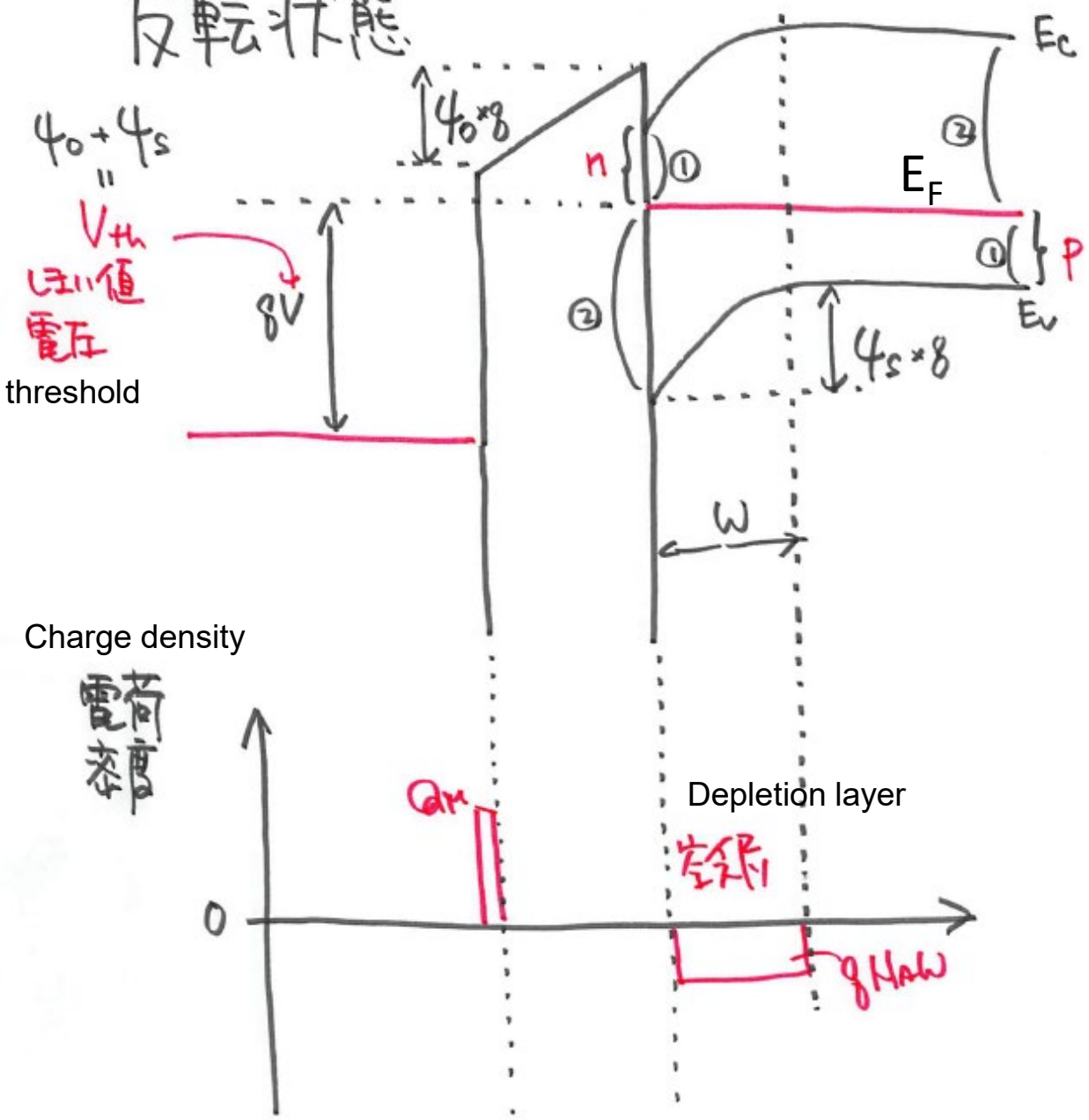
ムーアの法則

Moore's law

Number of transistors on a chip doubles in 1.5 ~ 2 years

Inversion

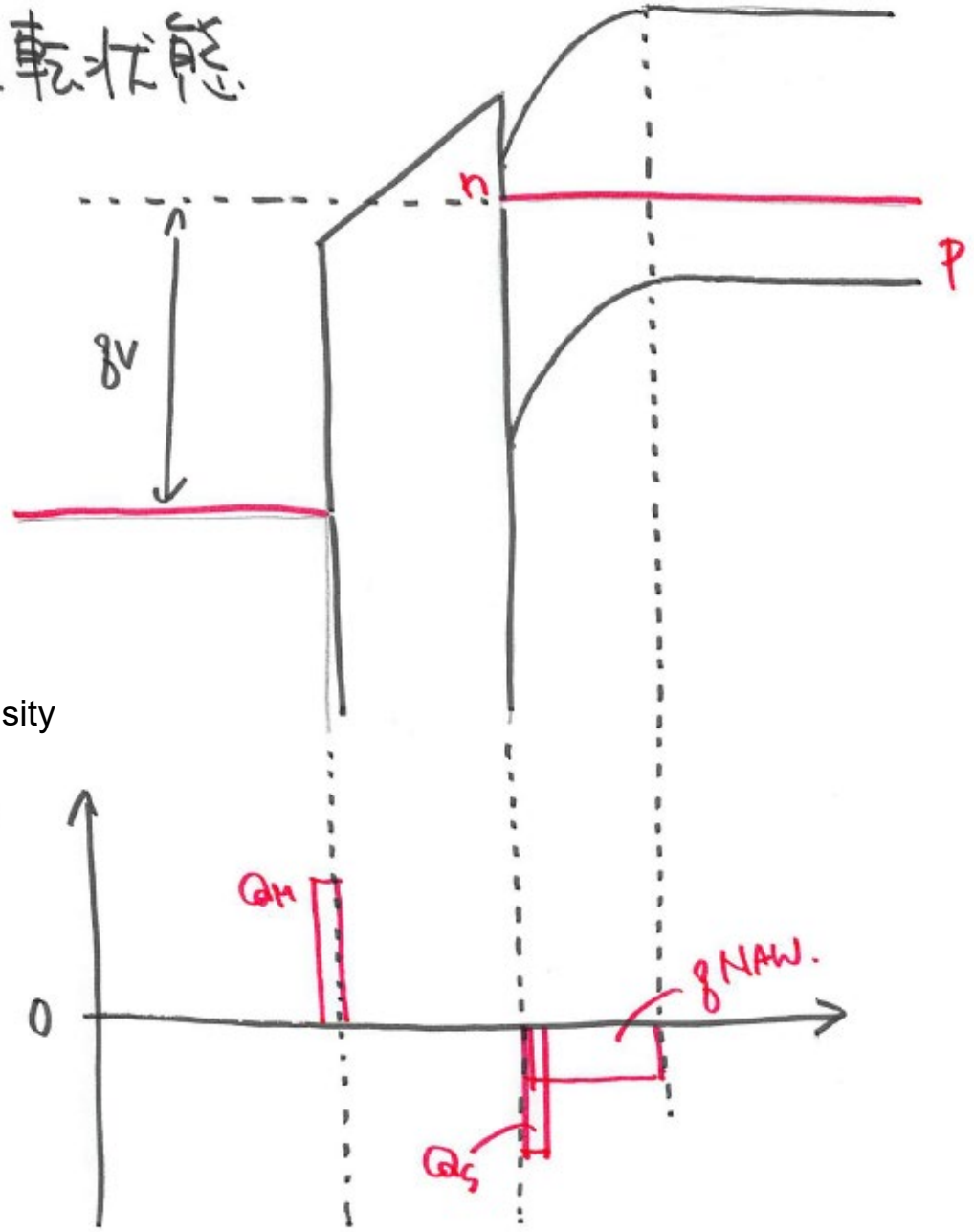
反転状態

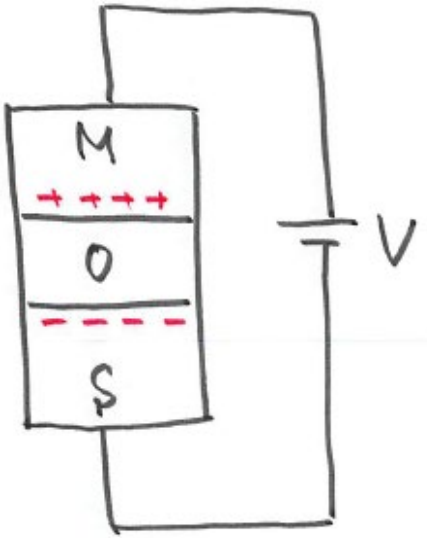


threshold

Strong inversion

強反転状態





Charge density

電荷密度

Exercise1

Derive the surface potential (Ψ_S) at the onset of inversion when the acceptor density in Si (N_A) is 1×10^{16} /cm^3.

Si のアクセプター濃度(N_A) を 1×10^{16} /cm^3 とする。
反転状態における表面ポテンシャル (Ψ_S) を求めよ.

Band gap

Si のバンドギャップ $E_g = 1.12$ eV , $kT = 0.026$ eV at 300K,
$N_V = 2.66\times10^{19}$ /cm^3 , $q = 1.6\times10^{-19}$
$\varepsilon_S = 11.9 \times 8.85\times10^{-12}$ F/m (Si の誘電率)
$\varepsilon_{ox} = 3.9 \times 8.85\times10^{-12}$ F/m (SiO_2 〃)

permittivity

permittivity

$$C_{ox} = \frac{\varepsilon_{ox}}{t}$$

伝導電子密度

Conduction electron density

$$n = N_c \exp\left(-\frac{E_c - E_F}{kT}\right)$$

ホール密度

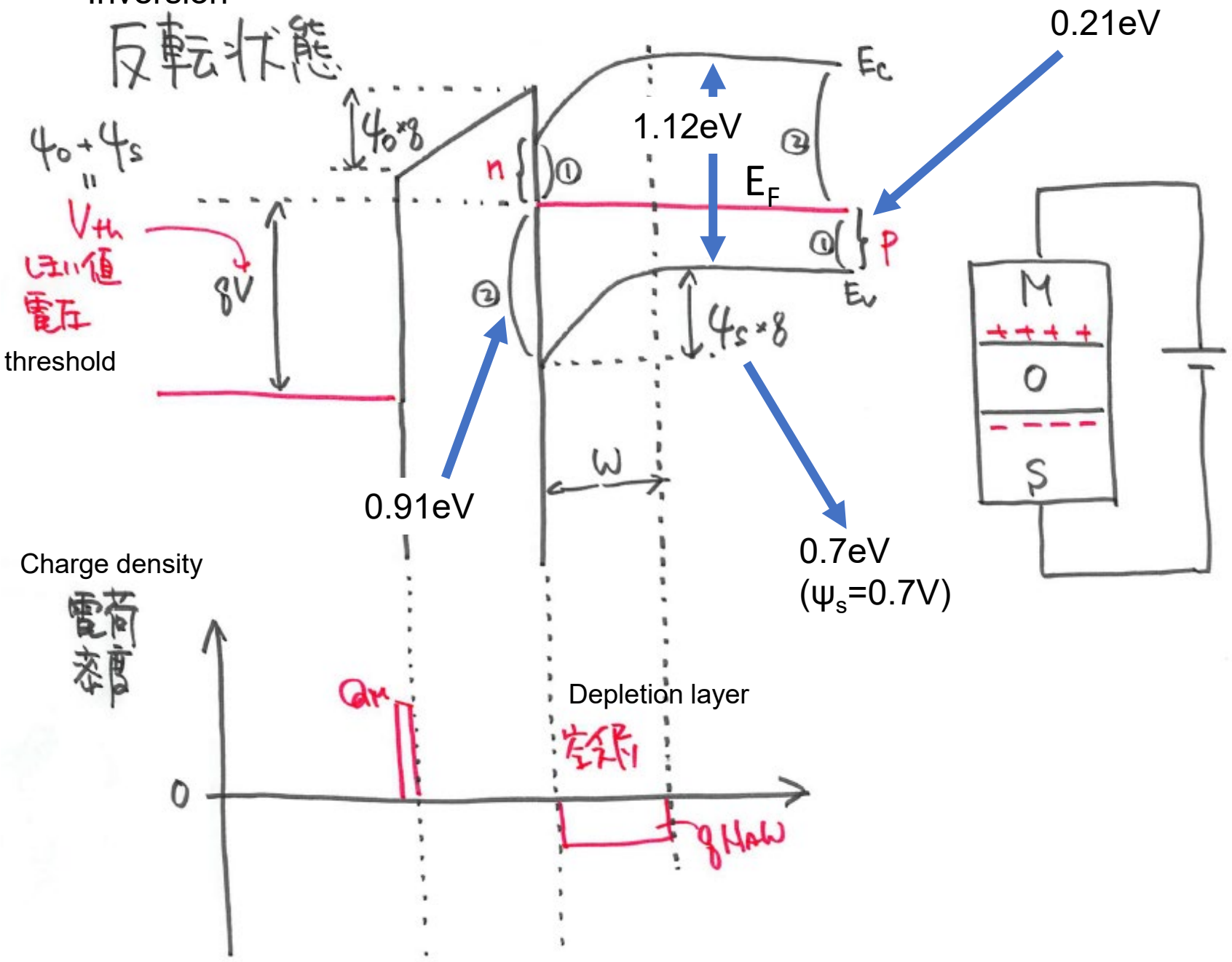
Hole density

$$p = N_v \exp\left(-\frac{E_F - E_v}{kT}\right)$$

Acceptor density N_A = 1×10^{16} /cm^3

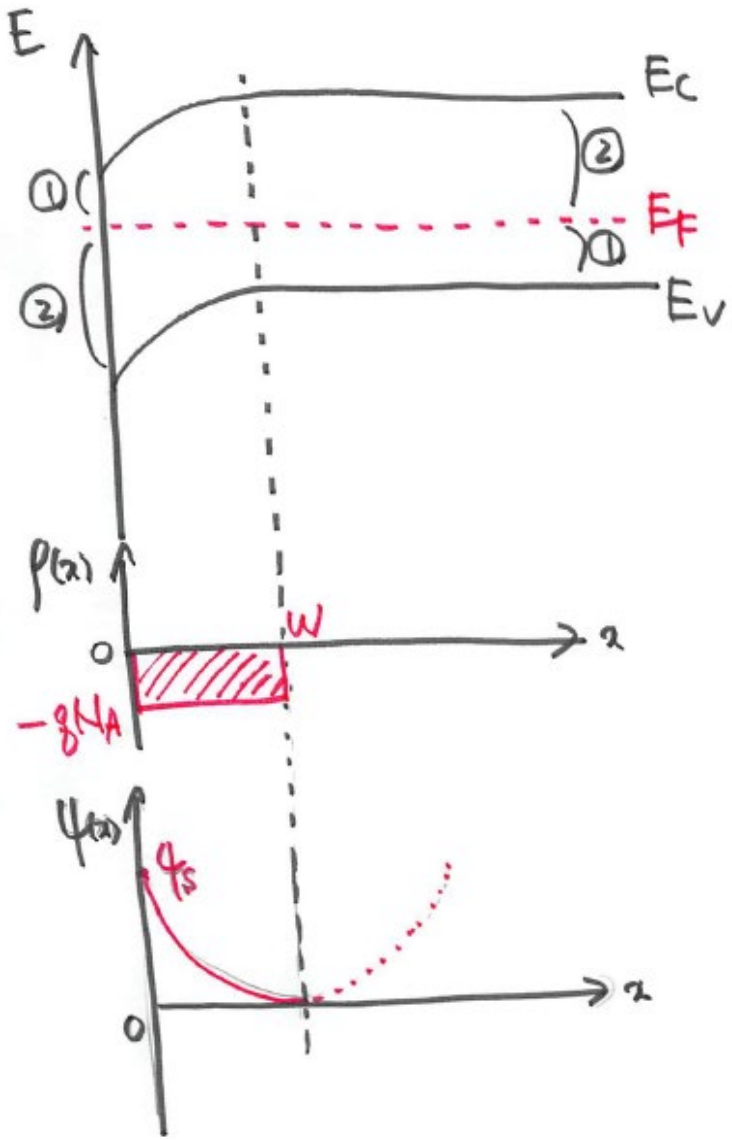
Inversion

反転状態



Evaluation of surface potential

表面ポテンシャルの導出.



Poisson's equation

Poisson方程式

$$\frac{d^2\psi(x)}{dx^2} = -\frac{\rho(x)}{\varepsilon_s}$$ ← $-qN_A$

Electric field

電場

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$E(W)=0$.

$$-E(x) = \frac{d\psi(x)}{dx} = \frac{qN_A}{\varepsilon_s}x + A = \frac{qN_A}{\varepsilon_s}(x-W)$$

↓

$\psi(W)=0$.

$$\psi(x) = \frac{qN_A}{\varepsilon_s}\frac{(x-W)^2}{2} + \cancel{B}$$

$$\psi_s = \psi(0) = \frac{qN_A}{2\varepsilon_s}W^2$$

表面ポテンシャル.

Surface potential

$$V_{th} = \psi_s + \frac{qN_AW}{C_{ox}}$$

しきい値電圧

Threshold

酸化物薄膜の静電容量

Capacitance of oxide layer

Exercise1

Evaluate the depletion layer width (W) at the onset of inversion when the acceptor density in Si (N_A) is $1x10^{16}$ /cm^3.

Si のアクセプター濃度(N_A) を $1x10^{16}$ /cm^3 とする。このとき、反転状態における空乏層幅(W)を求めよ。

Band gap

Si のバンドギャップ $E_g = 1.12\,eV$, $kT = 0.026\,eV$ at 300K,

$N_V = 2.66 \times 10^{19}/cm^3$, $q = 1.6 \times 10^{-19}$

permittivity

$\varepsilon_S = 11.9 \times 8.85 \times 10^{-12}\,F/m$ (Si の誘電率)

$\varepsilon_{ox} = 3.9 \times 8.85 \times 10^{-12}\,F/m$ (SiO_2 〃 permittivity)

$$C_{ox} = \frac{\varepsilon_{ox}}{t}$$