2.1 Structure and functions of MOSFET

Principle of MOSFET

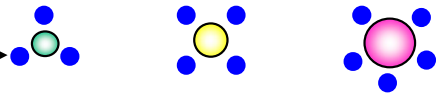
2.1.1 PN junction

Electrical conductivity control 1

Periodic table

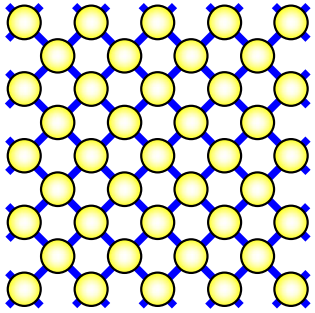
	III	IV	V	
	B	C	N	
	Al	Si	P	
	Ga	Ge	As	
	In	Sn	Sb	

Electron (Blue dot)

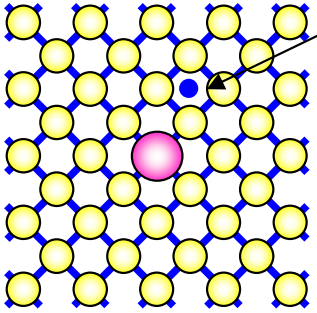


* A free electron (自由電子) is not bound to an atom.

Free Electron (*)

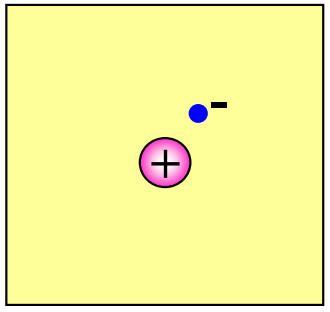


Crystal of Si



P(Phosphorous)-doped Si (*)

* Doping: Introducing an impurity



Simplified sketch

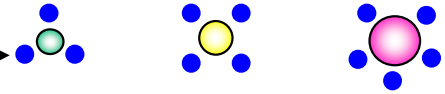
Electrical conductivity control 2

Periodic table

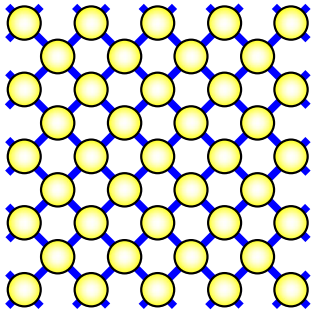
	III	IV	V	
	B	C	N	
	Al	Si	P	
	Ga	Ge	As	
	In	Sn	Sb	

* A hole is an ionized Si atom by transferring a valence electron to an impurity.

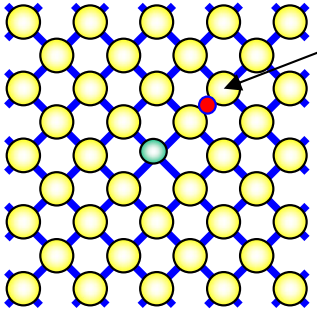
Electron (Blue dot)



Hole (*)

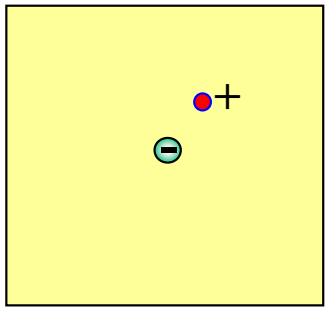


Crystal of Si



B(Boron)-doped Si (*)

* Doping: Introducing an impurity



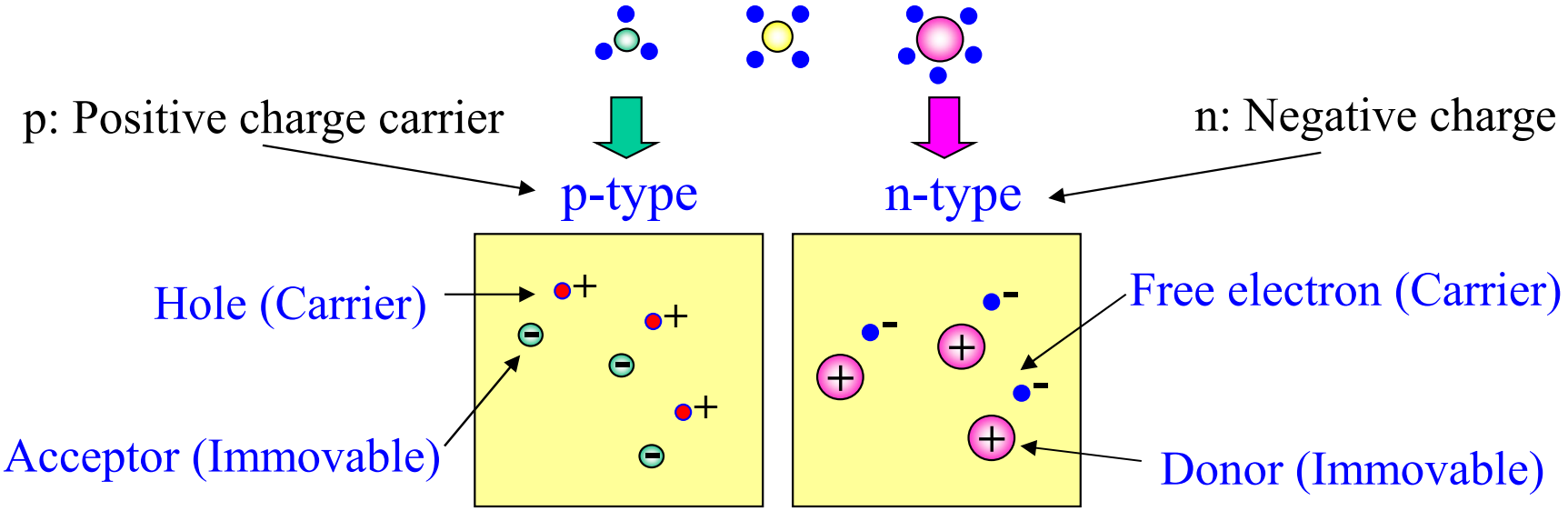
Simplified sketch

Conductivity type of semiconductor

	III	IV	V	
	B	C	N	
	Al	Si	P	
	Ga	Ge	As	
	In	Sn	Sb	

Non-doped semiconductor = Intrinsic Semiconductor

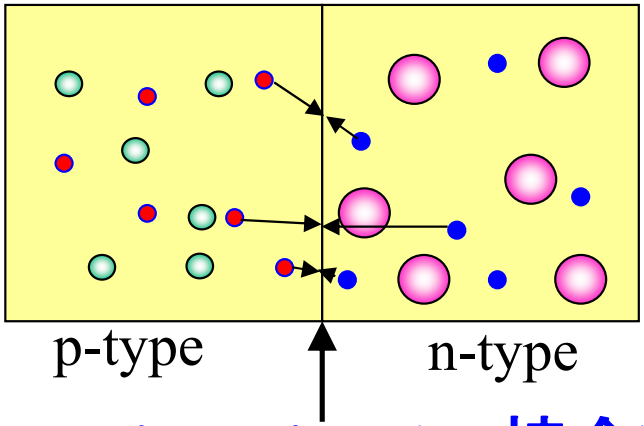
A free electron and a hole can carry a charge (Carrier).



The number of carriers equals to the number of accepters or donors.

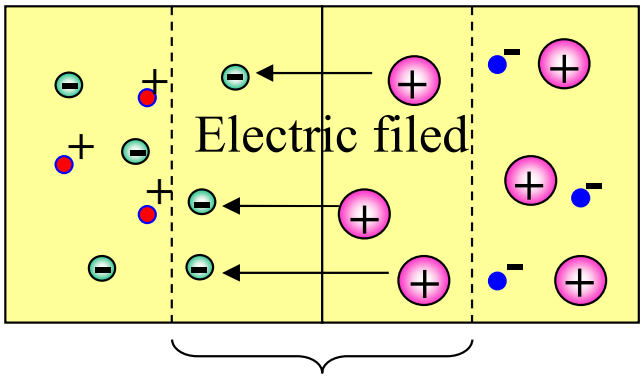
Electric field of pn junction

A pn junction is formed at a boundary between the p-type semiconductor and the n-type semiconductor.



pn junction (pn接合)

Free electrons and holes are recombined in the vicinity of the pn junction, and a depletion layer of carriers are formed.

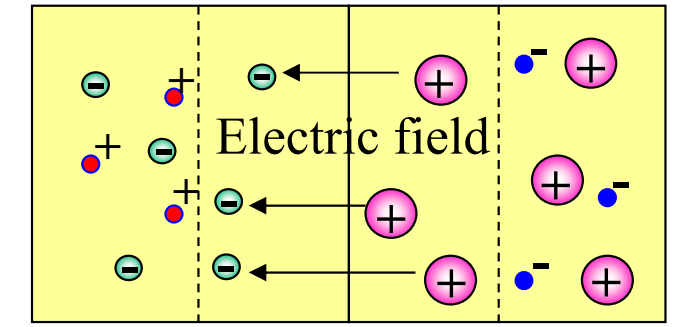


Depletion layer (空乏層)

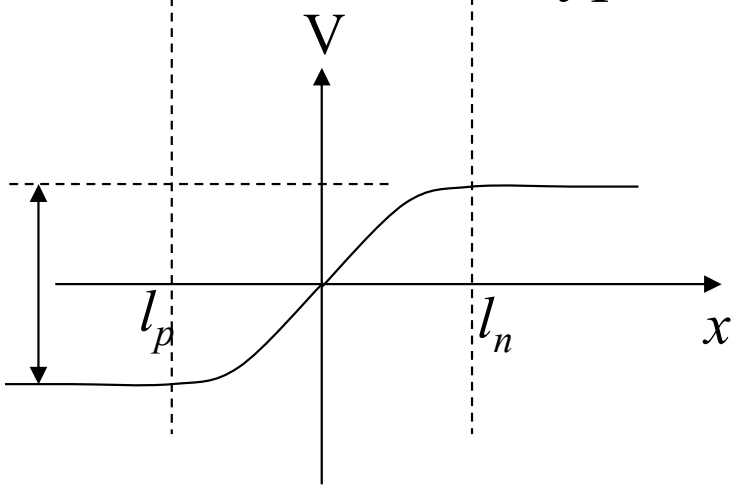
The ionized donors and acceptors forms the built-in electric field in the depletion layer.

$$\frac{dE}{dx} = \frac{\rho}{\epsilon_0 \varepsilon_{Si}} \quad \text{(Gauss's law)}$$

Voltage of pn junction



The built-in voltage V_B is generated by the built-in electric field.



Built-in voltage V_B
(内蔵電位)

$$E = -\frac{dV}{dx}$$

$$dV = -E \cdot dx$$

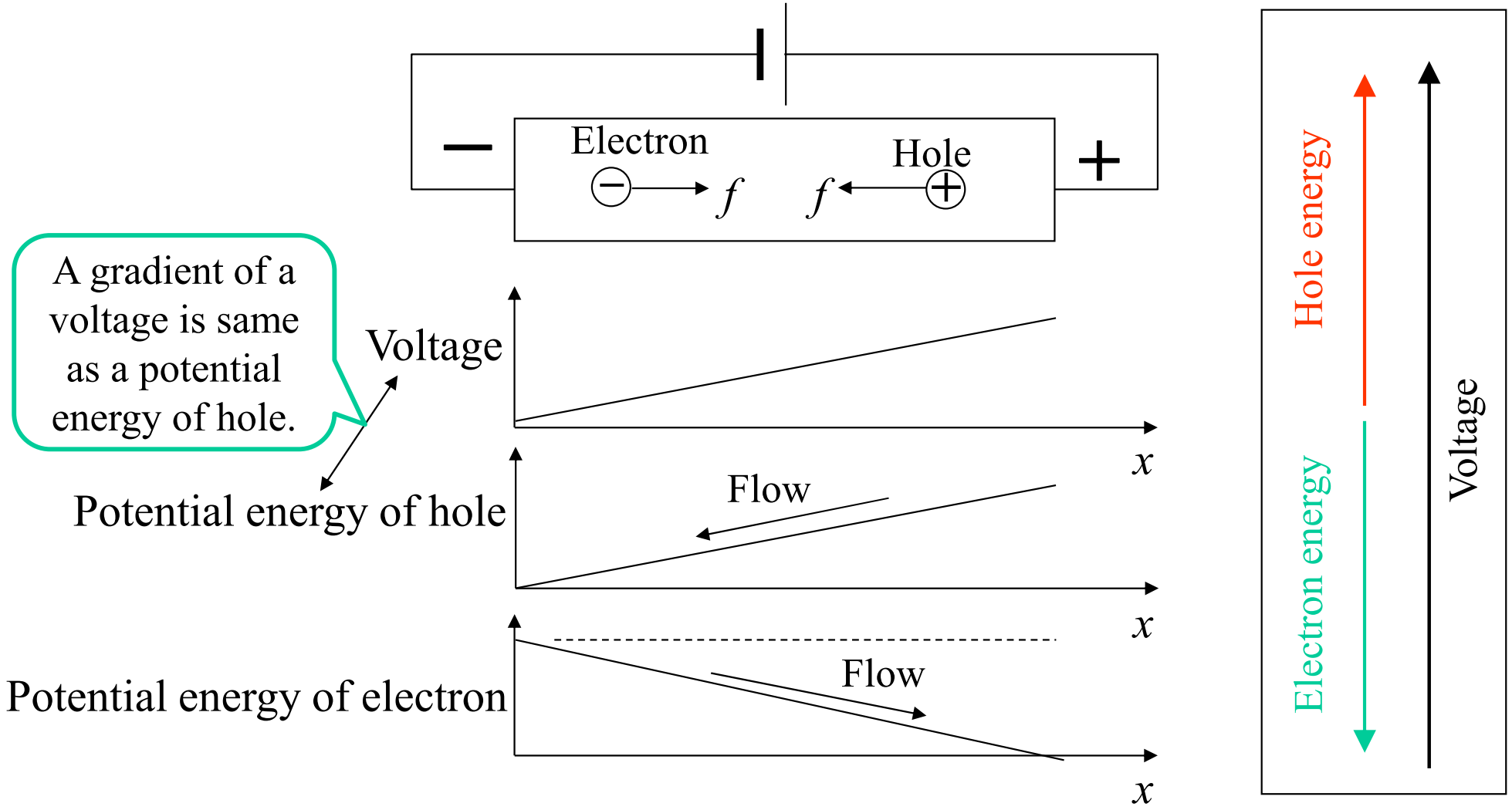
$$V_B = -\int_{l_p}^{n} E \cdot dx$$

Note: The current does not flow through the pn junction because the electrostatic force and the diffusion of the carrier are balanced in the equilibrium state.

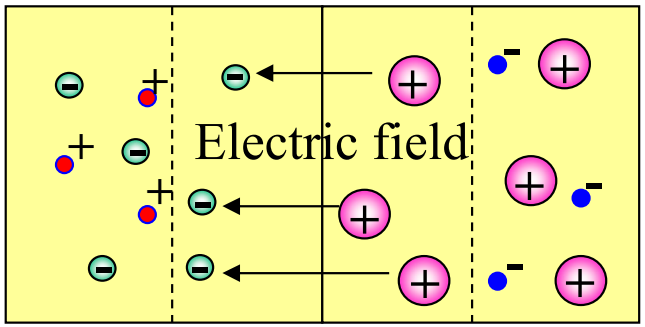
用語解説

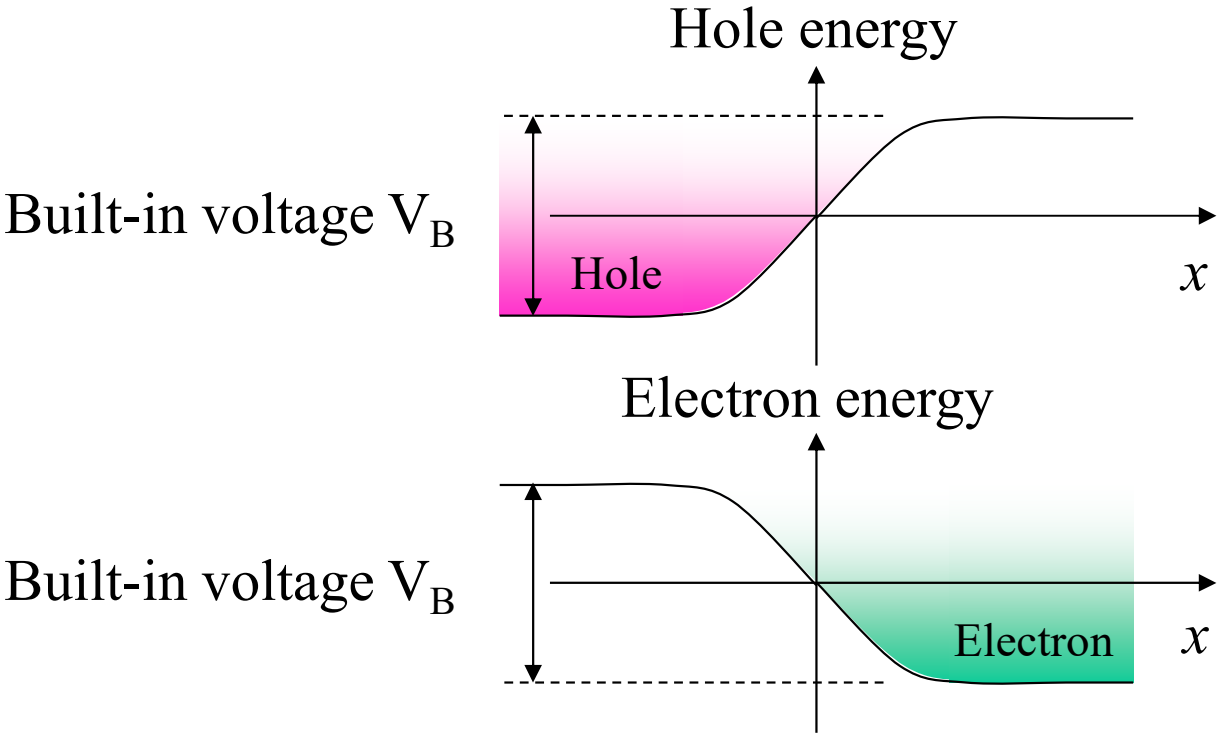
- Equilibrium state
  - 平衡状態（熱平衡状態）
  - 外部系とのエネルギーの授受が無い状態
- Steady state
  - 定常状態
  - 時間的変化が無い状態（交流電圧振幅や周波数が変化しない状態も含む）
- Transient state
  - 過渡状態
  - 時間的変化がある状態

Potential energy of electron and hole



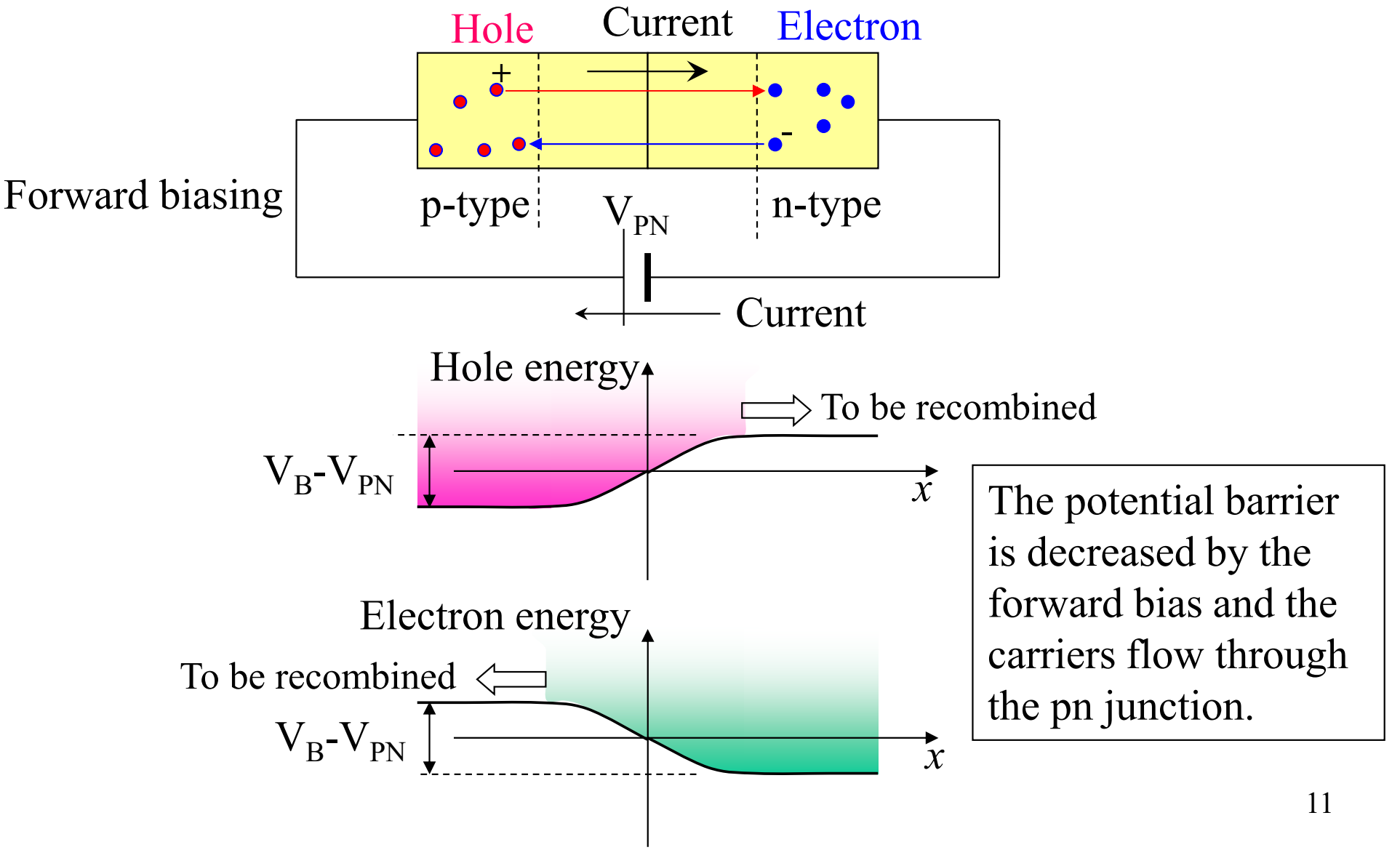
Distribution of carriers





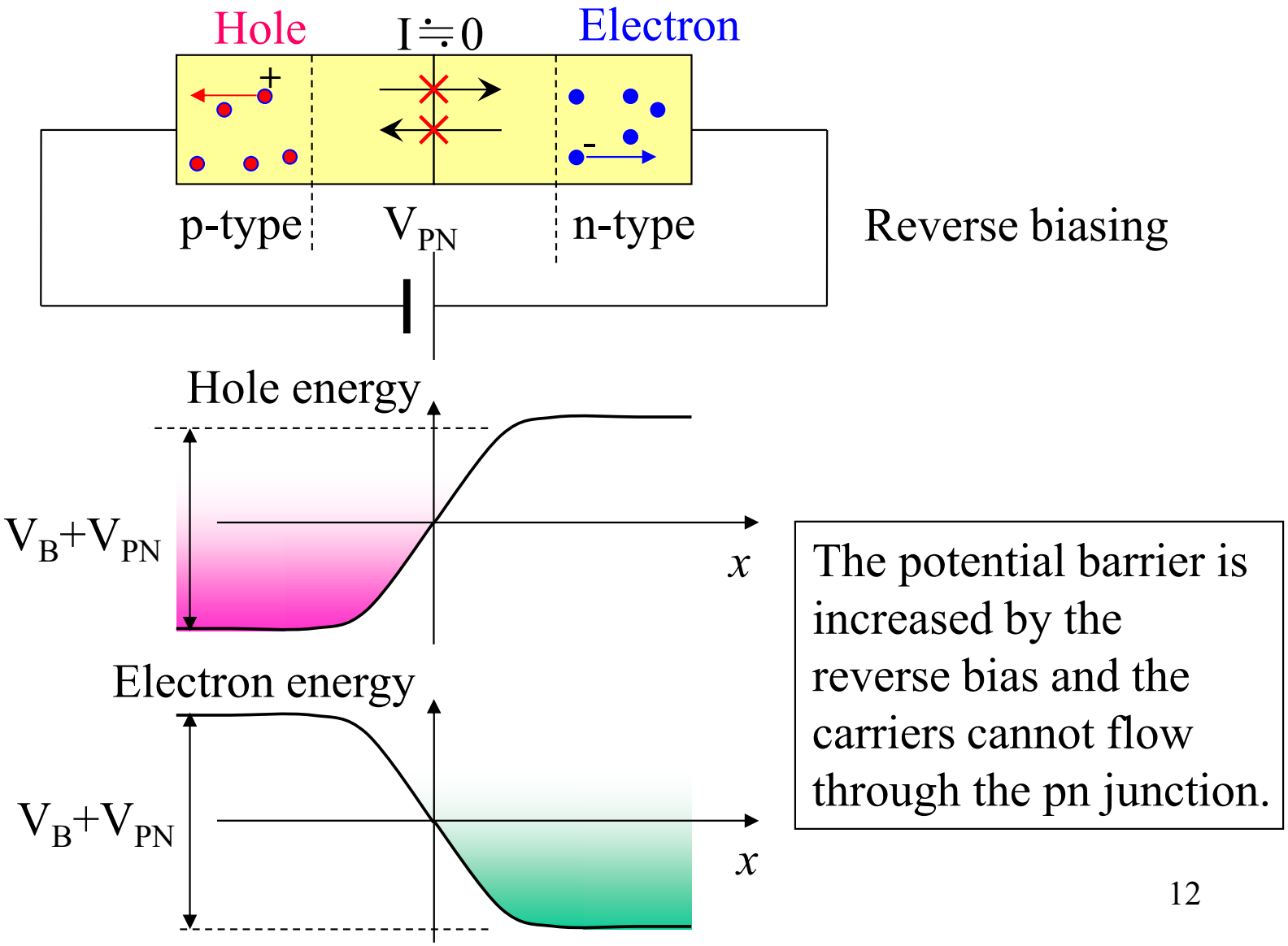
The carriers are gathered on the low-potential side.

Forward biasing of pn junction



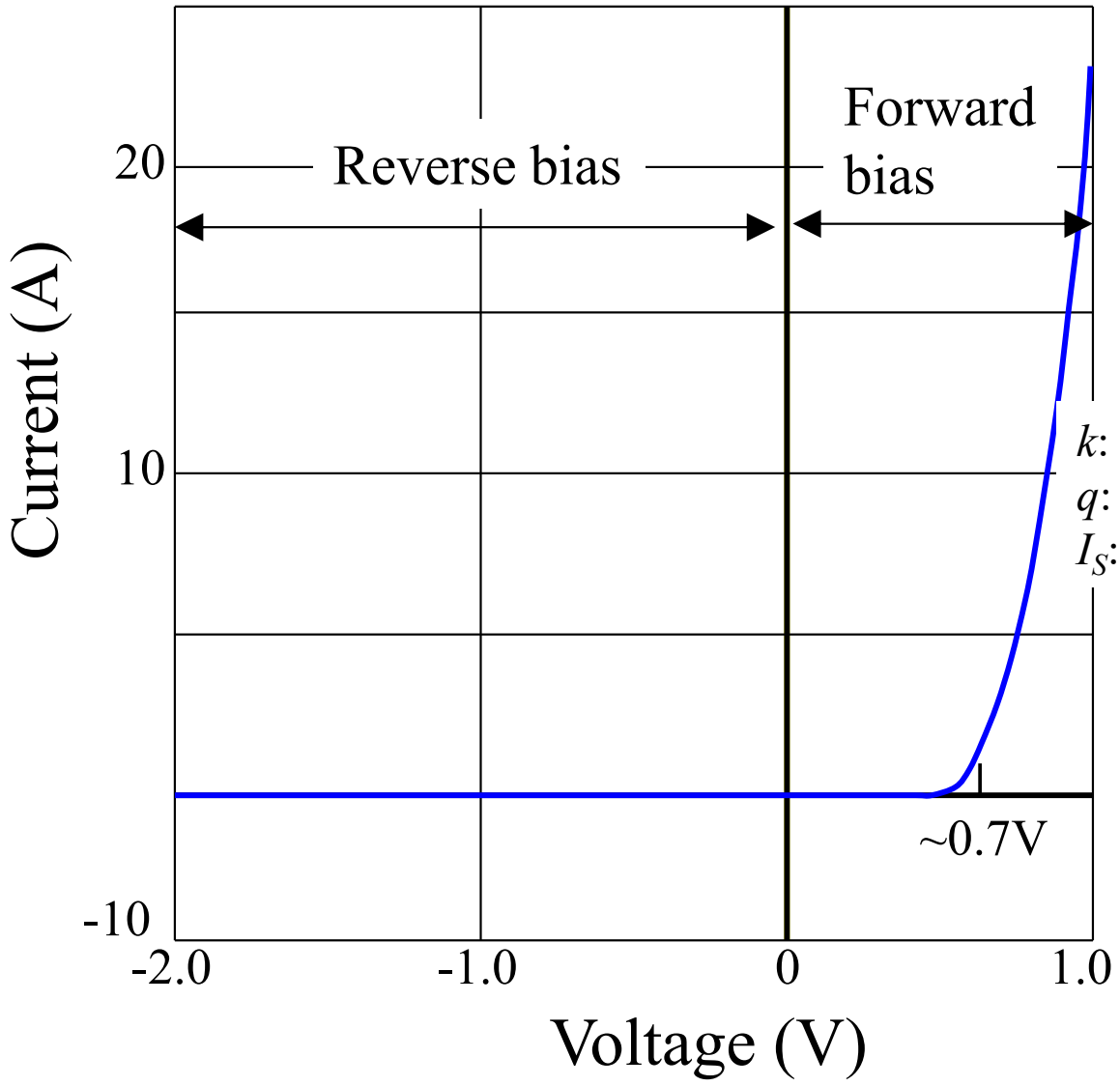
The potential barrier is decreased by the forward bias and the carriers flow through the pn junction.

Reverse biasing of pn junction



The potential barrier is increased by the reverse bias and the carriers cannot flow through the pn junction.

I-V characteristic of pn junction



Device model equation

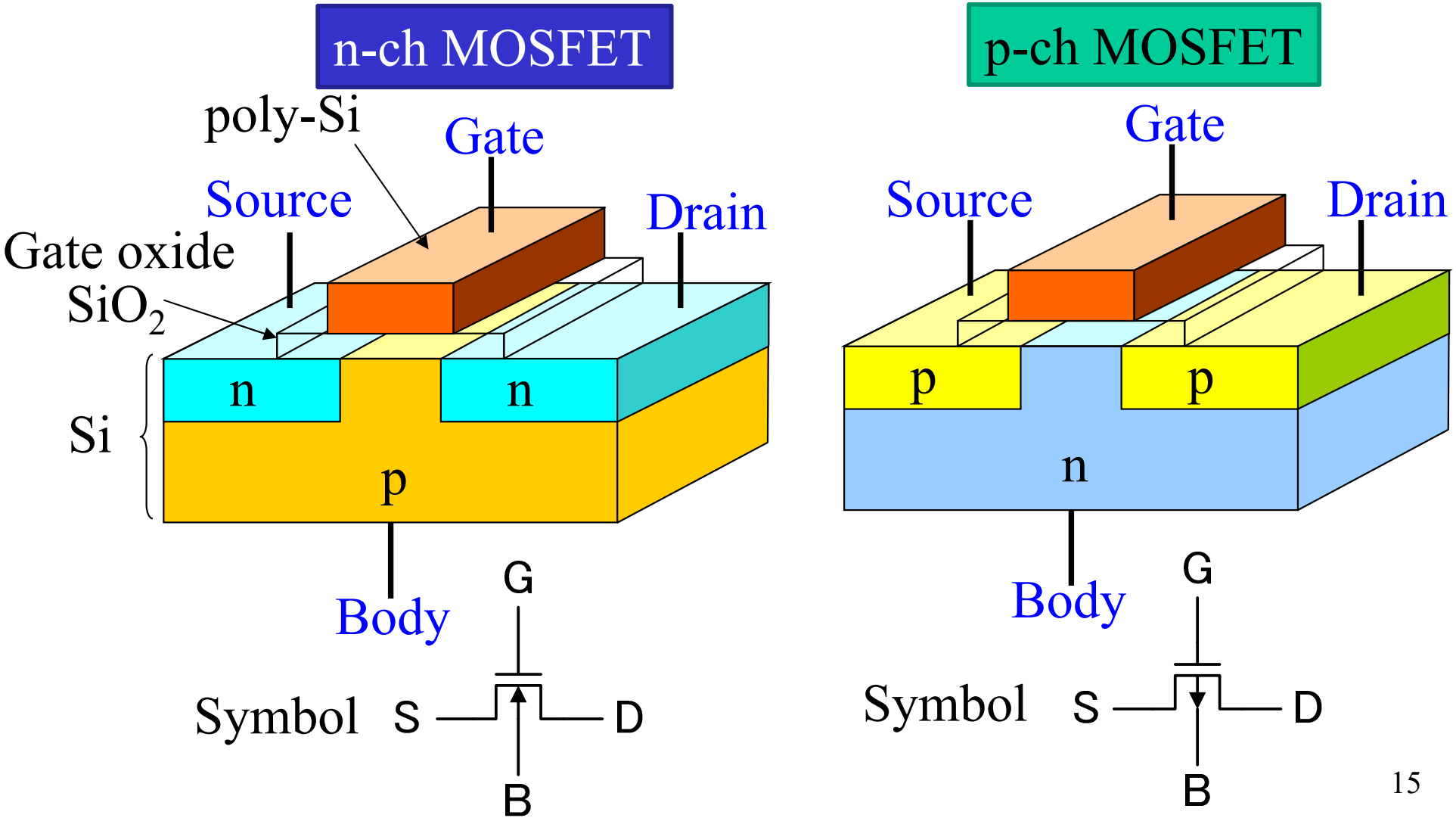
$$I_{PN} = I_S(e^{\frac{q \cdot V_{PN}}{k \cdot T}} - 1)$$

k: Boltzmann's constant ($1.380649 \cdot 10^{-23}$ J/K)
q: Electronic charge ($1.60 \cdot 10^{-19}$ coulomb)
I_S: Reverse saturation current (A)

2.1.2 Structure of MOSFET

Structure of MOSFET

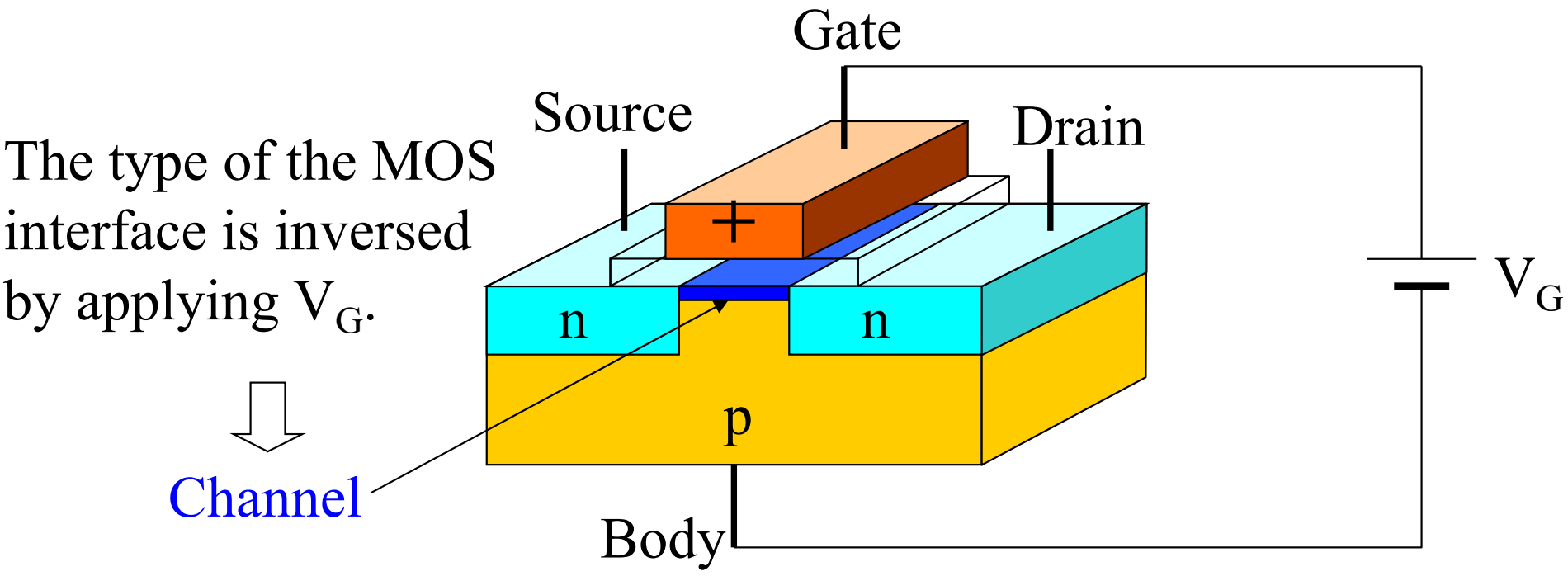
MOSFET (Metal-Oxide-Semiconductor Field Effect Transistor)



Switching of n-ch MOSFET

The free electrons are generated by lowering the potential at the SiO_2/Si interface (MOS interface) and the source and drain is electrically conducted.

The type of the MOS interface is inversed by applying V_G.

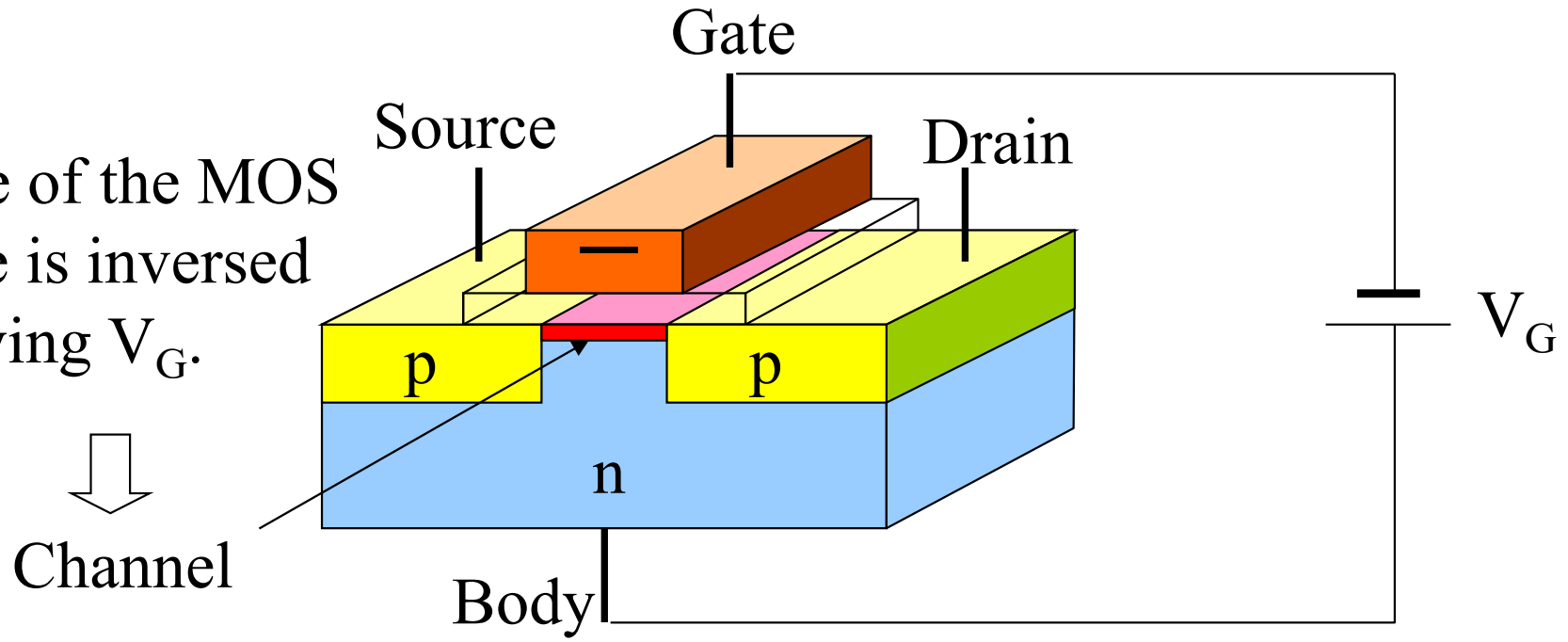


n-ch MOSFET

Switching of p-ch MOSFET

The holes are generated by lowering the potential at the SiO_2/Si interface (MOS interface) and the source and drain is electrically conducted.

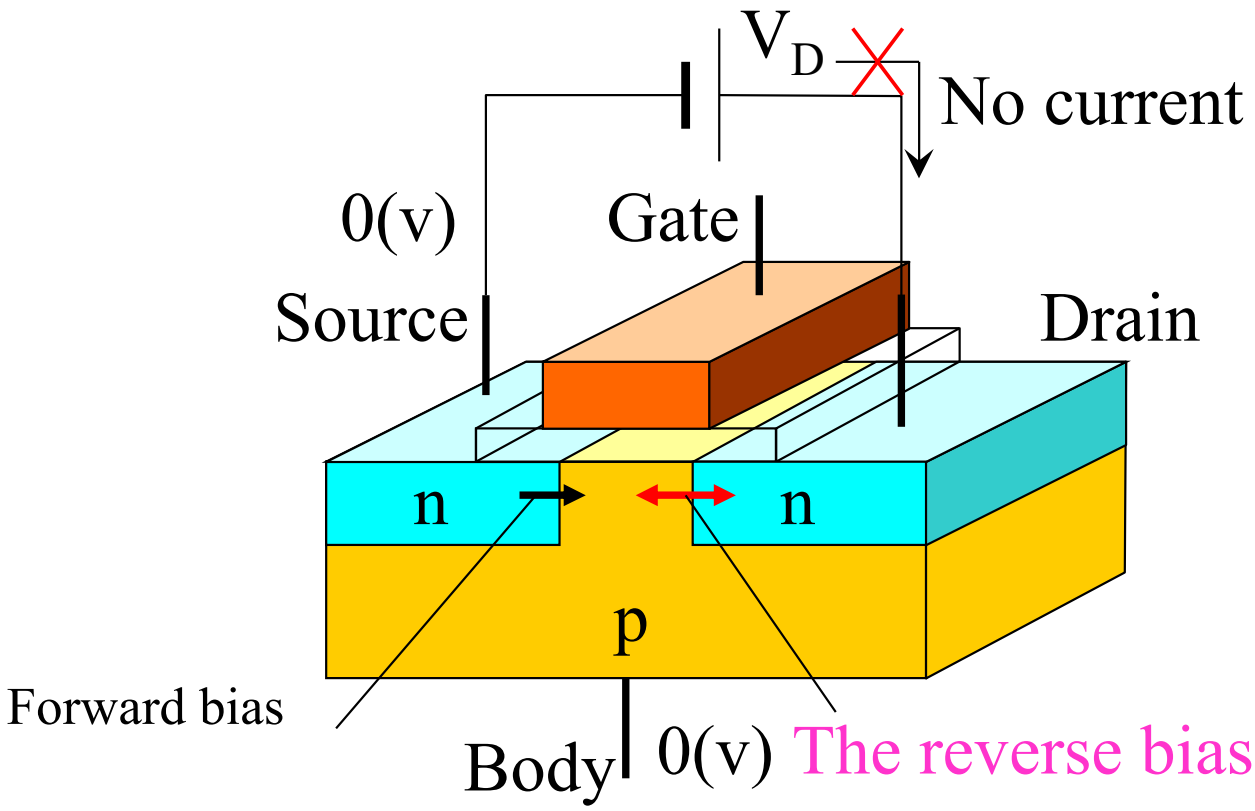
The type of the MOS interface is inversed by applying V_G.



p-ch MOSFET

OFF state of n-ch MOSFET

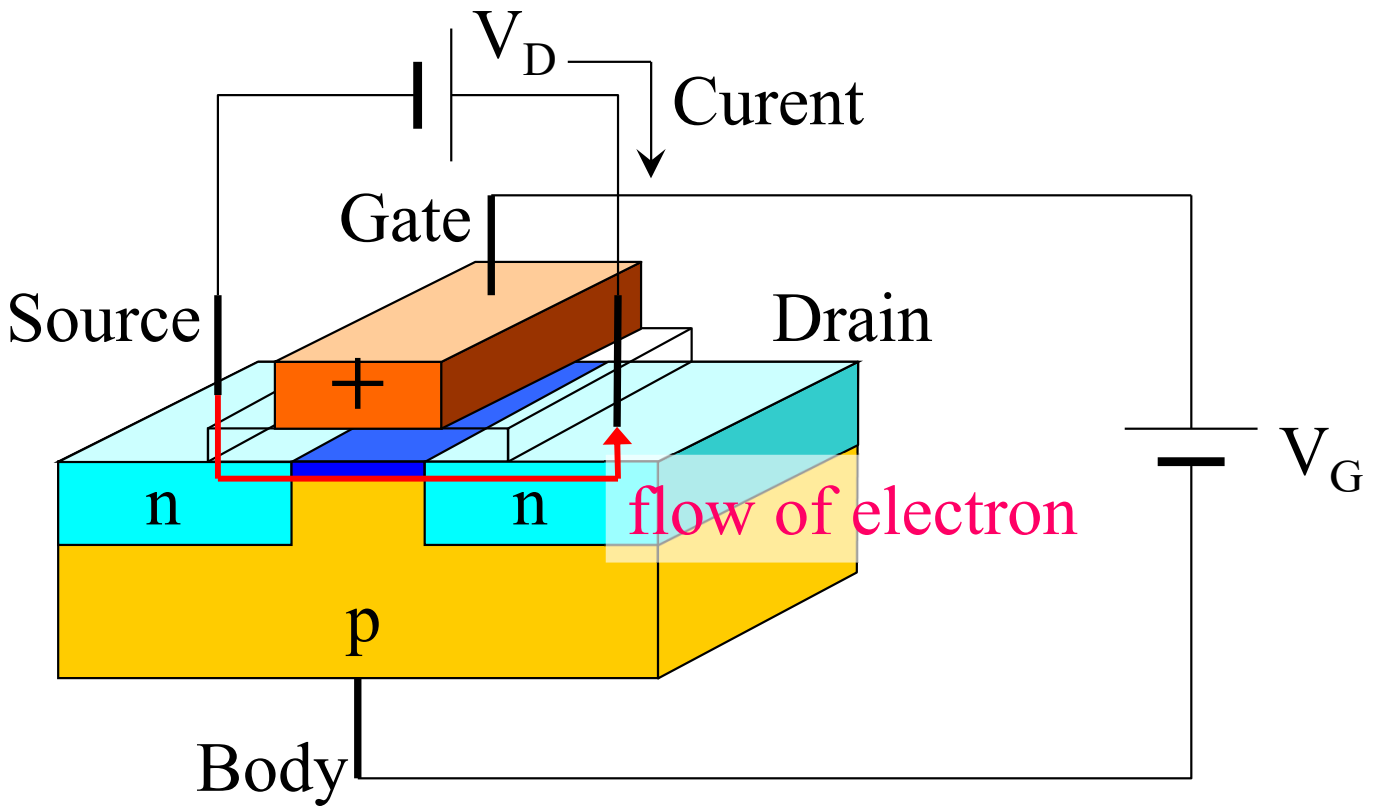
The current flow is blocked by the pn junction that is reverse-biased.



n-ch MOSFET

ON state of n-ch MOSFET

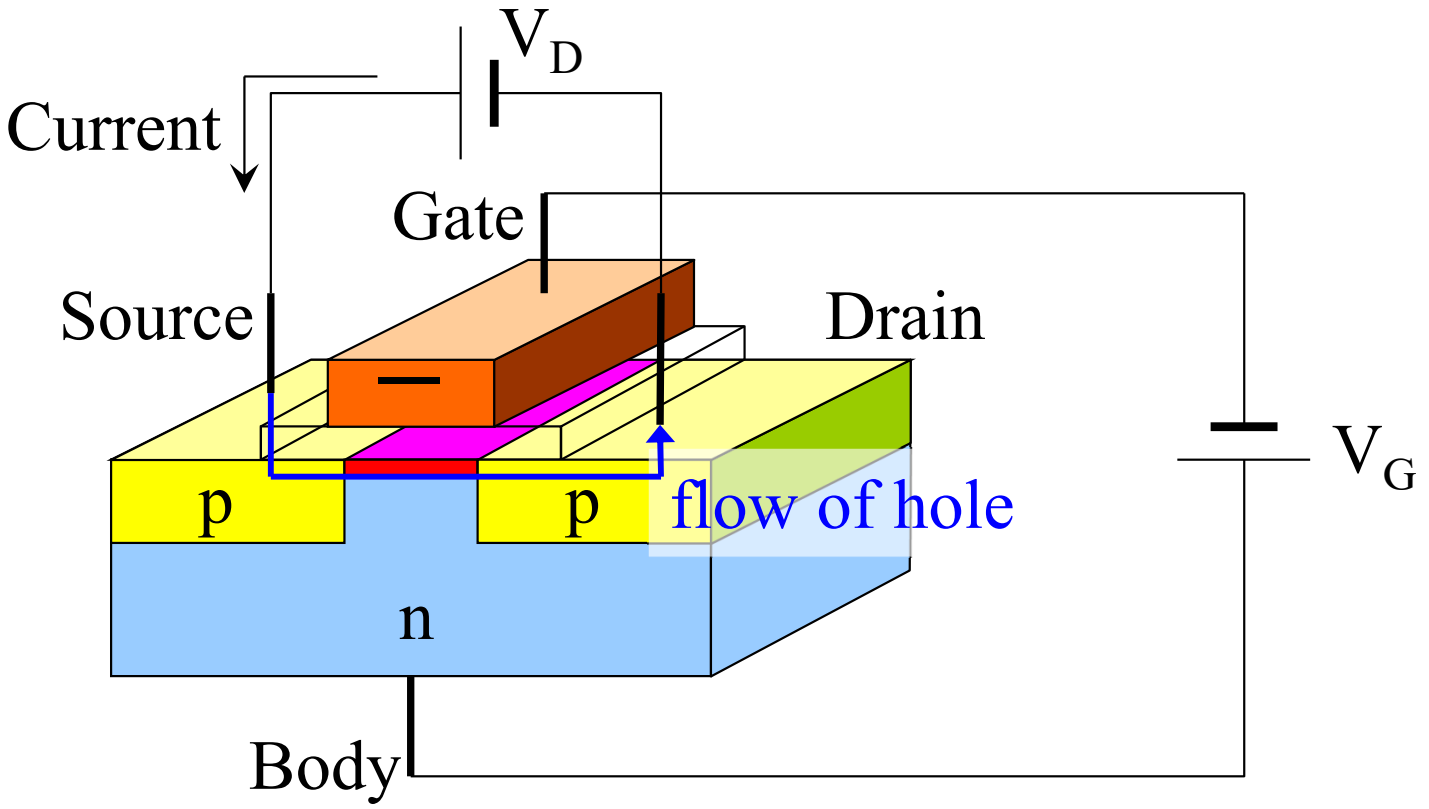
The electron flows through the channel at MOS interface.



n-ch MOSFET

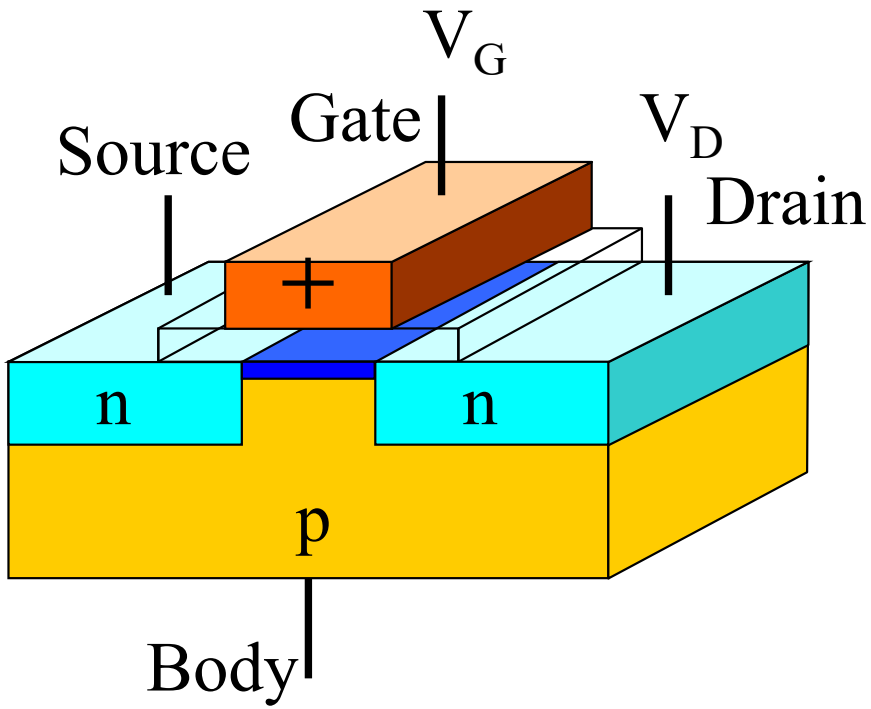
ON state of p-ch MOSFET

The hole flows through the channel at MOS interface.

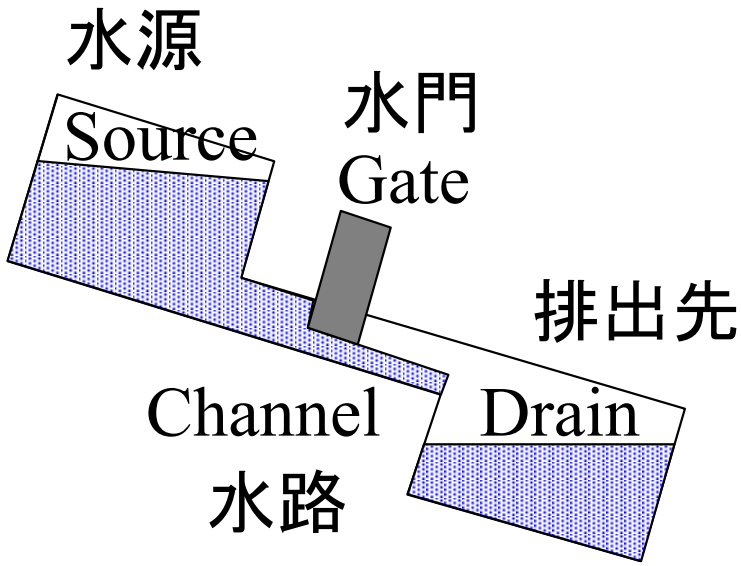


p-ch MOSFET

The origin of the electrode name



Analogy

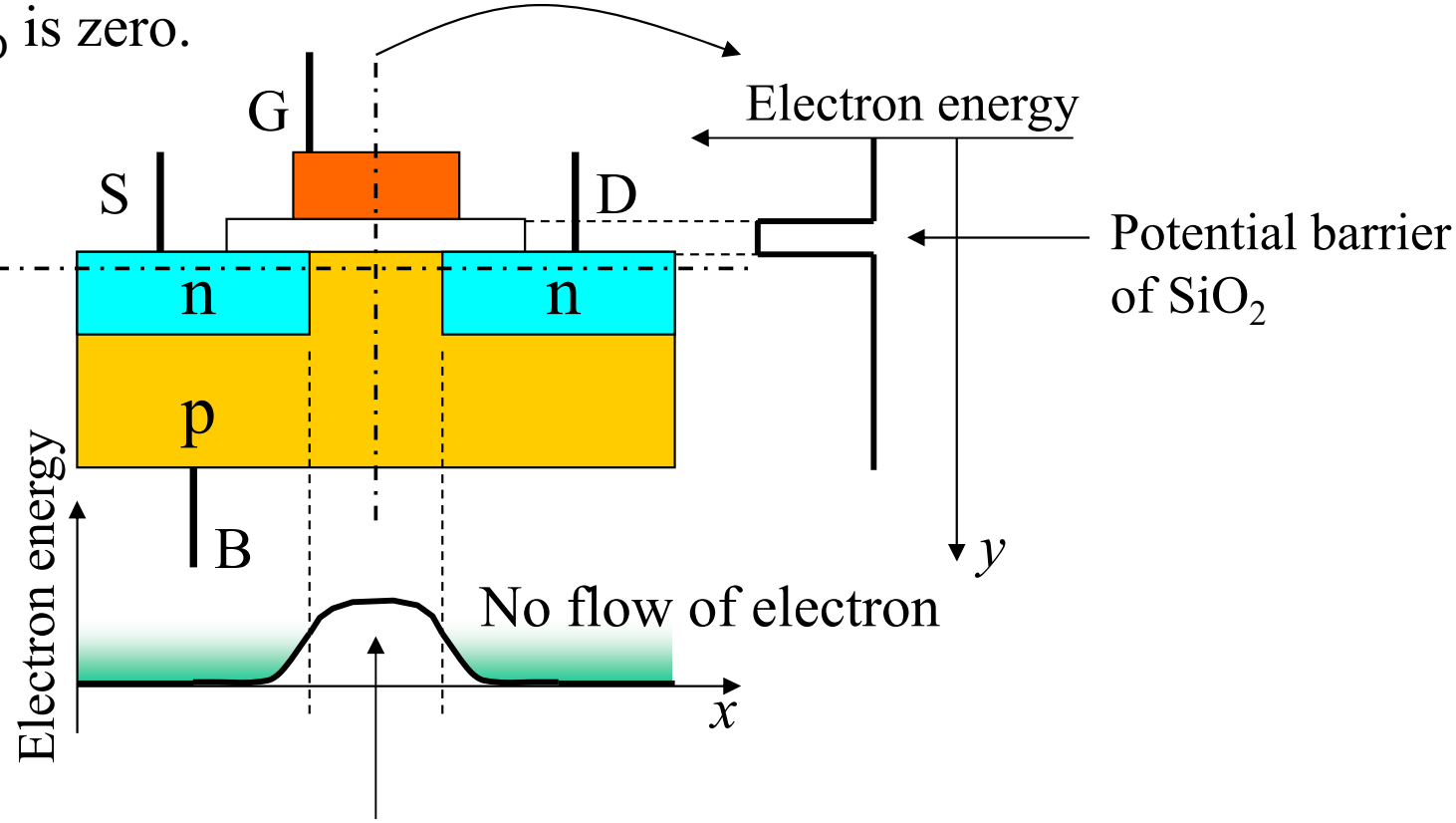


Note: Transistor = Trans-resistor

Distribution of electron in MOSFET 1

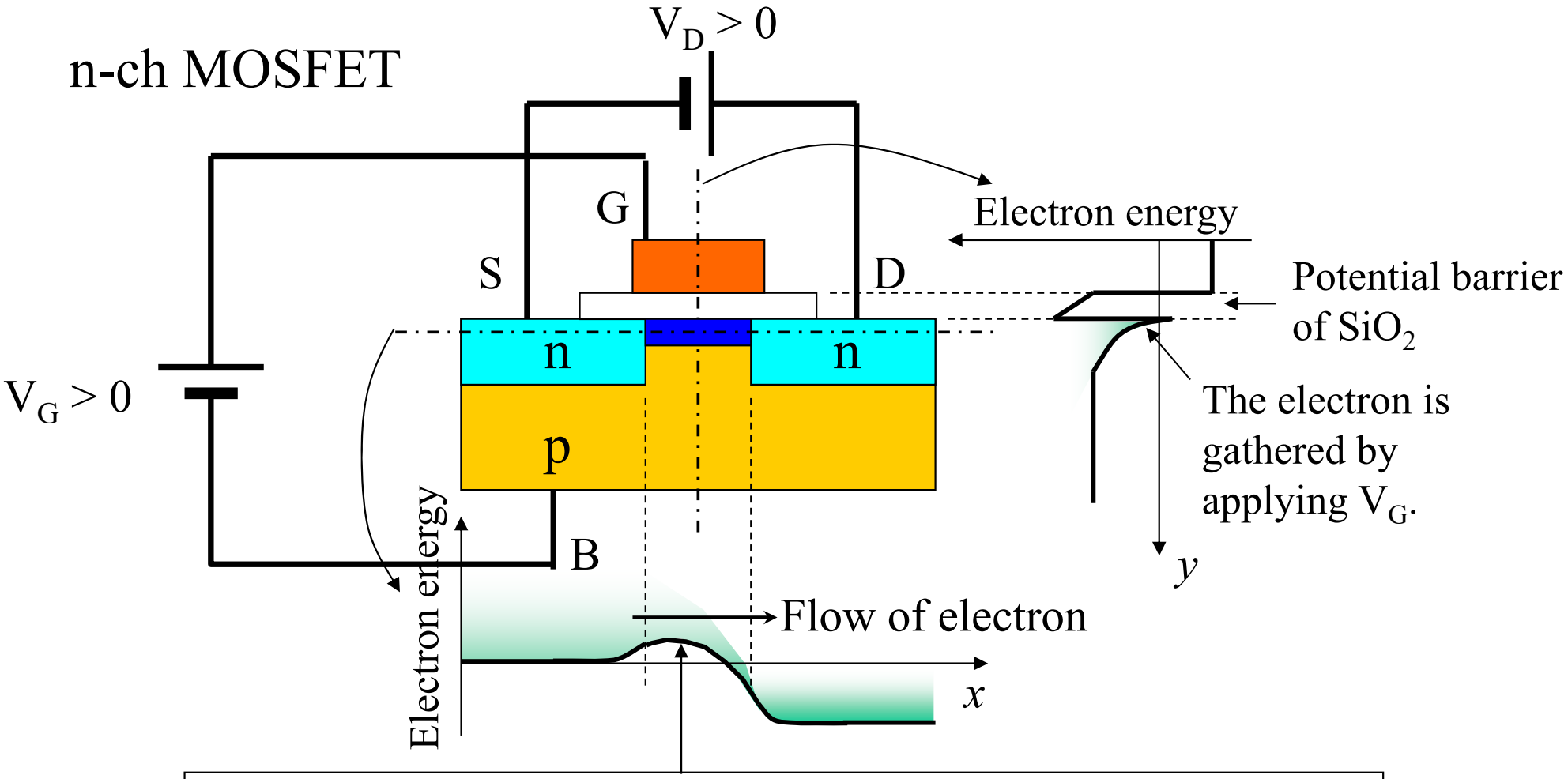
n-ch MOSFET

The V_G and the V_D is zero.



The potential barrier of p-type semiconductor is enough high and the electron cannot flow through the p-type region.

Distribution of electron in MOSFET 2



The height of the potential barrier is decreased by applying V_G and the electron flows from the source to the drain.