Subgroup meeting-10/12
Introduction of thermal transport

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outline

- Thermal conductivity
- Micro-scale thermal conduction
- Mean free path

Micro-scale

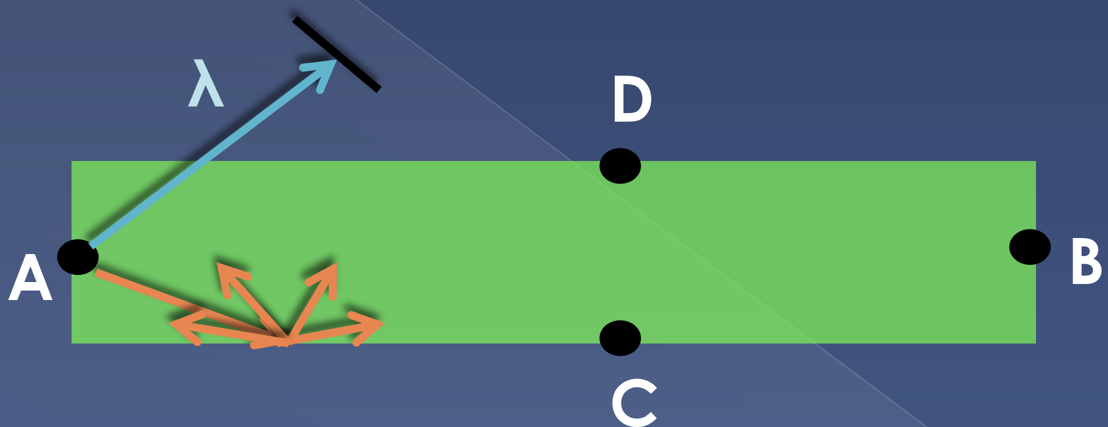
- In what scale can we lower the conductivity of phonons effectively?

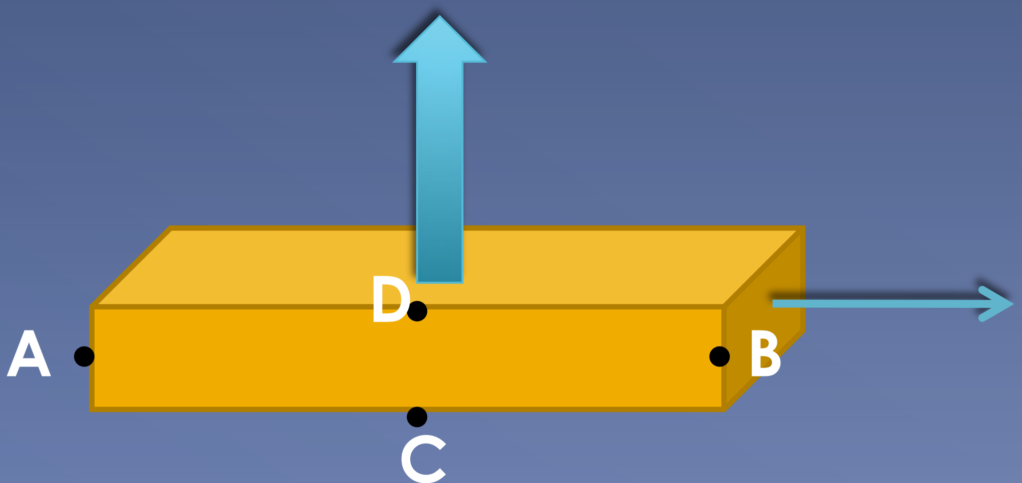
- Depend on mean free path
- Different geometric structures

Thermal conductivity

- Heat flux $$j_u = -K\frac{\partial T}{\partial x}$$
- Depends on temp gradient
- Not single direction
- Collision

Micro-scale





K: thermal conductivity

$K_{A\text{-}B}$: ~ 0

boundary scattering

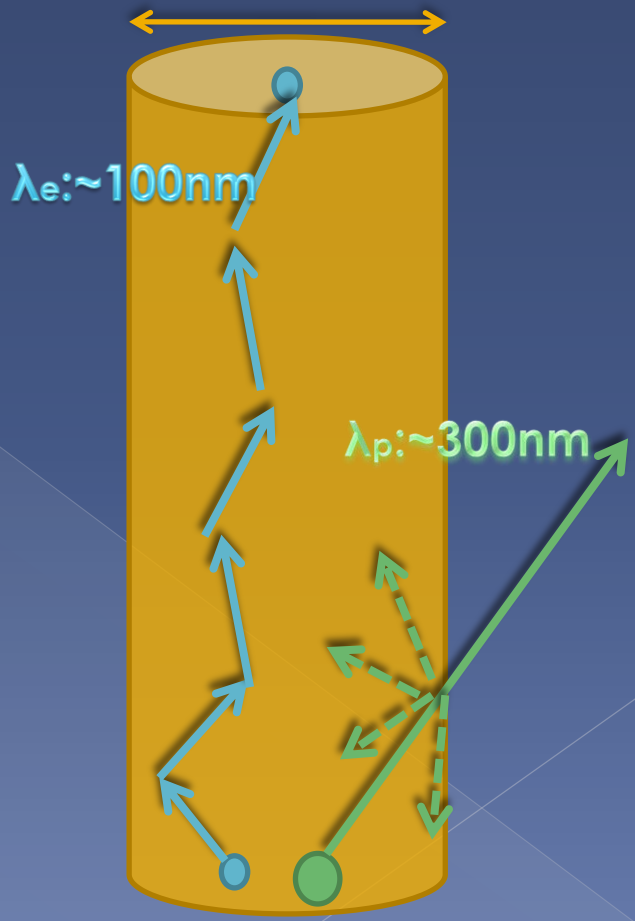
$K_{C\text{-}D}$: ~ ∞

ballistic

Micro-scale

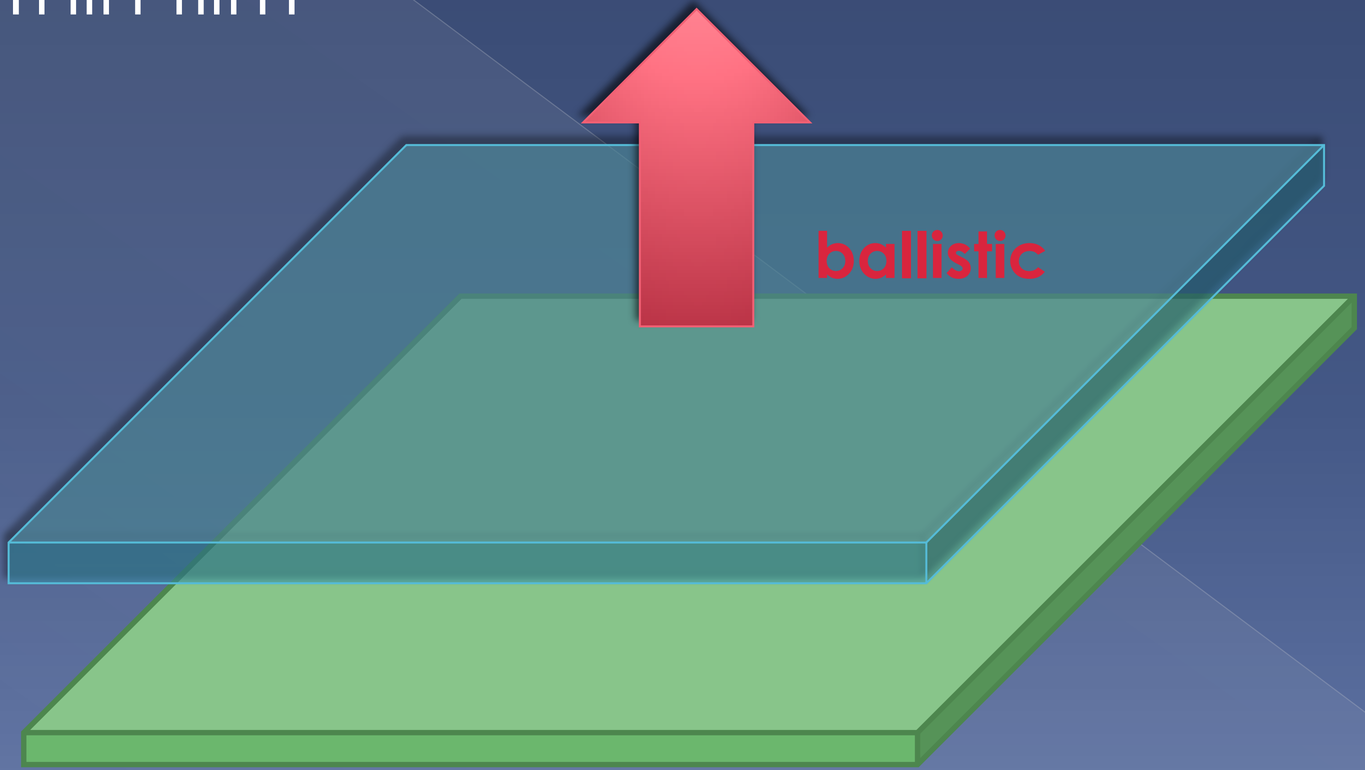
- Nanowire
- Boundary scattering

- Diameter ~200nm
- Electron mean free path ~100nm
- Phonon mean free path ~from 5nm to 10mm



Micro-scale

- Thin film



Micro-scale

- **Boundary scattering:**

  Phonon energy scattered by boundary(local potential difference) before the original theoretical mean free path.

Micro-scale

- **General consideration**
  Nano scale (0.1~1μm)

- Large scale
  →ex: Umklapp scattering process
  (phonon-phonon scattering)

- Small scale
  →different scattering mechanism

Mean free path

- Phonon Thermal conductivity **K**

$$K = \frac{1}{3} C v l$$

- C: total phonon heat capacity
  v : average phonon velocity
  l : average phonon mean free path

Mean free path

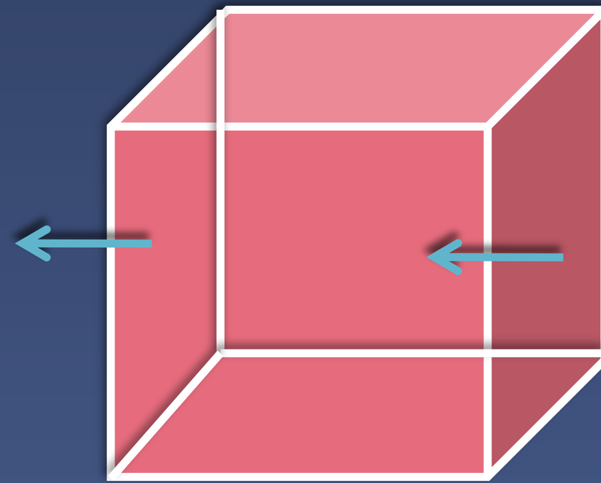
$$\Delta T = \frac{dT}{dx} l = \frac{dT}{dx} v_x \tau$$

$$j_u = -\langle v_x \rangle n c \Delta T$$

$$j_u = -n \langle v_x^2 \rangle c\tau \frac{dT}{dx}$$

$$= -\boxed{\frac{1}{3} n \langle v^2 \rangle c\tau} \frac{dT}{dx}$$

→ K



Flux(#) in x-direction

$$\frac{1}{2} \langle | v_x | \rangle n$$

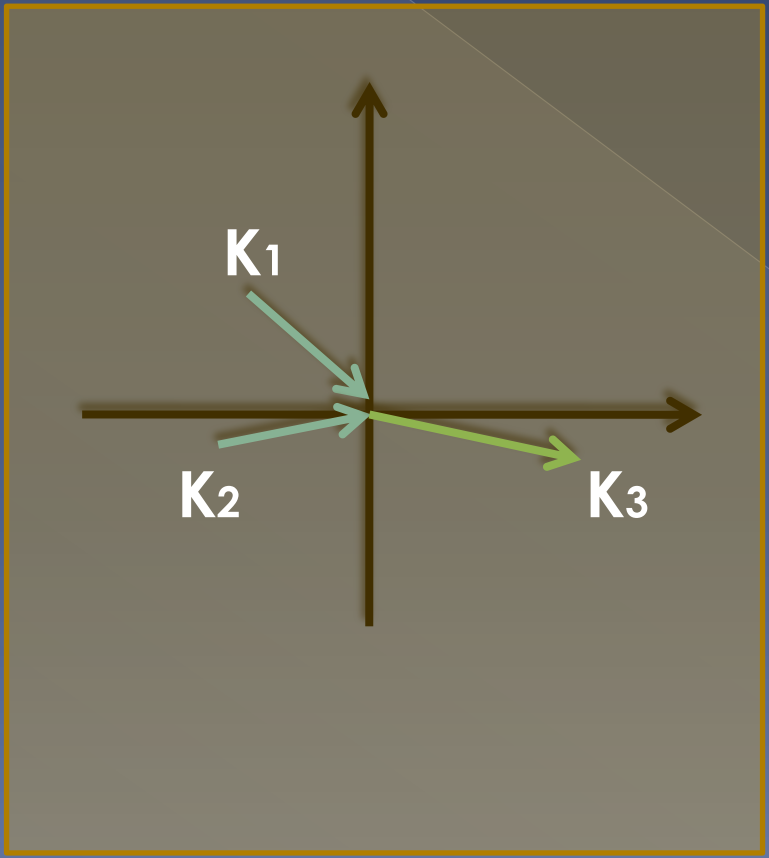
$$\Delta E = c\Delta T$$

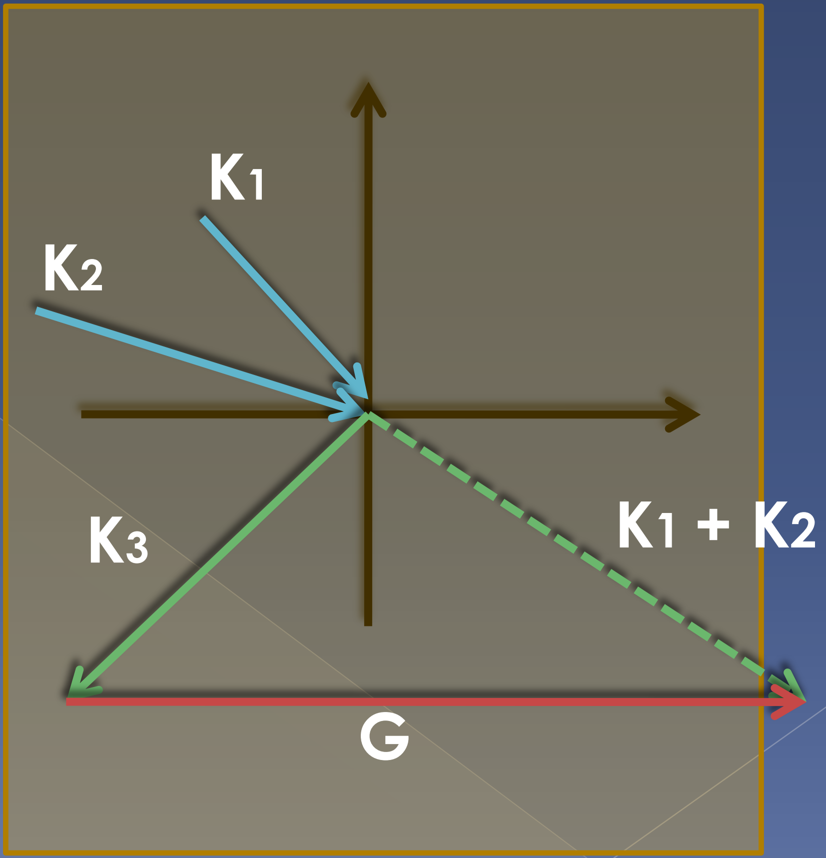
Mean free path

$$K = \frac{1}{3} C v l$$

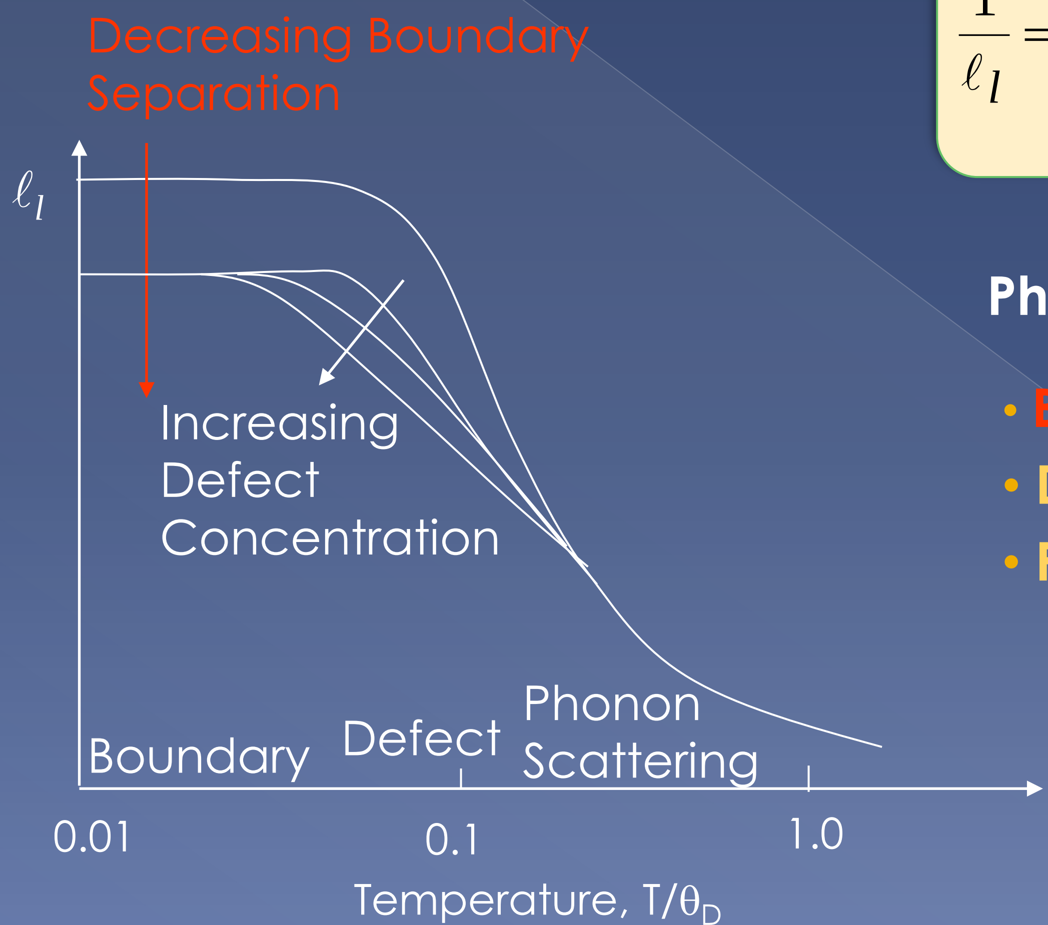
- Relation between K and l
- How do we describe l (average mean free path)?

Umklapp scattering process





Phonon Thermal Conductivity



Matthiessen Rule:

$$\frac{1}{\ell_l} = \frac{1}{\ell_{defect}} + \frac{1}{\ell_{boundary}} + \frac{1}{\ell_{phonon}}$$

Phonon Scattering Mechanisms

- **Boundary Scattering**
- **Defect & Dislocation Scattering**
- **Phonon-Phonon Scattering**

Thank you for your attention