Estimating evaporation rate

Revised on 2025/August/25th

Purpose of this text

We sometimes evaporate the materials in the UHV chamber for depositing them onto a substrate.
While the evaporation temperature differs depending on the material, the evaporation temperature is often not written in the paper (only the evaporation rate is written).

In this document, I will briefly introduce how to estimate the evaporation rate from the vapor pressure graph, using Sn as an example.

Although the melting point of Sn is ~230 ℃, the effective deposition of Sn needs ~800℃.
Such a high temperature is hard to reach using a normal hand-made evaporator.
We also introduce how we did to reach high temperatures.
(Note that the Sn evaporation finally failed, although we reached the desired temperature. We found something like Sn-oxide. We don't know if this is because of the evaporator or not.)

Estimation of evaporation rate of metals

According to the kinetics theory of gases, the number of atoms that collide with the surface is expressed by

$N = 3.5 \times 10^{22} p(MT)^{-1/2}$ ($cm^{-2}s^{-1}$)

p: pressure (torr), M: molecular weight, T: temperature (K)

Number of atoms in monolayer: ~10^{15} atoms/cm^2

For example: Sn deposition (molecular weight: 119)

$N = 0.32 \times 10^{22} p/\sqrt{T}$ ($cm^{-2}s^{-1}$)

Deposition rate (r: ML/s) and pressure:

$r \times 10^{15} = 0.32 \times 10^{22} p/\sqrt{T}$

$p = 3.1r\sqrt{T} \times 10^{-7}$ [torr]~$r \times 10^{-5}$ [torr]

Here 770℃ is assumed for rough estimation.

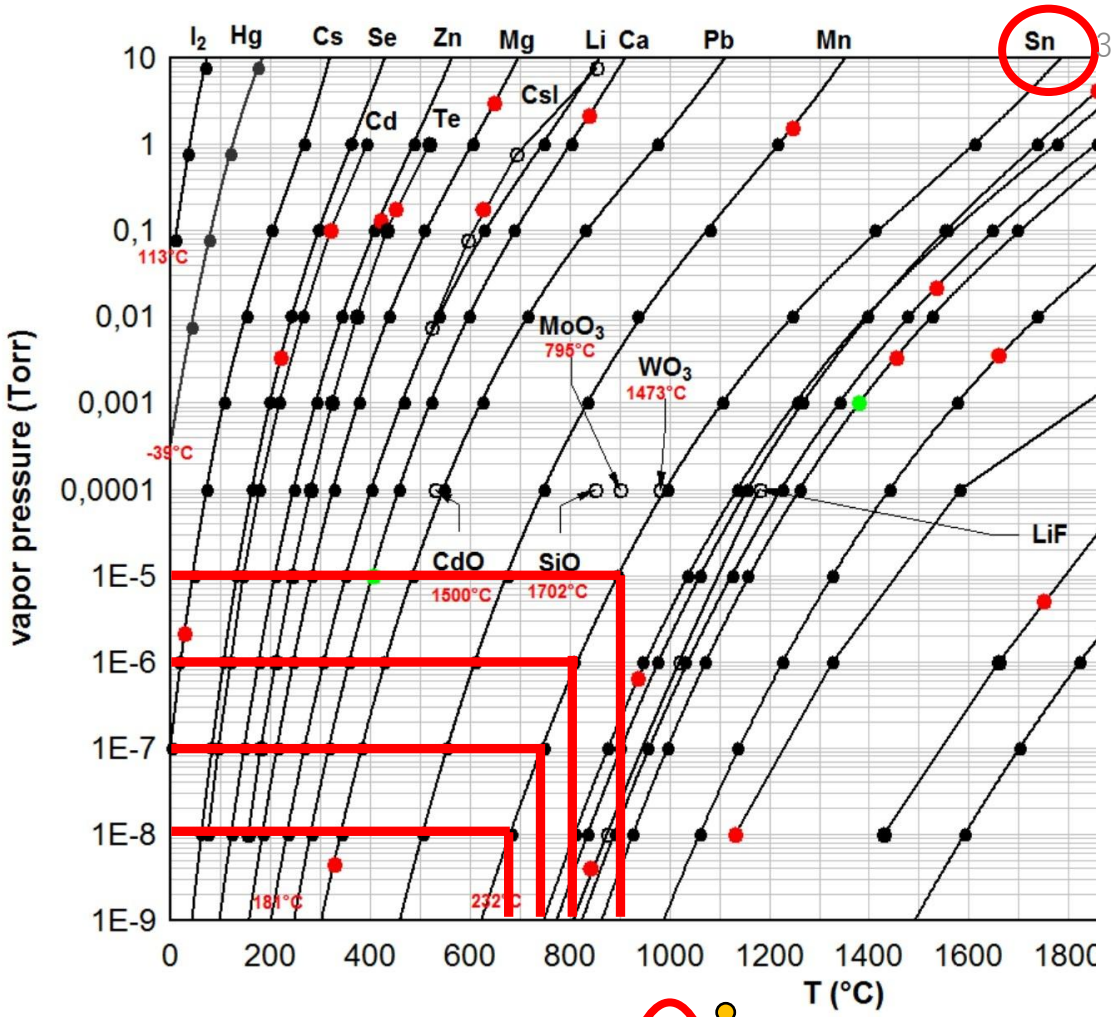
By referring the vapor pressure curve:

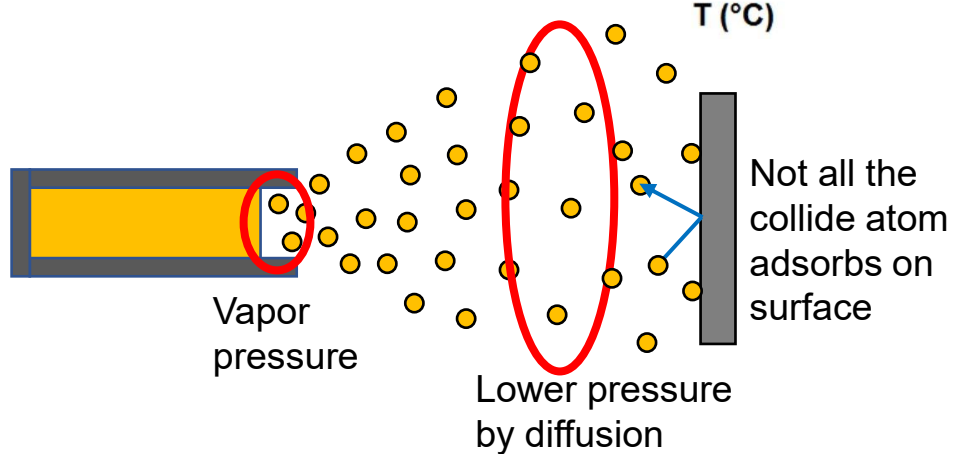
For
- 1 ML/s: $p = 1 \times 10^{-5}$ →~900℃
- 0.1 ML/s: $p = 1 \times 10^{-6}$ →~800℃
- 0.01 ML/s: $p = 1 \times 10^{-7}$ →~730℃
- 0.001 ML/s: $p = 1 \times 10^{-8}$ →~680℃

In real evaporation, **much higher temperatures** would be necessary because of the following reasons:

(i) Diffusion of vapors before reaching the sample.

(ii) Low adsorption probability.

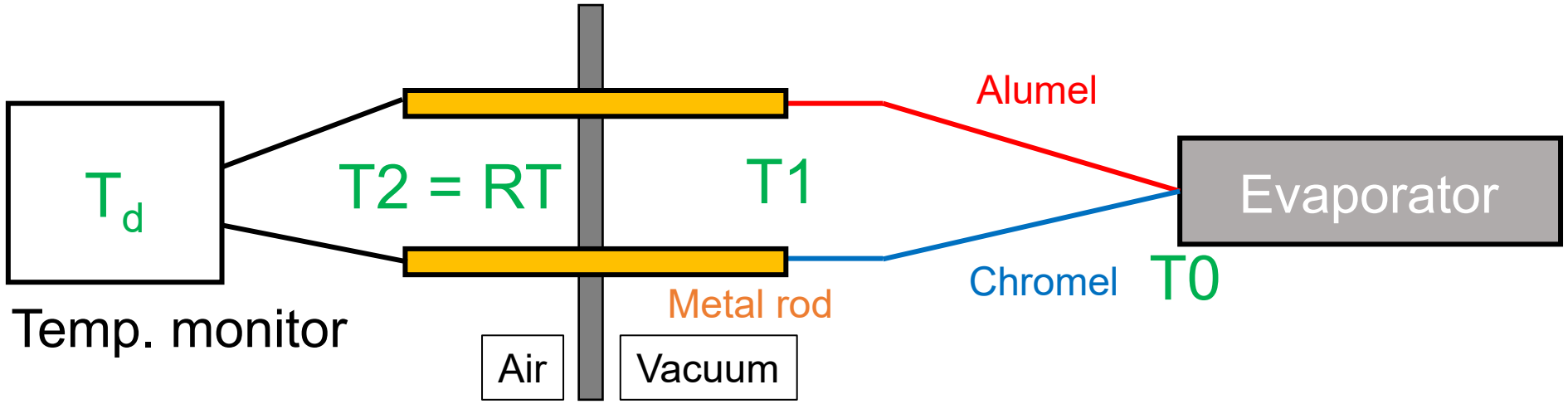




Sn evaporation temperature in other studies

Reference	Temperature	Rate
M. Maniraj et al., PRB 98, 205419 (2018).	1100 K	
J. Deng et al., Nat. Mater. 17, 1081 (2018)	800℃	0.1~0.5 ML/min
P. Sadhukhan et al., Appl. Surf. Sci. 506, 144606 (2020).	1080 K 1140 K	0.055 ML/min 0.44 ML/min
M. Maniraj et al., Commun. Phys. 2, 12 (2019).	1150 K	

Error in thermo couple



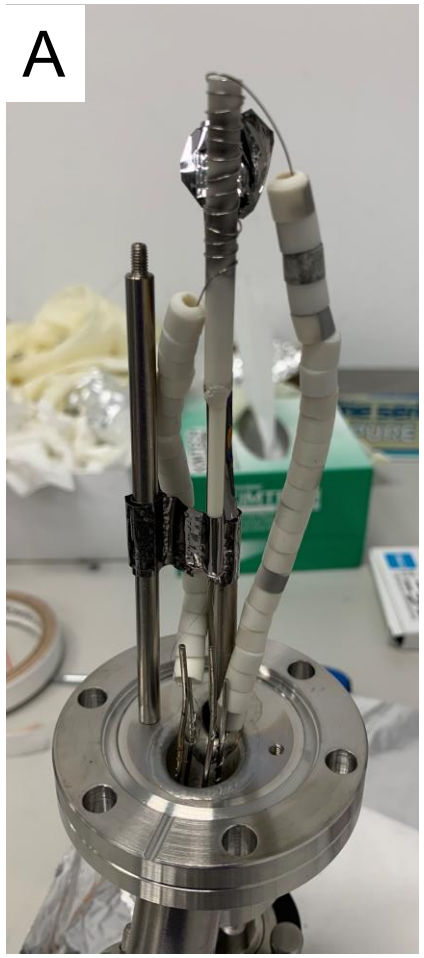
Our evaporator setup:

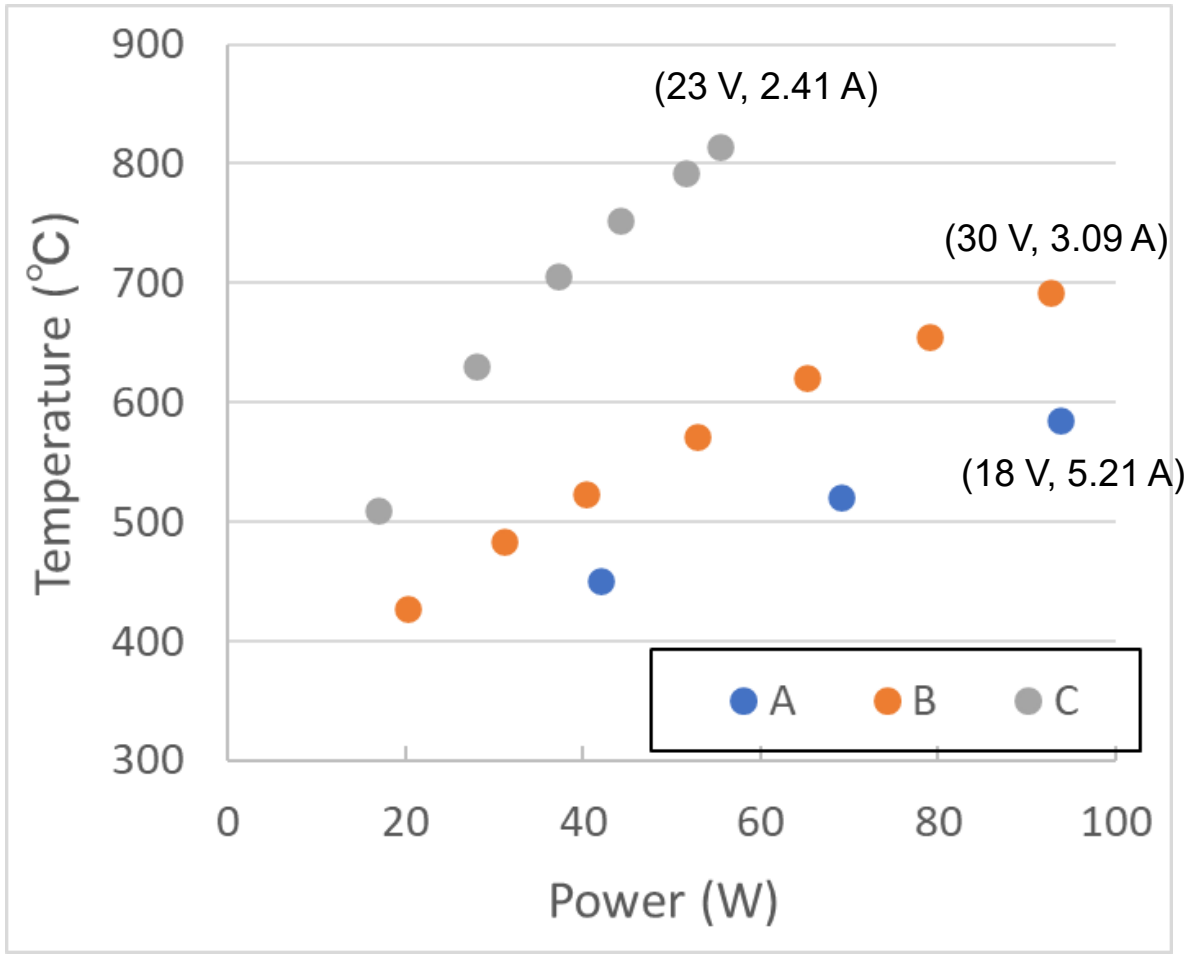
The K type thermocouple is connected to the evaporator. The other side of Alumel and Chromel is connected to a metal rod.

The thermocouple generates the voltage in proportion to the T0-T1. **The temperature change in metal rod (T1-T2) is not included.**

Therefore, if the vacuum side of the metal rod becomes hot, the displayed temperature (Td) is lower than the real temperature (Td<T0).

Evaporator setting for efficient heating

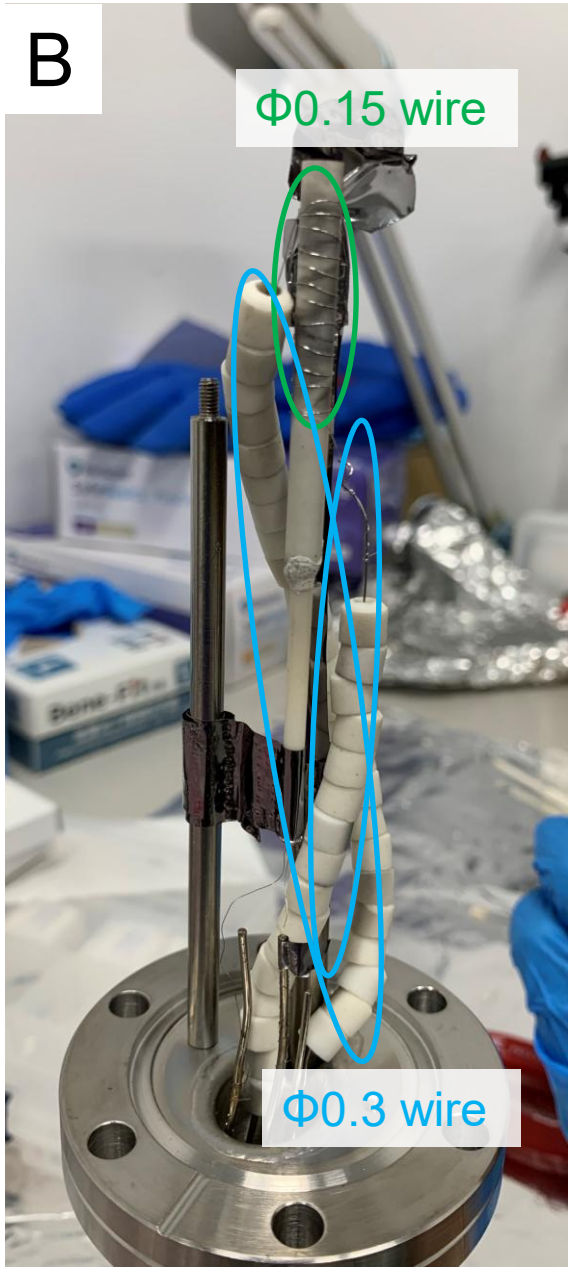




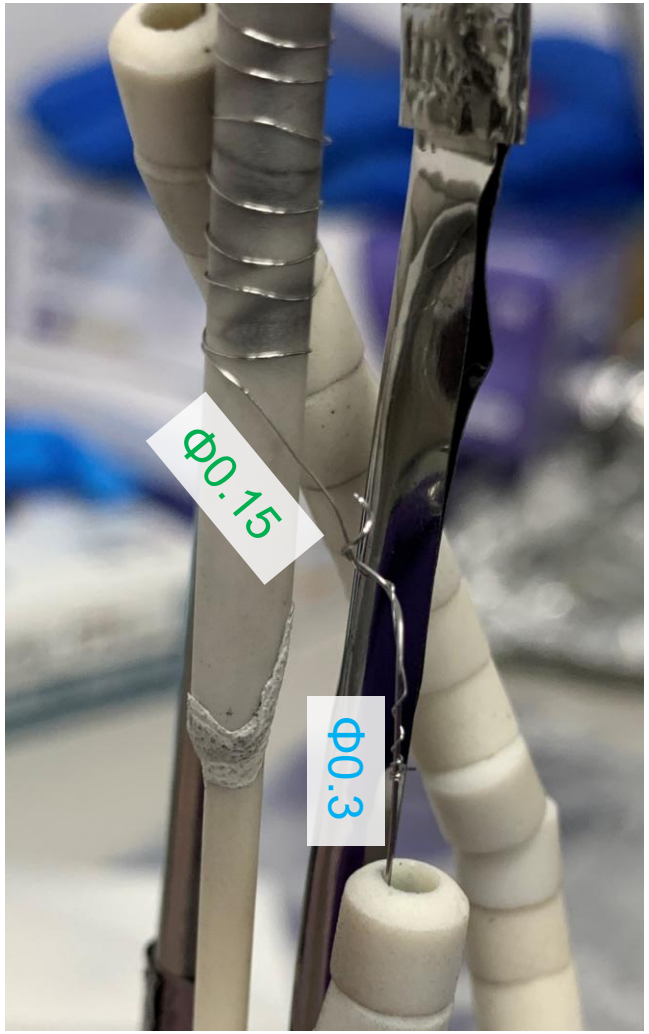
Type A: Filament: Φ0.3 mm W wire (Normally used setting)
Type B: Filament: Φ0.3 mm + 0.15 mm W wire
(For the effective heating of the crucible by using a high resistance wire at the crucible part).
Type C: Type B + a cover around the crucible
(For reflecting the radiation from the filament back to inside).

Detailed pictures of B and C

B



↓Connection between wires.
Two wires are entangled each other.



C

A cover made by 0.05 mm thick Ta foil

From top side

From bottom side