Introduction

- **Nb$_3$Sn cavity**: smaller heat load at 4.2 K & higher efficiency than Nb cavity
- Possible to operate at 4.2 K using a cryocooler
- Nb$_3$Sn coating method for the cavity: Vapor diffusion
- Best cavity performance at present.
- $Q_0 = 3.0 \times 10^{10}$ (at low field, 4.2 K), Eacc max = 22.5 MV/m [1]
- Nb$_3$Sn cavity R&D was started at KEK.
- To realize a Nb$_3$Sn cavity cryomodules with the cryocooler
- Constructed the coating system for development of Nb$_3$Sn coating cavities

**Requirement for Nb$_3$Sn Coating System**

- Nb$_3$Sn coating temperature by vapor diffusion
- Coating temperature: around 1100°C
- Avoid the growth of Nb-Sn compound
- formed Nb$_3$Sn when tin composition ratio 17-25 at%
- Cleanliness inside of the coating system
- Impurities are possible to degrade the cavity performance
- To prevent contamination from coating chamber
  ➞ **Need to prepare coating chamber made of Nb**
- To prevent contamination outside of the system.
  ➞ **Need to build clean booth**
- Condition for uniform coating
- The mean free path of the tin needs to be short

**Design of Nb$_3$Sn Coating System**

- Furnace
  - Operation temperature: 100°C ~ 1200°C ($\pm$ 10 °C)
  - Vacuum pressure: $< 1 \times 10^{-4}$ Pa (RT)
    - $< 1 \times 10^{-2}$ Pa (600°C)
    - $< 1 \times 10^{-1}$ Pa (1200°C)
- Coating Chamber
  - Material: Nb (ASTM commercial grade)
  - Inner size: $\Phi 305$ [mm] × 2272 [mm] (Cavity)
    + $\Phi 30$ [mm] × 80 [mm] (Tin crucible)
  - Vacuum pressure: $< 1 \times 10^{-5}$ Pa (RT, after baking)
    $< 1 \times 10^{-4}$ Pa (Coating process)
  - Tin heater
  - Maximum temperature: 1500°C
  - Tin crucible & Tin chloride crucible
  - Material: tungsten
  - Clean booth
  - Class 3, 2m in height, 1m in width, and 4m in length

**Commissioning of Furnace**

- After constructing, stand-alone test was performed.
  - Furnace
    - 500°C for 4.5 hours: Nucleation
    - 1100°C for 3 hours: Coating, Annealing
  - Tin heater
    - 1300°C for 1.5 hours: Coating
  - Vacuum pressure of the coating chamber was less than $1 \times 10^{-4}$
  - The coating system is possible to coat Nb$_3$Sn film

**Summary and Outlook**

- At KEK, Nb$_3$Sn coating system was constructed.
- Consists of the furnace, the Nb coating chamber, and the tin crucible heater.
- After constructing the coating system, the stand-alone test was performed.
  - Furnace: 500 °C for 4.5 hours, 1100°C for 3 hours
  - Tin crucible heater: 1100°C for 1.5 hours
  - The coating parameter was able to be realize using the furnace.
- We will study Nb$_3$Sn coating for high-efficiency Nb$_3$Sn cavity using the coating system.