２００６年度基礎技術開発結果報告

『A15-SC線絶縁被覆に関する研究』[A]

『超流動He中の沸騰熱伝達に関する基礎研究』[B]

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超伝導低温工学センター勉強会
2007.06.08

A Cooperative Experiment

Heat Transfer Characteristics of Electrical Insulation in He-IIp

『A15-SC線絶縁被覆に関する研究』

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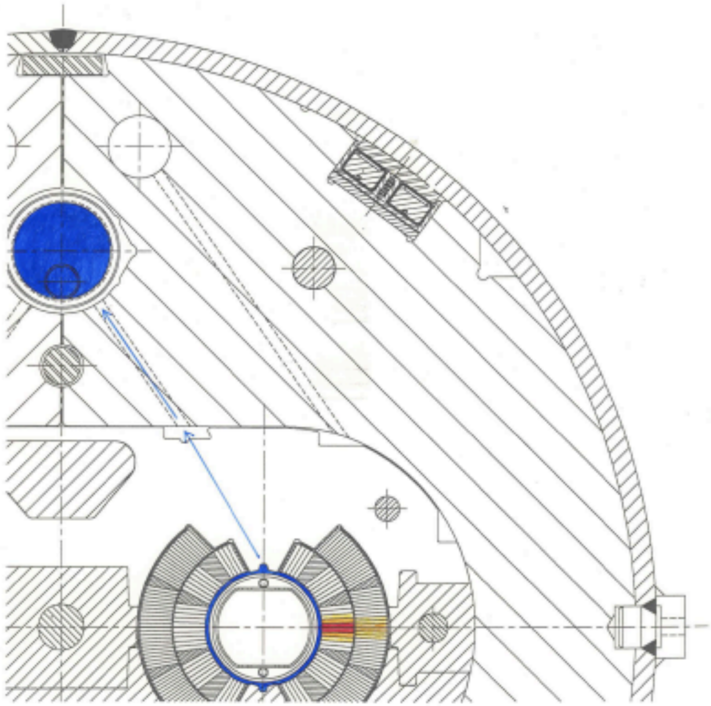
Carried out at Saclay, March, 2007

Reminder

- Heat transfer from the conductor to the cold source define the temperature margin

- Electrical insulation is the largest thermal barrier against cooling

- Electrical insulation can be
  - Non-existent
  - Monolith
  - For LHC magnet
    - $T_{conductor}$=1.9 K or $T_{conductor}$~4 K [Burnod 1994]

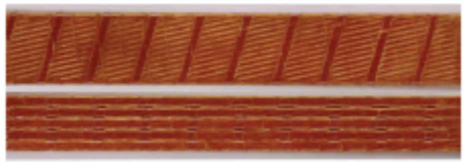


- Previous works focused on the thermal paths (He II)
  - Creating paths between the conductors by wrapping different configurations and minimizing the glue…
  - No complete work on the solid material (holes, conductive insert or porosity)

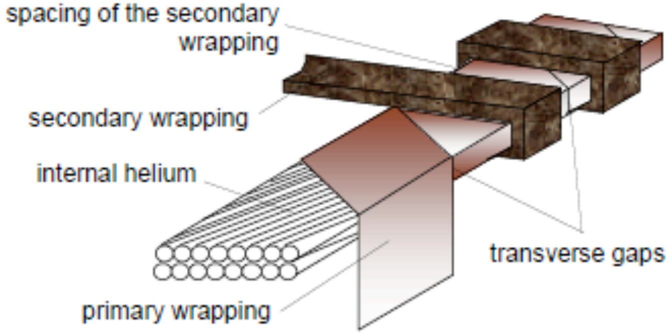
The *classical* insulation

- Historical insulation : 2 wrappings
  - First wrapping in polyimide with 50% overlap
  - Second wrapping in epoxy resin-impregnated fiberglass with gap

-
- The LHC insulation work : 2 wrappings
  - First wrapping in polyimide with 50% overlap
  - Second wrapping in polyimide with polyimide glue with gap



- Current LHC Insulation : 3 wrappings [Meuris 1999]
  - First 2 wrappings with no overlap
  - Last wrapping with a gap

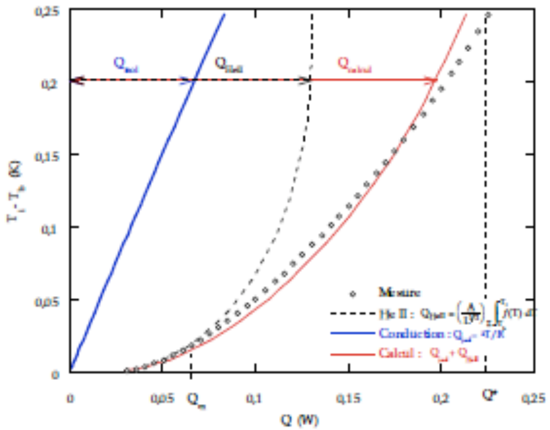


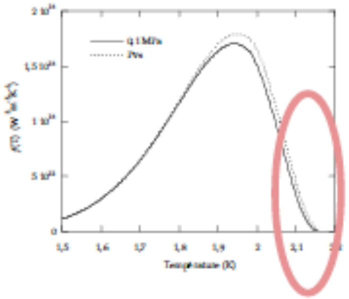
Heat transfer in *classical* insulation (2/2)

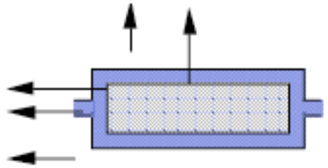
dapnia
cea
saclay

- Importance of conduction in the insulation
  - For Large ΔT, He II HT < Conduction HT

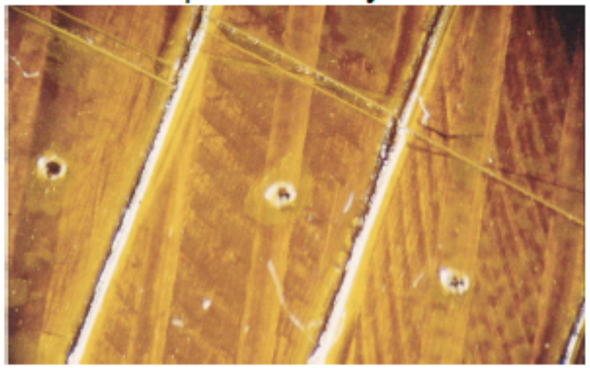
[Kimura 1999] and [Baudouy 2OO1]

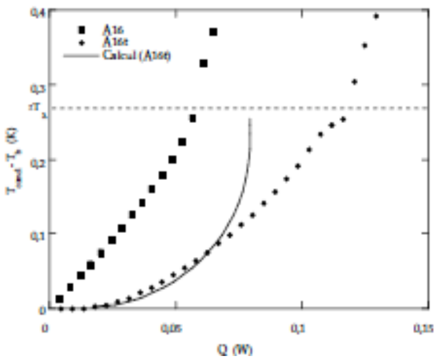






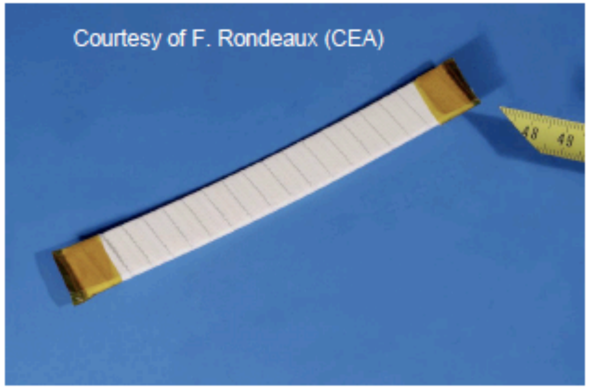
- Importance small face porosity [Baudouy 1996]
  - Artificial permeability with 6 holes of ϕ 200 µm





The *ceramic* insulation

- For the next generation of high field magnets, Nb_3Sn is considered
- Higher heat deposition than in current magnets is expected
  - Beam losses : 10 mW/cm^3 (LHC) and 50 to 80 mW/cm^3 (LHC upgrade)
- Since 1997, development by J.M. Rey and F. Rondeaux
  - Ceramic materials are investigated in replacement for the classical insulation (Fiberglass + epoxy resin impregnated after heat treatment)
  - One step process
    - Obtain a coil after heat treatment (Same than Nb_3Sn) with no impregnation
    - Good wrapping and resistance to heat, reduce fabrication complexity and costs
  - Increase the volume of He in the insulation and the thermal path
    - Higher enthalpy reserve and overall thermal conductivity
- Innovative insulation for Nb_3Sn magnet
  - Fiberglass tape + Ceramic precursor
  - (80%SiO_2 + argil) [Puissegur 2004]



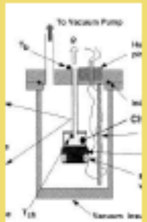
Courtesy of F. Rondeaux (CEA)

He II Heat transfer in confined geometry

dapnia

cea

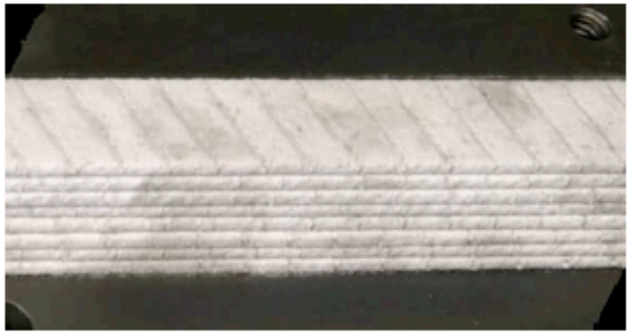
saclay



- Physical law in He II modified by the geometry?
  - Properties modified?
  - A(T), ρ_s, …

  - HT regimes modified?
  - Landau regime
  - Superfluid turbulence (fully developed?)

- Modeling sufficient?
  - Coupling between solid and He II
  - Porous media model?



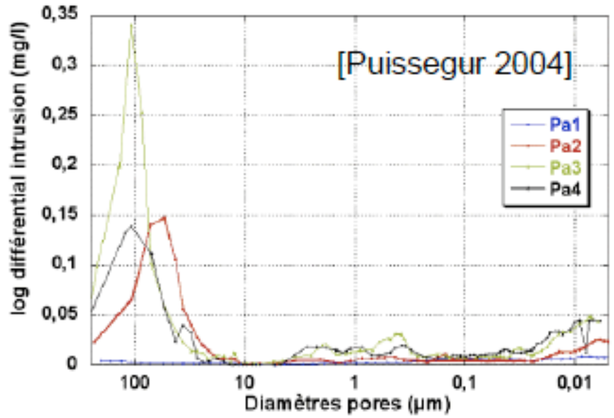
Heat transfer considerations

	Ceramic	*Classical* (Polyimid)
• Geometry	Porous	Channels (slits)
• Pore size, d	~100 µm	10 µm at Saclay (determined) 100 µm at KEK (determined)
• Porosity,ε	4.5 to 29 %	~1 % (ratio of A_{HeII}/A_{total})
• Conductivity, k	≈4 10^{-2} W/Km	k_{kapton}≈10^{-2} W/Km @ 2 K
• Kapitza conductance	h_k=3200 W/m²K	h_k=4000 W/m²K @ 1.5 K

– Thickness < 10 µm for a Kapitza resistance influence…

→ What is the influence of the geometry on the total HT?

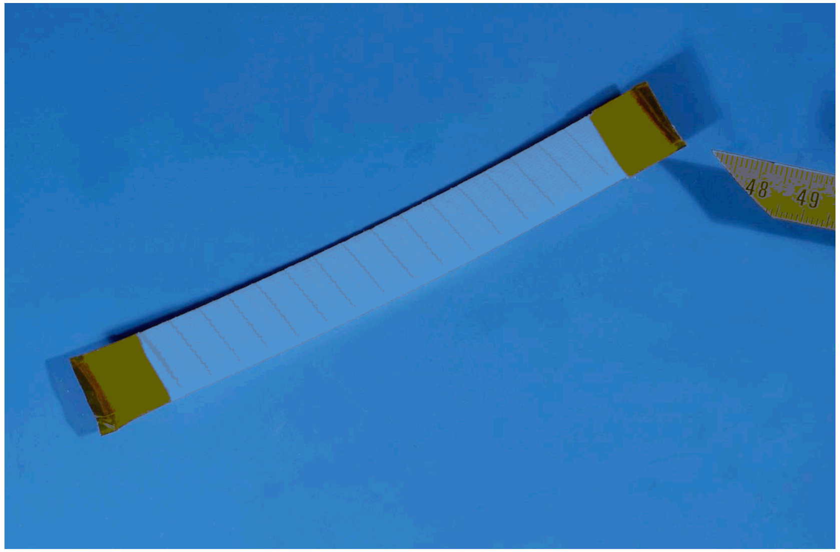
→ Helium + conduction = Insulation?



A Cooperative Experimental Study

- Heat transfer characteristics of a new type electrical insulation system developed by CEA/Saclay.
- Method of “stack model measurement” using with CuNi dummy cable developed by KEK applied.
- Test carried out CEA/Saclay based on collaboration program between KEK and CEA/Saclay.

- An “innovative” electrical insulation system were prepared at Saclay (glass fiber tape + ceramic)



Courteys of F. Rondeaux (CEA)

- **At three cooling schemes to be tested**
  - superfluid helium at 1 atm (tested at Saclay)
  - supercritical helium (will be tested at KEK)
  - pool boiling He I at 4.2 K and 1 atm

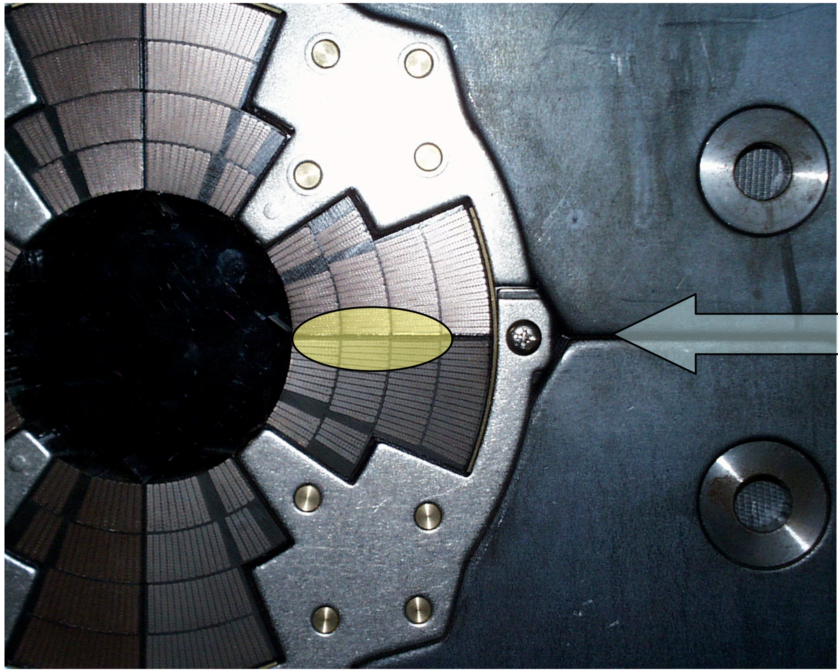
NED Program (1/3)

- Collaboration between CEA-Saclay, KEK, CERN and RAL
  - Tests in He II at CERN and Saclay
  - Tests in SHe at KEK
- Construction of a Double bath Cryostat (WUT and CEA-Saclay)
- Construction of molds by KEK (N. Kimura)
- Construction of 1D HT drum

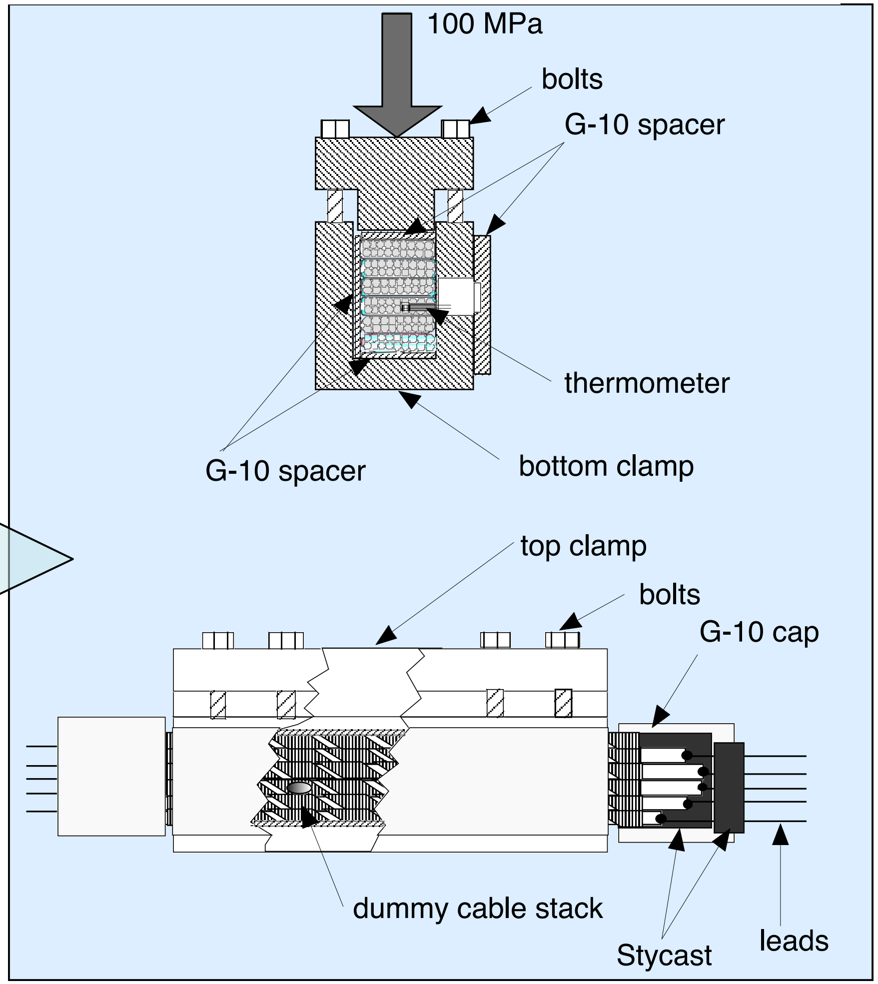
[Chorowski 2006]

Test Sample：

Structure as same as real superconducting magnet



Cross section of superconducting coil



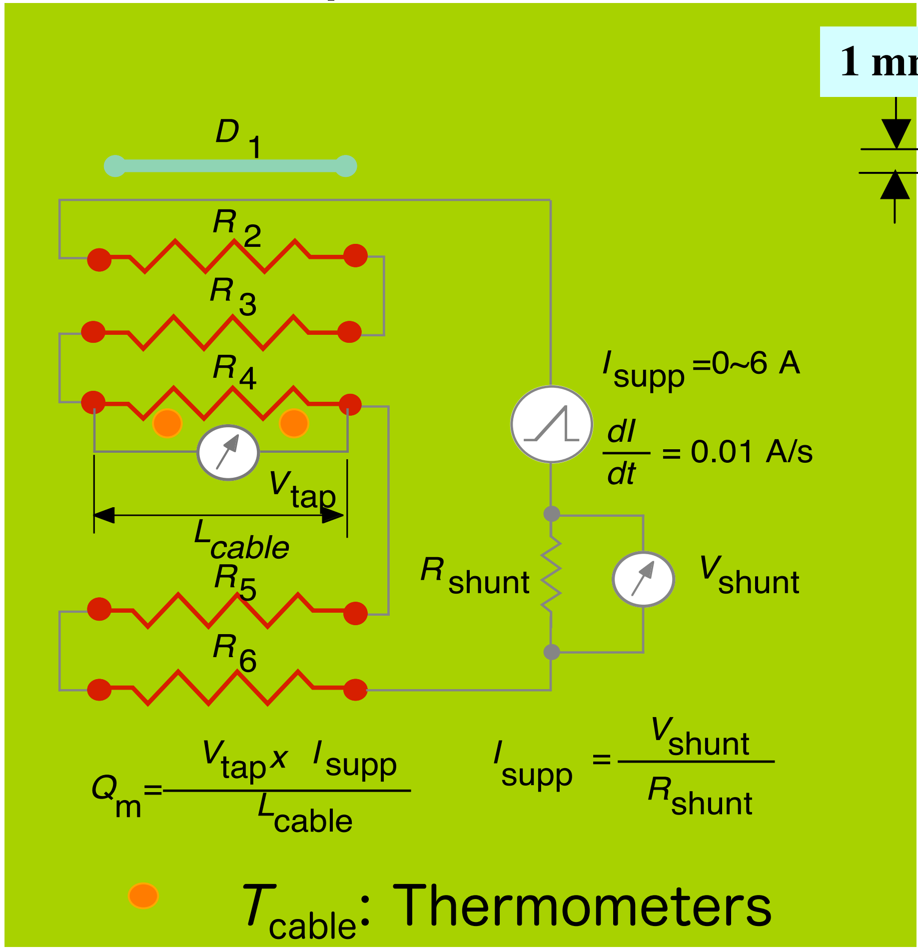
Structure of dummy coil

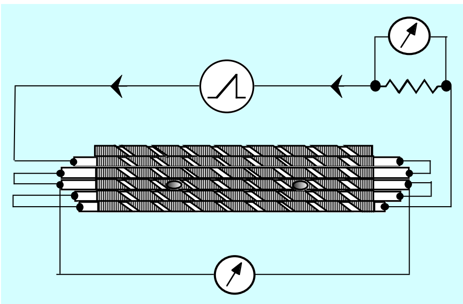
Method of Heat Transfer Measurement

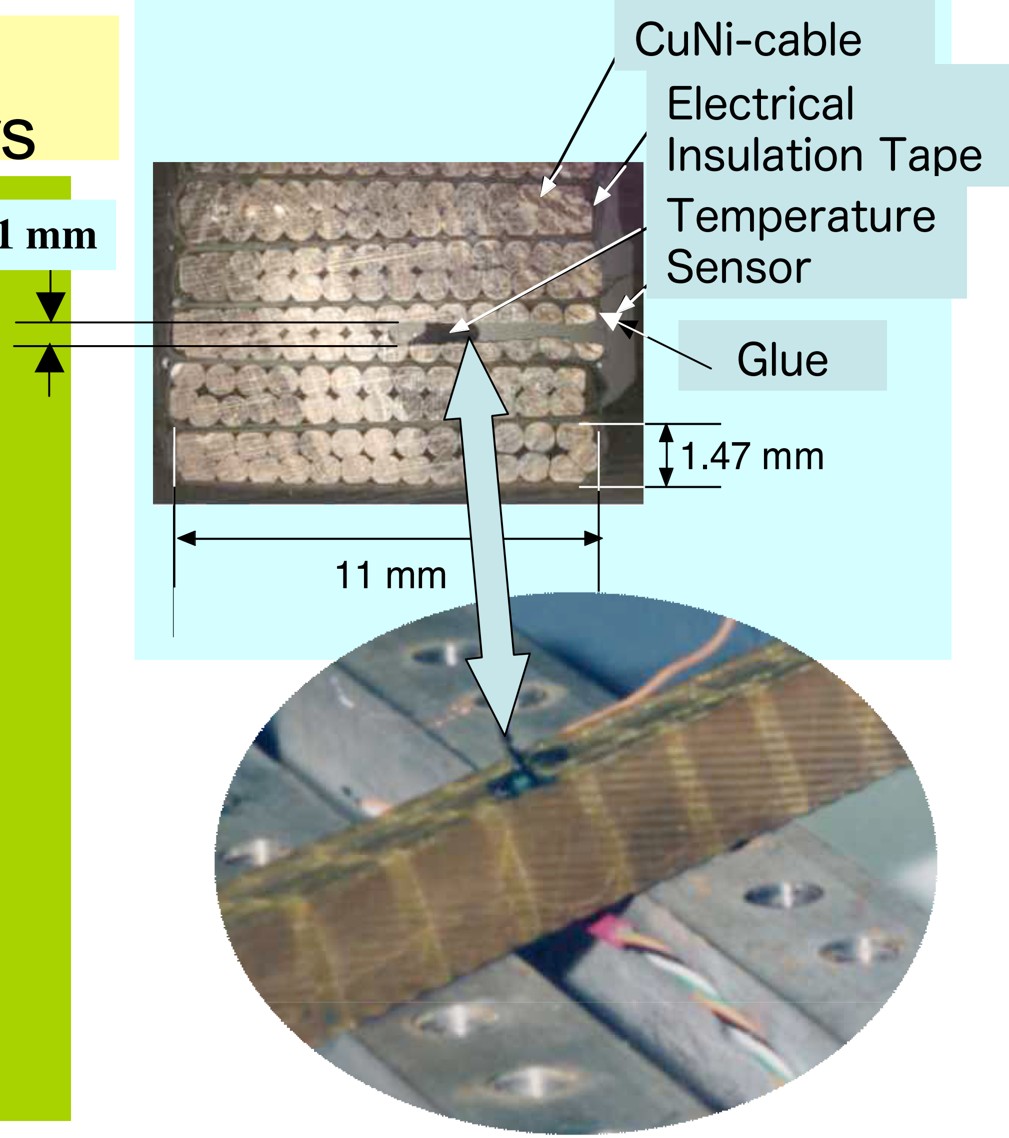
- Temperature rise due to Beam induced heating
  - Identical configuration with superconducting cable,

    but resistive cable
    - Joule heating to simulate internal nuclear heating
    - Temperature measurement to know heat flux

Heater circuit and temperature sensors



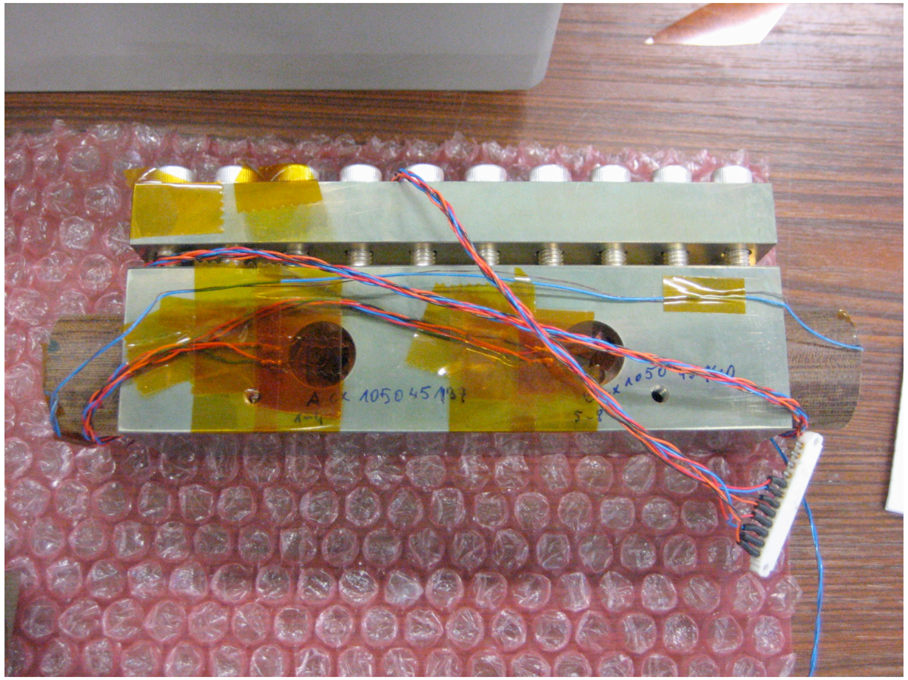




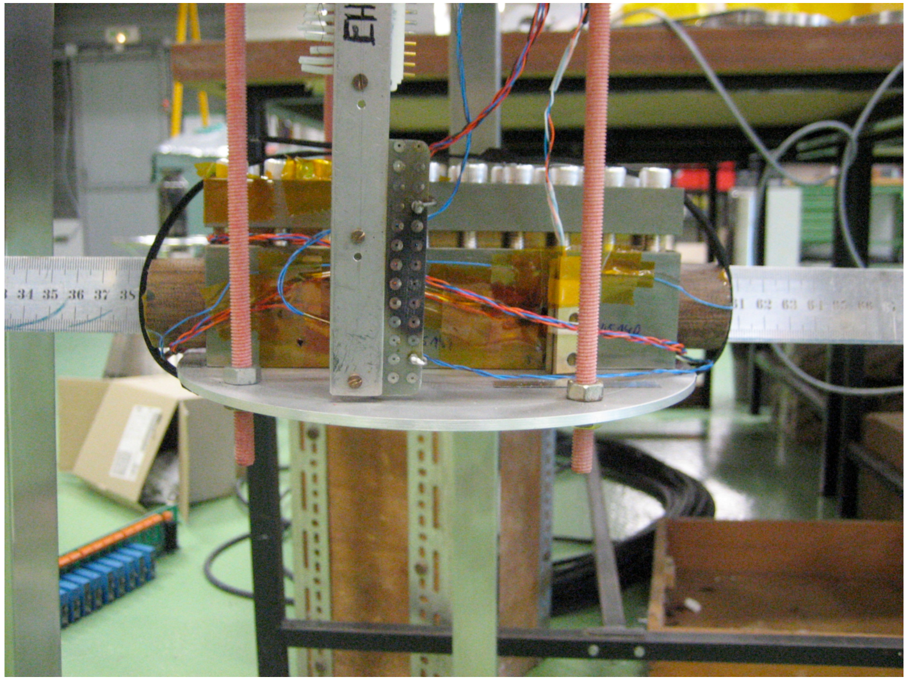
Cross-section of dummy coil and temperature sensors

Experimental setup : Stack experiment

- Stack of five insulated conductors under mechanical constraint
- Conductor = CuNi Strands Ø 0.8 mm (w=11 mm x t=1.5 mm)

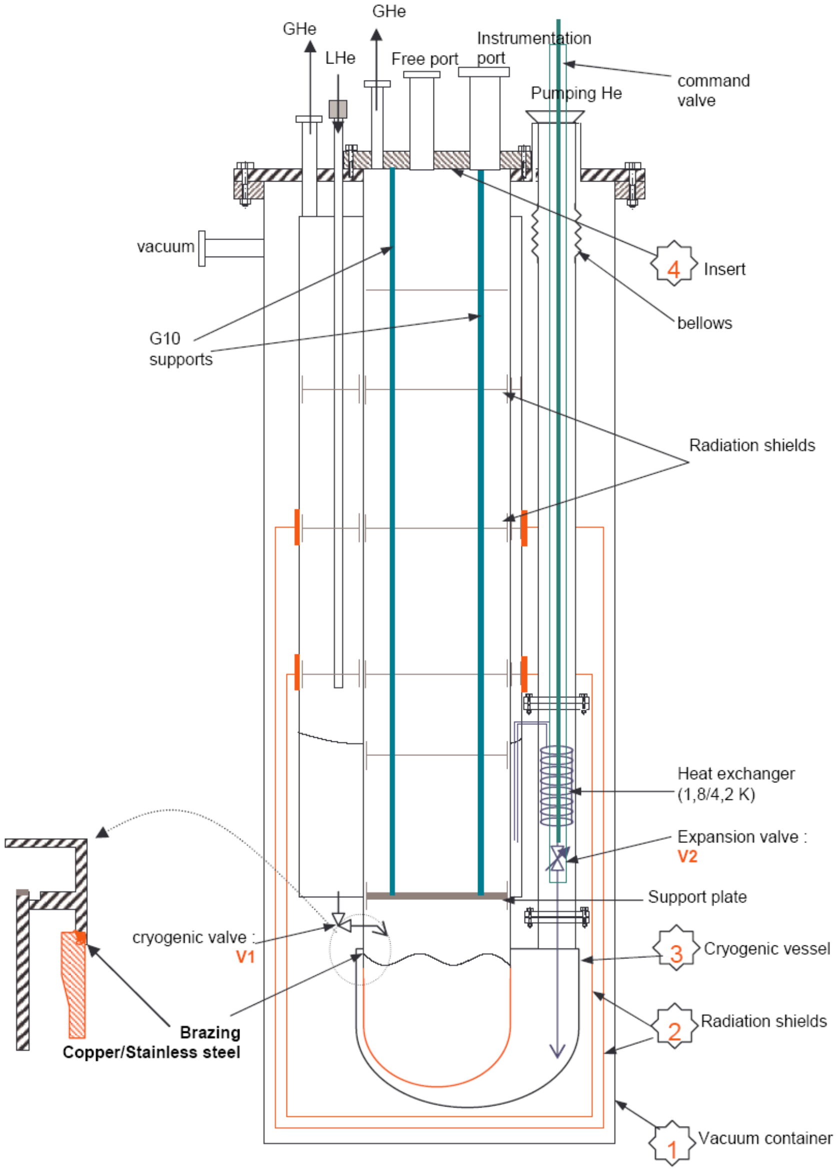


Mechanical structure design
and manufacture by KEK



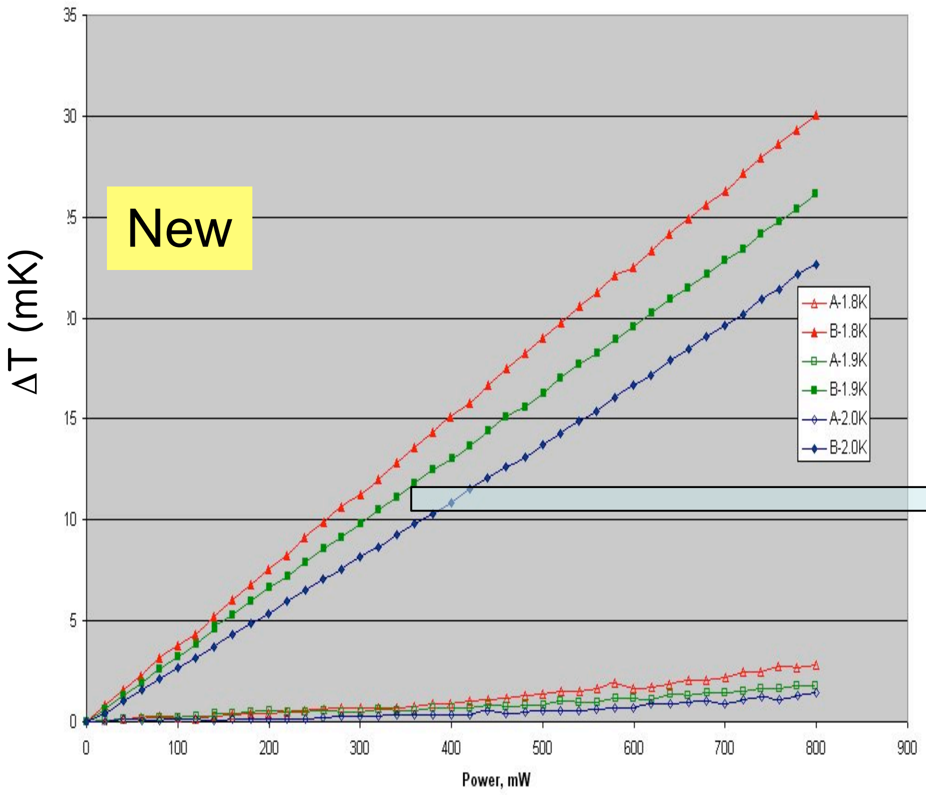
Construction and installation work
by Saclay

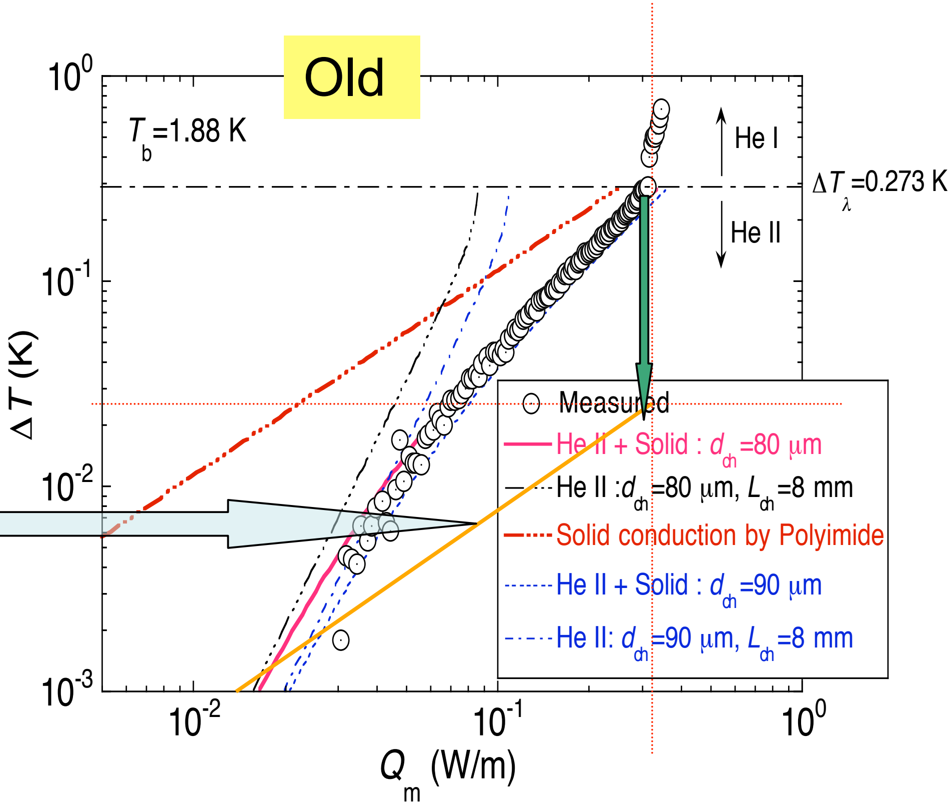
He II double-bath Eperiment at Saclay



Photograph of the double bath cryostat at Saclay

Comparison of new type and classical insulation





- New type insulation:
  Temperature difference between cable and bath is proportional to heat input. It seems that new type insulation has good performance compared with classical insulation such as LHC.
- Classical insulation system:
  Heat transfer of the classical insulation is obeyed complex of Gorter-Mellink region of He II and solid conduction.

Experimental Results

- *Temperature difference between in the cable and bath is proportional to heat input.*

- *It is clear that new insulation has sufficiently large conductance compared with classical insulation such as LHC.*

- *Good performance were (considered to be) given by heat transfer pass through the porous in the insulation tape.*

- *The stack model, tested at Saclay, will be transferred to KEK and measured heat transfer performance under Super Critical Helium, this Autumn.*

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『超流動He中の沸騰熱伝達に関する基礎研究』

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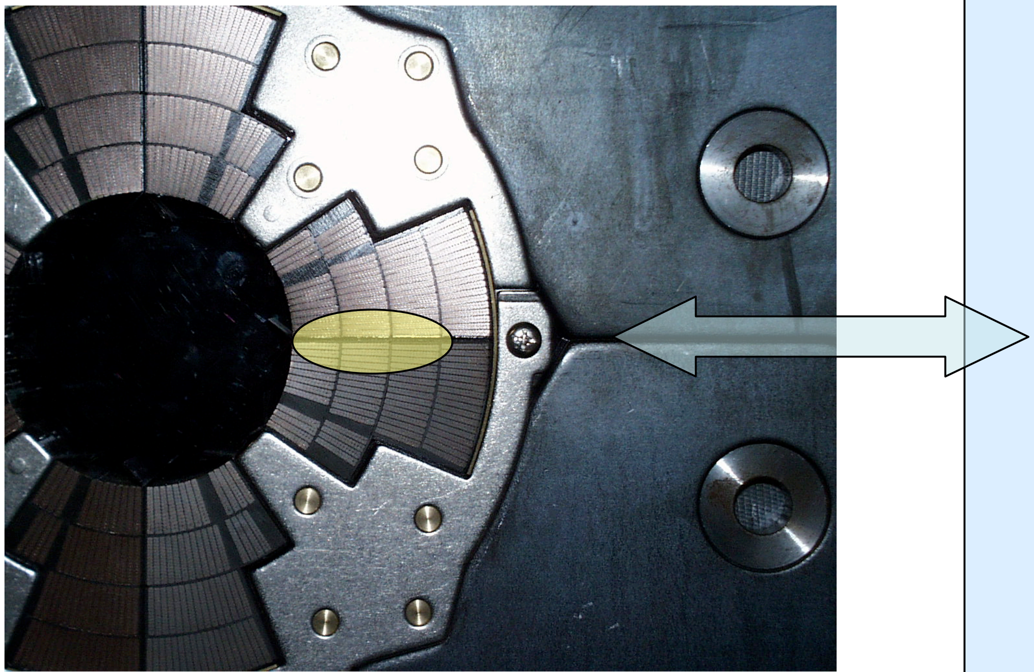
2007.06.08

Narrow channel in superconducting magnet



Cross section of superconducting coil

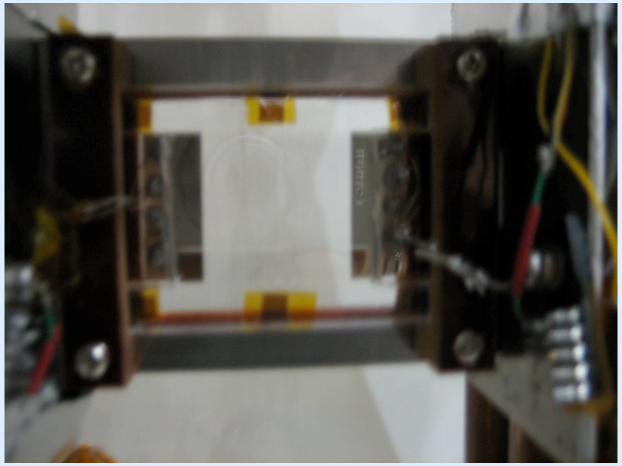


Photo of heater assembly

狭小流路中の沸騰現象の可視化

Narrow Two Dimensional Channel：
透明ヒータ（酸化インジウム薄膜）とガラスによって形成

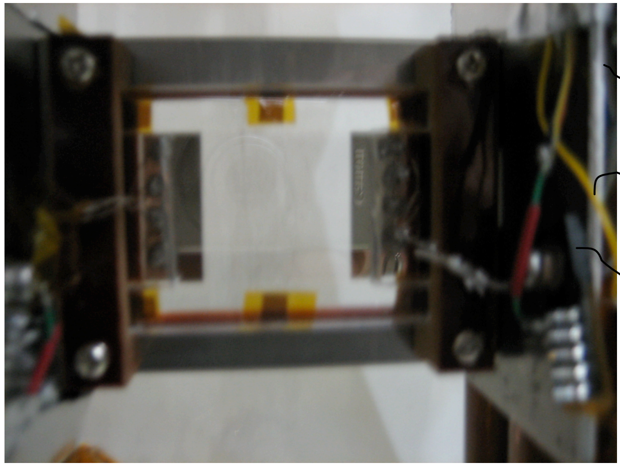
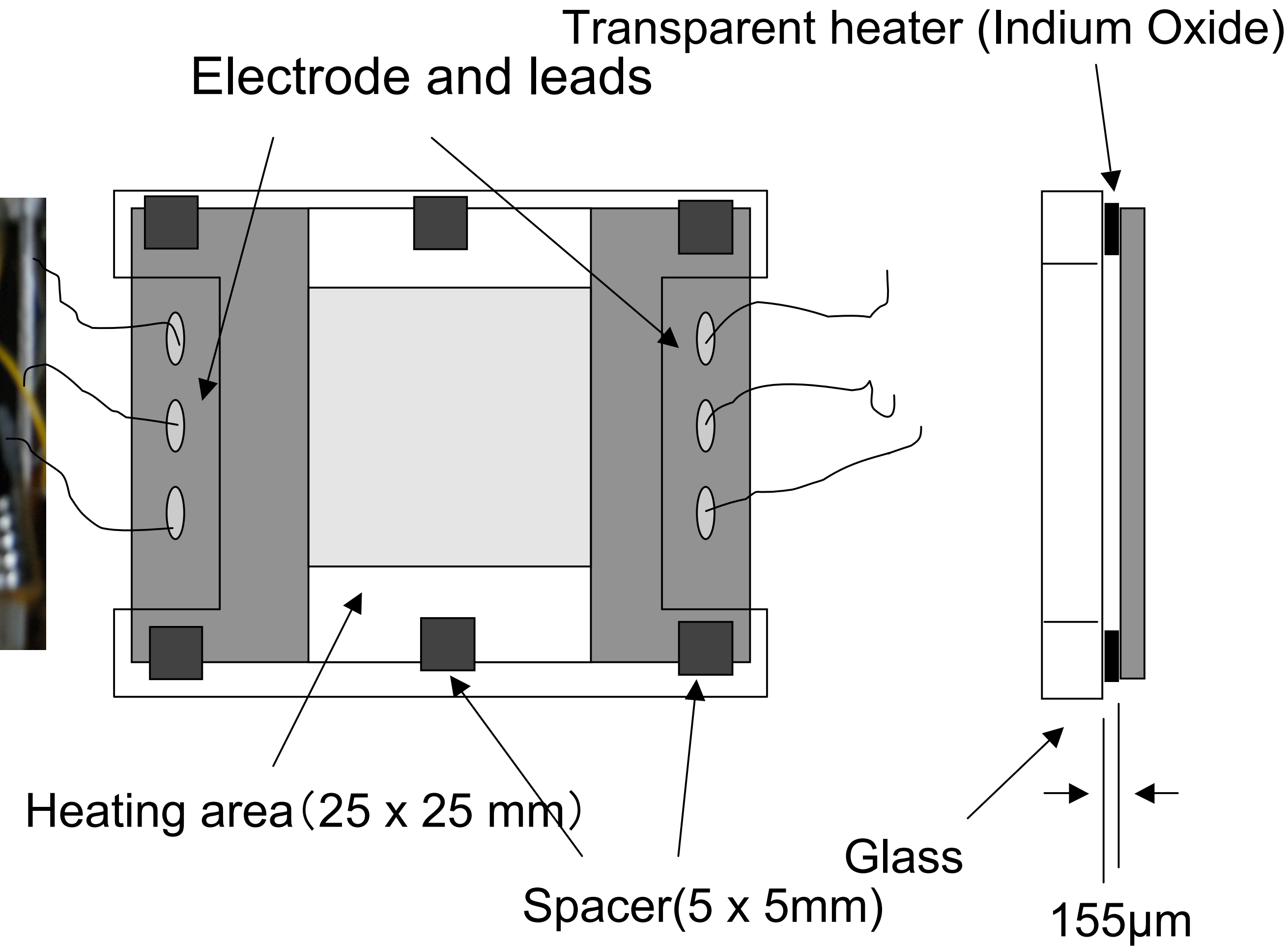


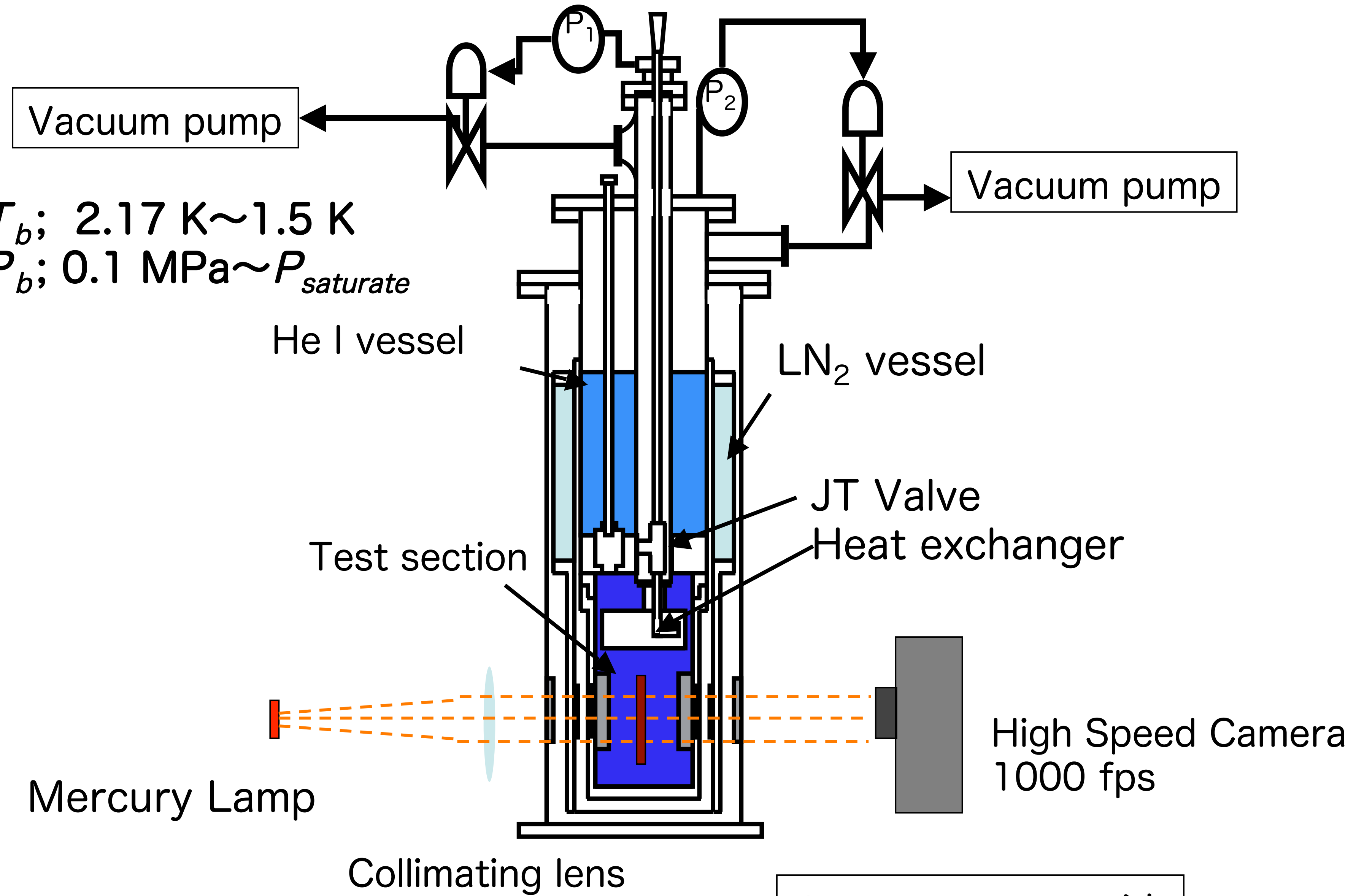
Photo of heater assembly



加熱方法：時間に対して方形状の電流を0.8 sec　印加

Claudet type cryostat;

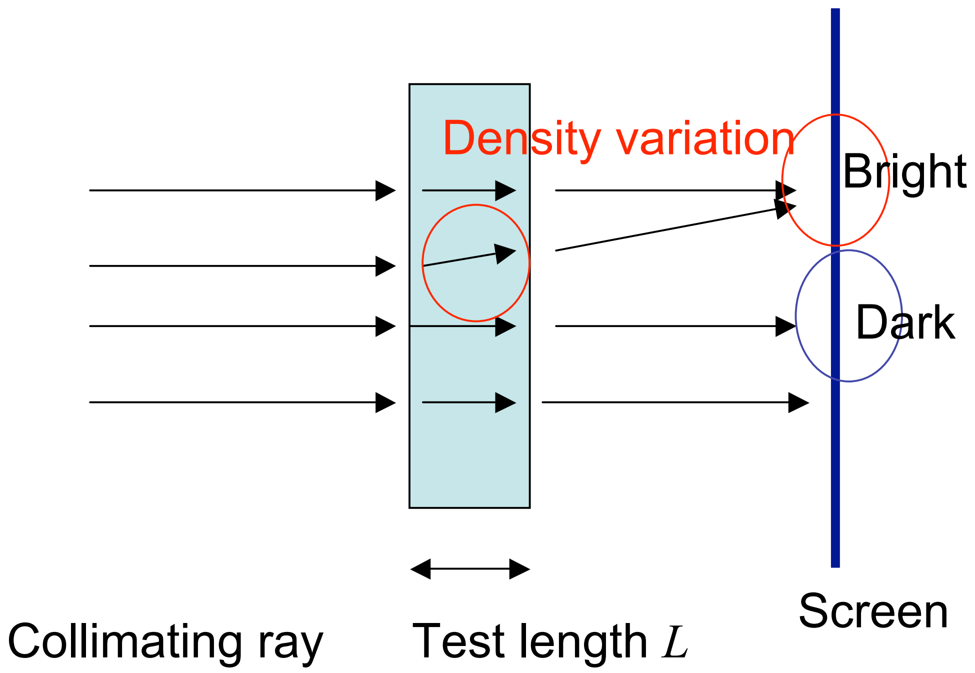
T_b; 2.17 K～1.5 K
P_b; 0.1 MPa～$P_{saturate}$

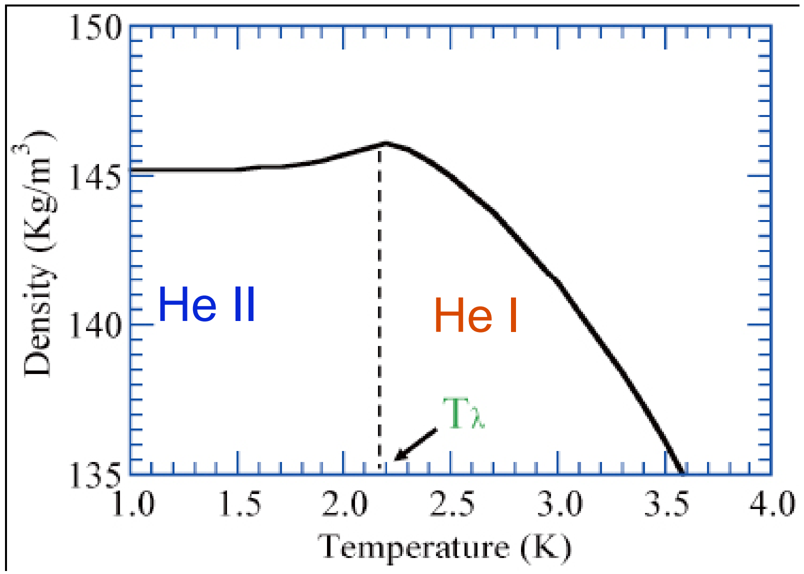


Shadowgraph法

Visualization method

Shadowgraph Method

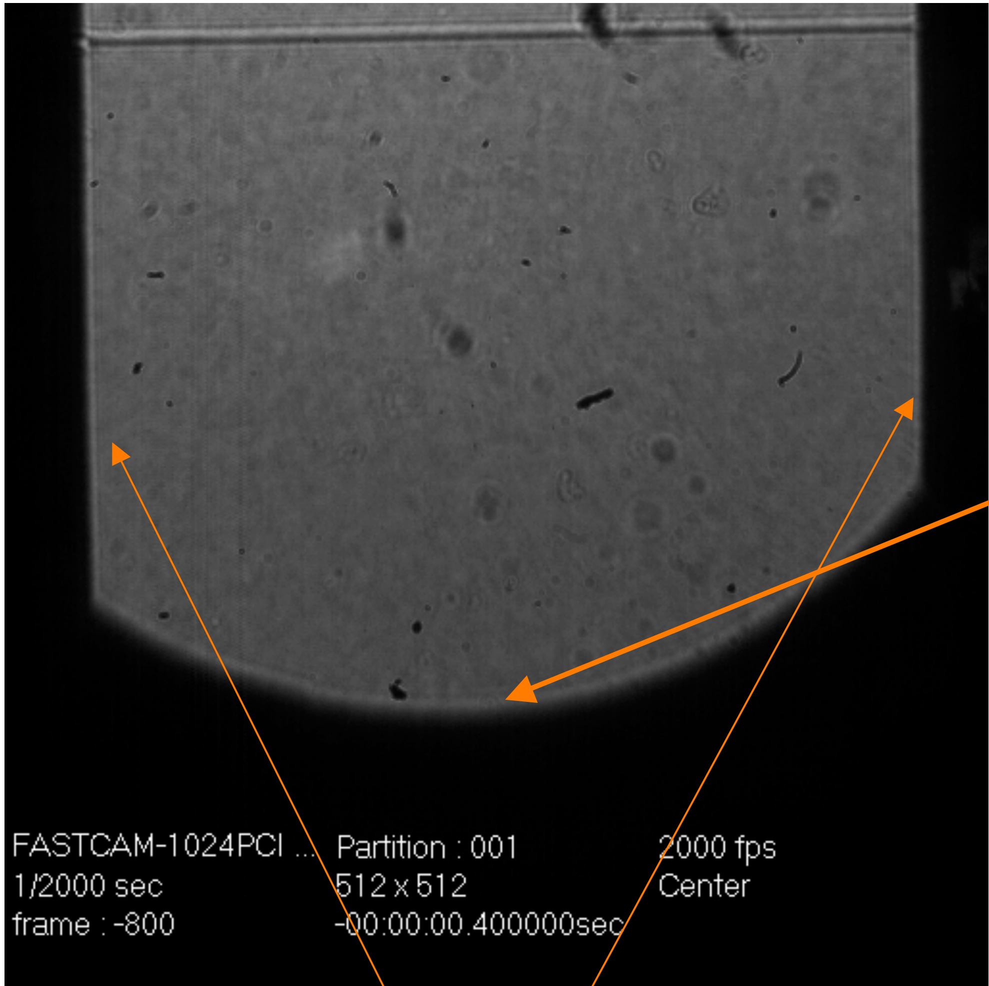




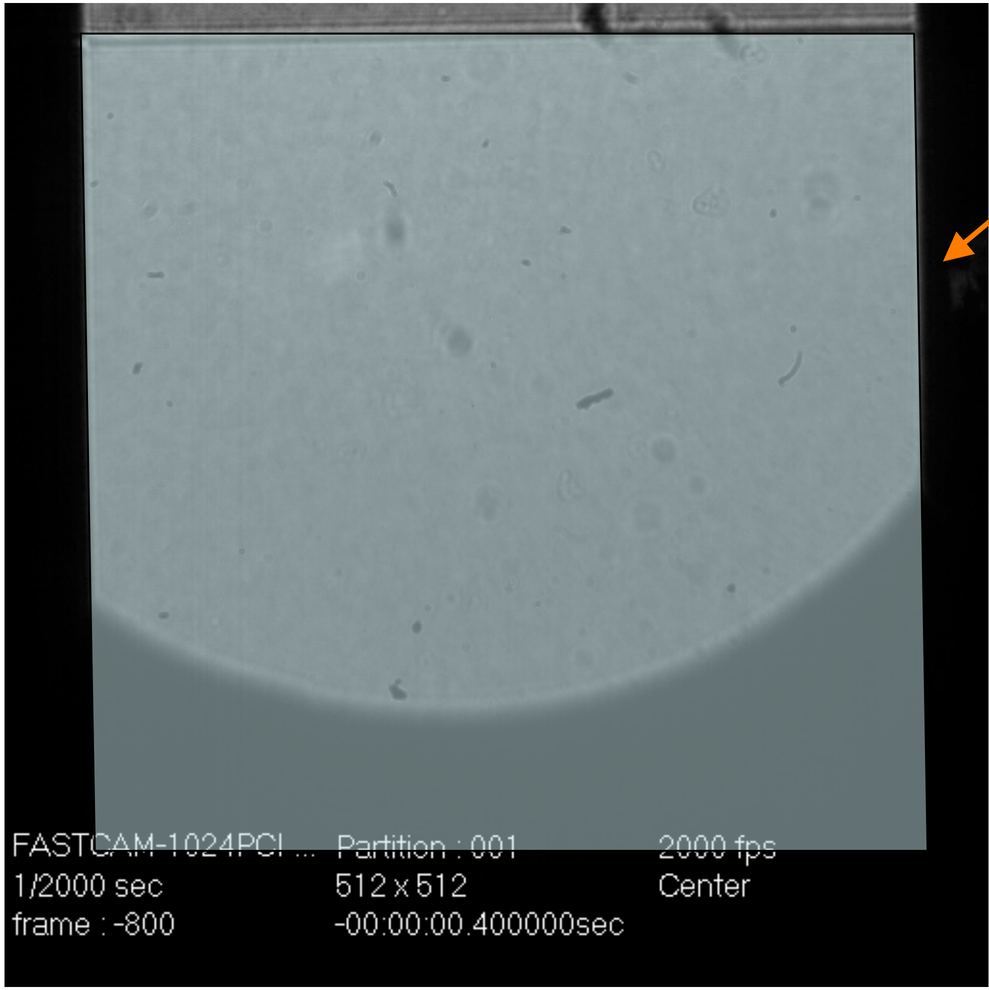
He II中でのシャドウグラフ法

気液界面やHe II－He I界面 など密度変化の大きい箇所が明暗のある像となって現れる。

He II 膜沸騰の撮影例



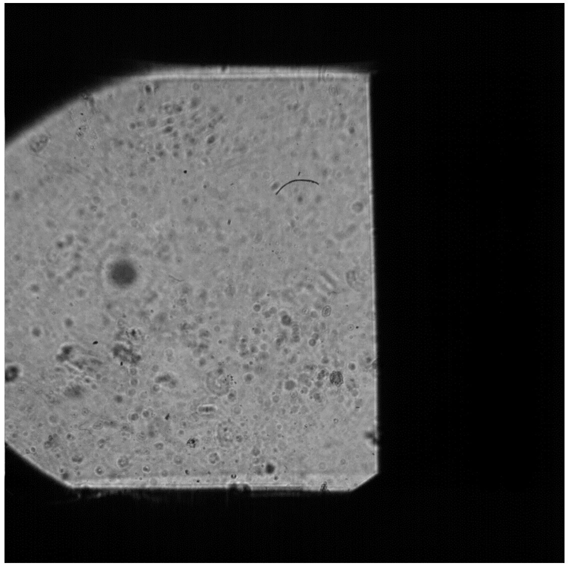
He II 膜沸騰の撮影例

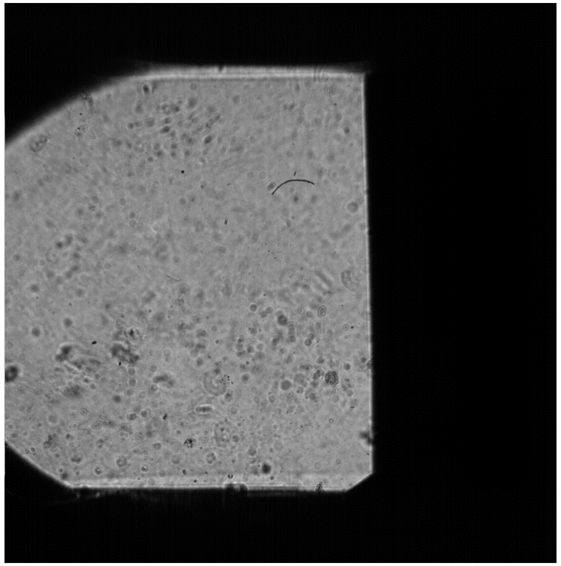


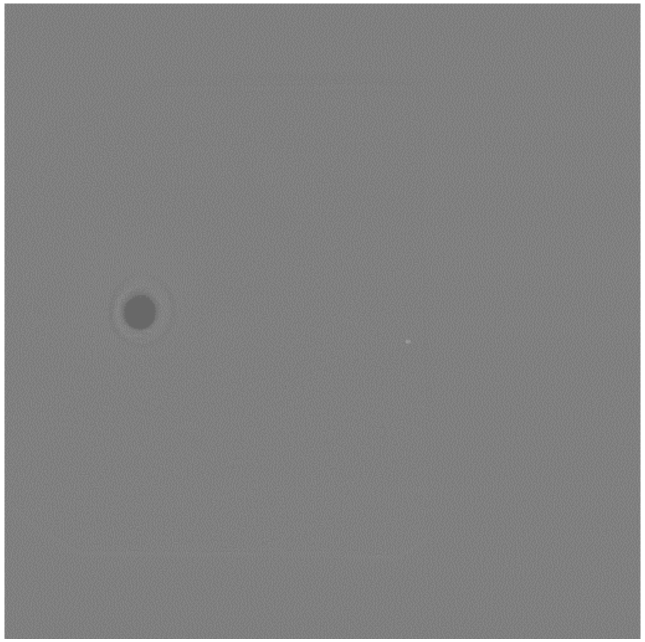
加熱部

開放系：1.9 K 飽和He II

Image processing

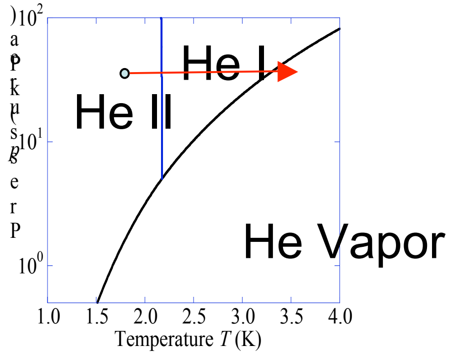


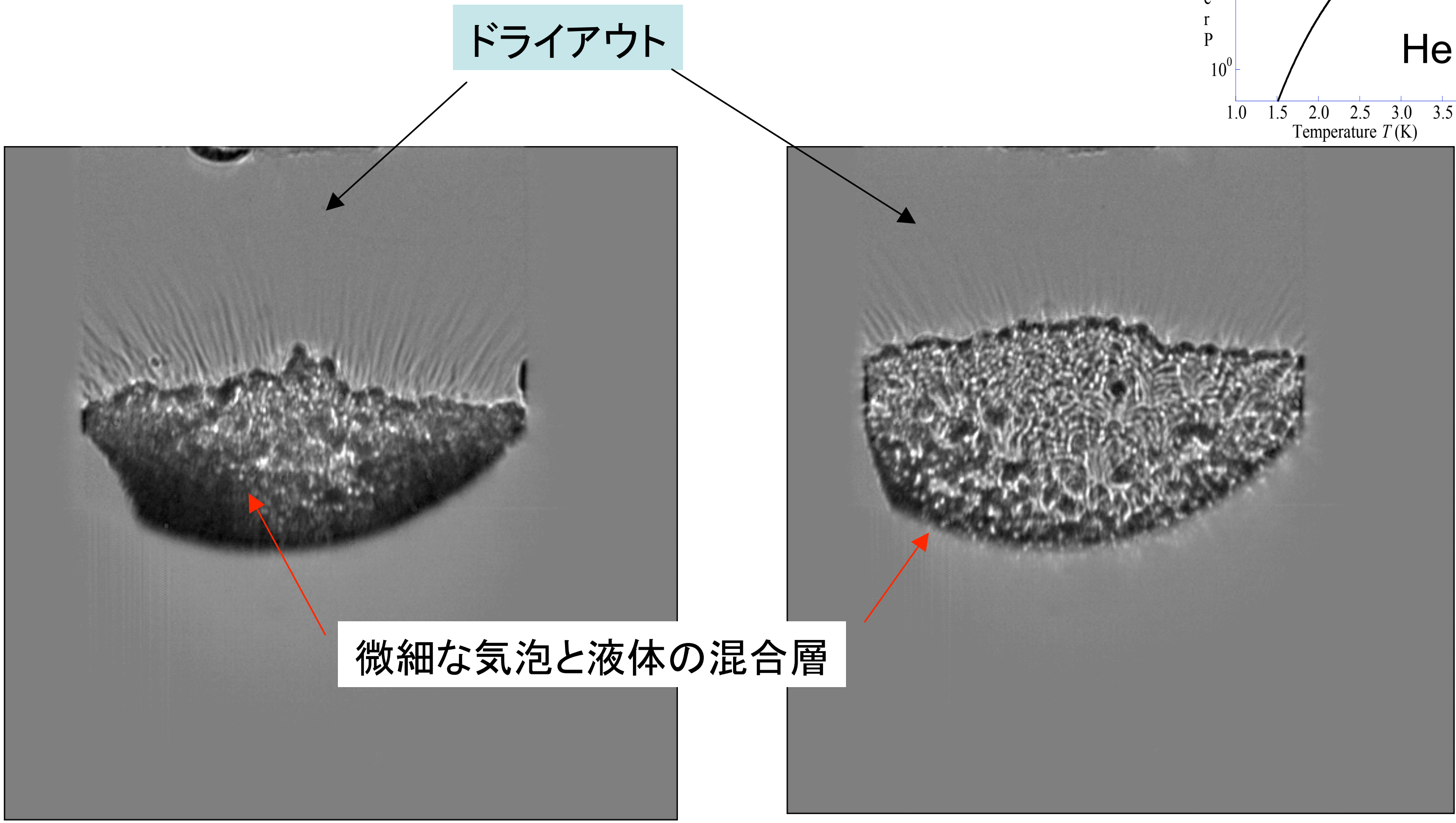




バックグラウンドノイズ除去
によるS/N比向上

可視化された狭小流路中のHeIIの沸騰

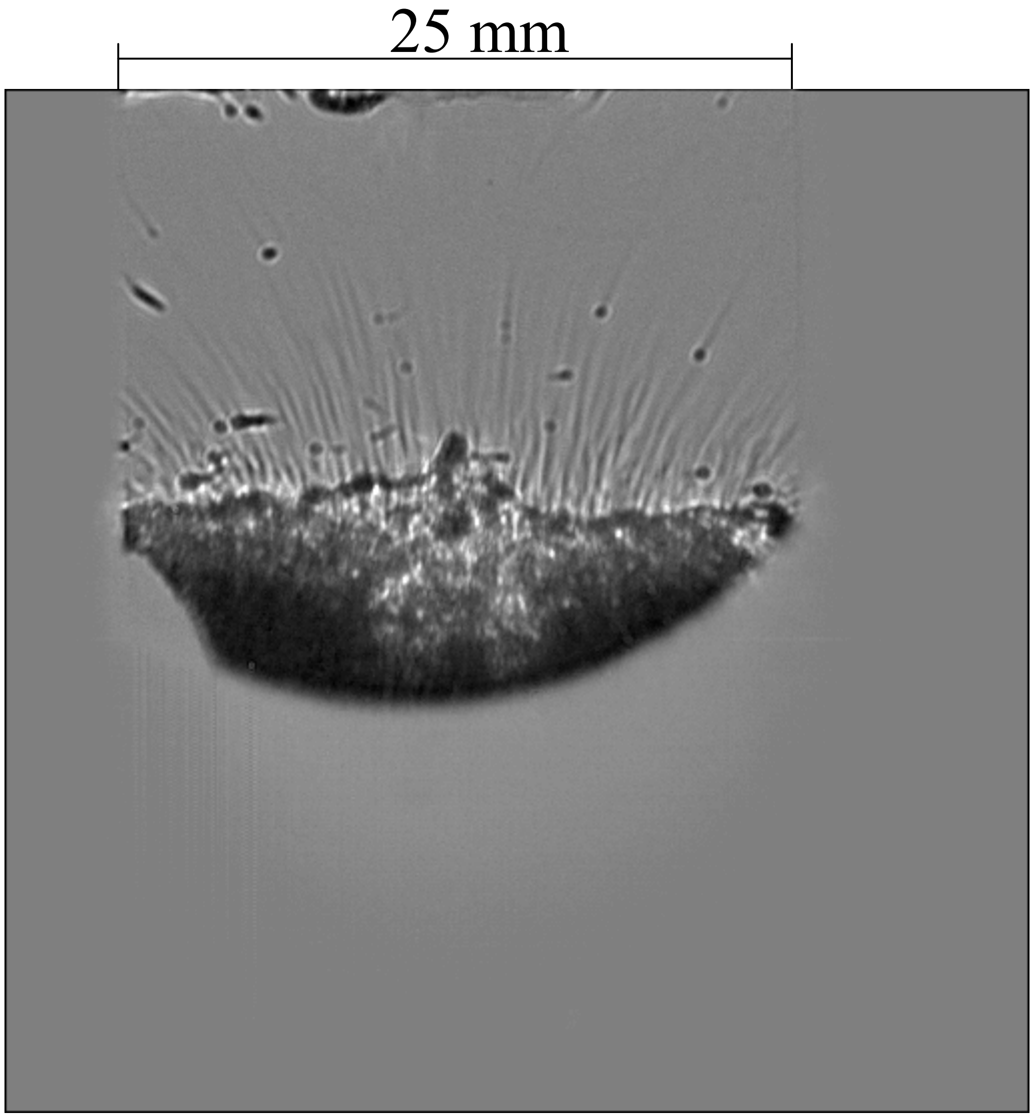


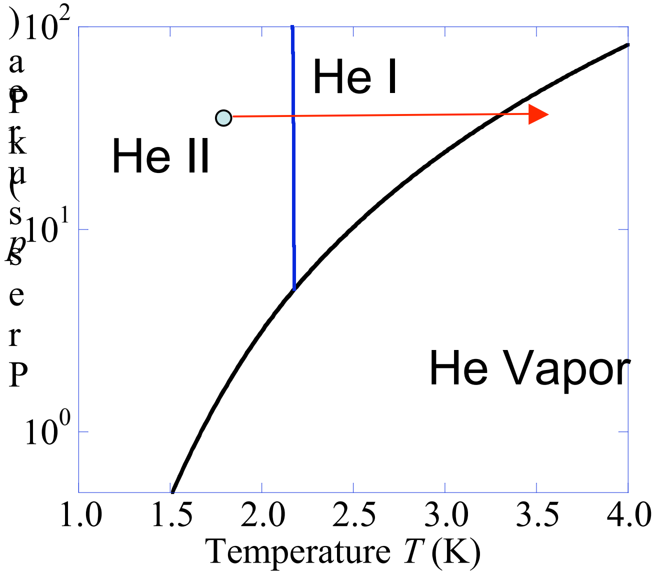


Strongly film boiling mode. P_b = 101.3 kPa

T_b = 1.9 K, q = 3 W = 0.48 W/cm^2

圧力に依存して変わる沸騰モード例を三つ

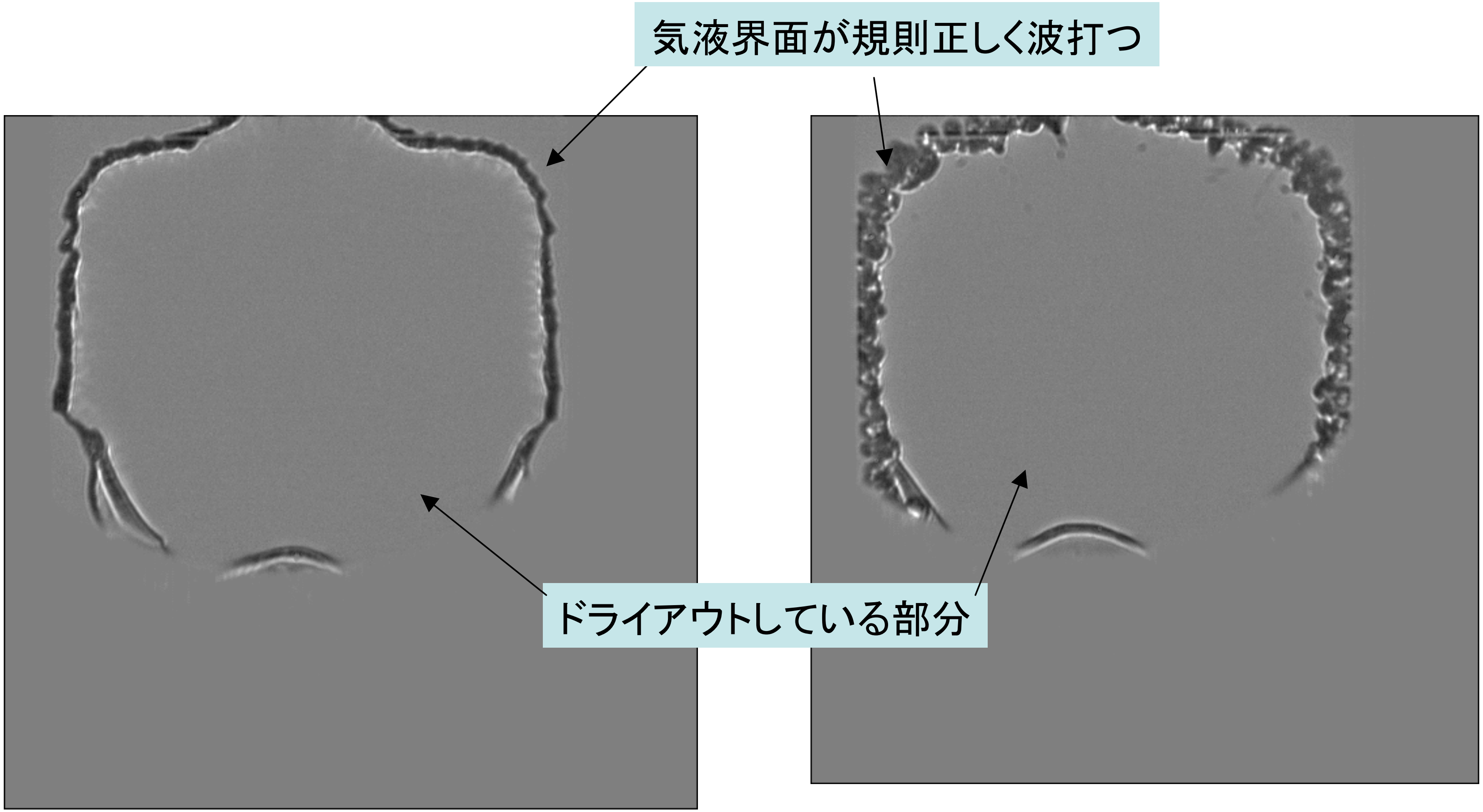




再生速度1/50倍

Strongly film boiling mode. P_b = 101.3 kPa

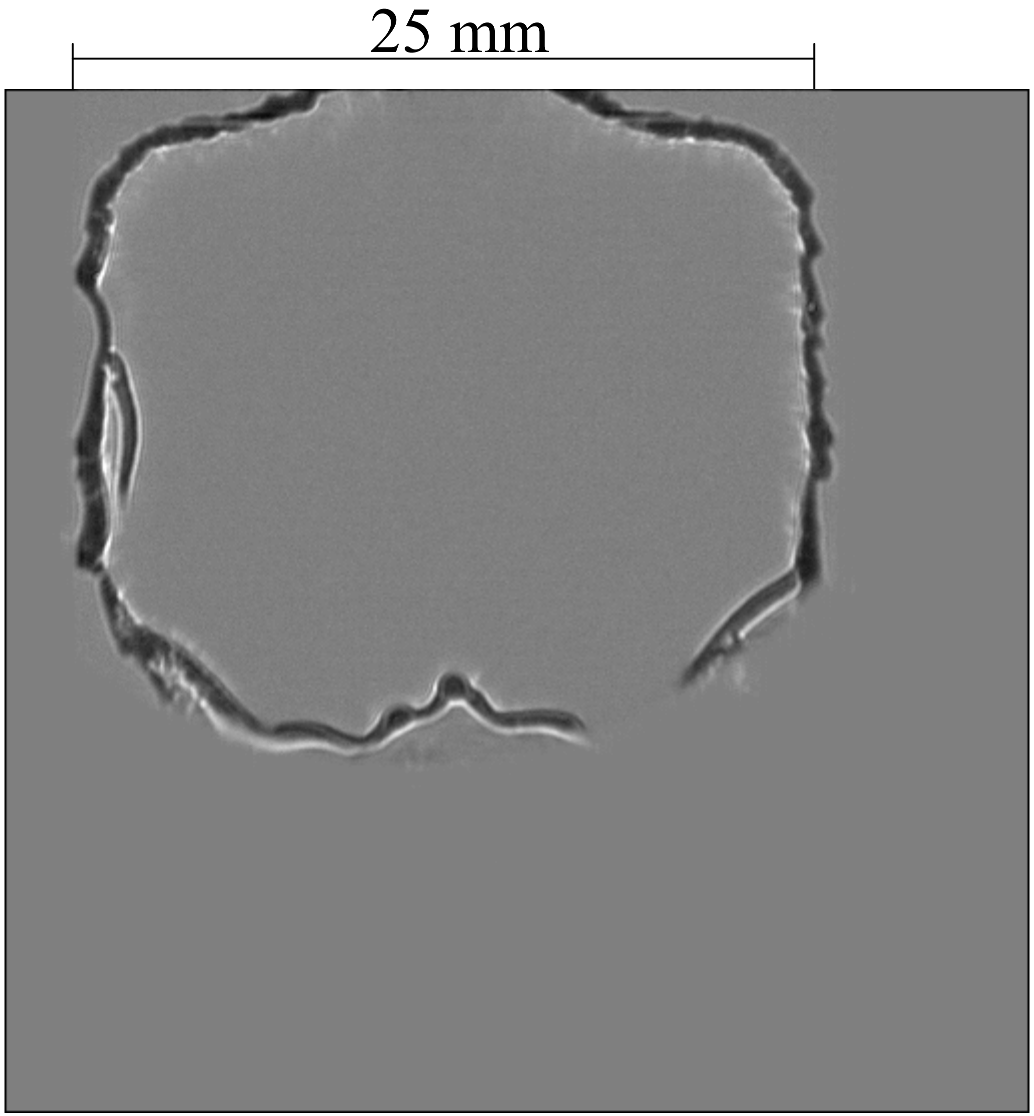
T_b = 1.9 K, q = 3 W = 0.48 W/cm^2

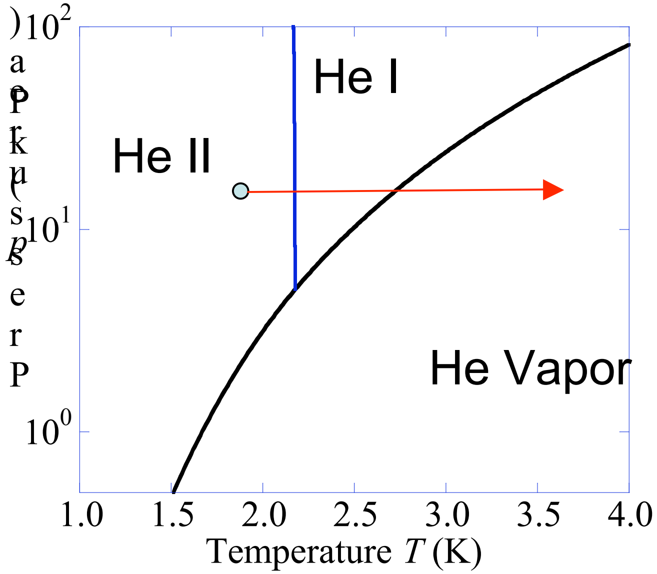


Weakly subcooled film boiling mode

P_b = 13.3 kPa

T_b = 1.9 K, q = 3 W = 0.48 W/cm^2





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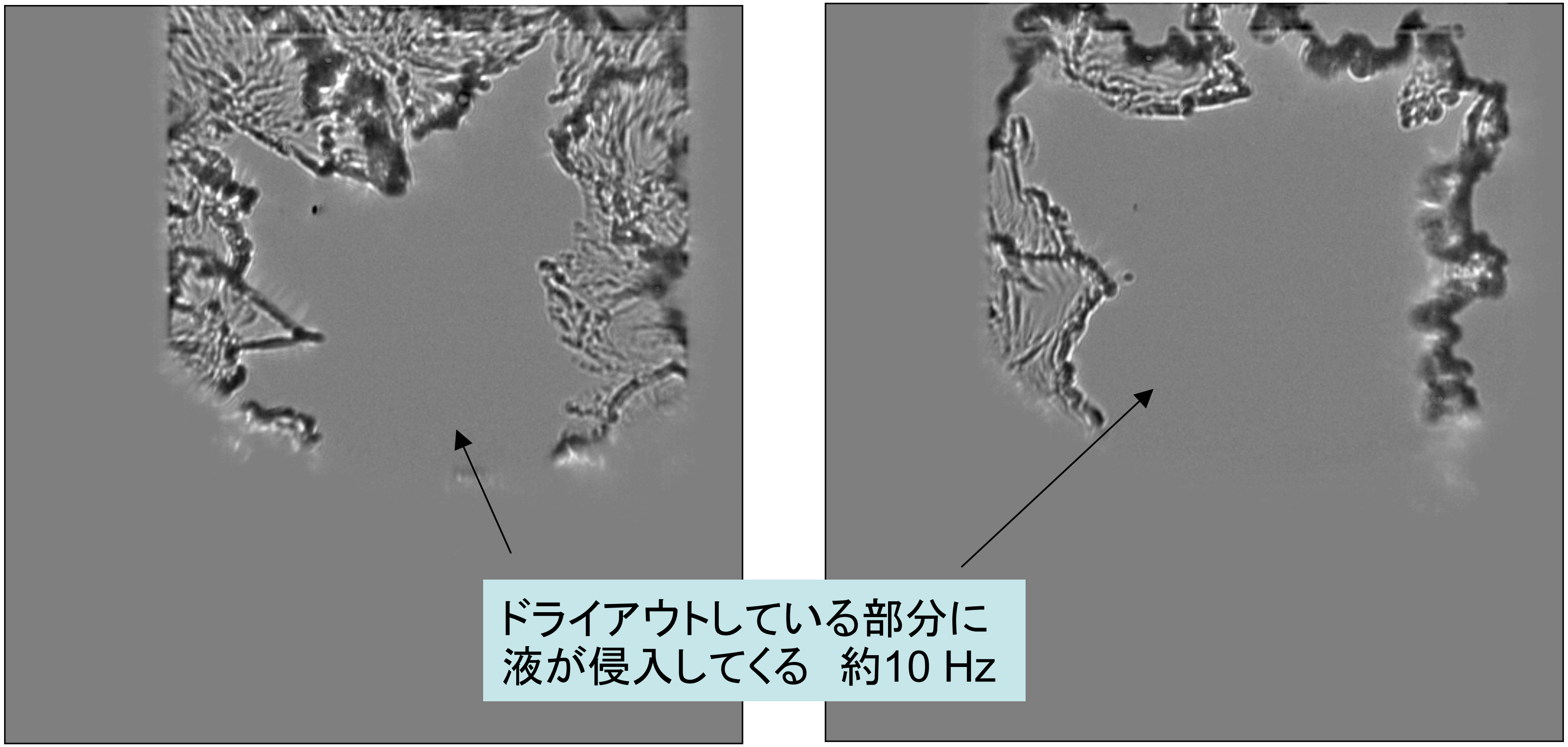
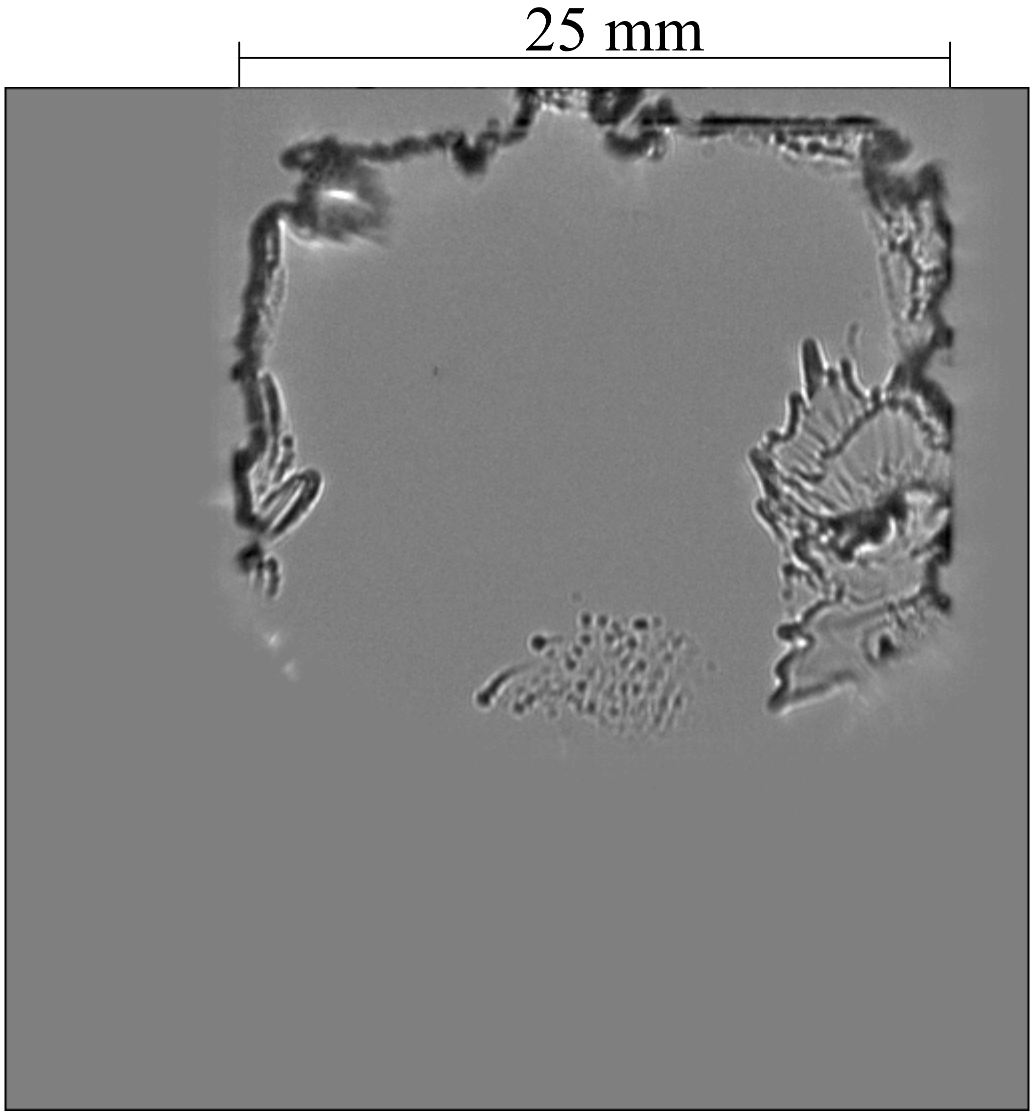
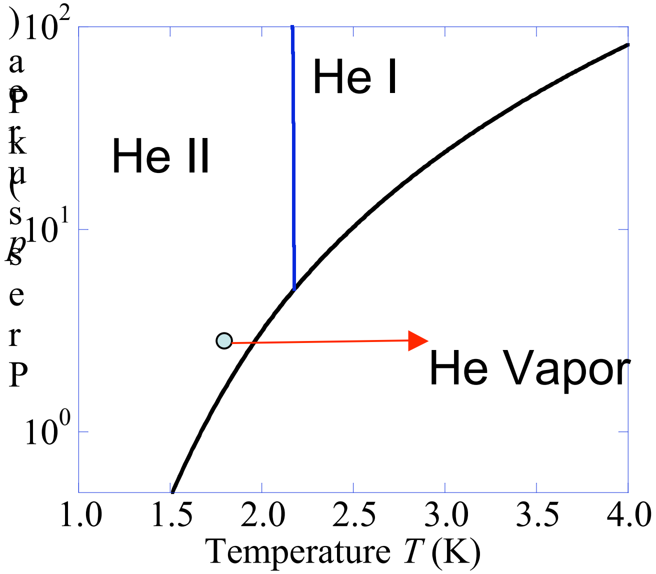


Under the Saturate Vapor Pressure Condition, Noisy film boiling

1.9 K, q = 3 W = 0.48 W/cm^2



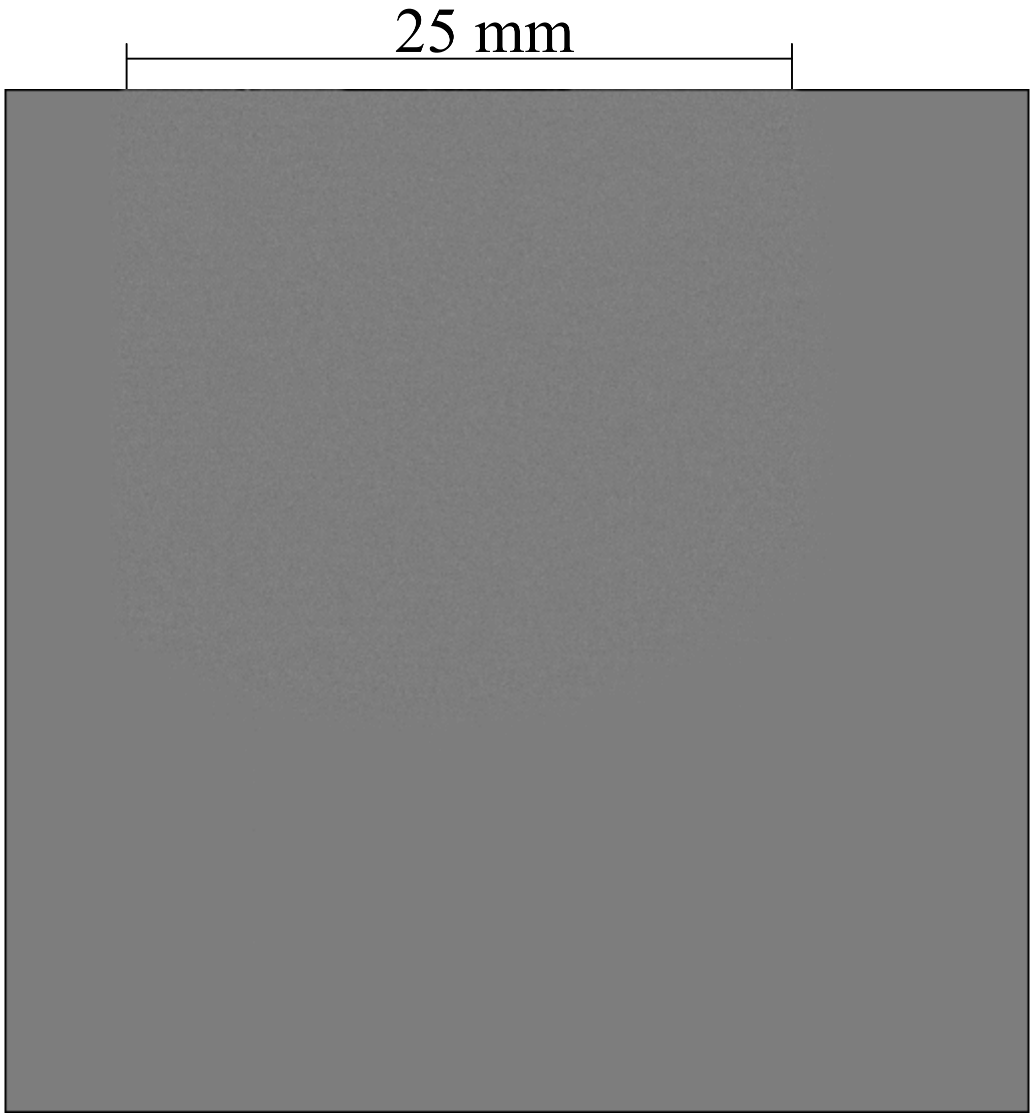


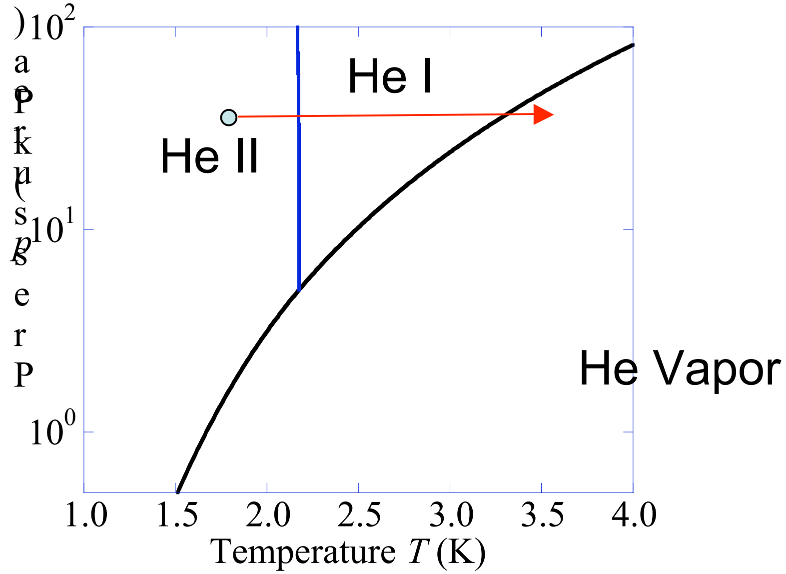
再生速度1/50倍

1.9 K, q = 3 W = 0.48 W/cm^2

Under the Saturate Vapor Pressure Condition, Noisy film boiling

Onset（1.9 K 101.3 kPa）

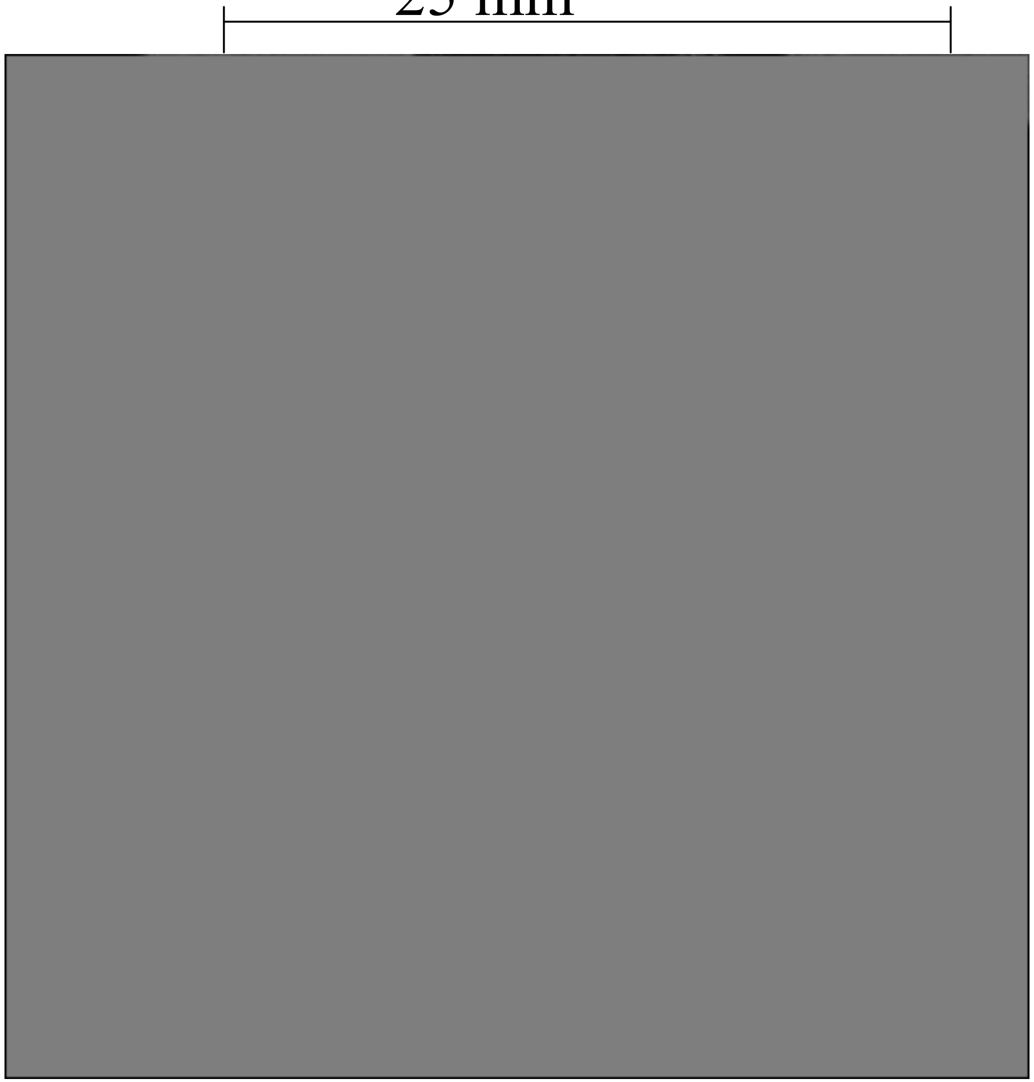


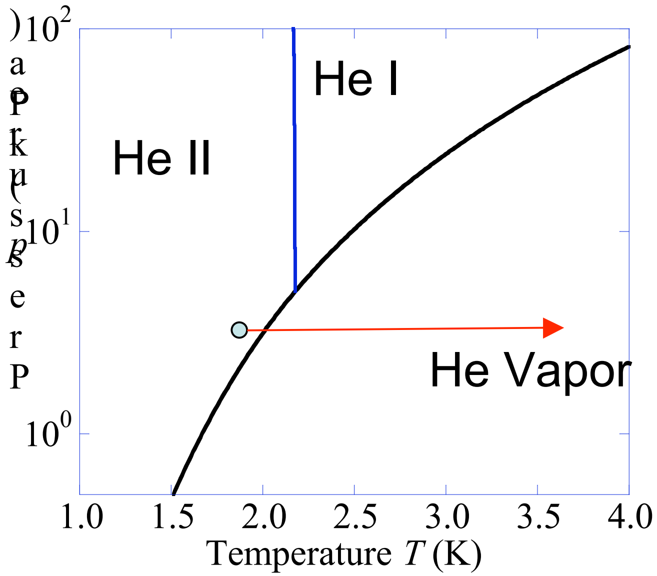


再生速度1/50倍

蒸気相の面積（黒い部分）の境界をトレース

Onset（1.9 K Saturate）



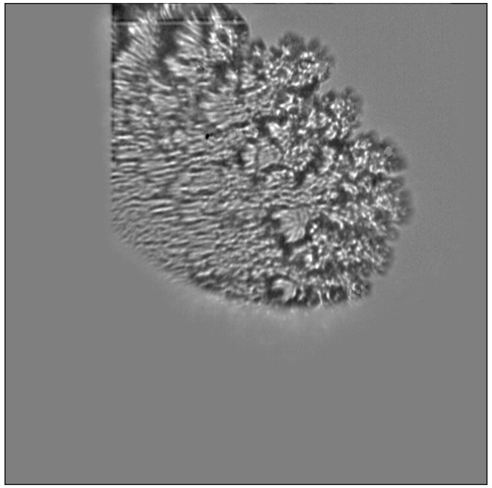


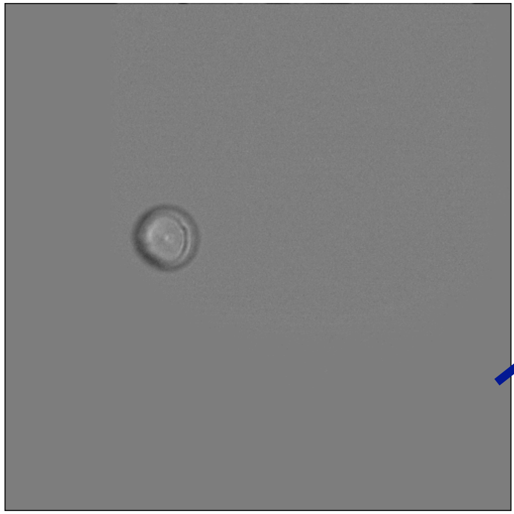
再生速度1/50倍

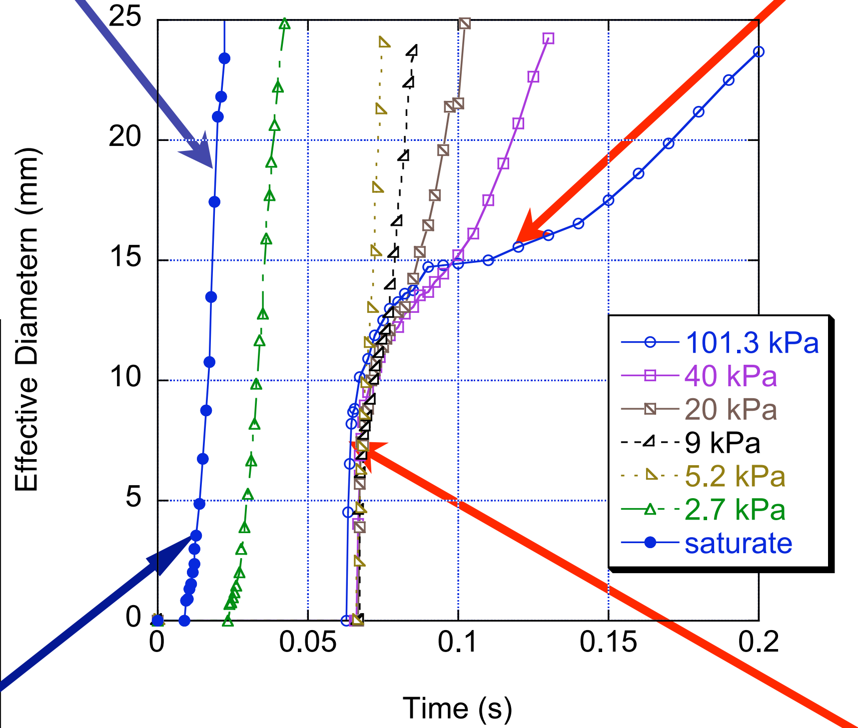
蒸気相の面積（黒い部分）の境界をトレース

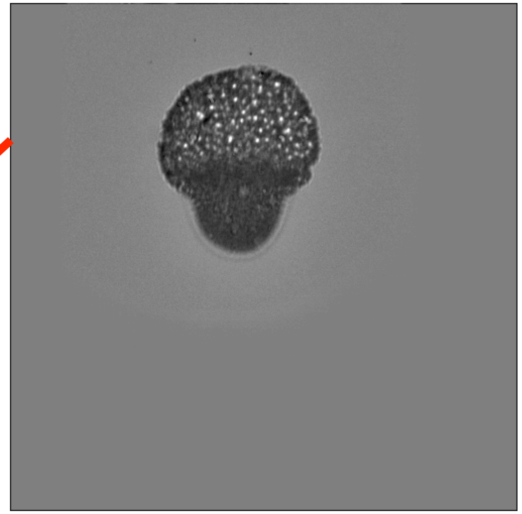
膜沸騰の発生初期における圧力依存性

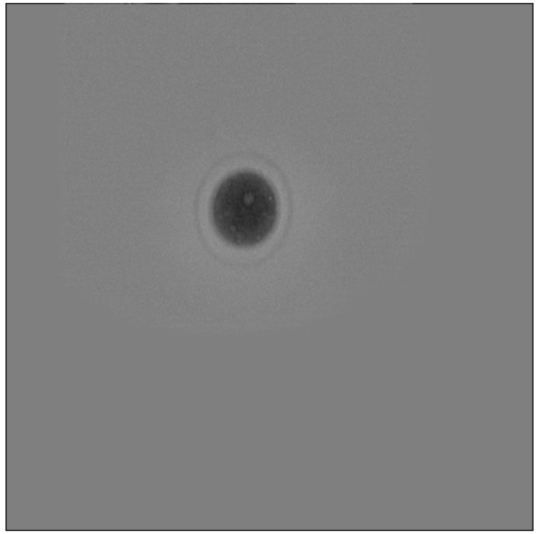
約 2 m/s











ある沸騰核から成長

He II-He I界面と気液界面が
重なる点が変曲点になる

ヒータ中央から成長