§14. Influence of the Superheating in He II on the Heat Transfer in Narrow Channels

Kobayashi, H. (Inst. of Quantum Sci. Nihon Univ.)

The study on heat transfer characteristics in a two-dimensional channel with the gap distance of a sub-millimeter is important to compact He II-cooled apparatuses. It is estimated from studies on the heat transfer from a good conductor to He II [1] that He II below the λ-point pressure P_λ (He II$_S$) is better than that in He II above P_λ (He II$_P$) in such narrow 2D-channel. Depending on the bath pressure P_b, either the subcooled He I (sub-He I) or the superheated He I (^{S}He I) [2] nucleates at the hottest spot on the heated surface at the critical heat flux Q_λ. The partial insulation with ^{S}He I brings about an intermediate state above Q_λ as well as in He II$_P$.[1] Although the large viscosity and the small heat conduction are common both in ^{S}He I and sub-He I, the former does not impede so the cooling the heated conductor, since ^{S}He I disrupts easily because of its metastability.

To confirm the expected characteristics in He II$_S$, the experiment was carried out by the use of disk shaped conductors. Figure 1 shows the two-dimensional channel with gap distance g of 0.15 mm. The channel is made between Cu disk and an insulator disk. The Cu disk of 10 mm in radius r_0 and 13 mm in thickness and the insulator disk of 11 mm in radius make the radial 2D-channel. In this configuration, the phase transitions occur always at the center of the heated surface. The temperatures of He in the channel T ($T_{1\sim6}$), were measured with chip-resistors. The temperature of Cu disk ($T_{C1\sim3}$) was measured with Ge thermometers. In-situ pressure gauges indicate pressures in the channel P_c and in the bath P_b.

Figure 2 shows T and ΔP_c ($=P_c - P_b$) as a function of heat Q with parameter of P_b. At Q_N, ΔP_c suddenly increases due to the onset of boiling. In the intermediate state between Q_λ and Q_N, the maximum of T_1 reaches ~ 2.45 K beyond the lambda temperature (= 2.18 K). The results on ΔP_c and T vs. Q prove that the intermediate state in He II$_S$ is composed of ^{S}He I and He II$_S$. This means also that the good conductor stabilizes not only ^{S}He II but also ^{S}He I. Sharp transition at Q_λ is avoidable due to the appearance of the intermediate state as expected. At the other critical heat Q_N, the boiling triggers the transition from the intermediate state to the mixed state in which T is much lower than in He II$_P$. Both the intermediate state and the mixed state stand against mechanical disturbances.

The appearance of the reversible intermediate state allows He II-cool apparatuses to make the fullest use of Q_λ without unnecessary margin. In general, the heat transfer rate in He II$_S$ is higher than in He II$_P$, especially in the mixed state.

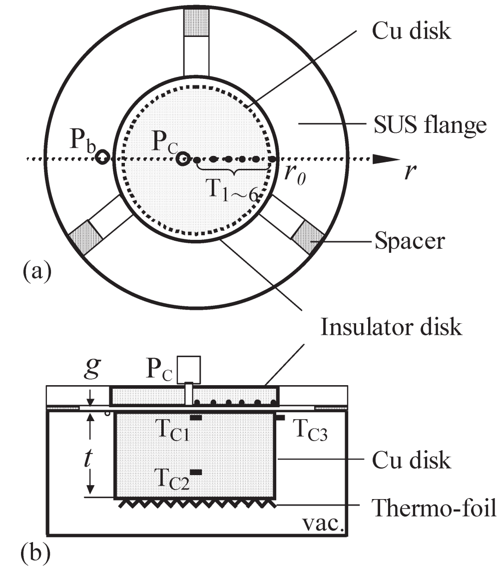

Fig. 1 Schematics of the two-dimensional channel. (a)The top view, (b) the view cut along the diameter. Solid marks indicate thermometers. P_C and P_b are in-situ pressure gauges.

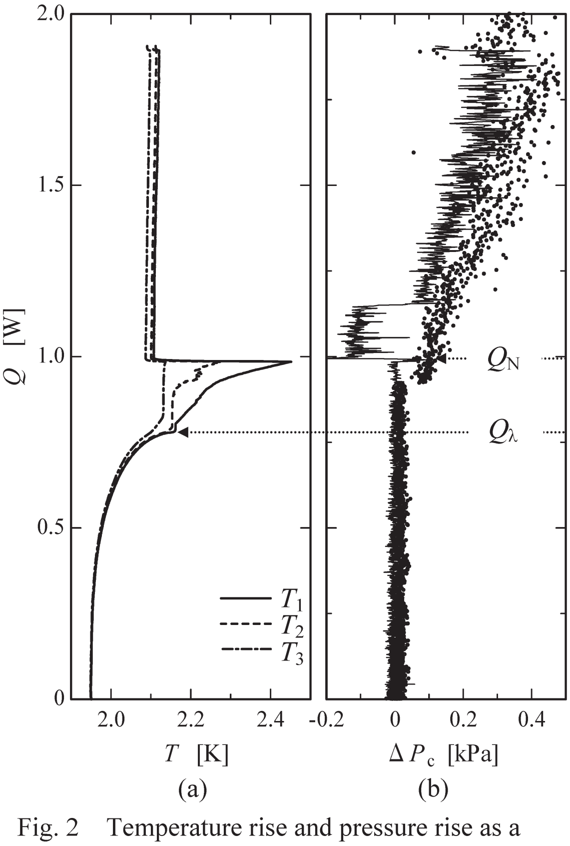

Fig. 2 Temperature rise and pressure rise as a function of Q
(a) T vs. Q, (b) ΔP_c vs. Q The intermediate state appears between Q_λ and Q_N. Broken lines: P_b=102.4 kPa, solid: P_b= 3.5 kPa. T_b=2.0 K.

References
1) Kobayashi, H. et al. Cryogenics **37** (1997) 851
2) Nishigaki, K. et al. Phys. Rev. B **33** (1986) 1657
3) Danilchenko BA. et al. Cryogenics **29** (1989) 444