Reflection of second sound thermal pulse obliquely incident on He II free surface

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Abstract

Reflection and evaporation as a result of oblique impingement of a thermal pulse on a He II free surface were experimentally investigated through the temperature variation measurement and with the aid of an optical visualization. A refracted evaporation vapor wave appears for small angles of incidence of a thermal pulse, and even a total reflection of an incident thermal pulse takes place at a free surface for larger angles of incidence than a critical value. In the present experimental study, the temperature reflection coefficient of a thermal pulse was measured.

Key words: He II evaporation; refraction of evaporation wave; thermal pulse reflection coefficient; total reflection

1. Introduction

Reflection and evaporation caused by a thermal pulse impingement on a He II free surface have been investigated in a series of experiments [1]. In the present study, a special attention was paid to the oblique incidence of a thermal pulse on a free surface. Application of He II environment to this kind of experiment brings two advantages: A He II-vapor co-existing system can be regarded as a practically pure single-component system because any non-condensible gas components are in frozen state. And heat input to a He II free surface is accomplished in the form of a propagating wave, that is a second sound thermal pulse, and thus the magnitude of the heat flux and the heating duration can be well defined.

Oblique impingement of a thermal pulse on a free surface gives rise to two-dimensional features in reflection and evaporation processes. An evaporation vapor wave is, in general, refracted while an incident thermal pulse may be even totally reflected on a free surface for larger angles of incidence. The validity of the equality condition between the normal fluid velocity and the vapor velocity [2] can be experimentally checked. In the present experimental study, the temperature reflection coefficient of a thermal pulse was measured with a superconductive temperature sensor, and the transient gas dynamic behavior in the evaporated vapor was also investigated with the aid of an optical visualization.

2. Experimental Set-up and Procedure

The experimental cell is shown in Fig. 1. It is a rectangular solid surrounded with four adiabatic walls. The planar heater composed of thin film metal is fixed at the bottom. In-house made superconductive temperature sensors made of thin film of gold (230 Å) and tin (990 Å) vacuum deposited on the surface of a quartz fiber with a diameter of 40μm are installed in the cell. The cell is set in the dewar inclined at a specified angle with respect to the free surface, equal to the angle of incidence, θ_i. The planar heater generates a thermal pulse with a duration of several hundred μ-seconds to impinge on the free surface. Upon the impingement, major portion of the thermal pulse is reflected and only a part of energy is consumed in evaporation process. The temperature sensors measure the temperatures of both impinging and reflected thermal pulses. The whole thermo-fluid dynamic phenomena are visualized with the aid of a Schlieren optical system.

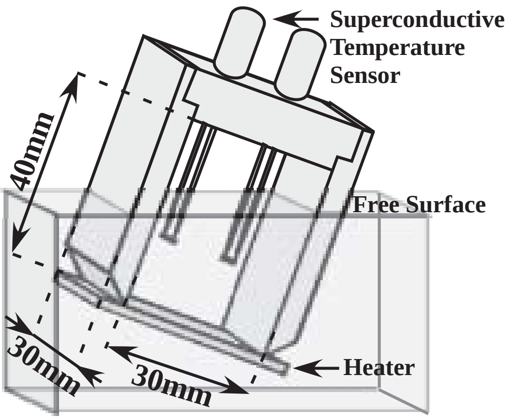

Fig. 1. Schematical view of the experimental cell

3. Results and Discussion

The temperature rises in impinging and reflected thermal pulses, ΔT_i and ΔT_r, were measured at a location rather close to the free surface but apart from the adiabatic side walls to avoid the effect of diffraction. The data are reduced to the form of the temperature reflection coefficient, $R_{22} = \Delta T_r/\Delta T_i$ as a function of the temperature and θ_i. The experimental data of R_{22} evaluated at the wave fronts are plotted in Fig. 2 as a function of the temperature by taking θ_i as a parameter. It may be considered that the diminution in R_{22} from unity primarily results from the energy consumption for evaporation. All the experimental data for $\theta_i = 0$ (normal incidence), obtained in the present study and by Furukawa [3] and Wiechert etc. [4], coincide well with each other. It is evident that they are considerably larger than the result of the Chernikova-Khalatnikov theory [5]. The large discrepancy arises from the fact that this theory is a kind of an equilibrium theory that takes no account of the effects of non-equilibrium Knudsen layer formed in the vapor adjacent to an evaporating phase surface and of the non-unity condensation coefficient. It is evident that R_{22} increases with θ_i due to the refraction effect and it finally reaches unity at larger θ_i than a critical value θ_{cr} at which value a total reflection of an incident thermal pulse takes place. The physical explanation of the dependence of R_{22} on θ_i is as follows: For θ_i smaller than θ_{cr} where the speed of evaporation wave, nearly equal to the speed of sound of helium vapor, is smaller than the speed of the incident pulse front along the free surface, an evaporation wave is formed as an envelope of the evaporation wave family originating from the phase surface. On the other hand, for θ_i larger than θ_{cr} where the speed of sound of helium vapor is larger than that of incident pulse front along the free surface, no definite evaporation wave front can be formed. In the latter situation, evaporation at the incident point of a pulse front on the free surface would take place in a vapor space occupied with vapor of higher pressure already evaporated from the free surface. Thus evaporation is highly suppressed and a total reflection occurs.

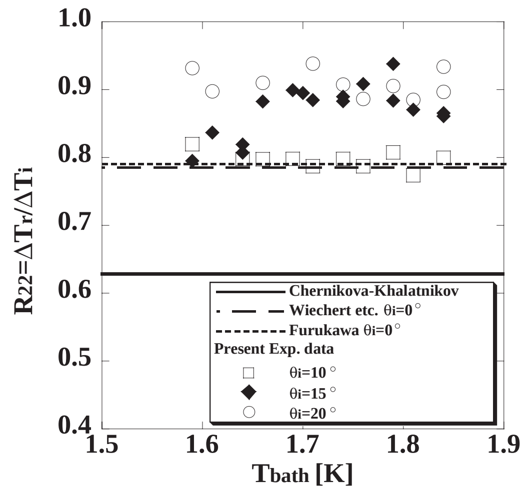

Fig. 2. Temperature reflection coefficient of a thermal pulse at He II-vapor phase surface, $R_{22} = \Delta T_r/\Delta T_i$ as a function of the He II temperature by taking the angle of incidence, θ_i as a parameter.

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