# Melting and Growth of Solid $^4$He by Ultrasound

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**Abstract**

A solid-liquid interface of $^4$He was prepared between two transducers and ultrasound was applied to it perpendicularly. Solid $^4$He was grown when the ultrasound was applied to the interface from the solid side and melted from the liquid side at temperatures below 750mK. Above 750mK it was melted in both sound directions. This growth and melting is explained qualitatively by the acoustic radiation pressure and the temperature dependent sound transmission coefficients. Using this new way of operating the interface the mobility of the interface was measured in growing and melting cases separately and found to have different values in some crystal orientations.

*Key words:* quantum solids, crystal growth, ultrasound

## 1. Introduction

Mobility of solid-liquid interface in $^4$He is extremely large at low temperatures because superfluid very effectively carries mass and heat which are released in the phase conversion[1]. Mobility is limited by the collision with quasi-particles in bulk phases: rotons and phonons, the number of which decrease at low temperatures. When a sound wave is incident to the interface, pressure oscillation of the sound induces crystallization and melting in its frequency. The interface becomes a node which reflected the sound wave. Reflection coefficient measurement is a good way to obtain the interface mobility[2–4].

As mentioned, thermal phonons play an important role in determining the mobility, but what happens if we artificially introduce a sound wave to the interface except for the reflection? The sound wave can be regarded as a phonon beam and these phonons generally carry momentum. When they are reflected by the interface, momentum is transferred to the interface and it feels the force. This is what is called an acoustic radiation pressure[5,6]. We observed this effect, and the sound wave did induce crystallization and melting. We used it to manipulate the interface and measured relaxation times for growth and melting separately.

## 2. Experimental

We prepared two transducers in a cell. Their separation was 10 mm and sound directions were vertical. Frequency of sound was about 10 MHz. Large $^4$He crystal was grown in the cell, occupying the lower half space. Solid-liquid interface was adjusted midway between the two transducers. It was horizontally flat because of the gravity. When sound was applied downward or from the liquid side, the crystal was always melted. When sound was applied upward or from the crystal side, the crystal grew below 750 mK and melted above it. This growth and melting is explained qualitatively by the acoustic radiation pressure and the temperature dependent sound transmission coefficients[5,7,8]. So we can manipulate the interface by a sound pulse and ob-

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serve its relaxation to the equilibrium position thereafter. Making use of the sound velocity difference in solid and liquid, the position of the interface was determined. Details of surface height measurement are given in Ref. [8]. Sound pulse of 1 msec duration and 200 $W/m^2$ power density was typically used for the manipulation and that of 5 $\mu$sec duration for monitoring the surface height. Figure 1 is the time evolution of surface height at a temperature of 695 mK after sound pulse from the liquid side (crosses) and the solid side (circles). Exponential relaxation can be clearly seen and time constant $\tau$ was obtained by fitting (solid lines).

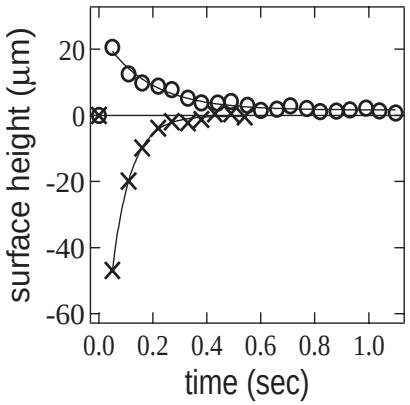


Fig. 1. Time evolutions of surface height at 695 mK. Manipulation pulse was sent at $t$ =0. Crosses indicate growth after melting and open circles melting after growth.

## 3. Results and Discussion

Because sound pulse from both liquid and solid induced not crystallization but melting above 750 mK, we can only measure $\tau$ of growth after melting in the high temperature region. Below 750 mK, however, we can separately measure $\tau$ in two relaxation processes using different sound directions. Time constant of relaxation $\tau$ is plotted in Fig. 2 for two crystals at various temperatures. Crystal 1 had a sound velocity of 540 m/sec. Here, closed triangles are the case incident from the liquid side and open triangles are that from the solid side. No significant difference in relaxation time can be seen in this crystal even below 750 mK. Crystal 2 had a sound velocity of 550 m/sec. Closed circles are the case of sound from the liquid side and open circles from the solid side. Above 750 mK $\tau$ was not so much different in the two sound directions, both of which induced only melting. Below 750 mK there is a clear difference in the two cases. Relaxation was slower in melting after growth than in growth after melting.

Solid-liquid interface of crystal 2 was close to c-facet and that of crystal 1 was rough considering the sound velocity. Thus the anisotropy of the relaxation process is probably related to facet. Usually it is believed that melting of crystal is faster than growth because melting is limited by the fastest or rough surface and growth is limited by the slowest or faceted surface. This is not true in crystal 2. In our experimental situation the interface was manipulated locally and the obtained mobility is thought to be intrinsic to the particular crystal orientation.

Damping of crystallization wave[9] and reflection coefficient of sound[3,4] provided information on the mobility of the interface. However, these methods cannot be used to measure the mobility in melting and growth separately. No systematic study of melting velocity has been performed in $^4$He crystal. Using acoustic radiation pressure we were able to manipulate the interface easily and measure the mobility in the two cases.

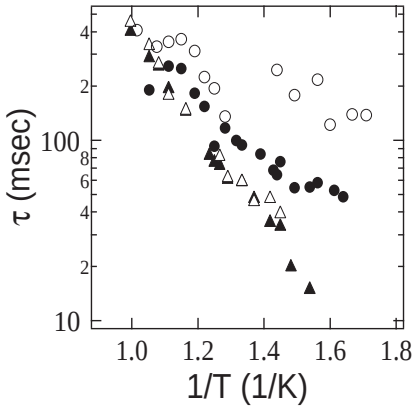


Fig. 2. Temperature dependences of surface height relaxation time. Triangles are for crystal 1 and circles for crystal 2. Closed symbols indicate incident from the liquid side and open symbols from the solid side.

## References


[1] S. Balibar, P. Nozières, Solid State Commun. **92** (1994) 19.

[2] B. Castaing, P. Nozières, J. Physique, **41** (1980) 701.

[3] B. Castaing, S. Balibar, C. Laroche, J. Physique, **41** (1980) 897.

[4] M.B. Manning, M.J. Moelter, C. Elbaum, J. Low Temp. Phys. **61** (1985) 447.

[5] F.E. Borgnis, Rev. Mod. Phys. **25** (1953) 653.

[6] M. Sato, T. Fujii, Phys. Rev. E**64** (2001) 026311.

[7] R. Nomura, Y. Suzuki, S. Kimura, Y. Okuda, to be published.

[8] R. Nomura, M. Maekawa, Y. Suzuki, Y. Okumura, Y. Okuda, J. Low Temp. Phys. **126** (2002) 39.

[9] C.L. Wang, G. Agnolet, Phys. Rev. Lett. **69** (1992) 2102.