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Manipulation of solid-liquid interface of ^{4}He by acoustic radiation pressure

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Acoustic radiation pressure is thought to be very useful for solid ^{4}He experiment under the microgravity. We observed that solid-liquid interface of ^{4}He was manipulated by the acoustic wave. We applied the sound pulse perpendicularly to the flat interface between two transducers. The interface moved to the sound direction at low temperatures. We also checked how the interface moved when sound was applied parallel to the interface. Dynamics of the interface during and after the sound pulse were recorded by a high speed CCD camera.

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Introduction

In the microgravity environment it is very important to control an object without a direct contact. For this purpose acoustic radiation pressure is a useful tool. It was used for investigating the dynamics of liquid drops [1,2] and for passive stabilization of liquid capillary bridges [3] in the low-gravity.

In case of a crystal growth experiment under the microgravity it is not easy to keep and control the crystal at a proper position. Once it detaches from a wall and starts to move freely, it is very difficult to stop it especially in a superfluid that has no viscosity. It will be very helpful if one can control the motion of ^{4}He crystal easily. This kind of technique will also be used to study new types of dynamics like a shape evolution of rotating quantum crystal under the microgravity, collision or friction between two quantum crystals and so on. Acoustic radiation pressure is thought to be a good way to manipulate the crystal.

We found that solid-liquid interface of ^{4}He, which is known to have an ultrahigh mobility [4,5], could be manipulated by sound wave. When the sound pulse was applied from the liquid side to the flat interface, the solid was melted at all temperatures below 1.2 K. But when the sound pulse was applied from the solid side the solid was melted above 750 mK and grown below it [6,7]. These interface motion were driven by acoustic radiation pressure. In quantum mechanical representations radiation pressure is interpreted as momentum transfer from phonons to the interface [8]. We recorded the dynamics of interface during and after the sound pulse by a high-speed CCD camera.

Experimental results and discussions

Experiment was performed in a cell cooled by a dilution refrigerator. It had optical access from room

Fig. 1. Melting of ^{4}He crystal induced by sound wave from the liquid side.

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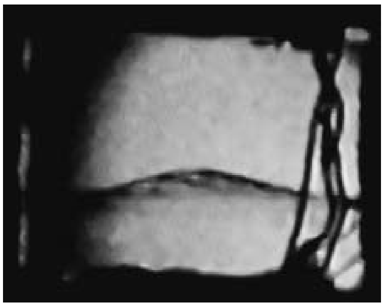

Fig. 2. Crystallization of ^{4}He induced by sound wave from the solid side.

temperature and we could observe ^{4}He crystal down to 50 mK. Two longitudinal transducers faced each other were prepared in a cell. Their resonance frequency was about 10 MHz and distance was 10 mm. Sound directions were vertical. Large ^{4}He crystal was grown in the cell and occupied the lower half space. Solid-liquid interface was adjusted midway between the two transducers. It was horizontally flat without sound because of the gravity. Sound pulse was applied to the interface from the liquid side or downward by the upper transducer and from the solid side or upward by the lower transducer. We also set up two other transducers. Sound direction of them was horizontal or parallel to the interface. One was for longitudinal sound and the other was for transverse sound.

Figure 1 is the shape of a solid-liquid interface while sound wave was applied from the liquid side. Melting was induced at around the center of the cell where the sound wave was actually applied. Temperature was about 150 mK and typical sound power density for these figures was about 200 W/m^2. When sound was applied from the solid side at the same temperature, the crystal was grown as shown in Fig. 2. So the interface was pushed to the direction of sound at these low temperatures. We could induce both crystallization and melting easily by changing the direction of acoustic wave.

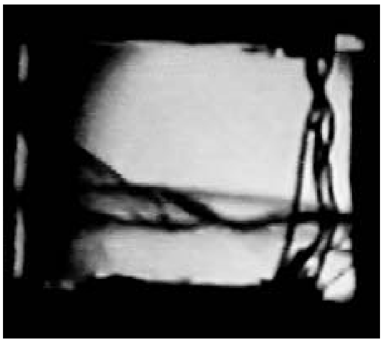

Fig. 4. Crystallization of ^{4}He induced by sound wave from left to right.

We also applied sound horizontally and checked how the interface responded to it. Sound direction was parallel to the interface in this case. Longitudinal sound was applied from left to right at around 150 mK and it stochastically induced melting (Fig. 3) or crystallization (Fig. 4) in the vicinity of the transducer. These observations support the idea that acoustic radiation pressure was the cause of the interface motion. The interface motion was driven not because solid or liquid were thermodynamically favored but because the interface felt the force directly from the sound wave. Initial tiny slope of the interface probably determined whether crystallization or melting was induced. When transverse sound was applied from right to left it always induced crystallization (Fig. 5) because it can propagate only through the solid.

Using a high-speed CCD camera interface dynamics were recorded during and after a sound pulse. Sound pulse of 1 msec duration was applied at $t = 0$ from the liquid side. First it induced downward motion of the interface. Then the interface oscillated around the equilibrium position as shown in Fig. 6. White rectangle in the first image is the region shown in the following. Temperature was 380 mK in this case. When the sound pulse was applied from the solid

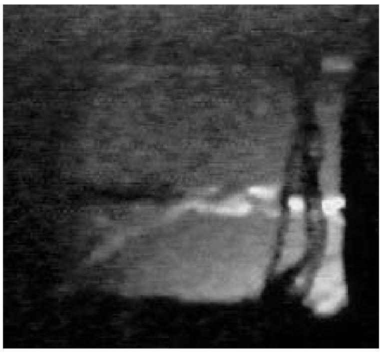

Fig. 3. Melting of ^{4}He crystal induced by sound wave from left to right.

Fig. 5. Crystallization of ^{4}He induced by transverse sound wave from right to left.

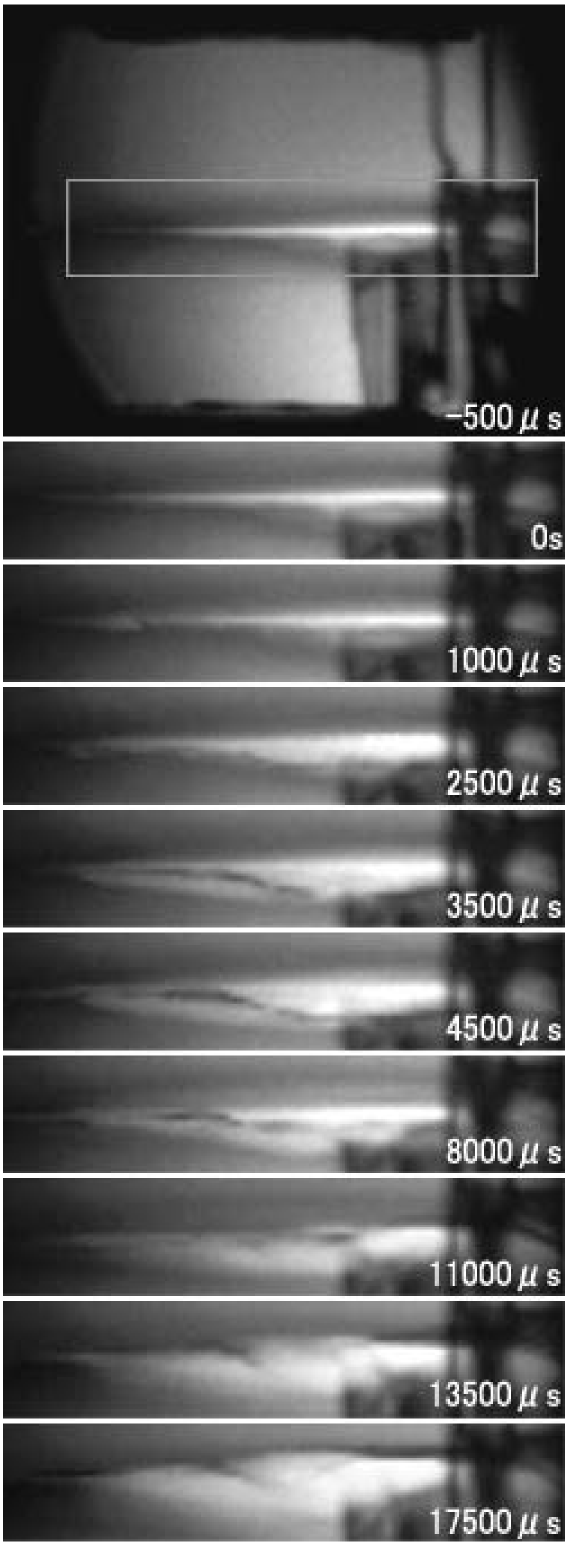

Fig. 6. High-speed dynamics of solid-liquid interface triggered by sound pulse from the liquid side. White rectangle in the first image is the region shown in the following. Numbers indicate time after the sound pulse in μsec.

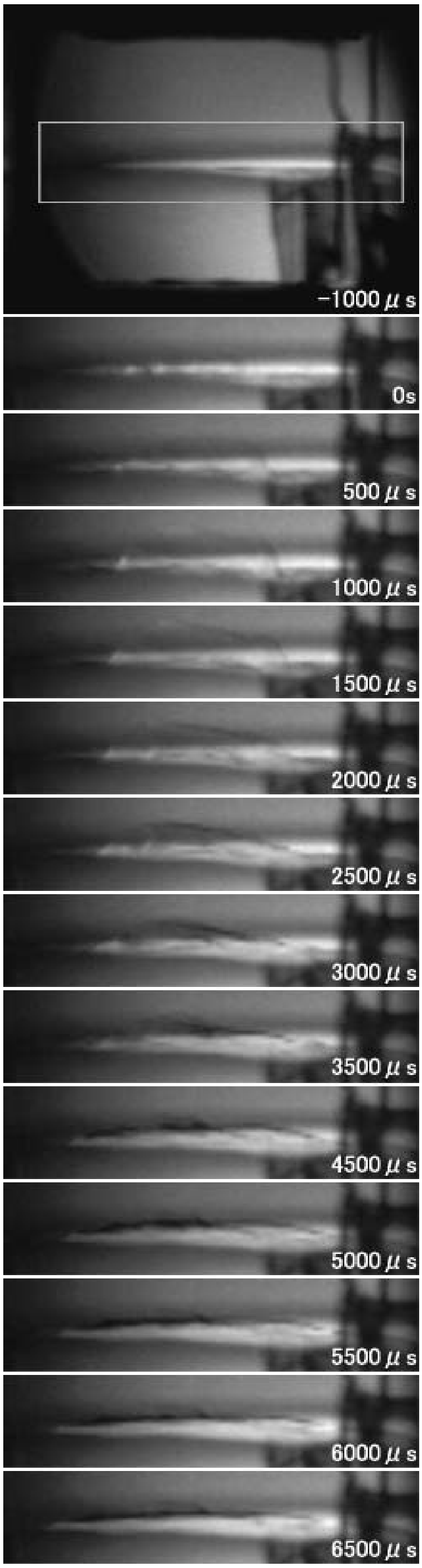

Fig. 7. High-speed dynamics of solid-liquid interface triggered by sound pulse from the solid side. White rectangle in the first image is the region shown in the following. Numbers indicate time after the sound pulse in μsec.

side it induced upward motion of the interface first as shown in Fig. 7. These observations demonstrated that interface oscillation or crystallization wave could be excited by the acoustic pulse.

When we make a small ^{4}He crystal and apply sound wave to it what will happen? Will it be completely melted or move to the sound direction? It will be very interesting to see if we can move not only the solid-liquid interface but also crystal itself. If this is possible radiation pressure can be used to manipulate ^{4}He crystal in the microgravity.

SUMMARY

We demonstrated that solid-liquid interface of ^{4}He could be manipulated by sound wave. The interface motion, which was triggered by acoustic radiation pressure, was recorded by using a high-speed CCD camera. It is our future theme to check whether we can manipulate not only the interface but also the crystal itself by acoustic radiation pressure.

Acknowledgement

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