Slippage of nonsuperfluid helium films

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Abstract

We measured the slippage of nonsuperfluid ^{4}He films adsorbed on two kinds of the substrates, grafoil and hectorite, and found that a large part of these films undergo slipping at low temperatures. Furthermore, it was found that the ^{4}He areal density dependence of the slippage is rather different between these substrates. In hectorite, the slippage is inhibited as the fluid state appears at absolute zero. On the other hand, in grafoil, this state does not suppress the slippage, at least, as the ^{4}He areal density is low. This may be attributed to the difference in the structure of these films.

Key words: slippage, nonsuperfluid helium film, graphite, hectorite

Slippage of physisorbed films relative to the lateral oscillation of a substrate has attracted considerable interest because of a study on the atomic-scale mechanism of sliding friction.[1] Krim and her colleagues[2] found a partial slippage of noble-gas monolayer films on a noble-metal substrate at 77 K. Simulation using the modified Frenkel-Kontorova model showed that the nature of the sliding friction depends strongly on the interatomic force between the substrate and the film.[3] Since this force of a helium atom is very weak, one may expect nonsuperfluid helium films to slide easily on a substrate. In the previous paper,[4] we have reported the slippage of these films adsorbed on hectorite. It is therefore of great interest to make a comparison between various substrates. In this paper we report the difference in slippage between two kinds of the substrates, grafoil and hectorite.

To measure the slippage of nonsuperfluid helium films, we applied two techniques: the quartz-crystal microbalance (QCM) technique for grafoil and the ultrasonic technique for a two-dimensional porous material, hectorite.

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The ultrasonic technique has been reported in detail previously, so we give a short description of the QCM technique here. A resonator used for QCM was an AT-cut quartz-crystal of 5.0 MHz. A piece of grafoil was pasted uniformly on Ag electrodes of the crystal. The resonant frequency and amplitude were measured using the transmission circuit. If the film adsorbed on grafoil starts to slip relative to the lateral oscillation, the resonant frequency and amplitude are modulated. This change is characterized by the value of $\omega\tau$, where τ is the slip time and ω is the angular frequency of oscillation. At $\omega\tau \sim 1$, an rapid increase in the resonant frequency and a decrease in the amplitude are observed. On the other hand, in the ultrasonic technique, the change in the sound velocity and attenuation of the pellet are indicative of the slippage.

We measured the slippage of nonsuperfluid helium films, and found that these films adsorbed on both the substrates undergo slipping at a certain condition.

In the QCM measurements for grafoil, the resonant frequency increased accompanied with a small dip in the amplitude as the temperature was lowered. On the other hand, in the ultrasonic measurements for hectorite, the sound velocity increased gradually accompanied with an attenuation peak. These demonstrate clearly that the films undergo slipping relative to the lateral oscillation at a certain temperature, and that

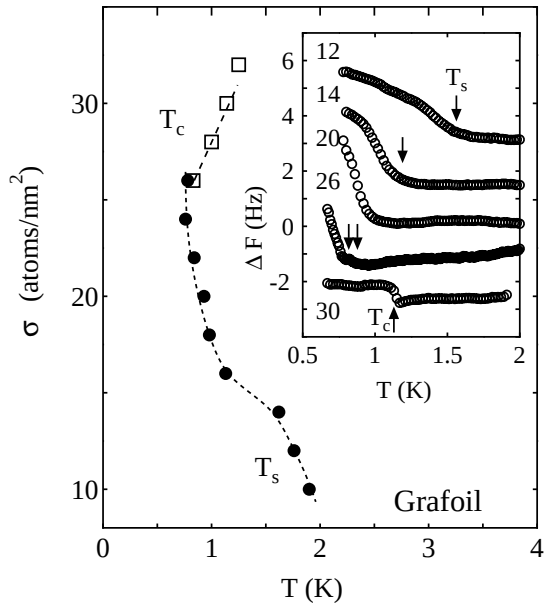

Fig. 1. Slip temperature T_s for grafoil as a function of ^{4}He areal density, together with the superfluid onset T_c. Inset: Variation of the resonant frequency for various ^{4}He areal density. Figures represent the areal density in the unit of atoms/nm^2. The arrows indicate T_s and T_c.

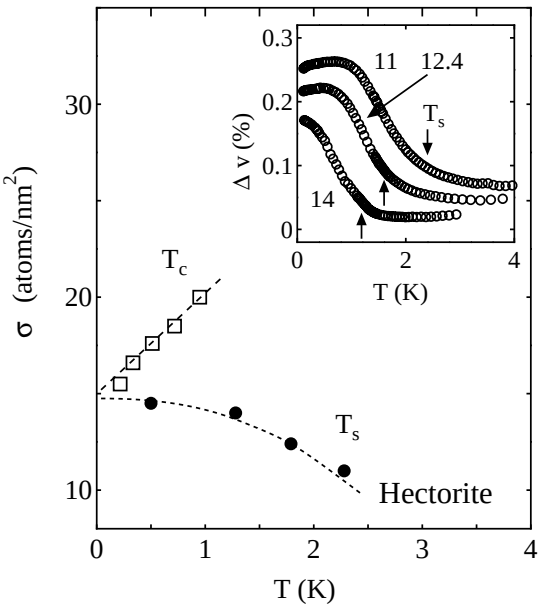

Fig. 2. Slip temperature T_s for hectorite as a function of ^{4}He areal density, together with the superfluid onset T_c. Inset: Variation of the sound velocity for various ^{4}He areal density. Figures represent the areal density in the unit of atoms/nm^2. The arrows indicate T_s.

the frictional force is rather small at low temperatures. From the increase in the resonant frequency and in the sound velocity, it was found a large amount of ^{4}He adatoms ($\sim$30 %) contribute to this slippage at low temperatures. Therefore, we believe that the slippage will be observed for various substrates and is a rather common feature of these films.

The slip temperature T_s was plotted in Figs. 1 and 2 as a function of ^{4}He areal density, together with the superfluid onset T_c. Here, T_s is defined as the temperature when the film starts to slip. It is of interest to compare T_s between grafoil and hectorite. For the ^{4}He areal density of $\sim$ 10 atoms/nm^2, T_s was $\sim$ 2 K, irrespective of the substrate. In hectorite, T_s decreased monotonically with increasing ^{4}He areal density, and tended towards absolute zero at 15 atoms/nm^2. On the other hand, in grafoil, T_s changed stepwise around 15 atoms/nm^2. Above this density, T_s was little affected by increasing ^{4}He areal density, at least, up to 26 atoms/nm^2.

As seen in the figure, in hectorite, the slippage was suppressed when the superfluidity was observed, i.e., above the ^{4}He areal density at which the fluid state appears at absolute zero, the slippage is inhibited. On the other hand, in grafoil, at 26 atoms/nm^2, the superfluidity was observed together with the slippage. In addition, from the torsional oscillator measurements for grafoil, the superfluidity was reported above 22 atoms/nm^2.[5] These suggest that the fluid state of grafoil does *not* suppress the slippage, in contrast to hectorite. The difference between grafoil and hectorite may be attributed to the difference in the structure of these films.

In summary, we measured the slippage of nonsuperfluid ^{4}He films adsorbed on two kinds of the substrates, grafoil and hectorite, and found that a large part of these films undergo slipping at low temperatures. In addition, it was found that the ^{4}He areal density dependence in T_s is different between these substrates, which suggests that the structure of film is closely related to the slippage.

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