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^{3}He impurity effects on the growth kinetics of ^{4}He crystals

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We report on the growth kinetics of ^{4}He crystals with a small amount of ^{3}He impurities around 0.8K. The growth resistance was measured using the response of the charged liquid-solid interface with respect to an externally applied voltage. In 5ppm and 10ppm ^{3}He mixtures, it is found that (1) the relaxation process can be expressed as an exponential behavior, (2) the growth resistance becomes larger compared to pure ^{4}He and does not have a strong ^{3}He concentration dependence, and (3) the temperature dependence of the growth resistance is much the same as for pure ^{4}He. We discuss several possible explanations of the present experiment.

1. INTRODUCTION

From early visual observations it is known that adding a small amount of ^{3}He impurities drastically affects the shape of ^{4}He crystals. In 1992 Wang and Agnolet[1] found that at low temperatures a very small amount of ^{3}He impurities increases the growth resistance $(m_4 K_T)^{-1}$.

Regarding the crystal growth of dilute ^{3}He mixtures, Bowley and Edwards[2] discussed the effects on the basis of the idea that ^{3}He atoms are reflected at the solid-liquid interface. On the other hand, Buristrov and Dubovskii[3] pointed out the importance of ^{3}He mass flow in front of a moving solid-liquid interface.

In order to deduce the ^{3}He impurity effect quantitatively in the high temperature region, we measured the growth resistance using the response of a charged interface.

2. EXPERIMENTAL

The experiment was performed in a ^{3}He cryostat with optical access from the bottom. The sample cell worked as an interferometer and the change in crystal height was detected by a shift of the interference fringes. Afer growing the crystal, electron bubbles were introduced into the liquid by a field emission tip and pulled downwards to the solid-liquid interface by an externally applied field. These were trapped at the interface.

After changing the applied field, in the case where the crystal growth does not show nonlinear behavior, the height of the crystal approaches the new equilibrium exponentially. Then, the relaxation time is proportional to the growth resistance.

Different dilute ^{3}He mixtures, 5ppm and 10ppm ^{3}He, were prepared at room temperature. A single crystal was grown slowly around 0.8K. Atomically rough surfaces were chosen for the measurement.

3. RESULTS AND DISCUSSION

Figure 1 shows the growth resistance of 10ppm of several measurements as a function of temperature as well as the extrapolated lines of pure ^{4}He (dashed lines) which are considered as the fastest and slowest axes of pure ^{4}He[4]. Without respect to temperature, the relaxation process can be well expressed as an exponential behavior.

Figure 2 shows the growth reistance at 0.83K as a function of the ^{3}He concentration. The scatter is attributed to crystal orientation.

From the present experiment, it is found that (1) the relaxation process can be expressed as an exponential behavior, (2) the growth resistance becomes larger compared to pure ^{4}He and does not have a strong ^{3}He concentration dependence, and (3) the temperature dependence of the growth resistance is much the same as for pure ^{4}He.

Next, let us consider several possibilities to explain these properties:

(a) the reflection of ^{3}He atoms at the solid-liquid interface: This contribution was evaluated by Bow-

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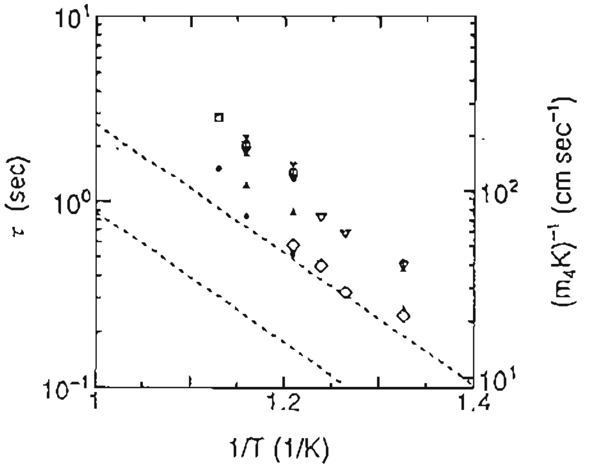

Figure 1: Temperature dependence of the growth resistance of a 10ppm ^{3}He mixture. Different symbols correspond to different crystals.

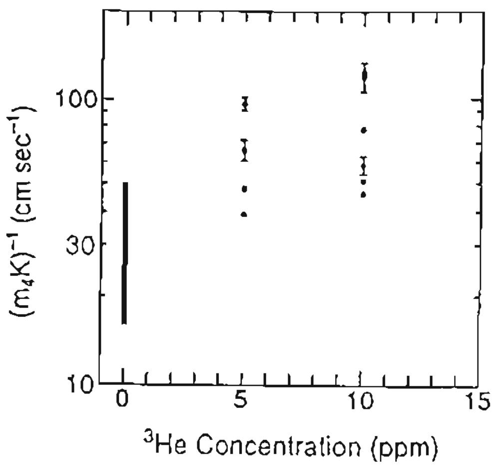

Figure 2: Concentration dependence of the growth resistance at 0.83K.

ley and Edwards[2]. Using the typical values of this experiment, we found that this contribution is too small.

(b) the ^{3}He mass flow in front of a moving interface: Buristov and Dubovskii's theory[3] explains the large enhancement of the growth resistance. There are, however, discrepancies between theory and experiment. Their theory suggests that the growth resistance depends strongly on ^{3}He concentration and that the relaxation process shows nonlinear behavior.

(c) the effect of adsorped ^{3}He atoms at the interface: The enhancement of the growth resistance may be explained by the change in the scattering potential of rotons associated with adsorbed ^{3}He atoms. Rolley *et al.*[5] found that the binding energy of ^{3}He atoms at the interface is 4.3K. If we adopt their results, few ^{3}He atoms are adsorped at the interface (about 0.05 monolayer). So it may be difficult to explain the change in the growth kinetics.

(d) the effect of the decrease of the thermal conductivity in the liquid: As discussed in detail by Balibar *et al.*[6], the effective growth reistance $(m_4K_e)^{-1}$ increases due to the finite thermal conductivity, which is given by

$$(m_4K_e)^{-1} = (m_4K_T)^{-1} + (\rho_c R_K/T)(J_E/J + b/c)^2, \quad (1)$$

where J and J_E/T are the currents of mass and entropy crossing the interface, R_K is the Kapitza resistance. Here, we use the same notation as used in Ref. 6.

In pure ^{4}He, the heat propagates very effectively in the superfluid ^{4}He and the correction to $(m_4K_T)^{-1}$ is not large. On the other hand, the effective thermal conductivity in the liquid of dilute ^{3}He mixtures decreases drastically. Thus the main channel of heat flow seems to be the crystal rather than the superfluid ^{3}He-^{4}He mixtures.

Using Eq.(1), we found that the effective growth resistance becomes about twice as large as that of pure ^{4}He and also shows much the same temperature dependence as pure ^{4}He.

In summary, it is found that a small amount of ^{3}He impurities affects the growth kinetics of ^{4}He crystals around 0.8K. The observed enhancement of the growth resistance may be attributable to the decrease of the effective thermal conductivitity in dilute ^{3}He mixtures.

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