Faceting of ^{3}He crystals

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Abstract

We report on our optical observations on bcc ^{3}He crystals in the temperature range of $8\dots55$ mK. With our interferometric technique we were able to identify at least three different types of facets, (110), (100), and (211), at temperatures up to 55 mK. Previously, only the (110) facet was observed at such high temperatures with its roughening transition at 100 mK.

Key words: helium3; solid helium; faceting;

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1. Introduction

At low enough temperatures the surface of a crystal in equilibrium should have facets, which are atomically smooth planes in the high symmetry directions provided by the crystal lattice. As it was shown by Landau [1], at $T = 0$ the steps which separate terraces of different atomic layers on a facet have positive energy due to the Van der Waals interaction. This leads to the conclusion that in equilibrium the facet has a finite size, proportional to the step free energy β [1]: $R \sim L\beta/(\alpha d)$, where L is the characteristic size of a crystal, α is the surface tension and d is the step height.

However, when temperature increases, the step free energy decreases due to thermal fluctuations and becomes zero at certain temperature. The facet becomes unstable with respect to spontaneous creation of steps, and the surface becomes rough.

The two surface states, smooth and rough, are separated with the so called roughening transition, first considered by Burton, Cabrera, and Frank [2]. Each type of facet has its own roughening transition temperature. Fisher and Weeks [3] have suggested the universal relation for the roughening transition temperature

$$T_R = \frac{2d^2}{\pi}(\gamma_x\gamma_y)^{1/2}, \tag{1}$$

where $\gamma_x = \alpha + \partial^2\alpha/\partial n_x^2$ and $\gamma_y = \alpha + \partial^2\alpha/\partial n_y^2$ are the two principal components of the surface stiffness. On ^{4}He crystals three different types of facets have been observed, and Eq. (1) is in a good agreement with measured roughening transition temperature for the basal c–facet.

In recent experiments on bcc ^{3}He crystals [4] altogether eleven different types of facets have been observed, which makes ^{3}He particularly interesting as a system where the model conceptions of the liquid–solid interface could be checked. Up to now the roughening transition temperature has been measured only for the (110) facet, $T_{R,110} \approx 100$ mK [5].

2. Experiment

The observations of facets on the equilibrium crystal shape close to the roughening transition is a very difficult task. As the step free energy is close to zero, the

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equilibrium facet size is very small (see Introduction). Moreover, in the case of ^{3}He extremely big latent heat and very poor thermal conductivity of the normal liquid result in time constant of the order of several days.

Another possibility to detect a facet is to observe crystal during growth. Rough surfaces which have significant density of nucleation cites to stick atoms from the liquid phase, grow relatively fast. On the contrary, facets can only grow by means of the motion of the steps, which are typically present on facets due to the screw dislocations. This anisotropy of growth leads to the increase of the size of facets, which thus can become observable.

In order to obtain a big single ^{3}He crystal from the normal liquid one should grow the existing seed very slowly. There are two effects which can destroy the experiment. First, there is the well-known Mullins–Sekerka instability of the solidification front, which results in creation of "fingers" on the moving surface [7]. For a ^{3}He crystal of 1 mm size at 50 mK the critical velocity of the interface is $v_{ins} \sim 0.2\,\mu m/$s. Second, the surface of the growing crystal has somewhat lower temperature with respect to the liquid far away of the crystal due to the Pomeranchuk effect. Thus, if the corresponding pressure difference exceeds the threshold for the crystal nucleation ($\sim$ 3 mbar), a new crystal appears and starts to grow instead of the present one. The critical velocity for such process could be estimated to be $v_{nucl} \sim 0.1\,\mu m/$s at 50 mK.

For imaging ^{3}He crystals we used a low temperature Fabry-Pèrot interferometer (see Ref. 6 for the description). Measurements were done in the compressional cell, pressurized by ^{4}He. We have adjustable cold valve in the ^{4}He line mounted on the mixing chamber plate, which allows us to apply compression rate less than 10^{-8} cm^3/s.

3. Results

We observed ^{3}He crystals in a temperature range of 8...55 mK. Typical interferogram is shown in Fig. 1; facets manifest themselves as areas of parallel equidistant fringes. By fitting the intensity distribution within these areas with a sinus–like function, we have obtained the density of the fringes and their slope, which gives the orientation of the facet.

The measured angles between facets were compared with angles between the planes in bcc-lattice. Facets with highest step height d should appear at higher temperature, those are (from high to low d): (110), (100), (211), (310), … . We note that the neighbouring facets of (110) and (100) types can form only angles of 45° and 60°. If facets of the (211) type are also present, angles of 30°, 33.6° and 35.3° are additionally possible.

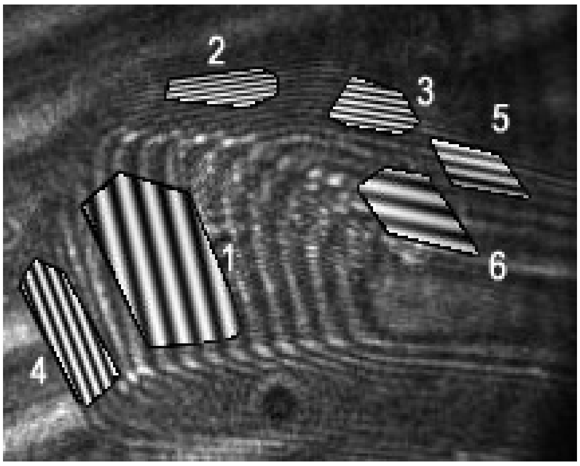

Fig. 1. Interferogram of a growing ^{3}He crystal at 55 mK. Images of 6 resolved facets are replaced with the results of the fitting procedure (see text).

At all temperatures we have found that angles between some facets are much less than 45°. For example, in Fig. 1 the angle between facets 3 and 6 is 30° ± 5°, and between facets 5 and 6 even less. This leads to the conclusion, that at least 3 different types of facets are present on the crystal shape up to 55 mK. Unfortunately, in most cases we were not able to determine the orientation of the crystal unambiguously.

Our observations suggest that first three roughening transitions in ^{3}He fall into the narrow temperature range of 55...100 mK. This fact is in contradiction with the universal relation (Eq. 1), which predicts $T_{R,110}/T_{R,211} = 3$, assuming the isotropic surface tension.

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