The Effect of the Crystal Quality on hcp Phase Nucleation in bcc ^{4}He Overcooled

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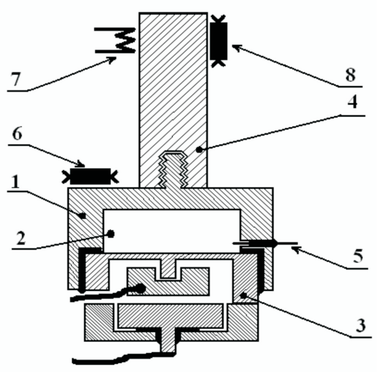
Motivation

There are no systematic experimental data concerning influence of crystal quality on nucleation kinetics in ^{4}He crystals.

Experimental technique



1 body (Cu)
2 specimen cavity (h=1mm, Ø=10mm)
3 capacity pressure gauge (BeCu)
4 cold finger (Cu)
5 filling capillary (stainless steel)
6 resistance thermometer of the cell
7 heater of the thermo-stabilizator.
8 resistance thermometer for thermo-stabilization.

Experimental procedure

•Øbject	solid ^{4}He
•Growth technique	blocking capillary
•Measurements	precise pressure measurement; pressure (acuracy 5 mbar, resolution 1 mbar); temperature (acuracy 3 mK, resolution 1 mK); period 1 sec
•Annealing	3 stages (on the melting curve, at the temperature 5-25 mK below the melting curve, and thermocycling in one-phase region)

Initial data

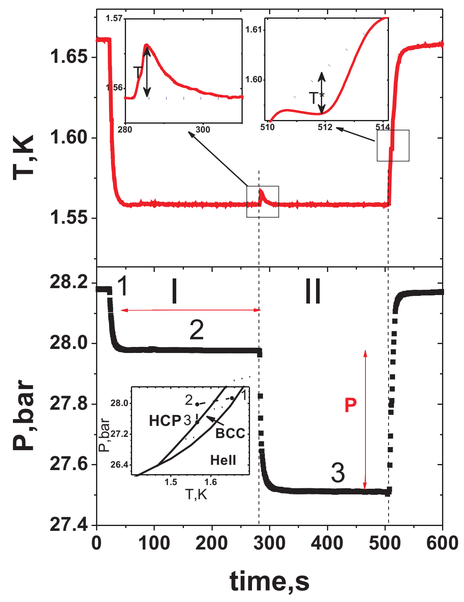


Fig.1 - Typical run through P-T phase diagram under cooling and heating of the crystal ^{4}He [2].

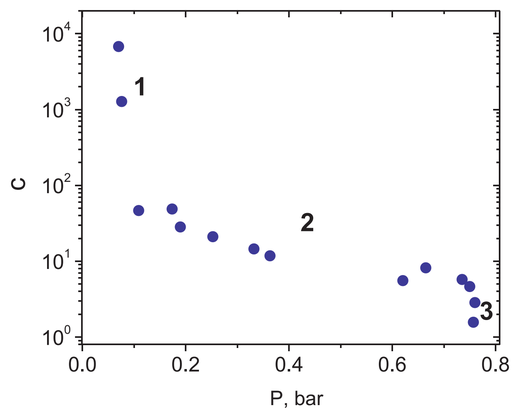


Fig. 2 - Time delay τ of bcc-hcp phase transition in overcooled BCC crystal as function of "overpressing" τ P.
1, 2, 3 - specific areas τ (τ P) dependence.

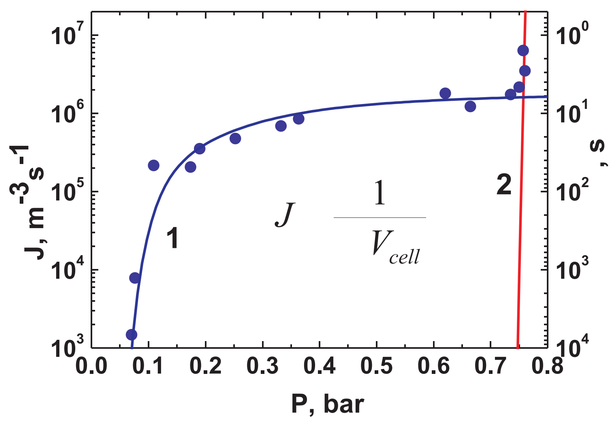


Fig. 3 - Nucleation frequency as function of "overpressing" τ P.
1 - data are fitted by Eq.(1) - heterogeneous nucleation;
2 - Results of fitting Ref.[1] by Eq.(2) - homogeneous nucleation.

$$P \quad 1.2 \quad 10^6 \exp\frac{0.11}{(P)^2} \quad 5.1 \quad 10^5 \exp\frac{0.022}{(P)^2} \qquad (1)$$

$$J_{\text{hom}} \quad N_0 w \exp\frac{16 \quad {}^3_{hb}V_{bcc}{}^2}{3k_B T(G)^2} \quad 6 \; 10^{33} \exp\frac{42.6}{(P)^2} \qquad (2)$$

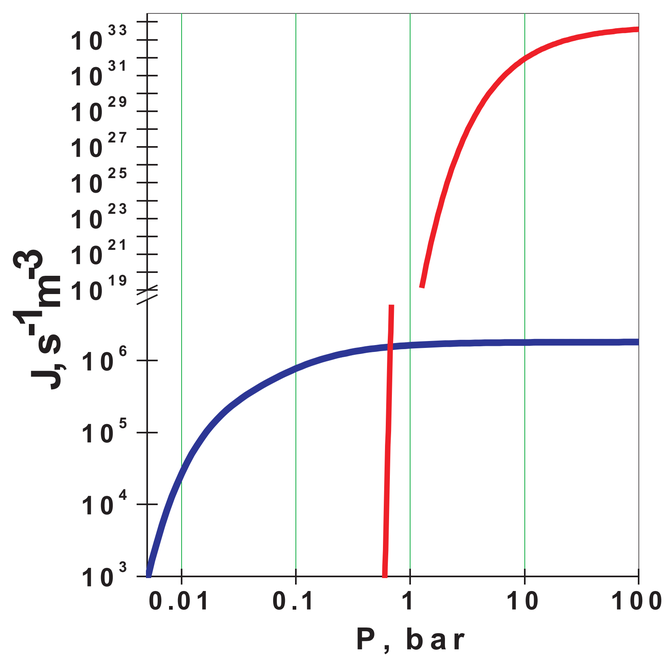


Fig. 4 - Fig. 3 in the full scale

The influence of cycling

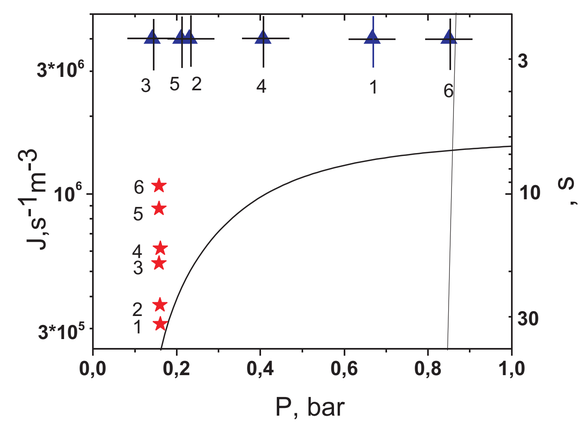


Fig. 5 (stars) - influence of cyclic overcooling of the bcc sample on nucleation frequency; (triangles) - influence of cyclic overcooling of the bcc sample on attainable values P at T=1.55 K (numerals corresponds to cycle number). Solid lines are from fig.4

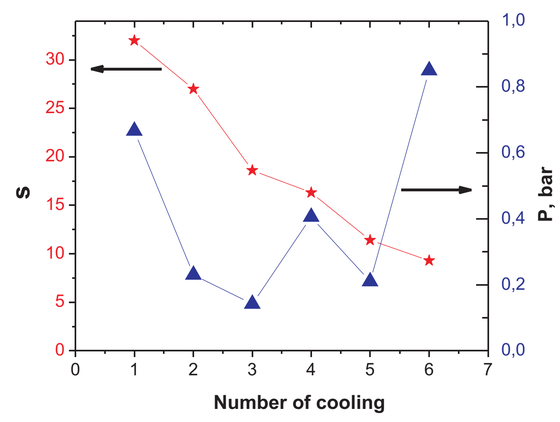


Fig. 6 (stars) - influence of cyclic overcooling of bcc sample on delay of phase transition beginning; (triangles) - attainable overpressure P at continuous cyclic overcooling of bcc sample from T=1.55 K. T=1.55 K (numerals corresponds to cycle number). Solid lines are from fig.4.

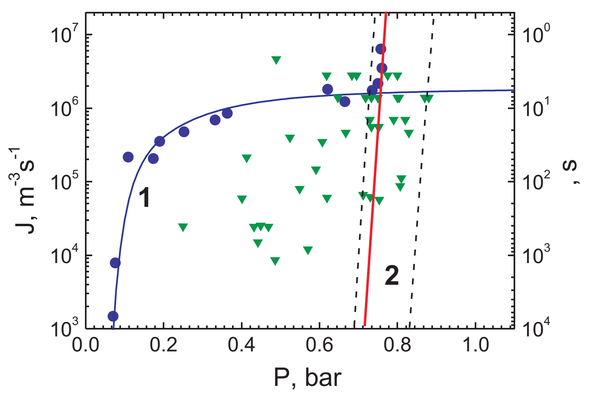


Fig. 7 Nucleation frequency dependence on overpressure at overcooling un-annealed bcc samples (triangles) in comparison with data for annealed samples(circles). (-------) - overcooled bcc phase existing boundaries. (solid line) - homogeneous nucleation from [1] at T=1.55 K (numerals corresponds to cycle number). Solid lines are from fig.4

Abstract

Pure ^{4}He bcc crystals are studied by precise pressure measurement technique under constant overcooling ΔT. The bcc-hcp phase transition is accompanied by both a sharp pressure decrease ΔP under constant volume condition and a simultaneous appreciable heat release in the sample up to few mK. Depending on ΔT, the measured life-time of the metastable bcc phase is from several seconds to several hours. The dependence of nucleation frequency J $^{-1}$ on overpressure ΔP for the bcc-hcp phase transition in good annealed ^{4}He crystals demonstrates both homo- and heterogeneous nucleation mechanisms under different values of ΔP. It is shown that homogeneous nucleation is not realized in un-annealed crystals as well as in crystals undergone the bcc-hcp phase transition even under maximal available ΔT 0.08 K and ΔP 1 bar. A contribution of possible diferent centers of nucleation to heterogeneous nucleation kinetics is discussed.

The line of attainable overcooling

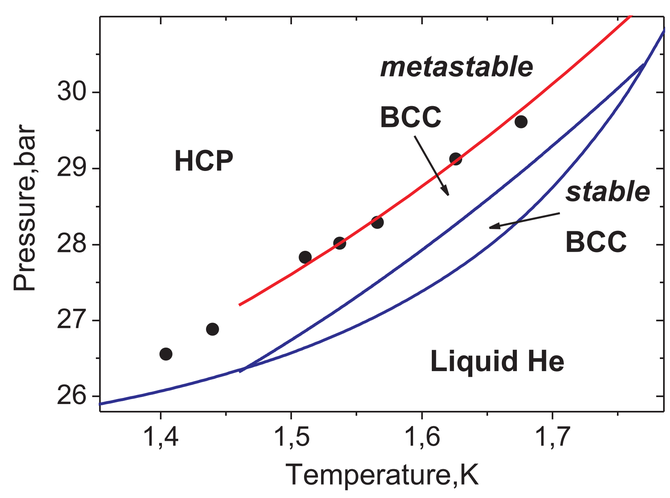


Fig. 8 - Data from work [1]

Conclusions

1. Comparison of nucleation mechanism in annealed and un-annealed overcooled bcc samples is performed.

2. It is shown that only heterogeneous nucleation can realized in un-annealed crystals. A contribution of possible different nucleation centers in heterogeneous nucleation kinetics is discussed.

3. Influence of cyclic overcooling of bcc crystals on J, ΔP, and life-time is shown.

References

[1] V. Grigor'ev, N. Mikhin, E. Rudavskii, Ye. Vekhov. The bcc-hcp Phase Transition in ^{4}He: Comparison with the Theory of Homogeneous Nucleation. Journal Low Temp. Phys., 2008, Vol. 150, Nos.1/2, p. 47–56.

[2] A. Birchenko, Ye. Vekhov, N. Mikhin, A. Polev, E. Rudavskii. Kinetics of the bcc–hcp transition in ^{4}He off the melting curve. Fiz. Nizk. Temp. Vol. 32, p. 1471 (2006) [Low Temp. Phys. Vol. 32, p. 1118 (2006)].

Acknowledgments

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For notes