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The Hysteresis of bcc-hcp Transition in Solid ^{3}He-^{4}He Mixture

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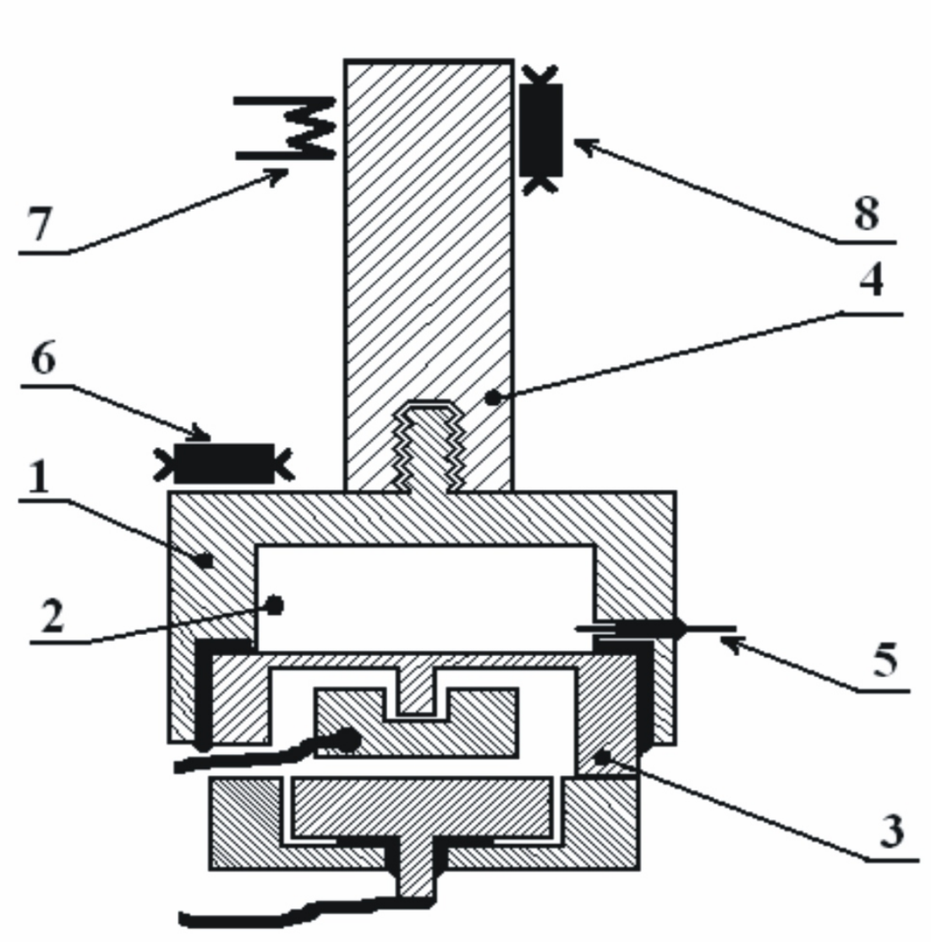
Motivation

- No systematic experimental data on thermodynamic of bcc-hcp transition in solid mixture ^{3}He-^{4}He (1% ^{3}He)
- There are no precise *P-T* phase diagram within bcc phase
- No systematic data on hysteresis effects

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 thermostabilizor.
8 resistance thermometer for

Experimental procedure

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

Results

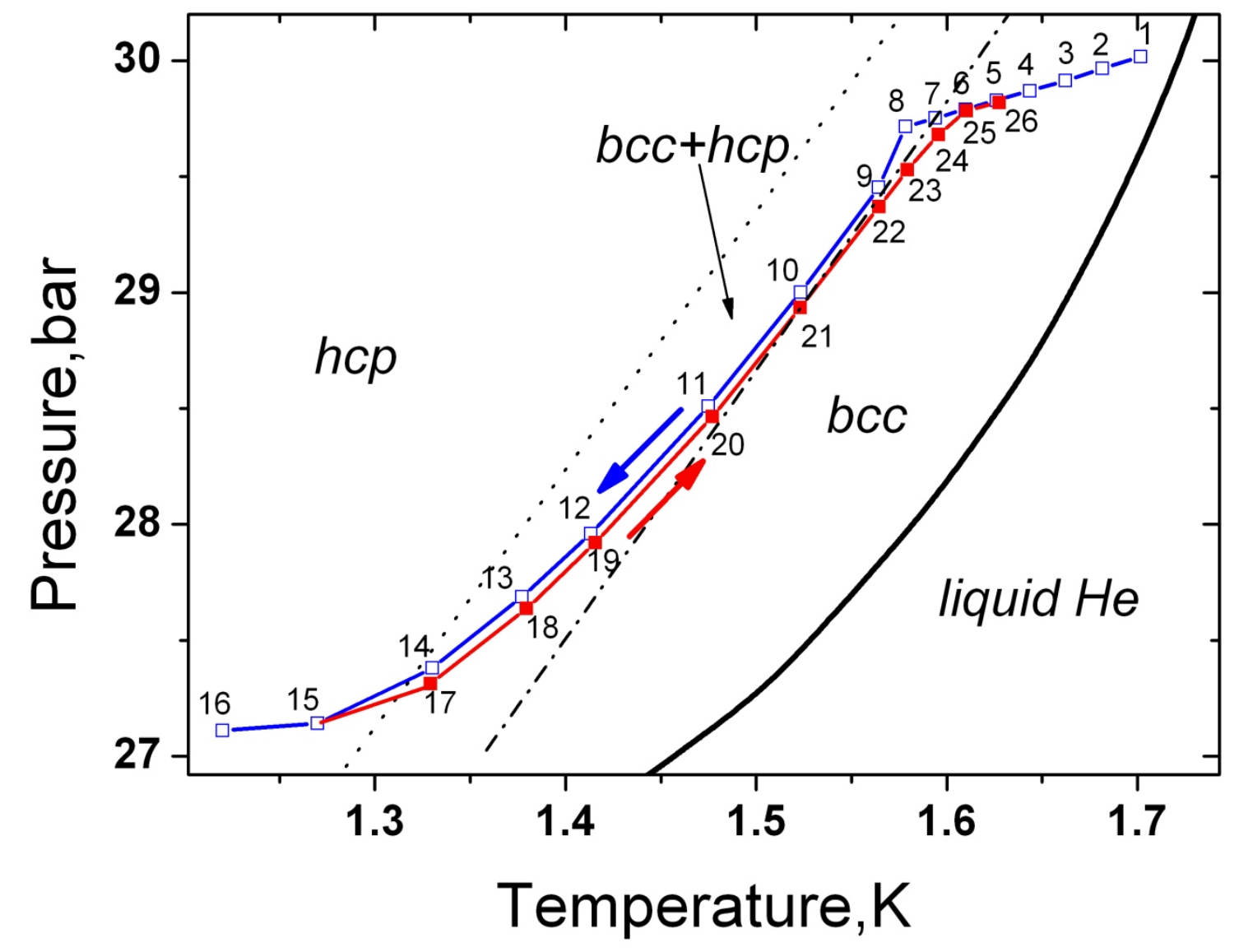
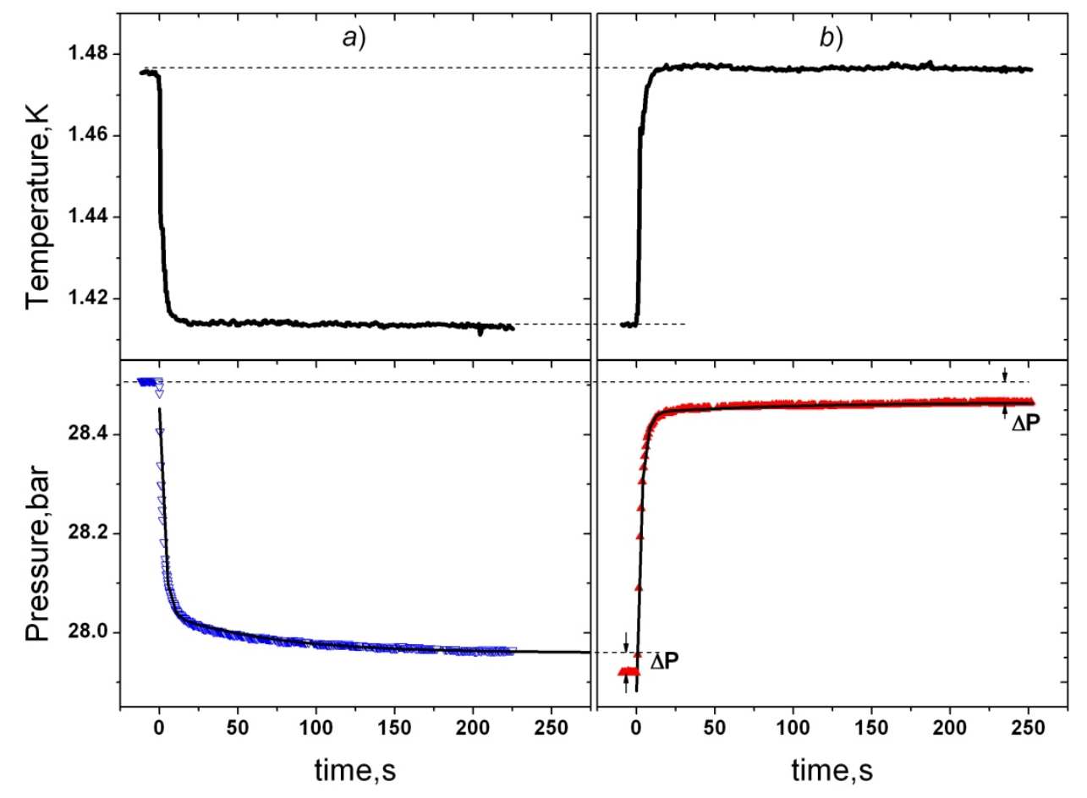


Fig.1 - Typical run through P-T phase diagram under cooling and heating of the sample 1% ^{3}He in ^{4}He.

Initial data



The hysteresis loop

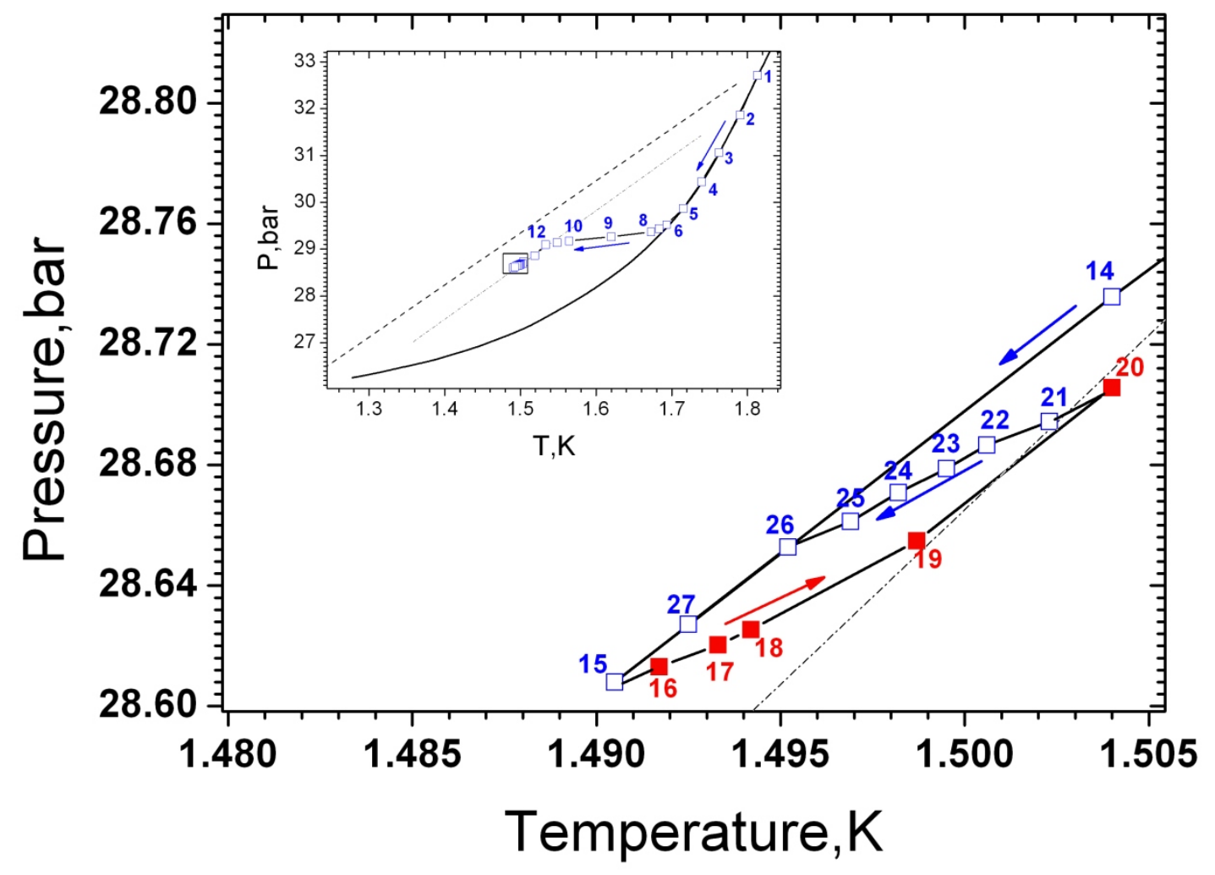
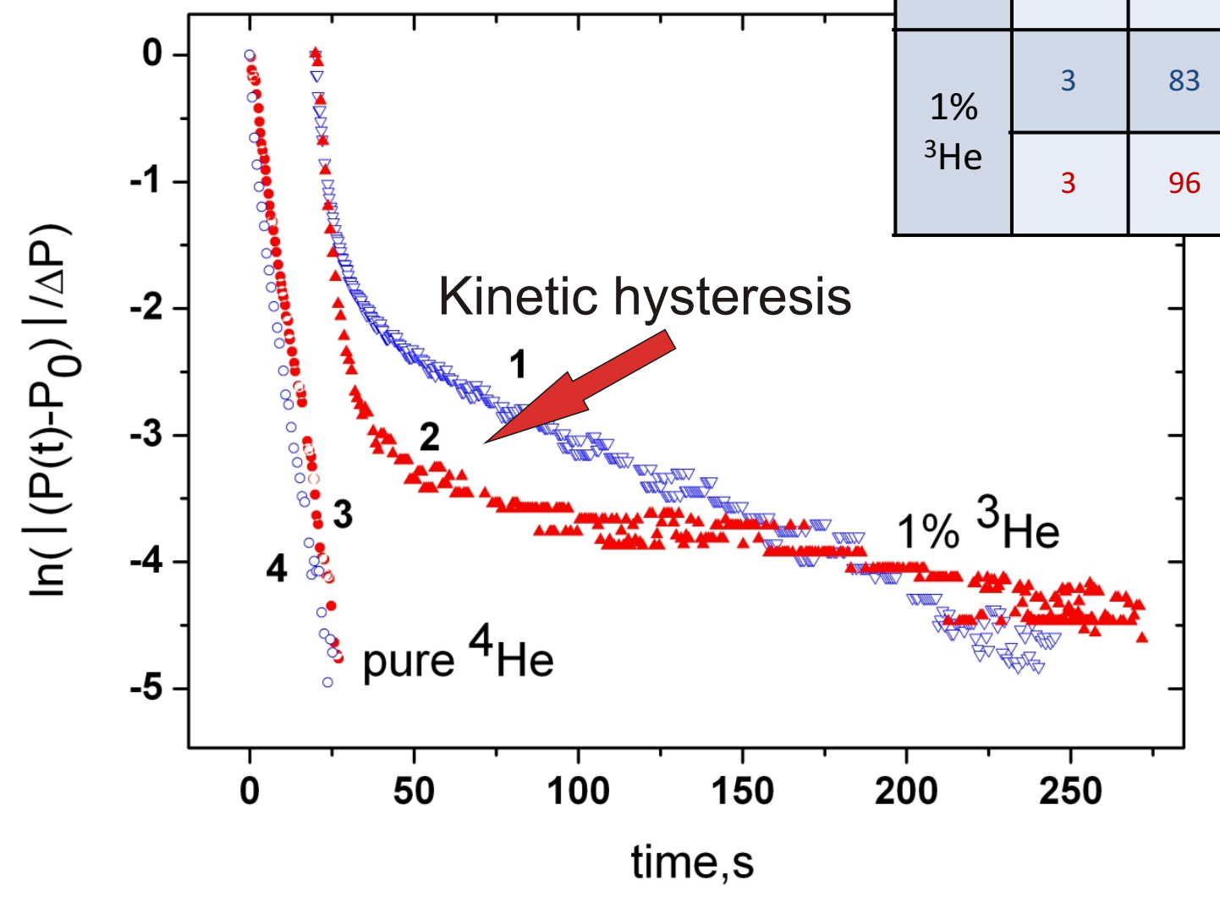


Fig. 3 - Step-wise cooling and heating within bcc-hcp region



	τ_1,s	a_1,%	τ_2,s	a_2, %	
^{4}He	5	100	0	0	cool
	5	100	0	0	heat
1% ^{3}He	3	83	67	17	cool
	3	96	91	4	heat

Fig. 4 - Kinetics of pressure changing during step-wise cooling and heating of two-phase sample 1% 3He-4He;
cooling (Ti=1.681K, Tf=1.667K) and heating (Ti=1.550K, Tf=1.648K) of pure 4He.

Constructing of phase diagram

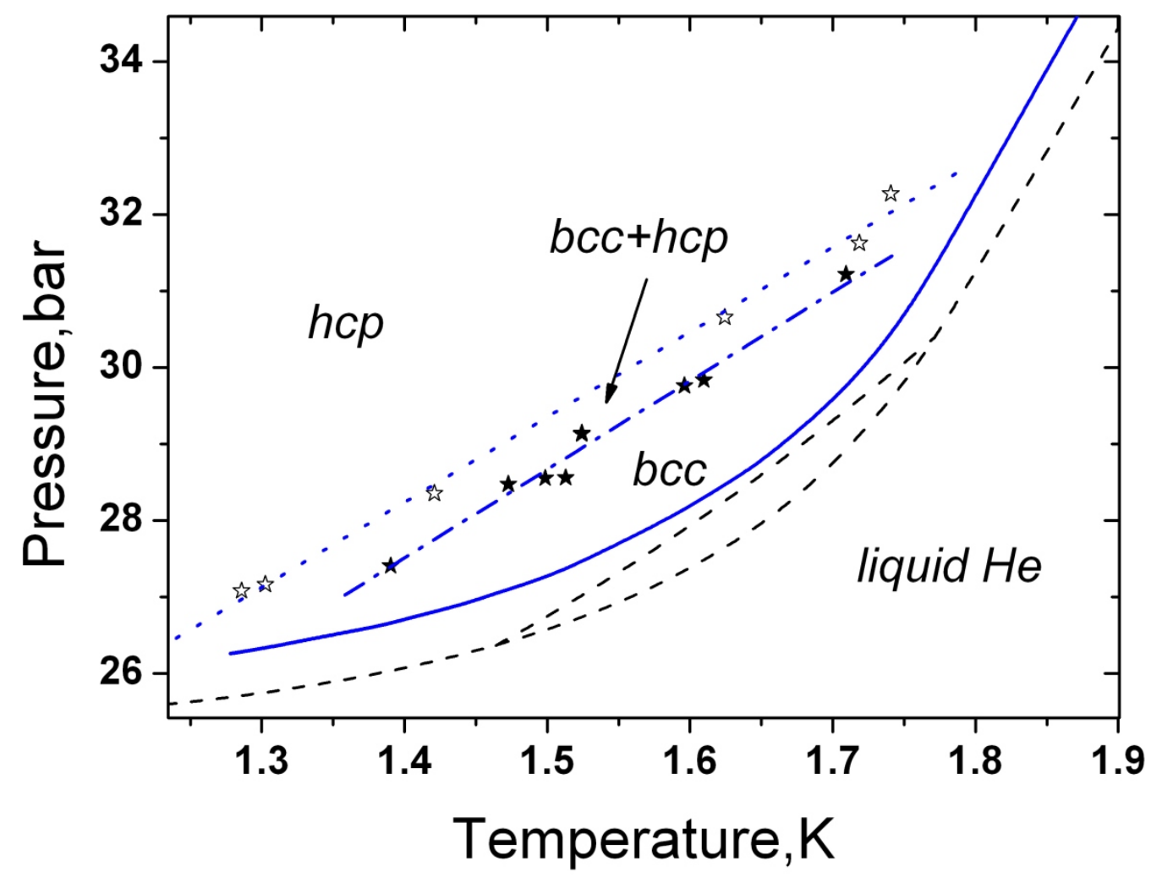


Fig. 5 - *P-T* phase diagram for pure ^{4}He (black lines) and 1% ^{3}He in ^{4}He mixture (blue lines)

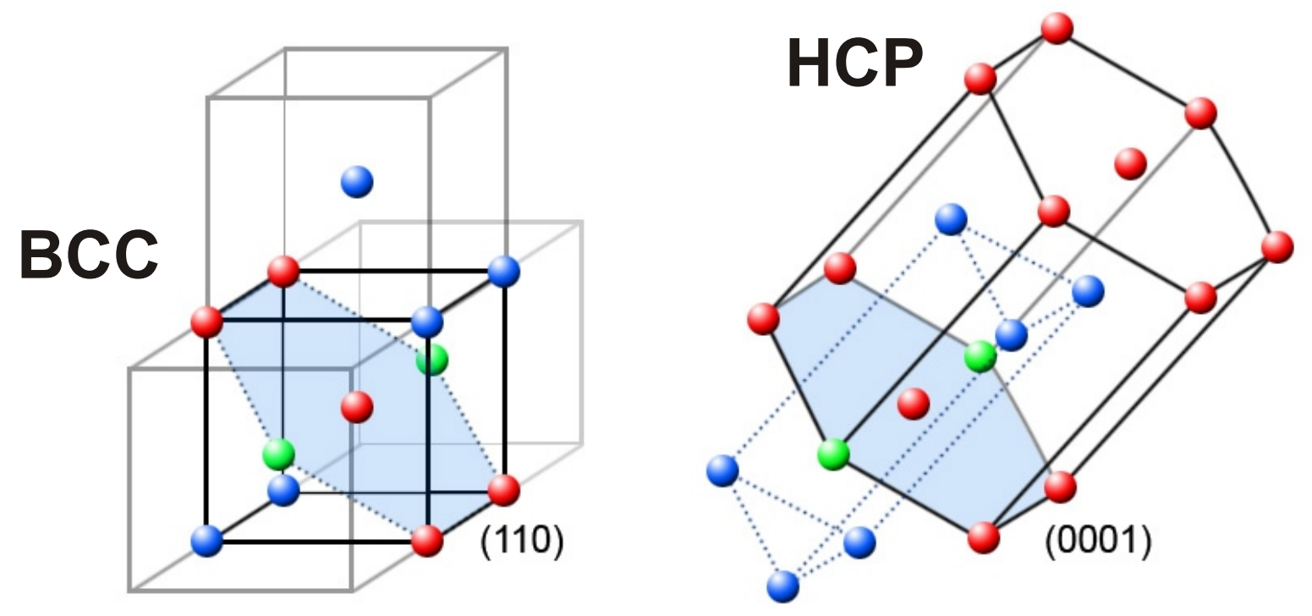


Fig. 6 - Scheme of bcc to hcp phase transition

Table 1 - Data for solid helium near bcc-hcp transition

phase structure	x%^{3}He	dP/dT, bar/K	τ_1,c	τ_2,c
bcc	0	2.0 - 2.5	3-5	0
hcp	0	0.25 - 1.0	1-2	0
bcc/hcp	0	11-16	2-5	0; 10-20
bcc	1	1.4 - 3.2	3-5	0
hcp	1	0.5 - 1.5	1-2	0
bcc/hcp	1	6 - 12	3-7	65-100

$$P(t) = P_0 \pm \Delta P\left[\alpha\cdot\exp\left(-\frac{t}{\tau_1}\right)+(1-\alpha)\exp\left(-\frac{t}{\tau_2}\right)\right]$$

For notes

Abstract

The hysteresis effect of bcc-hcp phase transition in dilute ^{3}He - ^{4}He solid mixture is observed experimentally. The experiments are carried out using precise pressure measurement technique on samples produced by blocking capillary method. Samples studied contain 1 % of ^{3}He in ^{4}He. It has been found that during step-wise temperature variation within two-phase region, the cooling line in P- T diagram is located substantially upper than the heating one. Under thermocycling in bcc/hcp region the system makes closed cycle. Such an effect is not observed in pure ^{4}He, so that it is caused by the presence of ^{3}He impurities in ^{4}He matrix.

The presence of impurities in the mixtures changes the character of exponential pressure relaxation during step-wise temperature variation of two-phase sample adding the long range relaxation time tau2 to the short time tau1 which is the only relaxation constant in the pure ^{4}He [1]. Note, that pressure relaxation in single-phase regions of the mixtures is described by one exponential law, just as in pure ^{4}He. We propose the physical model of the ^{3}He - ^{4}He mixed crystal to describe the thermodynamics of the phenomena observed. The ^{3}He impurities in the ^{4}He host matrix trap the second phase domains which form mesoscopic coherent polydomain superstructure (CPS). The impurities are isotropic dilatation centers in anisotropic bcc or hcp host lattices. They produce anisotropic internal stresses around each of the impurity and form the second phase regions (hcp in bcc, and vice versa) along the plane systems. These systems are incline to the crystal instability which is caused by the corresponding lattice transformation (the {110}c system in bcc lattice and {0001}h system in hcp one). The difference in the hcp CPS inside of bcc host lattice and the bcc CPS inside of hcp host lattice is the reason of the different behavior of the solid mixture during the bcc-hcp and hcp-bcc transformation under cooling or heating of the sample, respectively. The coherence in the individual domains in the superstructure leads to the reproducible hysteresis on *P -T* phase diagram of the solid mixture. The hysteresis is a closed thermodynamical cycle realized on the degrees of freedom of the CPS.

1. A.P. Birchenko, Ye.O. Vekhov, N.P. Mikhin, A.V. Polev, and E.Ya. Rudavskii, Low Temperature Physics, 32, 1118 (2006).

Conclusions

- **Kinetic and thermodynamic hysteresises were found during bcc-hcp transition in dilute solid mixtures ^{3}He in ^{4}He.**
- **For the first time, the *P-T* phase diagram was constructed for the bcc/hcp region.**
- **Theoretical model is proposed for explanation of effects observed.**

Acknowledgments

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