New fixed point on the basis of In-Bi eutectic system for perspective space-borne standard low-temperature fixed-point blackbodies

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Reliable climate change monitoring requires high-quality long-term time series of atmospheric and surface remote temperature measured with space-borne radiometric IR instruments. This task can be solved through the development of incorporating the phase transition phenomenon space-borne blackbodies with an increased stability intended for IR instruments in-flight calibration. For the said purpose a number of phase-change materials (PCMs) with melt-freeze temperatures/fixed points located in the dynamic temperature range of Earth observation systems (~ 230÷350 K) are potentially applicable [1, 2]. Space-flight experiments on the melt-freeze transition in zero gravity of potentially applicable PCMs – individual substances and eutectic alloys – are absolutely necessary in the sequence of works on developing the novel space-borne standard fixed-point blackbodies.

SPACE-FLIGHT EXPERIMENT "KALIBR" – AN ESSENTIAL STEP ON THE WAY

The need for space-flight experiments follows from the fact that phase transition thermometric characteristics of a blackbody's working substance/PCM may alter in zero gravity. And for this reason characteristics of a fixed-point blackbody itself may alter in zero gravity as well.

In the line with this, the space-flight experiment "Kalibr" had been performed in 2014 on board the "Foton-M" #4 reentrant vehicle by using the space-borne standard blackbody test model (KALIBR) based on the melt transition of Ga (~ 303 K). The melting plateaus of Ga in zero gravity had been obtained, and performance of the space-borne low-temperature fixed-point blackbody test model/prototype KALIBR was investigated [3, 4].

NEW In-Bi EUTECTIC FIXED POINT

Along with Ga, the eutectic alloys Ga-In, Ga-Sn, and Ga-Zn as potentially suitable PCMs will be examined in zero gravity in the upcoming experiment on board the ISS ("Reper-Kalibr", stage 1). On ground preliminary experiments showed that these substances are really promising regarding the task of developing space-borne fixed-point blackbodies [5]. At the same time, having the melt temperatures quite close to each other they form a rather narrow "on-orbit calibration scale" (~ 289÷303 K).

This makes highly desirable to involve some other PCMs in addition to the aforesaid substances. With the use for this purpose the In-Bi eutectic system (~ 345 K) and water "the on-orbit calibration scale" will be significantly expanded (~ 273÷345 K).

For this reason, the In-Bi eutectic system was chosen as a PCM for the space-borne fixed-point blackbody test model KALIBR-2 being developed for the same name space-flight experiment on board the "Bion-M" #2 reentrant vehicle.

Laboratory study of the new In-Bi fixed point. In compliance with the specificity of space application the new fixed point on the basis of the In-Bi eutectic system was preliminary studied in small cells (in the same way as in previous work [5]). More precisely, the "In-Bi fixed point" (~ 345 K / ~ 72,5 ºC) is the melt temperature of the $In\text{-}In_2Bi$ eutectic alloy – a domain in the In-Bi phase diagram [6]. Three samples of the $In\text{-}In_2Bi$ alloy of different compositions were studied; typical melting plateaus are showed in the figure 1.

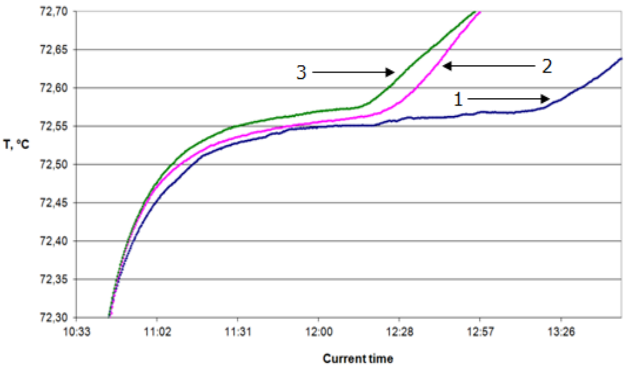

Figure 1. Melting plateaus of three samples of $In\text{-}In_2Bi$:

1 - 33,3 mass % Bi (approximate eutectic composition)
2 - 37,1 mass % Bi (hypereutectic composition)
3 - 24,0 mass % Bi (hypoeutectic composition)

In agreement with the theory melting plateaus of the sample close to eutectic composition and two other samples are found in practically the same temperature range. Though the melting plateaus of the hyper- and hypoeutectic alloys are shorter than one of the alloy close to eutectic composition (also in agreement with the theory) their quality is nevertheless quite appropriate: they last long enough, and irrespective of the plateau duration temperature drift at all plateaus does not exceed 30 mK (Fig. 1).

What is even more important regarding the final goal to ensure in-flight stability of space-borne IR instruments characteristics at the required level [2] – through the development of the novel high-stable space-borne blackbodies – that is a very good repeatability ~ 3 mK (1σ) of the In-Bi melting fixed point discovered in these experiments. (For simplicity, hereinafter we shall use the term "the In-Bi fixed point": by constituent elements.)

So, the ground-based study showed that the In-Bi eutectic system is a promising PCM for a space-borne fixed-point blackbody what explains the orientation of the space-flight experiment "Kalibr-2".

FUTURE SPACE-FLIGHT EXPERIMENTS INVOLVING THE In-Bi FIXED POINT INVESTIGATION IN ZERO GRAVITY

Space-flight experiment "Kalibr-2". Just like the experiment "Kalibr", the "Kalibr-2" pursues two interrelated goals. Firstly, investigation in zero gravity of the In-Bi eutectic system as a PCM for the perspective space-borne fixed-point blackbody with operational temperature ~ 345 K. The availability of such a blackbody should noticeably improve the quality of in-flight calibrations. And plus, testing of the space-borne standard blackbody prototype per se (in this case – utilizing the In-Bi fixed point).

Space-flight experiment "Reper-Kalibr". The space-flight experiment "Reper-Kalibr" as a whole (stages 1, 2) implies more thorough investigation of zero gravity influence on characteristics of a row of eutectic fixed points in connection with their use in the perspective space-borne calibration blackbodies. As for the In-Bi eutectic fixed point, it will be examined at the stage 2 of the "Reper-Kalibr".

As compared with the eutectic alloys on the basis of Ga (Ga-In, Ga-Sn, and Ga-Zn) which are the objects of investigation at the stage 1, the In-Bi eutectic system is even more interesting from a scientific perspective. (Another object of the stage 2 of the "Reper-Kalibr" – water – is also highly interesting from a scientific viewpoint.) The thing is, atomic weights of In and Bi differs among themselves more than atomic weight of Ga, on the one hand, differs from ones of In, Sn, and Zn, on the other hand. This fact makes the In-Bi eutectic system more "sensitive" to gravity.

Space-borne fixed-point blackbody prototype KALIBR-2 based on the In-Bi eutectic system. Coming back to the "Kalibr-2" space-flight experiment, it should be pointed out that its primary goal is nevertheless rather practical than scientific: testing the space-borne standard fixed-point blackbody prototype. This experiment will be helpful for developing a reasonable number of the space-borne calibration blackbodies with an increased stability which operational/fixed-point temperatures are within the dynamic temperature range of Earth observation systems (~ 230÷350 K).

The use of the new In-Bi eutectic fixed point for the said purpose enables to create a space-borne blackbody with operational temperature almost at the upper limit of the dynamic temperature range. Such a noticeable expansion of "the on-orbit calibration scale" ensures more qualified in-flight calibration of space-borne radiometric IR instruments operating in the dynamic temperature range, whose measurements are critical for reliable climate change monitoring.

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