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Spectral emissivity of technical titanium near the melting point

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An experimental study of the normal spectral emission ability of technical titanium grade VT1-00 in the melting region was carried out. The scheme of the upgraded direct vision radiometer with replaceable narrow-band dispersion filters of the spectral range $0.69-10.9\,\mu$m. is given. The estimation of the possibility of calculating the emission capacity of titanium according to electromagnetic theory is carried out..

Keywords: normal spectral emissivity, melting region, wavelength, titanium.

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Introduction

The study of the heat-transfer properties of solid and liquid metals at high temperatures is of great scientific interest and is of an applicable nature, since its results can be applied in the field of technological engineering and the design of electric power plants.

This paper presents an experimental study of the standard spectral emissivity of titanium in melting area.

Commercial titanium is widely used in a wide variety of industries and plants. High heat-resistance, lack of corrosion and mechanical performance determine the wide range of applications for titanium. The detailed information on the properties of commercial titanium and alloys based on it is given in [1].

Since all technological and technical processes of titanium processing take place in thermal production areas, it is necessary to know its exact heat-transfer properties, in particular, the emissivity of the metal under study, which allow optimizing the design and predicting the operating temperature parameters of radiant exchange.

The authors of this paper have studied the standard spectral emissivity of VT1-00 titanium, in which the mass fraction of aluminum is allowed no more than 0.3% in accordance with GOST 19807-91, in melting area. The temperature of the titanium melting area was taken from the recommended values according to the International Temperature Scale [2], which coincided with the melting temperature of the engineering sample.

The study was carried out on the experimental plant, the design of which is described in detail in [3]. Titanium was studied both in the polished solid phase and in the area of the melting point (liquid phase). The procedure for carrying out the experiment is similar to the procedure for measuring hemispherical total emissivity, presented in [4].

The experimental error was estimated by the authors and amounts to $3-8\%$ depending on the experimental temperatures. An improved direct viewing radiometer without focusing optics was used in the experiments (Fig. 1). The standard spectral emissivity of titanium was fixed by check points — pass bands of replaceable narrow-band filters. Applied dispersion narrow-band filters manufactured at the laboratory-pilot production of the Academy of Sciences Belarus and having passport spectral characteristics indicated in Table 1.

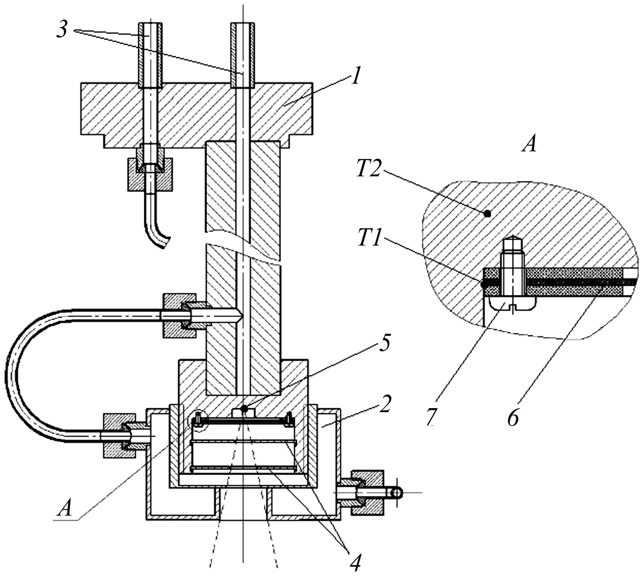

Figure 1. Schematic view of the radiometer: *1* — radiometer attachment flange to the cell body; **2** — thermostatic jacket; *3* — bushings for forced cooling of the radiometer body and current leads; *4* — internal apertures that determine the space angle of the radiometer; *5* — thermal converter-radiation detector (conditionally designated by a dot); *6* — removable optical filter; *7* — optical filter fixing screw; T_1, T_2 — chromel-copel thermocouples (conditional image).

Table 1. Spectral characteristics of the narrow-band filters

Filter No.	1	2	3	4	5	6
Filter pass band, μm	0.69	1.63	1.97	4.2	7.3	10.6

The thermal spectral flux from the metal surface was cut off by the pass band of the applied filter. Forced thermostatting was used in the experiments both for the body of the radiometer with apertures that determine the viewing angle, and for the optical filter itself. During the experiment, the temperature of the applied filter was monitored by a drilled lateral recess in the edge using an indium-cored chromel-copel thermocouple. Thus, the opportunity of adjusting the optical characteristic — pass band of the optical filter — due to potential heating during measurements was excluded. In addition, after a series of experiments, the pass band spectrum of the used removable optical filter was registered on spectrophotometers with the required wavelength bands and compared with the characteristics stated in the filter passport data.

It is also worth noting that after the experiments, the content of the main chemical element in the titanium samples was evaluated by X-ray fluorescence analysis in order to identify the diffusion of the substrate material — tantalic tape — into the sample under study. Studies have shown that adjustments in the chemical purity of titanium are not recorded.

1. Results of the measurements and discussion

At the study of the standard spectral emissivity titanium in the solid phase, a descending curve was obtained in the dependence of the emissivity ε_λ on the wavelength. The spectral dependence curve was recorded using the check points of the spectral transmission of the applied filters (Fig. 2). Comparison of the experimental parameters of the authors with other studies is presented in Table 2.

The discussion of the obtained values of the spectral emissivity of titanium in the solid phase resulted in the conclusion that the emissivity ε_λ increases with increasing temperature.

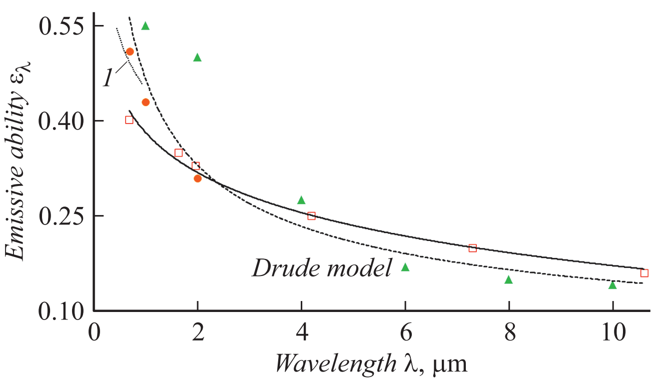

Figure 2. Standard spectral emissivity of titanium (solid phase) Triangle — [5]; circle — [6]; line *1* — [7]; square — measurements of the authors of this paper (solid-line curve — polynomial approximation). The result of calculation by the Drude model is also shown (dotted curve).

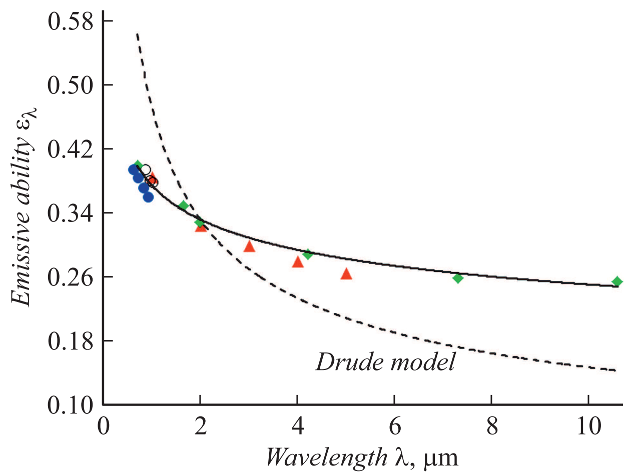

Figure 3. Standard spectral emissivity of titanium in the melting area (liquid phase) Blue circle — [11]; triangle — [12]; empty circle — [13]; rhombus — measurements of the authors of this paper (solid-line curve — polynomial approximation). The result of calculation by the Drude model is also shown (dotted curve).

The review of literature showed that the bulk of the experimental data on the spectral emissivity of titanium in the solid phase was studied in a small range of wavelengths and temperatures, and in some cases the studies were limited to a single measurement of a fixed wavelength [8–10].

The calculation carried out according by the Drude model showed satisfactory agreement with the experimental points over the entire spectrum of the experiment.

The experimental points for the liquid stage in the melting area (Fig. 3), as in the previous measurements of the solid phase, consist of check points — optical filter pass bands. Satisfactory agreement between the nature of the behavior and the experimental values ε_λ with the data [11–13] was obtained within the error range determined by the assessment of accuracy.

The authors obtained a smooth descending curve of standard spectral emissivity versus wavelength, limited by the spectral capabilities of the radiometer. Comparison of the experimental parameters of the authors with other studies is presented in Table 3.

The result of a theoretical calculation of the standard spectral emissivity is also given according to the classical electromagnetic theory (Drude formula [14]) using experimental data on the electrical resistance of titanium in the solid and liquid phases of the authors [15,16]. Theoretical calculation gives underestimated values ε_λ of the wavelength. This nature of the calculated standard spectral emissivity was analyzed in the paper [17] and was explained by the presence of a mechanism for adjusting the intraband transition of electrons in the metal crystal latitude, i.e., the transition of electrons from one energy level to another.

The fundamental non-applicability of the Drude formula in the area of short waves for calculating the emissivity of metals was noted by the author of the book [18].

Table 2. Characteristics of experimental parameters (solid phase)

Paper	[5]	[6]	[7]	This paper
Material	Titanium with a purity of 99.9%	Iodide titanium	Titanium with a purity of 99.9%	Titanium grade VT1-00
Temperature of the experiment, K	1614	1407	1823	1940
Wavelength band, μm	1–16	0.5–2	0.5–0.7	0.69–10.6
Measurement accuracy, %	Less than 4	3–10	1	3–8

Table 3. Characteristics of experimental parameters (liquid phase)

Paper	[11]	[12]	[13]	This paper
Material	Titanium with a purity of 99.9%	Titanium with a purity of 99.9%	Titanium with a purity of 99.9%	BT1-00
Temperature of the experiment, K	1945	1943	1941	1945
Wavelength band, μm	0.5–0.9	0.7–6	0.8–0.9	0.69–10.6
Measurement accuracy, %	5	up to 4	2–4	3–8

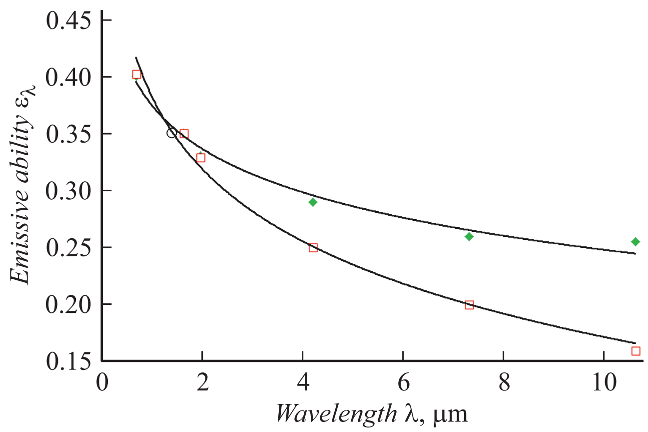

Figure 4. Standard spectral emissivity of solid and liquid titanium in the melting area. Square — measurements of the authors ($T = 1940$ K); rhombus — measurements of the authors ($T = 1945$ K); circle — X-point [19]. Solid-line curves — in-polynomial approximations.

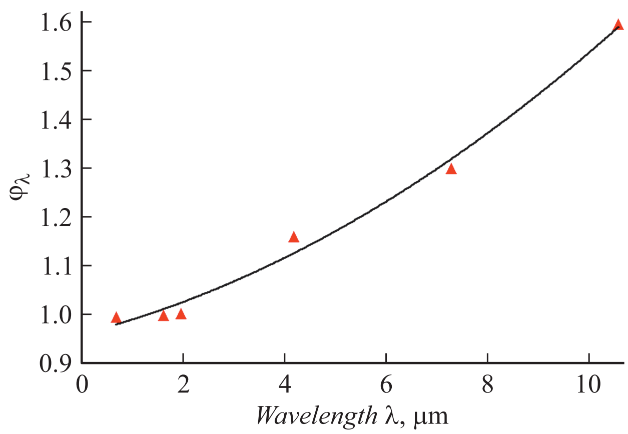

Figure 5. φ_λ value of titanium in the melting area. Triangle — values φ_λ calculated from the check points of the spectral characteristics of the applied narrow-band filters (Table 1); solid-line curve — approximation by a polynomial of the second degree.

In the general case, the Drude formula for metals based on the classical theory is fundamentally applicable and gives satisfactory agreement with experiment only starting from $\lambda \sim 10\,\mu$m.

Figure 4 shows the dependence of the standard spectral emissivity of liquid and solid titanium on the wavelength in the area of the melting temperature. The intersection of the fitted curves of the titanium liquid and solid phases suggests that at $\lambda \approx 1.1\,\mu$m ε_λ is independent of the metal temperature and the X-point area of titanium is presented . As is known, the area of the X-point, which is inherent in pure metals, is found in tungsten, molybdenum, tantalum, etc. [17–20].

Figure 5 shows the ratio φ_λ — standard spectral emissivity of titanium in the liquid phase — to the same value in the solid state near the melting point, as a function from wavelength:

$$\varphi_\lambda = \frac{\varepsilon_{\lambda,liquid}}{\varepsilon_{\lambda,solid}}.$$

For titanium in the area of $0.69\,\mu$m φ_λ is close to one (Fig. 5). It implies that the titanium emissions in the liquid and solid phases in the melting area are comparable to each other. The metal radiates in the same way, and the break in the standard spectral emissivity of titanium in the area of the melting temperature is not fixed.

The nature of this ratio is consistent with similar measurements of the spectral emissivity of a number of metals in the visible region (from 0.4 to $0.7\,\mu$m) [21]. As far the wavelength is growing, the value φ_λ starts deviating from one, with quite abrupt spike.

Conclusion

1. A study of the spectral emissivity of VT1-00 titanium was carried out on a modernized experimental stand. The spectral ranges from 0.69 to $10.6\,\mu$m of the solid and liquid phases in the area of titanium melting were studied.

2. The nature of the emissivity of the titanium solid phase in the melting area agrees satisfactorily with the experimental values of other authors and the Drude model.

3. The study of the liquid phase showed satisfactory agreement with numerous measurements by different authors. Calculations based on the Drude model give underestimated values over almost the entire spectral range of experimental measurements.

4. The authors assume that the X symmetry area of titanium is found in the wavelength band $1.1-1.5\,\mu$m with a fixed emissivity $\varepsilon_\lambda \approx 0.35$.

5. The ratio of φ_λ value of titanium in the melting area was obtained. An analysis of nature of this quantity as a function of the wavelength showed that in the short-wave region, the discontinuity in the emissivity is not fixed, and as the wavelength increases, a qualitative increase φ_λ is observed.

6. It is concluded that the wavelength depends on the ratio „liquid−solid" in the visible region of the spectrum, which is determined primarily by the direct interband transition.

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Conflict of interest

The authors declare that they have no conflict of interest.

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