

The existence of the effect of „bleaching“ of ice in the infrared range

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The effect of fresh ice „bleaching“ in both the visible and infrared ranges near a temperature of 0°C at wavelengths of $3.8\text{--}4.2\text{ }\mu\text{m}$ and $10\text{--}16\text{ }\mu\text{m}$ is shown. The maximum detected decrease in the absorption coefficient of the medium was $\sim 30\%$. The influence of the spatial arrangement of the base planes of the crystals on the effect, which is maximal when the electric field vector of the waves and the base plane are parallel, is confirmed.

Keywords: fresh ice, absorption coefficient, infrared range, phase transition, plasmon effects.

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Introduction

Some papers [1–4] reported the effect of ice „translucence“ which manifests itself in the decrease of the values of true and false parts of the relative complex dielectric permittivity of ice near the temperature of phase transition of ice–water in optical and microwave ranges. Such decrease of dielectric characteristics of natural media may lead to wrong interpretation of data of remote probing of cryospheric formations. Paper [5] may serve as representative, where the effect of ice „translucence“ was observed in the interval of temperatures $-1 \dots -0.2^{\circ}\text{C}$ based on the measurements of electromagnetic losses. As a result, the calculations for the plane-layered structure of air–ice–water at frequency of 3.4 GHz and ice thickness of 1.5 m show that the reduction in the brightness temperature, which characterizes the capacity of thermal radiation, reaches $\sim 30\text{ K}$. This corresponds to ice of much smaller thickness.

According to [1–4], the ratio of extreme frequencies, where this effect is detected, has the value 10^6 , namely from microwave to ultraviolet ranges. An unusually broad frequency range, where translucence is observed, indicates a special electrophysical behavior of ice. It should be noted that the cited papers contain no data on the effect in the infrared (IR) area of the spectrum. Currently this range is actively used in satellite systems to solve a broad circle of scientific and practical problems. For example, the normalized difference snow index (NDSI) depends on the ratio of the difference in the values of brightness in the visible (560 nm) and near infrared (1650 nm) areas of the spectrum to their sum [6–7]. Using the above index, the ice formations are identified in the period, when there is no snow [8–9]. Therefore, to analyze the data on the condition of frozen formations, knowledge on the radiative and absorbing characteristics of ice near the ice–water phase transition temperature in the infrared range is necessary, due to the detected effect of „translucence“ in

other ranges. The aim of this paper is to experimentally determine the effect of ice „translucence“ in the IR-range at wavelengths $3.8\text{--}4.2\text{ }\mu\text{m}$, $10\text{--}16\text{ }\mu\text{m}$, where this effect would seemingly manifest itself weaker for the reason of a higher value of the false part of the relative complex dielectric permittivity [10].

Experimental method

To study the effect of „translucence“ in the infrared range, the experimental setup was used, the diagram of which is presented in Fig. 1. The generator of emission was a halogen lamp (model HRS51), which is indicated in the diagram as (1). The lamp was heated with current that was considerably lower than the rated one to create a weak flow of emission and to exclude fast heating of the ice sample (3). The generation of the emission flow was stable, and capacity variations for a long time did not exceed 0.1% . To improve the sensitivity of a radiometric receiver, the signal was modulated using a rotary tab disc (2). Further, the modulated emission passed through the ice sample (3) and was recorded with a radiometric receiver (4) with a band from 2 to $25\text{ }\mu\text{m}$ and a photodetector (5) with a band from 380 nm to $1\text{ }\mu\text{m}$. In some experiments a photo diode Lms43PD-03CG by „LED Microsensor NT“ was used with a band of $3.8\text{--}4.2\text{ }\mu\text{m}$ at the level of 80% of the maximum sensitivity instead of a photodetector of visible range. It was possible to locate narrowband filters of IR range to narrow the band in the radiometric receiver. To measure temperature, a thermocouple (6) was used with precision 0.2°C . To reduce the speed of ice sample heating, a thermostat was used (7), with a precooled metal radiator placed on the bottom. To record the output signals from the metering instruments, a data collection system (8) by Agilent was used.

In process of the experiments, the ice plates were used with dimensions $5 \times 5\text{ cm}^2$ and thicknesses

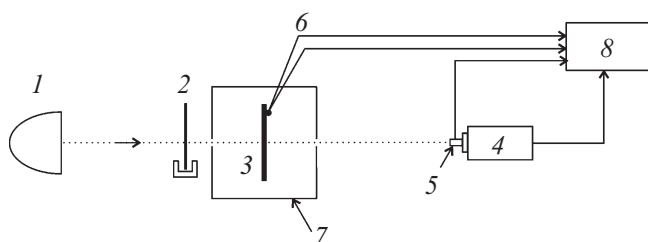


Figure 1. The experimental setup diagram for the research of the effect of „translucence“ in the IR-range: 1 — halogen lamp, 2 — modulator, 3 — ice sample, 4 — IR-radiometer at $2 \dots 25 \mu\text{m}$, 5 — photo diode of visible range, 6 — thermocouple, 7 — thermostat, 8 — data collection system.

from 0.1 to 3 mm. They were made as follows: water with different degree of mineralization was poured into the cuvette. The cuvette was placed into a freezing chamber with constant temperature $\sim -15^\circ\text{C}$. When ice was formed on the water surface, an ice plate of the required thickness was obtained. Mineralization of the source water with NaCl varied within 1–400 mg/l. The content of salt captured by ice was in the interval of 1–26 mg/kg, which corresponds to the ice in natural fresh water reservoirs. The small quantity of salts in ice is explained by the low coefficient of salt capture, which depends on temperature, type of salt and other external factors [11].

The manufactured samples were stored in the freezing chamber at $\sim -15^\circ\text{C}$. Further the sample was placed into an experimental setup, where a thermocouple was pressed to it. The air temperature in the room was around 21°C , therefore, heating of the ice sample was happening for 0.5–3 min. The experiment was completed after clear signs of sample thawing by visual detection of water on the surface of the ice sample. One and the same sample was used repeatedly (after completion of the experiment the sample was again placed into the freezing chamber).

Besides, the polarization microscope was used to find individual ice crystals in the sample. The intensity of the transmitted polarized emission was used to determine the direction of the main optical axis of ice crystals. The detailed study method is presented in [12].

Results and discussion

Using the measured values of the intensity of the emission passing through the ice samples, the absorption coefficient α was found, which was $\alpha = [1/h] \ln(I_0/I)$, where h — sample thickness, I_0 — intensity of emission without the sample, I — intensity of emission with the sample. Fig. 2 presents the results of one of the experiments.

Features of this experiment consist in the fact that an area is identified in the chart (Fig. 2, *a*), where the absorption coefficient decreases by $\sim 10\%$. Fig. 2, *b* shows a photograph taken in a polarization microscope with the

crossed polarizers. The picture captures individual ice crystals, the optical axis of which is directed at a certain angle to the photograph plane. If individual crystals have interference color, as in Fig. 2, *b*, their main optical axis is directed at a certain angle to the photograph plane. If individual crystals have darkening, as in Fig. 2, *b* and 3, *b*, their main optical axis is parallel to the optical axis of the microscope [12]. Using polarization patterns in Fig. 2, *b* and 3, *b* the conclusion may be made that the basis planes of crystals mostly coincide with the direction of the electric field vector of the passing emission.

After the experiments, the photographic evidence of the ice crystals was collected for the translucence area for their space and time variability as a result of destruction of the outer layers of the studied samples and subsequent freezing. It was found that individual crystals in the samples maintain their position and dimensions, which is confirmed by multiple polarization pictures of ice for a long period of time.

In the experiments, the results of which are presented in Fig. 3, *a* and 4, *a*, the heating of the samples leads to the decrease in the absorption coefficient both in the infrared area of the spectrum and in the visible range. In these experiments the absorption coefficient differs from the values obtained previously, for example [13–15]. It is related to the fact that a radiometric receiver, which was used in the experiment, has a rather broad band, where the absorbing characteristics of ice differ by an order of magnitude, depending on the wavelength. For example, at $\lambda = 11 \mu\text{m}$ $\alpha = 1090 \text{ cm}^{-1}$, and at $\lambda = 13 \mu\text{m}$ $\alpha = 104 \text{ cm}^{-1}$ [13]. Therefore, the chart includes the averaged absorption coefficient.

The conducted experiments show that at the location of the basis planes of ice crystals in parallel to the vector of the electric field intensity (Fig. 3, *b*, 4, *b*) you can expect the increase of the passing emission capacity. This feature was noticed before, too, for example, a [1–4]. In paper [16] it is shown experimentally that at the location of the basis planes of ice crystals in parallel to the vector of electric field intensity at frequency of 3.4 GHz the degree of decrease of the false part of the relative complex dielectric permittivity reached 5 times, and at the perpendicular location — 2.5 times. It should be noted that in papers [1–4] no special petrographic studies were conducted.

A question arises whether translucence is the result of interference in the plane-layered structures. To understand this, the calculations were made for the flat ice plate with thickness of 0.1 mm, where a wave with $\lambda = 15 \mu\text{m}$ falls normally. For this wavelength $\varepsilon' = 1.24$, and $\varepsilon'' = 0.0762$ [10]. No scattering in the medium was taken into account. According to the completed calculations, the ratio of the interfering emissions is 10^{-9} . Therefore, the „translucence“ effect is not related to the interference phenomena. It should be noted that water appearance on the surface of the ice plate is not taken into account. This is due to the fact that the effect of „translucence“ is observed in ice, even prior

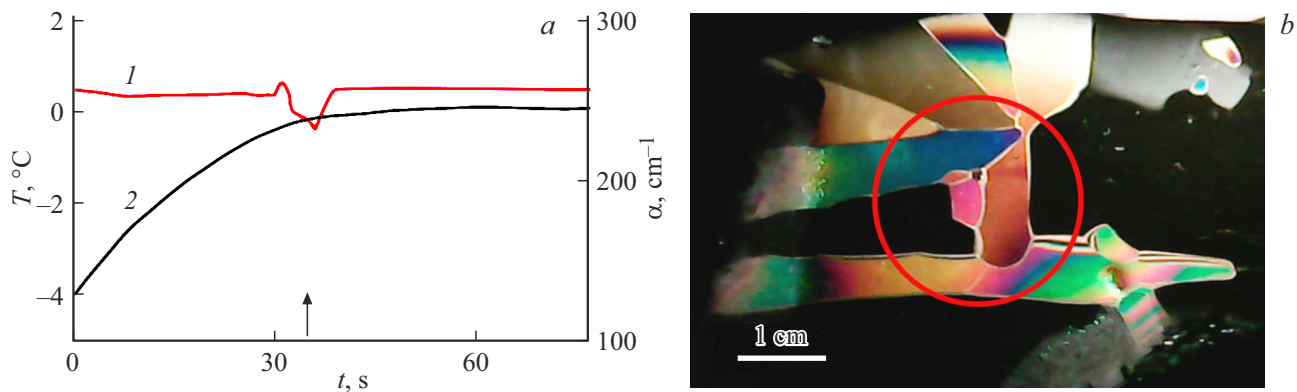


Figure 2. (a) The results of the absorption coefficient measurement in the range of $3.8\text{--}4.2\mu\text{m}$ (1) and temperature (2) in the ice sample with thickness of 0.1 mm depending on the time of heating, the arrow marks the effect of „translucence“. (b) The photograph of the ice sample through a polarization microscope with the crosslinked polarizer and analyzer, the circle marks the translucent area.

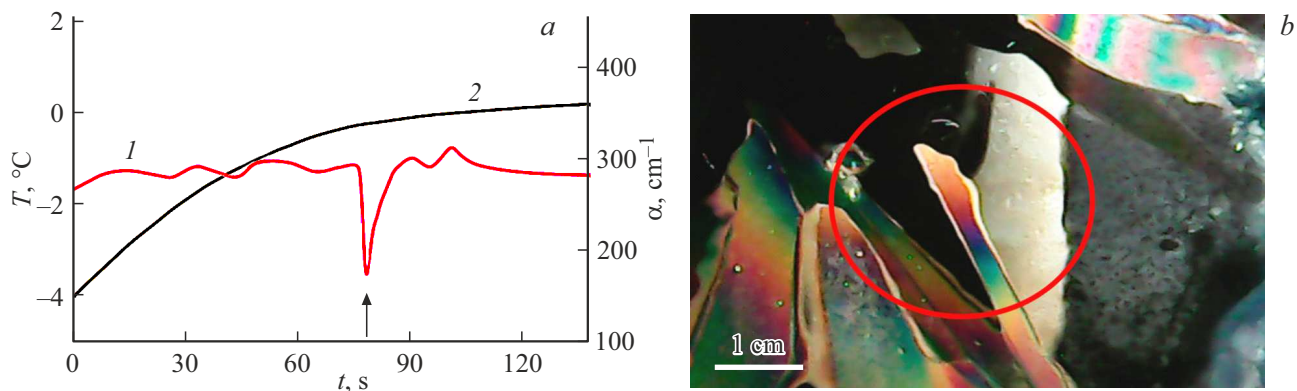


Figure 3. (a) The results of the absorption coefficient measurement in the range of $10\text{--}16\mu\text{m}$ (1) and temperature (2) in the ice sample with the thickness 0.1 mm depending on time of heating, the arrow marks the effect of „translucence“. (b) The photograph of the ice sample through a polarization microscope with the crosslinked polarizer and analyzer, the circle marks the translucent area.

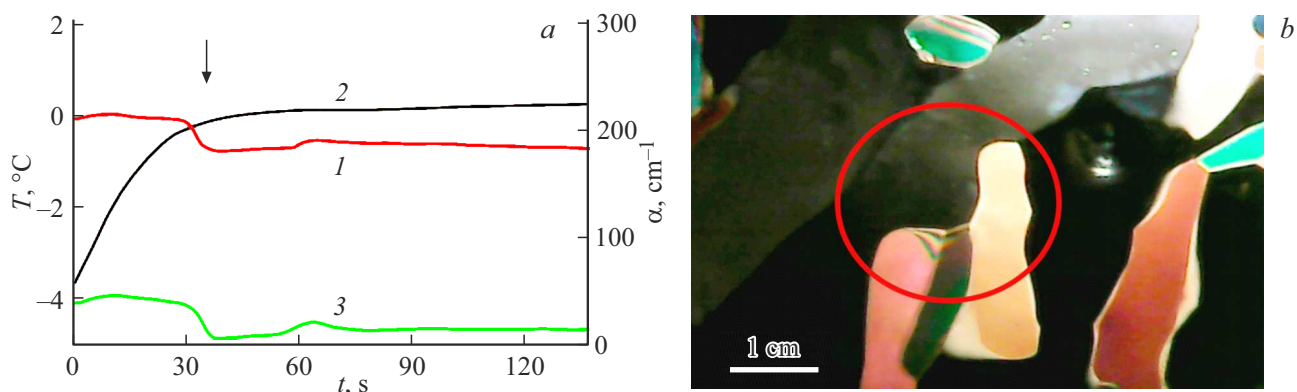


Figure 4. (a) The results of the absorption coefficient measurement at the wavelength $10\text{--}16\mu\text{m}$ (1) and in the visible (3) range in the ice sample depending on time; (2) — temperature of the ice sample with thickness of 0.1 mm. (b) The photograph of the ice sample through a polarization microscope with the crosslinked polarizer and analyzer, the circle marks the translucent area.

to water appearance, this is confirmed by the resonator measurements in the microwave range [1,2,4]. Therefore, it may be concluded that the effect of interference in these experiments is negligible.

The specified results do not contradict the hypothesis in paper [4] on the formation of plasmon effects related to the basis planes of ice crystals. As the sample temperature approaches 0°C , plastic flow occurs with the

formation of quasi-liquid films in layers parallel to the basis planes of crystals. Plasmon resonances arise in the island formations in the films due to the appearance of metal conductivity [17] caused by segnetoelectric ordering at the contact of ice and quasi-liquid layers, where the flow happens [4].

Conclusions

The method is proposed to simultaneously measure the capacity of the emission passing through the ice sample in the visible and infrared ranges of electromagnetic emission near the temperature of its thawing.

The effect of „translucence“ of the ice phase is found in the IR range at wavelengths $3.8\text{--}4.2\mu\text{m}$, $10\text{--}16\mu\text{m}$ at temperature of around 0°C .

Possibly, the effect of „translucence“ depends on the position of the basis planes of the ice crystals. Maximum capacity growth is observed in the parallel location of the electric field vector relative to the basis planes of the ice crystals. The maximum decrease of the attenuation coefficient in ice was $\sim 30\%$.

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