Thermal conductivity measurement of infrared optical fibers based on silver halide solid solution crystals

A Turabi\textsuperscript{1}, B P Zhilkin\textsuperscript{1}, L V Zhukova\textsuperscript{1}, A S Shmygalev\textsuperscript{2}, A V Rudenko\textsuperscript{2} and A S Korsakov\textsuperscript{1}

\textsuperscript{1}Ural Federal University named after the first President of Russia B.N. Yeltsin, Lenin Prospect, 51, Yekaterinburg, 620002, Russia
\textsuperscript{2}Institute of High Temperature Electrochemistry of the Ural Branch of the Russian Academy of Sciences, S. Kovalevskoi str., 22, Yekaterinburg, 620066, Russia

E-mail: a.m.turabi@urfu.ru

Abstract: The aim of the study is to measure the thermal conductivity of silver halide light guides based on crystals of the AgCl-AgBr system used in PSD production technologies. The conductivity temperature coefficient of the samples under study were determined by the laser flash method using the LFA 467 (Hyper Flash) installation. We studied mono- and polycrystalline samples of solid solutions with the composition AgCl\textsubscript{0.25}AgBr\textsubscript{0.75} in the temperature range 298–523 K. The thermal conductivity of the investigated materials was then calculated using literature data on density and heat capacity. The thermal conductivity coefficient ranges from 0.80±0.04 to 0.53±0.03 (W/m·K), depending on the microstructure of the sample.

1. Introductions

Infrared (IR) fibers based on crystals of solid solutions of silver halide [1–4], have wide applications and can be used to transmit IR radiation in the mid spectrum range of 2–25 µm [1]. These polycrystalline light guides can be used to provide efficient heat dissipation in power semiconductor devices (PSC) [5]. The efficiency of heat dissipation in PSC significantly depends on the thermal conductivity of the materials used.

One of the most common methods in the practice of measuring the thermal conductivity of materials is the Parker method [6], which also allows you to determine the thermal conductivity of materials. In earlier works of the authors [7] the thermal conductivity coefficient of silver-halide crystals based on solid solutions of AgCl-AgBr system was determined in the temperature range from –50 to +100°C, which reached values of (0.75 to 1.0) W/(m·K). There is no information on the higher-temperature dependence of the thermal conductivity coefficient for solid solutions of the AgCl-AgBr system. Therefore, the purpose of this study is to define the thermal conductivity of silver halide crystals based on the AgCl-AgBr system in the temperature range 298–523 K, by laser flash using the LFA 467 (Hyper Flash).

When calculating the thermal conductivity by the laser flash method used in the present work, mono- and polycrystalline samples of solid solutions of the composition were examined AgCl\textsubscript{0.25}AgBr\textsubscript{0.75}. Polycrystalline (crystallite size 1±0.2 µm) flat parallel plates were obtained by hot pressing, implemented using the Specac 15 Ton [8] manual hydraulic press. The thickness was
200 µm with an accuracy of ±5 µm. The load per sample area ∼ 150 mm² was 10 t and the temperature was 150 °C.

2. Experimental setup

The method makes it possible to obtain flat-parallel specimens with an optical surface. Monocrystalline flat-parallel samples were obtained from solid solution crystals of the AgCl₀.₂₅Br₀.₇₅ system by machining on a lathe, followed by chemical-mechanical polishing, sample thickness was 3000±15 µm, diameter 14 mm. To determine the temperature conductivity and heat capacity on the LFA 467 (Hyper Flash) installation, the samples obtained, previously blackened with graphite, were placed in a holder, then the front side of the plane-parallel sample of the test material was heated by a short laser pulse (figure 1).

![Flash Technique](image)

**Figure 1.** Laser flash method.

The pulse duration was 0.8 ms, the energy ranged from 5 to 10 J. The change in sample temperature was measured by an IR detector (InSb) cooled with liquid nitrogen, the initial cell temperature was measured by a thermocouple type S. As the protective atmosphere, purified argon with an initial purity of 99.998% was used. Measurements were carried out at isothermal exposure of samples after the rate of change of their temperature became less than 0.1 K/s. Heat released on the surface of the sample propagates through the sample and causes an increase in temperature on its rear surface. Temperature rise is measured as a function of time using an IR temperature detector. Analysis of the obtained temperature curve allows to determine temperature conductivity and heat capacity of samples (figure 2, figure 3).

3. Characterizations of the experimental setup

Measurement results at high temperatures are related to the difficulty of measuring heat fluxes when heat losses due to radiation and convective transport increase significantly. Therefore, instead of directly measuring the thermal conductivity coefficient (λ), it is calculated from the known relationship (1) using data on the heat capacity (Cₚ) J/(kg·K), density (ρ) (kg/m³) and temperature conductivity (a) of the substance m²/s: thermal conductivity (W/m·K)

\[
λ(T) = a(T) \cdot C_p(T) \cdot ρ(T).
\]
Figure 2. Sample of polycrystalline plate of the AgCl$_{0.25}$AgBr$_{0.75}$, thickness 200 µm: a – graph of the dependence of the temperature conductivity on the temperature, b – the graph of the dependence of the heat capacity on the temperature, c – the appearance of the sample.

Figure 3. Sample of monocrystalline plate of the AgCl$_{0.25}$AgBr$_{0.75}$, thickness 3000 µm: a – graph of the dependence of the temperature conductivity on the temperature, b – the graph of the dependence of the heat capacity on the temperature, c – the appearance of the sample.
The density of silver halide samples was taken from the source [9], for the composition \( \text{AgCl}_{0.25}\text{AgBr}_{0.75} \) – density is 6270 kg/m\(^3\) at room temperature. Using data from the source [7] by coefficient of linear thermal expansion equal to 0.000035 K\(^{-1}\) for \( \text{AgCl}_{0.25}\text{AgBr}_{0.75} \) composition, the density at 523 K was calculated which was 6125 kg/m\(^3\). The thermal conductivity values obtained from these data are shown on figure 4.

**Figure 4.** Dependence of thermal conductivity coefficient of silver halides of composition \( \text{AgCl}_{0.25}\text{AgBr}_{0.75} \) for: 1 – polycrystals, 2 – monocrystals.

**4. Conclusions**

The method of measuring thermal conductivity and temperature conductivity on mono- and polycrystals of silver halides was tested. Precision experimental data were obtained on the coefficient of temperature conductivity and heat capacity of silver halide mono- and polycrystals based on the AgCl-AgBr system. The coefficient of thermal conductivity is calculated, which lies in the range from 0.8±0.04 W/(m·K) to 0.53±0.03 W/(m·K), depending on the microstructure of the sample. The obtained data for polycrystalline plates can be used in thermophysical calculations of polycrystalline IR light conductors based on crystals of the AgCl-AgBr system in a wide temperature range.

**Acknowledgments**

The research has been supported by the grants of President of the Russian Federation, MD-5324.2021.4.

**References**

[1] Zhukova L V, Lvov A E, Salimgareev D D and Korsakov V S 2018 Domestic developments of IR optical materials based on solid solutions of silver halogenides and monovalent thallium *Optics and Spectroscopy (English translation of Optika i Spektroskopiya)* 125(6) 933–43

[2] Basov S, Dankner Y, Katzir A and Platkov M 2020 Technical note: noninvasive mid-IR fiberoptic evanescent wave spectroscopy (FEWS) for early detection of skin cancers *Medical Physics*. 47 5523–30

[3] Hocotz T et al U 2020 Synergy effect of combined near and mid-infrared fibre spectroscopy for diagnostics of abdominal cancer *Sensors* 20 1–19

[4] Butvina L N, Sereda O V, Butvina A L, Dianov E M, Lichkova N V and Zagorodnev V N 2009 Large-mode area single-mode microstructured optical fibre for the mid-IR region *Quantum Electronics* 39 283–6
[5] Nishchev K N, Novopol'tsев M I, Beglov V I, Okin M A and Lyutova E N 2015 Measurement of temperature conductivity of thin metal layers by laser flash method Physics and mathematics sciences 4(36) 101–10

[6] Parker W J, Jenkins R J, Butler C P and Abbott G L 1961 Flash method of determining thermal diffusivity, heat capacity and thermal conductivity J. Appl. Phys. 32(9) 1679–84

[7] Zhukova L V, Primerov N V, Korsakov A S and Chazov A I 2008 AgClxBr1 – x and AgClxBryI1-x-y crystals for IR engineering and optical fiber cables INORGANIC MATERIALS 44(12) 1372–7

[8] Korsakov A S, Vrublevsky D S, Korsakov V S and Zhukova L V 2015 Investigating the optical properties of polycrystalline AgCl1-xBrx (0≤x≤1) and Ag0.95Tl0.05Br0.95I0.05 for IR engineering Applied Optics 54(26) 8004–9

[9] Korsakov A, Zhukova L, Korsakova E and Zharikov E 2014 Structure modeling and growing AgClBr1-x, Ag1-xTlxBr1-xIx, and Ag1-xTlxClxIzBr1-y-z crystals for infrared fiber optics Journal of Crystal Growth 386 94–9