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Optical Fibers Based on Modified Silver Halide Crystalsfor Nuclear Power

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Abstract

We investigated the possibility of the deployment of AgBr – $TlBr_{0.46}I_{0.54}$MIR fibers in high ionizing radiation environment. For this purpose, we exposed plate samples made of AgBr – $TlBr_{0.46}I_{0.54}$crystals to β-ionizing radiation at a dose of 100 kGy. We revealed the radiation-induced translucence effect for these materials and assumed its nature. As the investigation showed the suitability of the fibers for the application in high ionizing radiation environment, the authors propose to use these fibers jointly with FTIR spectrometers for the online monitoring of various chemical processes at the nuclear power plants.

Keywords: modified silver halides, MIR fibers, FTIR spectroscopy, ionizing radiation resistance

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1. Introduction

The nuclear power generation in Russia has been steadily growing over the past five years. In 2017, its share was 19.25% of the total power generation [1]. In this connection, there is a large demand for equipment, which allows monitoring various chemical reactions taking place in high radiation environments, such as radioactive waste tanks, hot cells, or special force main sewage. Typically, the online Fourier-transform infrared spectroscopy (FTIR) is used for this purpose [2, 3], while FTIR spectrometers are placed directly in high radiation environments. It causes breaking the electronics of these devices after a short time. To avoid this, one can use special optical fibers to transmit data from a spectrometer located in a lower radiation environment to a high radiation one and vice versa. In the article, we propose AgBr – $TlBr_{0.46}I_{0.54}$ mid-infrared fibers as one of the possible solutions to solve this problem. Therefore, our study was aimed at evaluating the impact of an ionizing radiation on this material.

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2. Methods

We fabricated polycrystalline two-layer IR fiber of AgBr – $TlBr_{0.46}I_{0.54}$ crystals by means of extrusion technique. The fiber comprises a core and a cladding made of silver bromide crystals containing different percentage of $TlBr_{0.46}I_{0.54}$ solid solution; the core diameter is 900 ± 10 μm, the total fiber diameter is 1100 ± 15 μm, and its length is 1000 ± 10 mm. Such dimensions are chosen to simplify connecting the fiber with a FTIR spectrometer. The fibers are highly transparent in the spectral range of 4.0–26.0 μm, non-hygroscopic, and photo resistant [4]. It was found that they allowed determining chemical composition of various substances (including D_2O) in real-time and remotely with a detection limit of 10^{-3}–10^{-4} mol/l.

For studying the impact of ionizing radiation on AgBr-$TlBr_{0.46}I_{0.54}$ material, we used polycrystalline plate samples contained 1, 10, 21, 78, and 100 mol. % of $TlBr_{0.46}I_{0.54}$ in AgBr. The plates were produced by means of hot pressing technique using a manual hydraulic press Specac 15 Ton. The billets of the plates were heated to a temperature of 120–130°C (depending on the sample composition), then dwelled for 15 min and pressed at 6 tons for 1 min. with the following annealing at room temperature. This method allows obtaining the plane parallel plates with optical surfaces and thickness of around 300 μm. The photos of the obtained samples are shown in Figure 1.

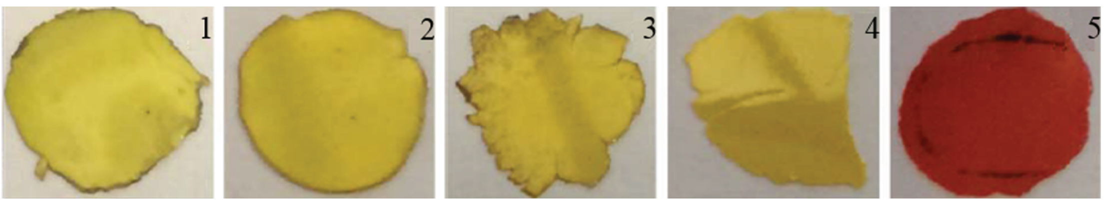

Figure 1: Photos of the samples with the following content of $TlBr_{0.46}I_{0.54}$ in AgBr: 1 – 1 mol.%; 2 – 10 mol.%; 3 – 21 mol.%; 4 – 78 mol.%; 5 – 100 mol.%.

Firstly, we obtained IR transmission spectra of these non-irradiated plates using a Shimadzu FTIR spectrometer IR Prestige-21. The recording conditions were as follows: the KBr beam divider, the mercury cadmium telluride (MCT) detector, the wavelength range of 4000–350 cm^{-1}, and resolution of 4 cm^{-1}.

Then, the irradiation experiment was conducted using a linear electron accelerator of model UELR-10-10S (R&D Center of Radiation Sterilization, Ural Federal University). This equipment has a standing-wave accelerating structure. Its electron energy is 10 MeV, the average beam power is 10 kW, and beam amperage is 1000 μA. For the irradiation, we used a conventional technique, described in [5]. In this way, the crystal plates were exposed to β-particles at a dose of 100 kGy. The dose rate of radiation

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was 0.3 kGy/s. Further, we registered IR transmission spectra of the irradiated plates immediately after irradiation and compared the results with those of non-irradiated plates.

3. Results

For the crystal samples containing 10, 21, 78, and 100 mol. % of $TlBr_{0,46}I_{0,54}$ in AgBr, upon irradiation, we observed an increase in the transmission level, which varied from 0.7 to 5.3% depending on the composition and the wavelength. Figure 2 shows an example of the changes in transmission for the sample containing 21 mol. % of $TlBr_{0,46}I_{0,54}$ in AgBr. As seen in this figure, the transmission of the irradiated plate is higher than that of the non-irradiated one in the wave number range from 4000 to about 950 cm^{-1} (the wavelength range of 2.5–10.6 μm). We assume that it is a radiation-induced translucence. Earlier, a similar effect for single crystals of TlBr-TlI solid solutions was reported in [6]. Probably, it is related with the annihilation of intrinsic defects in the AgBr-$TlBr_{0.46}I_{0.54}$ crystal lattice by the radiation-induced defects similarly to the process described for porous silicate glass in [7]. For longer wavelengths (beyond 10.6 μm), we observed a decrease in transmission upon irradiation.

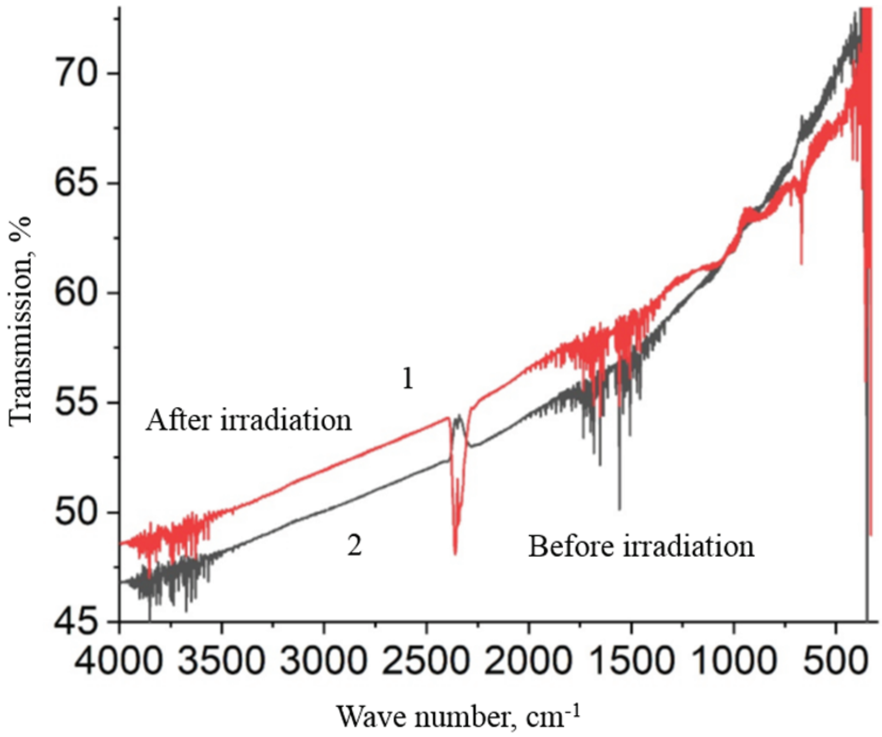

Figure 2: IR transmission spectra of the sample contained 21 mol.% of $TlBr_{0.46}I_{0.54}$ in AgBr: 1 – before irradiation; 2 – after irradiation.

Figure 3 represents the radiation-induced changes in samples' optical losses at various wavelengths depending on $TlBr_{0.46}I_{0.54}$ content in AgBr. For the irradiated sample containing 1 mol. % of $TlBr_{0.46}I_{0.54}$ in AgBr, we detected the largest increase of optical losses (about 11.5 %) at the wavelength of 3.0 μm, when compared to corresponding values of non-irradiated sample. Both compositions with 10 and 78 mol. % of $TlBr_{0.46}I_{0.54}$ in AgBr showed the largest reduction of optical losses by slightly more than 5 % at the wavelength of 14 μm. For the samples containing 10 and 78 mol. % of $TlBr_{0.46}I_{0.54}$ in AgBr and for pure $TlBr_{0.46}I_{0.54}$, we can note the decrease in optical losses at all investigated wavelengths (i.e., the translucence effect). Overall, ionizing radiation causes the increase of translucence with the rise of the wavelength in the range from 3 to 14 μm, except the pure $TlBr_{0.46}I_{0.54}$ sample, for which we observe more complex dependence. Thus, based on the results obtained, we can assess that AgBr-$TlBr_{0.46}I_{0.54}$ crystals possess rather high radiation resistance.

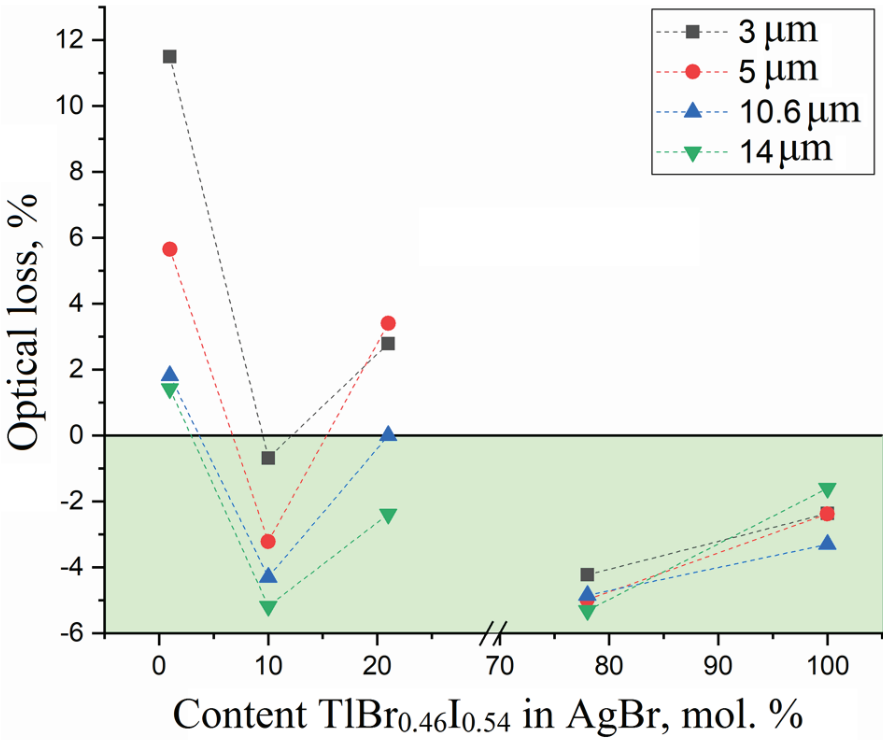

Figure 3: Changes in optical losses at different wavelengths upon irradiation depending on the sample composition.

4. Conclusion

We studied the impact of β-ionizing radiation at a dose of 100 kGy on AgBr-$TlBr_{0.46}I_{0.54}$ polycrystalline plates of various compositions. It was found that in most cases the transmission of the samples increased upon irradiation. We consider this effect as a translucence phenomenon due to the annihilation of crystals' intrinsic defects by radiation-induced defects. The largest rise of the transmission was a little bit more than 5 % and it was observed for the samples containing 10 and 78 mol. % of $TlBr_{0.46}I_{0.54}$ in AgBr at the wavelength of 14 μm. Since the plate samples have the same polycrystalline structure as the fibers in question, we may conclude that the irradiation by β-rays will have the same impact on these fibers. Summarizing the aforementioned, two-layer polycrystalline IR fibers made of AgBr-$TlBr_{0.46}I_{0.54}$ crystals, highly transparent in the spectral range of 4–26 μm and compatible with FTIR spectrometers, with proper calibration may be used in high radiation environments. We expect that they will be useful at the nuclear power plants for real-time remote IR spectroscopy, for example, for monitoring heavy water concentration in heavy water reactors.

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References

[1] Report on the functioning of Russian nuclear power plants in 2017. Retrieved from http://www.so-ups.ru, 2018 (accessed on 5 July 2018).

[2] Choi, S. Y., Choo, J., Chung, H., et al. (2003). Feasibility of Fourier Transform (FT) Infrared spectroscopy for monitoring heavy water concentration in pressurized heavy water reactor. *Vibrational Spectroscopy*, vol. 31, pp. 251–256.

[3] Lumetta, G. J., Braley, J. C., Peterson, J. M., et al. (2012). Separating and stabilizing phosphate from high-level radioactive waste: Process development and spectroscopic monitoring. *Environmental Science and Technology*, vol. 46, pp. 6190–6197.

[4] Korsakov, A., Salimgareev, D., Lvov, A., et al. (2016). Antireflective coating for AgBr - TlI and AgBr – $TlBr_{0.46}I_{0.54}$ solid solution crystals. *Optical Materials*, vol. 62, pp. 534–537.

[5] Shulgin, B., Ishchenko, A., Bazhukov, S., et al. (20 September 2016). Method for increasing the radiation resistance and stabilizing the light transmission of germanium silicate glass fibers. Ru Patent No. 2598093.

[6] Artyushenko, V. G., Voitsekhovskii, V. V., Kornienko, L. S., et al. (1984). Effect of ionizing radiation on optical properties of thallium halides. *Physica Status Solidi (A)*,

vol. 86, pp. 67–171.

[7] Meshkovsky, I. K., Safin, V. M., and Stepanov, V. E. (2000). High radiation durability of optical elements made of porous glass. *Optica Applicata*, vol. 30, pp. 591–593.