On the Possibility of Application Infrared Crystalline Fibers for Transfer of Temperature Signals from Bearings inside Nuclear Power Plants’ Containment

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Abstract. The possibility of application flexible infrared Nanopolycrystalline (PIR) fibers made from radiation-resistant crystal systems AgBr – TlI and AgBr – TIBr0.46I0.54, for contact-less measure temperature bearings of own needs mechanisms and signal temperature transmission from nuclear power plant containment is considered. Radiation resistant allows the use that crystals and PIR fibers in high radiation conditions up to 500 kGy, what opens great opportunities of involving that optical materials in atomics. The class of the presented materials is distinguished by a wide transmission range in the range from 0.4 to 60 µm for crystals and from 2.0 to 25 µm for PIR fibers without absorption window, low optical loss (up to 0.1 dB/m), high flexible. The PIR fibers proposed in this paper are made by extrusion from single crystals of silver and thallium halides and are transparent in the mid-infrared range from 2 to 25 µm, which, according to the laws of Planck and Wien, corresponds to temperatures from +1100 °C to −200 °C.

1. Introduction

Nowadays, in thermal and nuclear power engineering, resistance thermometers are used to control temperature of the bearings of own needs mechanisms, the action of which is based on the dependence of the electrical resistance of metals on temperature. Platinum and copper are used for the manufacture of sensing elements of standard resistance thermometers. Of these, only platinum possesses acceptable resistance to oxidation, which determines enough service life, and therefore platinum resistance thermometers have found wide application in thermal power engineering, including for measuring the temperature of the bearings of own needs mechanisms.

However, in nuclear power, the use of platinum as a material for sensitive elements of resistance thermometers installed in the containment of a nuclear power plant has a number of difficulties, since its activation in gamma and neutron fields leads to a change in the temperature characteristics of this material.

Natural platinum contains 6 different isotopes (190, 192, 194, 195, 196 and 198), the percentage of which in a wide range. Heat cross section of capture of natural platinum according to the estimate is 8...
b [1]. Comparing this value with the value of the radiation capture cross-section of various structural materials (Al-27 – 0.231 b; Fe-0 – 2.56 b; Zr-0 – 0.185 b [1]), it is obvious that the value of the capture cross-section for natural platinum is an order of magnitude higher than for structural materials. This leads to the fact that platinum is easily activated in radiation fields.

For measuring the temperature of the equipment installed in the containment, it may be useful in the future to use the method of remote transmission of the temperature signal in the form of infrared radiation from the controlled element using infrared optical fibers.

In this work, an assessment was made of the possibility of using flexible infrared optical fibers made of radiation-resistant crystal systems AgBr – TlI and AgBr – TlBrO.46I0.54, for transmission of the temperature signal of the bearings of own needs mechanisms from containment of the NPP.

2. Materials and Methods
The use of IR PIR fibers in fiber temperature sensors provides several advantages over existing methods and control devices, namely:

- in comparison with the thermoelectric method, it allows contactless temperature measurement in conditions of electromagnetic interference;
- in comparison with the thermoresistive method, it is inertialess, and also removes the problem of the influence of the temperature dependence of the resistance of communication lines on the accuracy of temperature measurement;
- compared to quartz fiber sensors, it directly measures from -20 to +300 °C due to direct transmission of infrared radiation from its sources to the receiver;
- allows to avoid the operation of activated sensitive elements in the conditions of gamma and neutron fields of the containment of the NPP.

In this paper, for the purpose of using in the containment of the NPP, the flexible infrared PIR fibers are considered, manufactured by scientific laboratory «Fiber Technologies and Photonics» at the Chemical-Technological Institute of the Ural Federal University named after the first President of Russia B. N. Yeltsin.

For the mid and far infrared range, there is a limited number of trans-parent materials with low optical loss. In particular, these are glasses based on chalcogenides, tellurides, fluorides, as well as crystals of silver halides and monovalent thallium.

The last class of materials presented is distinguished by a wide transmission range in the range from 0.4 to 60.0 μm for crystals and from 2.0 to 25.0 μm for PIR fibers without absorption windows, low optical losses (up to 0,1 dB/m), high flexibility. The transmission spectra of some silver and thallium halide PIR fibers are shown in figure 1.

Among halide materials stand out crystalline systems AgBr – TlI and AgBr – TlBrO,46I0,54, since crystals and fibers based on them are photo- and radiation-resistant, have tensile strength and flexibility up to 250 MPa, the critical bending radius of fibers depends on the PIR fiber diameter and reaches 1 mm.

Photo resistance provides the use of these materials without a special shell. Radiation resistance makes it possible to use crystals and PIR fibers under conditions of strong ionizing radiation up to 500 kGy, which opens up wide possibilities for the introduction of such optical materials into nuclear energy, radiation physics, and space technologies [2].

Studies of radiation resistance were carried out with β-irradiation of fibers with doses up to 500 kGy. As a result of the study, a significant drop in transmission was not observed; at a high content of thallium and iodine in the crystals, an increase in their transmission up to 5% was found. Figure 2 shows the relative transmittance obtained by comparing the transparency of the AgBr – TlBrO,46I0,54 optical fibers before and after irradiation with a dose of 200 kGy. The relative transmittance is estimated as a percentage, while the transmittance before irradiation is taken as 100%. The area of increasing transmission (values over 100%) is highlighted in Figure 2 in green. The figure shows two groups of curves, the left group of curves is plotted for systems with a TlBrO,46I0,54 content in AgBr up to 27%, and the right group of curves for systems with a TlBrO,46I0,54 content of more than 70%. The
transmission of the fibers before and after irradiation was estimated for fiber diameters of 3 μm, 5 μm, 10.6 μm, and 14 μm.

**Figure 1.** Wavelength dependence of the fiber transmission:
1 – comparison of the transmission spectra of the fibers based on the AgBr-TI system with AgCl-AgBr; 2 – transmission spectre of the PIR fibers based on the AgBr – TIBr$_{0.46}$I$_{0.54}$.

A similar study was carried out for fibers based on crystals of the AgBr – TI system under β- and γ-irradiation, as a result of which the resistance of the fibers to radiation was also observed without a decrease in their optical transmission [3].

**Figure 2.** Relative optical transmission of the PIR fibers with different TIBr$_{0.46}$I$_{0.54}$ content in AgBr.

3. Results
The optical fibers proposed in this work are transparent in the mid-infrared range from 2 to 25 μm, which, according to Planck's and Wien's laws, corresponds to temperatures from -200 to +1100 °C, respectively (figure 1 and figure 3). This temperature range and the properties listed above make it possible to use infrared PIR fibers as fiber channels for delivering an optical signal from hard-to-reach
places due to a wide spectral transmission range, flexibility and mechanical strength, in particular, for transmitting a bearings of own needs mechanisms temperature signal from the containment of a NPP.

**Figure 3.** Planck’s and Wein’s laws for the optical range. Working areas of infrared fiber and thermal imagers are indicated (NIR – near infrared range; MIR – medium infrared range; FIR – far infrared range).

To study the functional properties of infrared PIR fibers, authors used fibers with a cross-sectional diameter of 1.1 mm, without a protective sheath and with a critical bend radius of 1.24 mm. Since the influence of the number and radii of fiber bends plays a key role in laying fiber channels, the dependence of the optical transmittance on the bending radius of the fiber was studied [4]. As can be seen from the results shown in figure 4, transmission decreases with decreasing radius according to a logarithmic dependence, which is in good agreement with the laws of wave optics.

**Figure 4.** Dependence of the optical transmission coefficient from bend radius.
The second important parameter is the length of the fiber channel. Since the losses in halide fibers reach 0.1 dB/m, the maximum length of such channels is tens of meters with a limiting value of ≈ 50 m.

The properties of IR optical fibers open prospects for the use of IR optical fibers of systems AgBr – TII and AgBr – TIBr₀.₄₀₁₀.₅₄ in NPP devices. In this regard, the possibility of introducing optical fibers into the systems of external temperature measurement of equipment installed in the containment of a nuclear power plant with a VVER reactor was considered, namely, for monitoring the temperatures of bearings of own needs mechanisms (figure 5). The optical scheme for measuring temperature is shown in figure 6.

**Figure 5.** Route of PIR fiber to the Own Needs Mechanisms’ (ONM) bearings.

**Figure 6.** Overall scheme of object temperature measurements by thermographic method: 1 – an IR radiation source (bearing); 2 – IR-fiber; 3 – ZnSe-lens; 4 - thermal imager
The PIR fiber is laid into the inner part of the containment through the sealed lead-in (point 1). Further, taking into account the proportions of the containment and the height of the marks, the optimal path for laying the fiber to the measured surface of the ONM bearings is determined (point 4).

4. Discussion
Since the routing of cables of impulse lines and other instrumentation and automation devices from the containment to the serviced area depends on the layout of the equipment, it is an un-changeable factor and involves multiple bends. The equipment layout is determined by the compactness of the equipment arrangement.

The length of the fiber is determined by approximate calculations based on the available data. Thus, the path of laying the fiber, shown in figure 5, assumes the required length of the section of the fiber passing in the containment is about 24 m. With an allowable fiber length of up to 50 m, there is a margin for adding the fiber to a secondary device, which may be, for example, a thermal imaging camera. The number of fiber bends in a laying similar to that shown in figure 5 can reach 3–4, with only one bend at an angle of 90 degrees, the rest at angles less than 90 degrees. The bending radii were taken many times larger than the critical one. With such a number of bends, the optical loss is about 27%, which is an acceptable value providing high measurement accuracy.

5. Conclusion
Radiation resistance of flexible infrared PIR fibers made of AgBr – TII and AgBr – TIBr_{0.46}I_{0.54} crystal systems, their permissible maximum length, insignificance of optical losses with a small number of bends, allows positive to assess the possibility of their use for transmitting the signal of the surface temperature of the NPP equipment, in particular, the moving parts of the equipment installed in the pressurized volume of the NPP.

The advantages of using infrared PIR fibers for measuring the surface temperatures of equipment installed in a pressurized volume include: inertialness, clarity, radiation resistance. It should be especially noted that the use of this method makes it possible to avoid the operation of activated sensitive elements in conditions of gamma and neutron fields of the NPP containment volume.

Currently, many issues of applying the method of measuring temperature and transmitting a temperature signal using infrared fibers made of AgBr – TII and AgBr – TIBr_{0.46}I_{0.54} crystal systems require in-depth research, in particular, the question of more simpler than a thermal imaging camera, a secondary device for receiving a temperature signal and transmitting it to the SHC (software and hardware complex). At present, these issues are being investigated in the research laboratory «Fiber Technologies and Photonics» at the Chemical-Technological Institute of the Ural Federal University named after the first President of Russia B. N. Yeltsin.

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