Optical Glasses Transmittance Reduction Under Gamma Radiation Exposure at Different Temperatures

Arseniy A. Baluev, Roman K. Mozhaev, Vladislav P. Lukashin, Alexander A. Pechenkin

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)
JSC «SPELS» (Specialized Electronic Systems)
Russian Federation, Moscow, E-mail: aabal@spels.ru

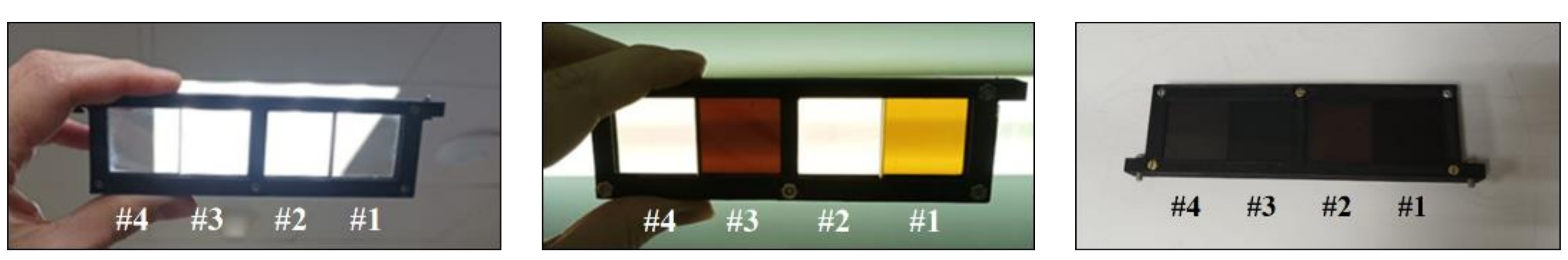
Abstract – The paper discusses the results of a study on the changes in transmittance coefficient of optical glasses at wavelengths of 455, 808, and 1550 nm under gamma radiation exposure up to a total accumulated dose of 2 Mrad at ambient temperatures of +25 °C and -30 °C are presented. The purpose of the study was a qualitative comparison of the radiation hardness of typical representatives of the classes of optical glasses: lanthanum crown, heavy flint, crown and heavy lanthanum flint.

I. Introduction

Optical glasses are colorless multi-component inorganic glasses used for manufacturing lenses, prisms, beam splitters, and other components of observation and measurement instruments in aerospace systems and specialized systems. As the accumulated dose increases, the optical properties of the glass deteriorate, particularly the transmittance coefficient, due to the formation of radiation-induced coloring centers in the material, which create induced light absorption [1], [2], [3], [4]. From the system's perspective, this would result in a loss of optical transmission capacity (throughput), which could disrupt its operation or even cause it to fail. Therefore, the assessment and consideration of optical system components radiation hardness is crucial during the design phase, especially for space applications, as radiation exposure levels vary for elements inside and outside the device's casing

II. Application optical glass in free-space optical communication systems

In a free-space optical communication systems, 808 nm wavelength lasers are used as pump sources for generating lasers at other wavelengths such as 532 nm (green), 1064 nm (infrared), 1550 nm (long-wavelength infrared), etc. [5], [6]. These wavelength lasers can be used in space communication systems for wireless interaction between satellites or with ground objects. The wavelength of 455 nm was chosen for a conservative estimation for worst-case scenarios, as the greatest attenuation coefficient is observed in the visible and ultraviolet regions [1], [2]. The induced absorption value in glasses at the same radiation doses varies depending on the type of glass, its doping impurities, and degree of doping [3], [4].



a) b) c)

d)

Fig. 3. Samples of glasses under lights to a day lamp before and after irradiation: Glass #1 (lanthanum crown), Glass #2 (heavy flint), Glass #3 (crown), and Glass #4 (heavy lanthanum flint);
a) before irradiation;
b) immediately after irradiation at ambient temperatures of +25 °C;
c) immediately after irradiation at ambient temperatures of -30 °C;
d) after irradiation 10 hours later at ambient temperatures of -30 °C (top) and 48 hours later at ambient temperatures of +25 °C (bottom)

III. Results of the study

The paper presents the results of transmittance coefficients changes of Glass #1 (lanthanum crown), Glass #2 (heavy flint), Glass #3 (crown), and Glass #4 (heavy lanthanum flint) at wavelengths of 455, 808, and 1550 nm under gamma radiation exposure up to a cumulative dose of 2 Mrad at ambient temperatures of +25 °C with dose rate of 2-3 rad/s and -30 °C with dose rate of 50 rad/s. Low temperature is considered critical for radiation hardness of glasses [1]. However, the radiation hardness of glass depends on glass type, the wavelength and irradiation parameters such as dose, dose rate and temperature mode [1], [2], [3], [4]. The study was conducted using the ^{137}Cs and ^{60}Co on MEPhI's isotope facilities.

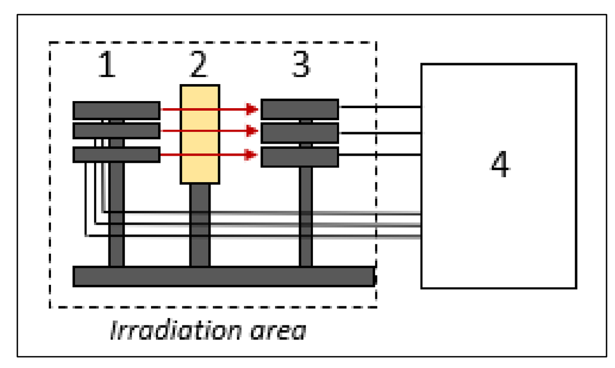


Fig. 1. Testing setup scheme for glass transmittance monitoring during irradiation

Photocurrent of the receiver (3) with the glass sample (2) installed (Fig. 1) was measured before, during pauses between exposure, and after exposure. Then, the glass sample was removed from the optical path of the sources (1) and receivers (2) of the optical signal, while the glass sample was not removed from the thermo-stabilized volume. The measurements were processed on a personal computer (4).

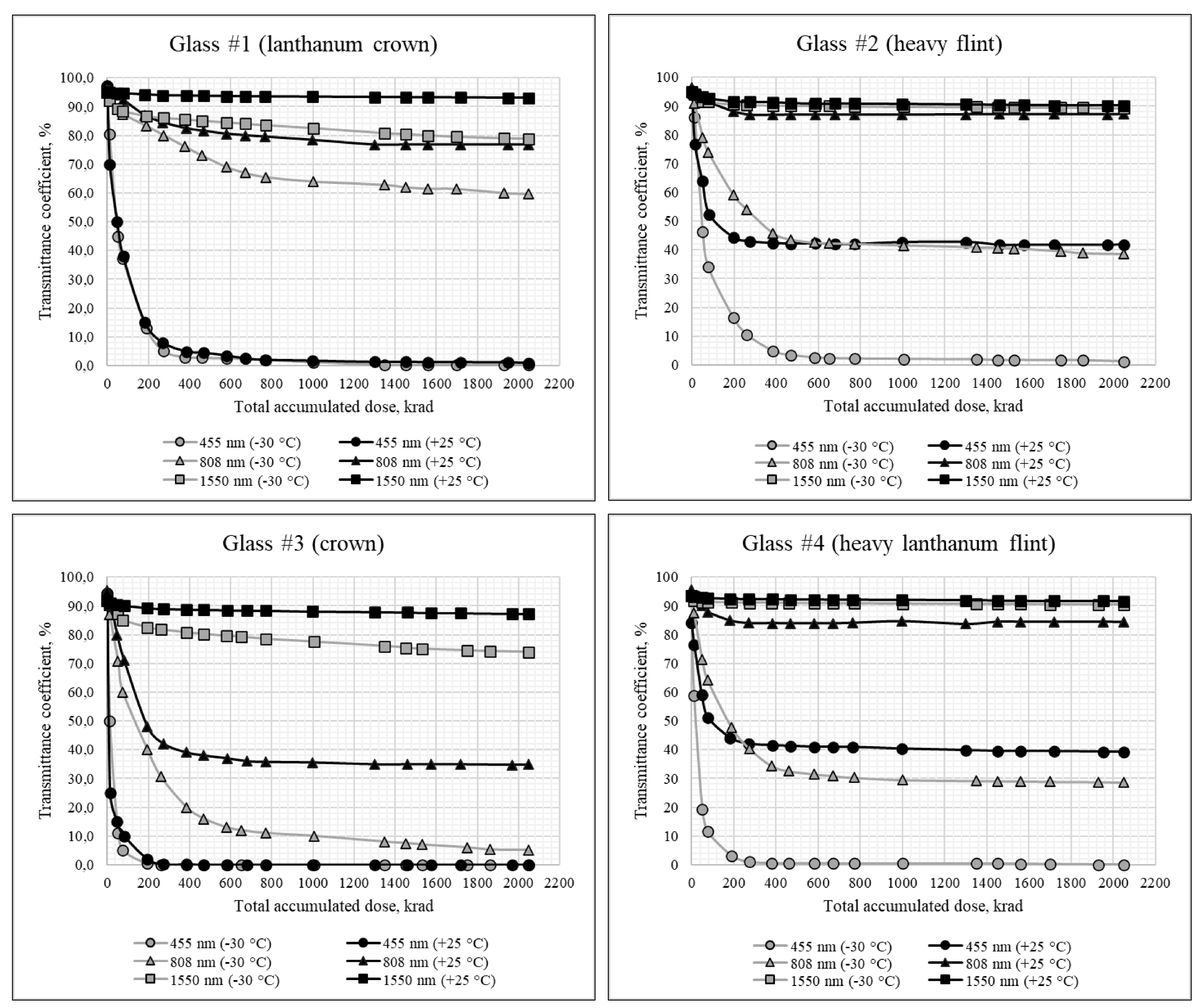


Fig. 2. Transmittance coefficient dependence on the accumulated dose of Glasses #1 - #4

Table I. Transmittance of glasses at 455, 808, 1550 nm before and after irradiation

Glass	Testing	455 nm		808 nm		1550 nm	
		+(25 ± 10) °C	-(30 ± 5) °C	+(25 ± 10) °C	-(30 ± 5) °C	+(25 ± 10) °C	-(30 ± 5) °C
Glass #1	Before	97,2 ± 2,9	97,2 ± 2,9	96,1 ± 3,8	96,1 ± 3,8	95,0 ± 3,8	95,0 ± 3,8
	2 Mrad	1,0 ± 0,1	0,2 ± 0,1	76,8 ± 3,8	59,6 ± 3,0	93,0 ± 4,7	78,9 ± 3,9
	After (24 h)	3,8 ± 0,1	1,6 ± 0,1	85,6 ± 3,4	93,5 ± 3,7	95,0 ± 3,8	95,0 ± 3,8
Glass #2	Before	94,0 ± 2,8	94,0 ± 2,8	96,4 ± 3,9	96,4 ± 3,9	94,9 ± 3,8	94,9 ± 3,8
	2 Mrad	41,8 ± 1,3	1,1 ± 0,1	87,2 ± 4,4	38,5 ± 1,9	90,2 ± 4,5	89,2 ± 4,5
	After (24 h)	53,1 ± 1,6	19,7 ± 0,6	88,4 ± 3,5	84,3 ± 3,4	93,1 ± 3,7	92,4 ± 3,7
Glass #3	Before	94,5 ± 2,8	94,5 ± 2,8	95,1 ± 3,8	95,1 ± 3,8	91,8 ± 3,7	91,8 ± 3,7
	2 Mrad	**0,1 ± 0,1**	**0,1 ± 0,1**	**34,8 ± 1,7**	**5,1 ± 0,3**	**91,7 ± 4,6**	**73,9 ± 3,7**
	After (24 h)	0,4 ± 0,1	0,2 ± 0,1	54,0 ± 2,2	53,1 ± 2,1	91,3 ± 3,7	86,0 ± 3,4
Glass #4	Before	84,0 ± 2,5	84,0 ± 2,5	95,6 ± 3,8	95,6 ± 3,8	93,5 ± 3,7	93,5 ± 3,7
	2 Mrad	39,2 ± 1,2	0,1 ± 0,1	84,4 ± 4,2	28,7 ± 1,4	91,7 ± 4,6	90,5 ± 4,5
	After (24 h)	59,4 ± 1,8	17,7 ± 0,5	85,8 ± 3,4	83,6 ± 3,3	91,3 ± 3,7	89,9 ± 3,6

The worst-case of radiation hardness can be identified in the case of Glass #3 (crown). It can be seen that the location of the crown in the area of increased dose load is undesirable. That may result in failure due to a significant loss of throughput. At a minimum, it is necessary to protect the part of the optical system and to set temperature mode for the crown. An alternative to crown is the lanthanum crown, which has demonstrated much higher radiation hardness. In the case of heavy flint or heavy lanthanum flint, these glasses can be moved to the area of increased ionizing dose.

It is noteworthy that radiation hardness of optical glass strongly depends on the wavelength of the laser source used in the optical system. At the wavelength of 455 nm, which was chosen for a conservative estimation for worst-case scenarios, a reconfiguration of the optical system would be necessary.

IV. Conclusion

Judging by the results the radiation hardness of glass depends on glass type, the wavelength and irradiation parameters such as dose, dose rate and temperature mode. The greatest change in transmittance coefficient was observed at a wavelength of 455 nm, while the smallest change was at 1550 nm. The critical mode was low environmental temperature, which was due to delayed processes of annealing radiation-induced color centers and glass relaxation, unlike in the case of increased temperature. After the end of exposure, partial restoration of the transmittance coefficient was observed, and after the total accumulated dose of 2 Mrad, significant annealing was observed in some glasses after 24 hous (Table I).

Such research helps determine which glasses (even those not considered radiation hardened) are suitable for use as external lenses and lenses that can withstand high dose levels, and which ones can be placed inside a protected case where there may be a different temperature mode.

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