PAPER • OPEN ACCESS

Systematic Study of LED Stimulated Recovery of Radiation Damage in Optical Materials

Systematic Study of LED Stimulated Recovery of Radiation Damage in Optical Materials

K K Sahbaz[1,2], B Bilki[1,3], H Dapo[4], C Kaya[4], M Kaya[4] and M Tosun[1,2]

[1] Beykent University, Istanbul, Turkey
[2] Ankara University, Ankara, Turkey
[3] University of Iowa, Iowa City, IA, USA
[4] Turkish Accelerator and Radiation Laboratory, Ankara, Turkey

E-mail: kutlu.kagan.sahbaz@cern.ch

Abstract. The radiation damage in optical materials mostly manifests itself as the loss of optical transmission. The optical materials recover from radiation damage to some extent in the presence of natural light, and at a faster rate in the presence of stimulating light. On the other hand, the systematic study of the dynamics of the recovery as a function of the stimulating light parameters such as its wavelength, intensity and exposure duration and method has not been performed in detail. We established an LED recovery station which provides pulsed and continuous light at various wavelengths at custom geometries. The study starts with the irradiation of optical samples at various gamma doses at a rate of 87.5 Gy/min. The optical transmittance of the samples are then measured in 200 nm - 1500 nm range for an extended period of time. Here we report on the details of the irradiation and recovery setups, and the results of recovery from radiation damage under different light exposure mechanisms.

1. Introduction

Ionizing radiation can sometimes be found as a high-frequency photon or sometimes as a particle with high kinetic energy. Natural radiation is produced by the energy difference between unstable nuclei as they pass to more stable states. Among the sources of radiation, unstable isotopes decaying in the soil and cosmic particles from space can be listed [1, 2]. The damage of natural-level radiation to materials is not dramatically high, but there are places with radiation levels significantly above normal levels such as scientific facilities and nuclear power plants.

Radiation causes loss of optical transmission in transparent materials. For some materials, this loss can heal by itself within a certain amount of time [1, 3]. Some external stimuli, such as sunlight, accelerate this process and extend the maximum recovery rate. For example; irradiated samples stimulated with RGB LED were observed to have an accelerated healing process and a higher final optical transmission [3]. On the other hand, a systematic study of the dynamics of the recovery as a function of the stimulating light parameters has not been performed in detail so far. In order to perform this systematic study, we established an LED recovery station which provides light at various wavelengths.

Here we report on the details of the irradiation and recovery setups, and the results of recovery of optical materials from radiation damage under different mechanisms of light stimulation.

2. Experimental setup

In order to start the systematic studies of recovery mechanisms from radiation damage in optical materials, we irradiated two sets of soda-lime float glass samples at the Medical Linac Facility of Turkish Accelerator and Radiation Laboratory (TARLA) [4, 5]. Figure 1 shows a sketch of the TARLA facility. The Medical Linac provides 6-21 MeV bremsstrahlung photons. The beam is approximately 10 cm diameter at the experimental location. The lateral uniformity is within 3 %, and the dose rate can be adjusted up to a maximum of 87.5 Gy/min.

We irradiated two sets of three soda-lime float glass samples. The total absorbed dose of the two sets of samples were 3.5 kGy and 7 kGy, both irradiated at a rate of 87.5 Gy/min. Immediately following the irradiation, one sample from each set was placed: in a dark box; in a room with ambient light; at the LED recovery station; as sketched in Fig. 2 (left).

The LED recovery station provides pulsed and continuous light at various wavelengths at custom locations. The station contains 5 different LEDs: ultraviolet (UV), blue, white, green and red. Figure 2 (right) shows the spectra of the LEDs used in the recovery station.

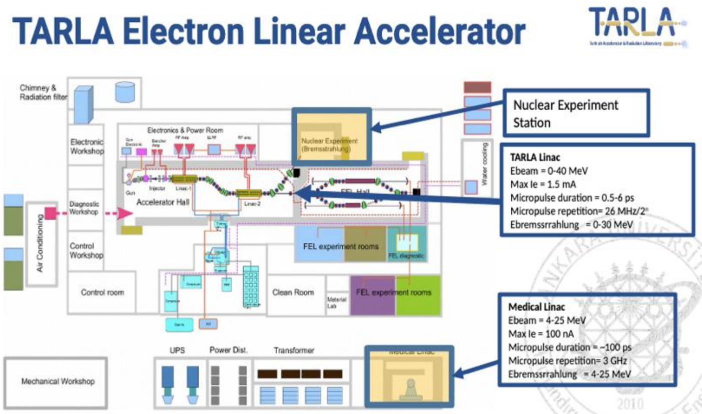

Figure 1. A sketch of the TARLA facility [4, 5].

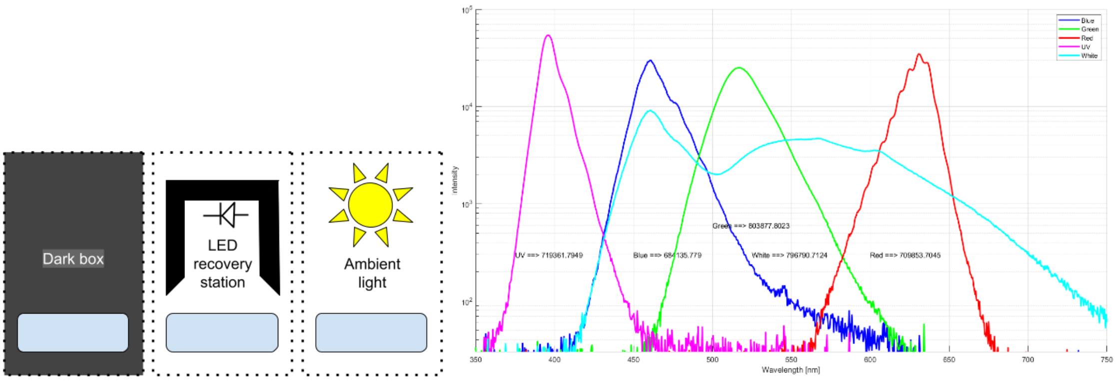

Figure 2. A sketch of the studied recovery stations (left) and the spectra of all the LEDs in the recovery station (right).

We brought all the LEDs to approximately the same photon intensity in order to minimize the systematics related to the operational parameters of the LEDs. The maximum variation between the intensities of the LEDs was 7%. Figure 3 (left) shows the integral of the intensities of the LEDs in the two recovery stations.

The LED stations were operated in a temperature controlled room. Figure 3 (center) shows the variation of the integral of the intensity for the UV LED. The day-night temperature variation is approximately 2 degrees and the fluctuation in the integral intensity is within 3 %.

Figure 3 (right) shows pictures of the LED station (top) and an irradiated glass sample with the recovery and measurement template attached on top (bottom).

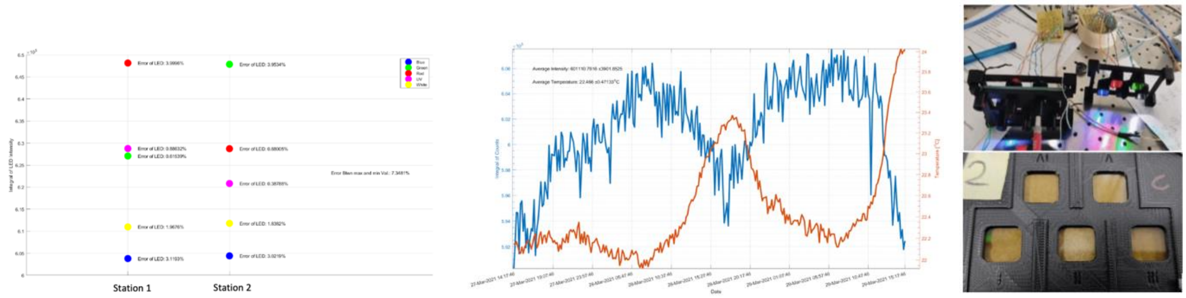

Figure 3. Integral of the LED intensities in the two recovery stations (left), the variation of the integral of the intensity for the UV LED in the temperature controlled room (center) and the pictures of the LED station (right top) and an irradiated glass sample with the recovery and measurement template attached on top (right bottom).

The optical transmittance of the samples were measured in 200 nm - 1500 nm range with Shimadzu UV-3600 Plus UV-VIS-NIR Spectrophotometer [6] for an extended period of time. This report covers the most recent results.

3. Experimental Results

A total of 6 glasses were irradiated, three of which received a total dose of 3.5 kGy and the other three received a total dose of 7 kGy, at a rate of 87.5 Gy/min. Irradiated samples were cut into appropriate sizes and attached on 3D-printed templates (see Fig. 3 right bottom).

Transmittance was measured on the samples after irradiation with a Shimadzu brand spectrometer every day. In addition, transmittance data on an unirradiated glass of the same type was acquired for the relative transmittance calculations.

Figure 4 shows the spectral dynamics of recovery from radiation damage for 3.5 kGy (top panel) and 7 kGy (bottom panel) irradiated samples in dark (column 1), room (column 2) conditions and white, UV, blue, green and red (columns 3-7) LED irradiation. The recovery under the UV illumination is manifestly more dominant compared to the other mechanisms of recovery.

Figure 5 shows the percent damage of the transmission for all the samples irradiated to 3.5 kGy (left) and 7 kGy (right) as a function of time. The recovery in dark is the slowest and least in amount as expected. The minimal recovery among the LEDs occurs for red illumination. Decreasing wavelength of LED illumination results in higher amounts of recovery in a shorter time interval.

Figure 6 shows the percent damage of the transmission for dark and UV-illuminated samples irradiated to 3.5 kGy (left) and 7 kGy (right) as a function of time together with the fits to the sum of an exponential and a constant, $ae^{-t/\tau}+c$, where τ is the time constant. The figure depicts the minimum and maximum recovery cases. As can be seen, both the recovery amounts and the timing characteristics are different with the UV illumination resulting in faster and better recovery. Table 1 shows the time constants and the permanent damage for the dark and UV-illuminated recovery cases for 3.5 kGy and 7 kGy irradiated samples. The time constants for dark room recovery are around 15 days, whereas for UV illumination, they are around 12 days. The permanent damage is also improved by more than 10 % for the case of UV illumination. The complete systematics will be studied once the recovery process is finalized.

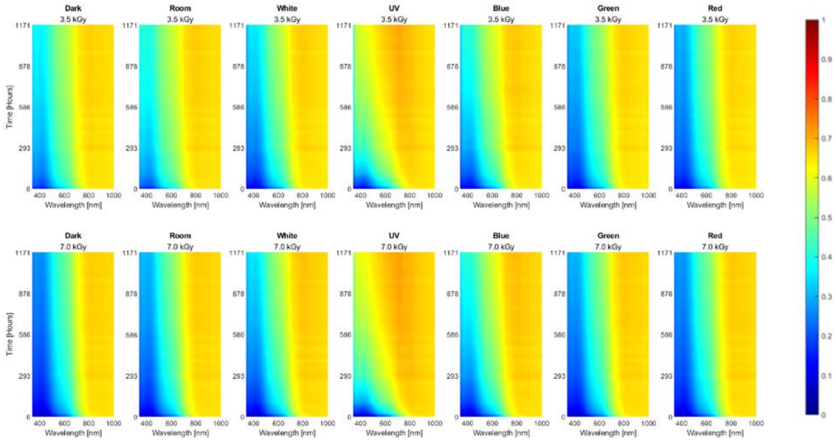

Figure 4. The spectral dynamics of recovery from radiation damage for 3.5 kGy (top panel) and 7 kGy (bottom panel) irradiated samples in dark (column 1), room (column 2) conditions and white, UV, blue, green and red (columns 3-7) LED irradiation.

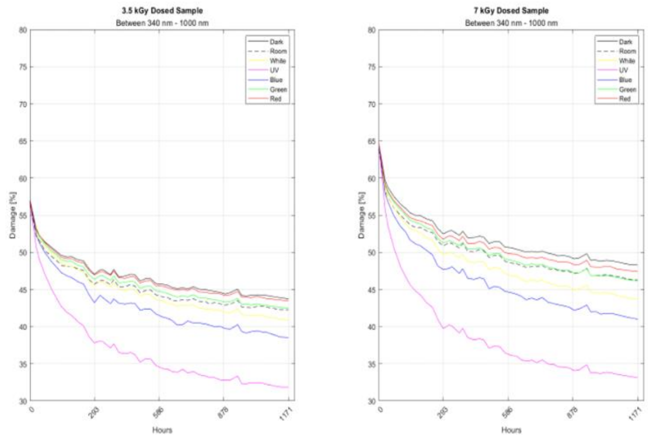

Figure 5. The percent damage of the transmission for all the samples irradiated to 3.5 kGy (left) and 7 kGy (right) as a function of time.

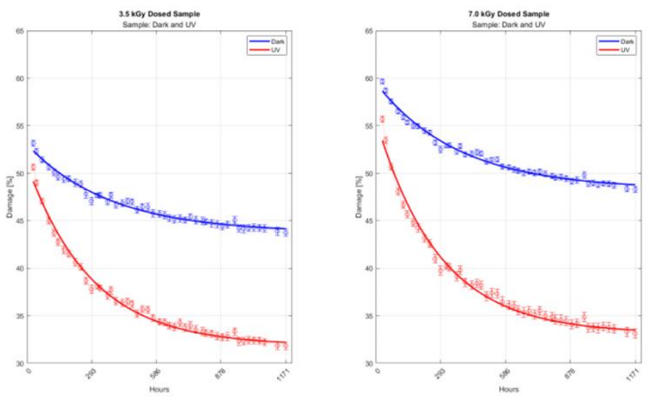

Figure 6. The percent damage of the transmission for dark and UV-illuminated samples irradiated to 3.5 kGy (left) and 7 kGy (right) together with the fits.

Table 1. The time constants and the permanent damage for the dark and UV-illuminated recovery cases for 3.5 kGy and 7 kGy irradiated samples.

	Dark		**UV**	
	Time Constant (hours)	Permanent Damage (%)	Time Constant (hours)	Permanent Damage (%)
3.5 kGy	375.5±22.7	43.7±2.4	292.2±13.8	31.9±4.7
7 kGy	372.6±21.5	48.3±2.8	284.0±15.2	33.1±5.5

4. Conclusions

In order to perform systematic studies of recovery from radiation damage under various conditions, we irradiated two sets of three soda-lime float glass samples to total doses of 3.5 kGy and 7 kGy at a rate of 87.5 Gy/min. Immediately following the irradiation, one sample from each set was placed: in a dark box; in a room with ambient light; at the LED recovery station. The optical transmittance of the samples were measured in 200 nm - 1500 nm range for an extended period of time.

The initial results from the continuing measurements indicate that the UV-LED stimulated sample both recovered faster and reached a better level at the end of 48 days. The second best result is with the blue-LED illuminated sample. According to this, the smaller the wavelength of the light used for stimulation, the more effective is the achieved recovery, both in terms of recovery amount and the rate of recovery. This phenomenon can be associated with the attenuation of light in the glass medium: as the attenuation coefficient increases, a larger number of photons are absorbed. In this way, the glass gets closer to its molecular structure before it was damaged by radiation.

The complete systematics will be established once the plateaus in the recovery are reached.

5. Acknowledgements

This work is supported by Tübitak grant no 118C224.

References

[1] Krane, K. S. (1987). Introductory Nuclear Physics (3rd ed.). Wiley.
[2] Knoll, G. F. (2000). Radiation Detection and Measurement (3rd ed.). Wiley.
[3] Wetzel, J., et.al., (2017). Using LEDs to stimulate the recovery of radiation damage to plastic scintillators. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 395, 13–16. doi:10.1016/j.nimb.2017.01.081
[4] Indico.tarla.org.tr. 2021. [online] Available at: <https://indico.tarla.org.tr/event/91/contributions/262/attachments/602/97/2018-10-22_tarla_sc_meeting.pdf> [Accessed 1 January 2021].
[5] Aksoy, A., et.al. (2018). Current status of Turkish accelerator and radiation laboratory in Ankara: the TARLA facility. Canadian Journal of Physics, 96(7), 837–842. doi:10.1139/cjp-2017-0750.
[6] https://www.ssi.shimadzu.com/