Afterglow of YAG:Ce single crystal scintillators for S(T)EM electron detectors

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One of the most used electron detection systems in S(T)EM is a system based on a scintillator-photomultiplier combination. As scintillation properties of the system can highly affect scanned image quality, many requirements are placed on the scintillator [1]. One of the requirements is short time response of a light emission pulse. The time response of scintillators usually follows sum of exponential decays with fast as well as with slow components [2]. The fast components are usually short enough to meet a typical scanning speed, however the slow ones can cause an undesirable afterglow. This can have a negative influence to the quality of the scanned image, such as image contrast decreasing and image blurring.

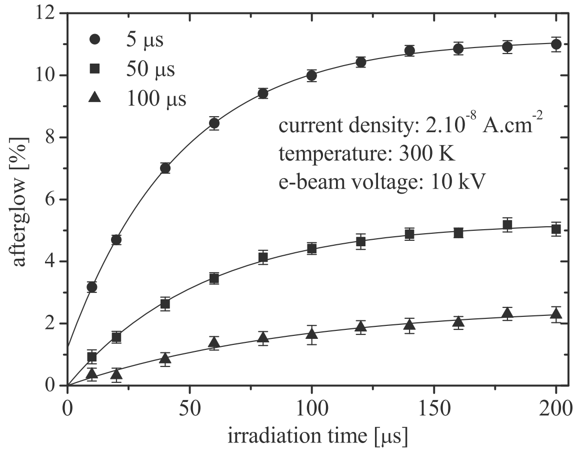
An objective of our work is a study of the slow decay component of scintillators. This paper is focused on the YAG:Ce single crystal scintillator which is widely used in S(T)EM. Experiments were carried out on a special apparatus, which simulates the scintillator-photomultiplier arrangement [3]. The Al-coated YAG:Ce (0.4 mol% Ce) singe crystal scintillator was placed towards to a 10 keV e-beam. To enable e-beam current measurement, a Faraday cage was located around the scintillator. For temperature measurement, the Faraday cage was equipped by an electric heater. Generated light was transferred via a light guide to a photomultiplier. Pulsed electron irradiation of the scintillator was performed by e-beam deflecting outside of an aperture. Light emission time response was recorded by an oscilloscope and the data processed by our own software.

The light emission of the YAG:Ce scintillator was studied in the main luminescent region with a peak at 550 nm. The afterglow was observed at defined times after the stop of the electron irradiation, specifically at 5 μs, 50 μs and 100 μs, respectively. They were expressed as a percentage of intensities at the end of the irradiation. First, dependence of the afterglow on scintillator irradiation time was observed. Results show, that the afterglow increases steeply with irradiation time increasing and saturates with longer times (Figure 1a). The measurement of the afterglow as a function of both the e-beam current (Figure 1b) and the scintillator temperature (Figure 1c) shows opposite tendency. The afterglow decreases with current as well as temperature increasing.

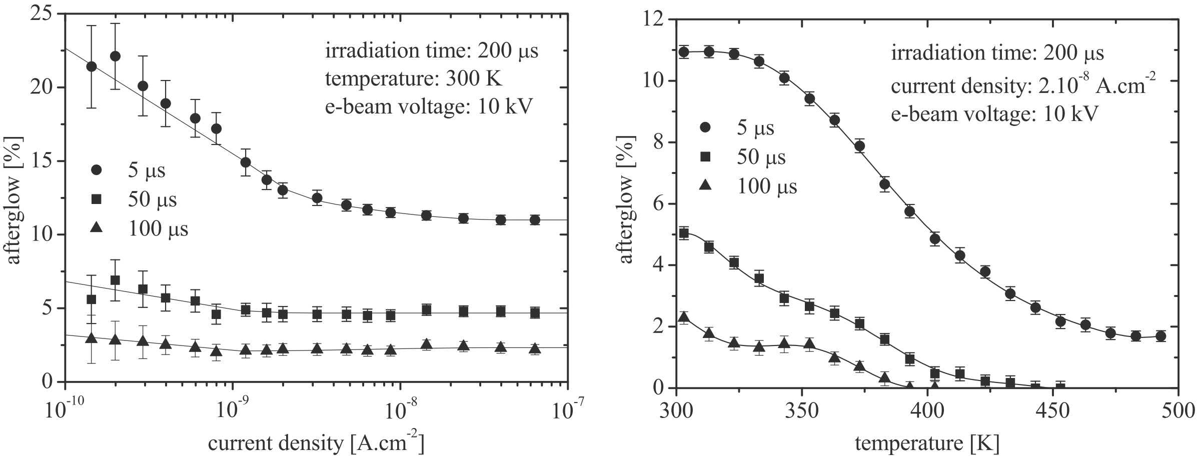
The obtained results can be interpreted based on a physical model of cathodoluminescence [4]. An important role plays the presence of capture centers, which act as traps for excitons. The captured excitons can escape from the traps after some time and contribute to the luminescence, leading to the afterglow. The traps are filled by the excitons with some probability during the irradiation and if the irradiation time increases, the afterglow will grow until the traps are filled. On the opposite side, the lattice temperature or the e-beam current contribute to the exciton releases from the traps.

Besides the physical understanding of the matter, important practical conclusions can be drawn. As the afterglow changes with the irradiation time, the same changes can arise during an image scanning. The image object with more adjacent bright pixels irradiates the scintillator for longer period and increase the afterglow, than the object with less adjacent bright pixels. In addition, the afterglow can increase if the signal electron current is low enough. These facts show that the afterglow depends on the bright pixel spatial arrangement as well as on their current intensities.

The afterglow influence on the scanned image can be reasonably reduced. Some solutions can be suggested. (1) Scanning speed can be reduced. If the scanning is slow enough, the afterglow will influence only the nearest pixels. However, an advantage of the fast scanning is lost. (2) Mathematical image reconstruction based on the scintillator time response knowledge can be applied. Such an approach could increase the image quality during the fast scanning; however, the realization could be difficult. (3) Afterglow reduction can be based on the afterglow temperature dependence. As written above, the YAG:Ce heating leads to the afterglow decrease. However, there should be considered light emission reduction due to the luminescence thermal quenching as well as some technical issues associated with the scintillator heating.



(a)



(b) (c)

Figure 1. The YAG:Ce single crystal afterglow in three different times after the stop of the irradiation as a function of (a) irradiation time, (b) current density and (c) YAG:Ce temp.

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