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

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1. Introduction

One of the most used electron detection systems in S(T)EM is a system based on a **scintillator-photomultiplier combination**. The combination with **YAG:Ce single crystal scintillator** will be presented here because of its wide usage.

Image quality can by highly affected by an used scintillator [1]. In high scanning speeds, **time response of the scintillator to an electron pulse** is a very important feature. Time response of YAG:Ce follows sum of exponential decays with fast and slow components [2]. The fast component is usually short enough to meet a typical scanning speeds, however **the slow components cause afterglow**. This undesirable effect can have negative influence to the scanned image quality, such as image contrast decreasing and image blurring.

In S(T)EM, a bright pixel from an observed object gives a pulse of signal electrons impinging on the scintillator.

Electron current density is current of the signal electrons per a scintillator surface.

Irradiation time is duration of the signal electron pulse impinging on the scintillator. It's dependent on

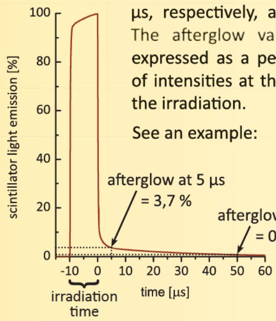
- scanning speed (dwell time per pixel)
- number of neighbouring bright pixels

In this presentation, there will be discussed

- how to measure the scintill. afterglow
- whether the afterglow depends on **the irradiation time** and **the current density**, or on other scintillator parameters, such as **temperature**.

Here, afterglow will be defined as a value of **scintillator light emission at defined time after stop of the electron irradiation**. In this presentation, the times 5 μs, 50 μs and 100 μs, respectively, are used. The afterglow values are expressed as a percentage of intensities at the end of the irradiation.

See an example:



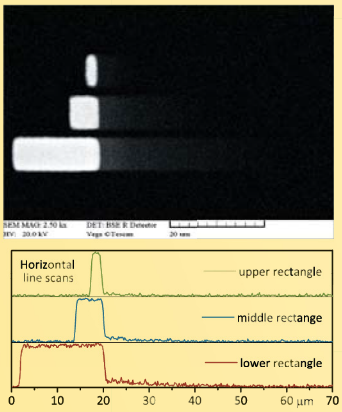
2. Experimental setup for afterglow analysis

We developed a special apparatus for scintillator afterglow examination [3]. An Al-coated disc-shaped scintillator (**A**) is placed towards to an e-beam (**B**). Emitted light is transferred through a light-guide (**C**) to a photomultiplier (**D**). To enable e-beam current measurement, a Faraday cage (**E**) is located around the scintillator. For temperature measurement, the Faraday cage is equipped by an electric heater. Pulsed electron irradiation of the scintillator is performed by e-beam deflecting outside of an aperture (**F**).

3. Influence of scintillation detection system on SEM images

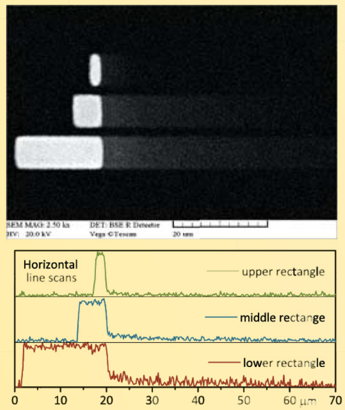
- A copper thin layer (thickness 5 μm) was deposited on a silicon substrate in the structure of horizontal rectangles.
- The sample was observed in a SEM Tescan Vega with 20 kV accelerating voltage in primary beam. For signal electron detection, a BSE scintillation detector with a standard **YAG:Ce single crystal scintillator** (produced by Crytur) was used.
- Image blurring appeared behind the contrastive rectangles in the direction of scanning (scanned left to right). The blurring was caused by the detection system. According our research, influence of a photomultiplier and other electronics can be neglected. **The image blurring is caused by the YAG:Ce afterglow.**
- **The blurring is dependent on observed image structure and scanning speed.** The reason is dependence of the afterglow on the scintillator irradiation time and the signal current density (see analysis below).

Scanning speed: **3,4 us/pixel** (slower),
No image averaging



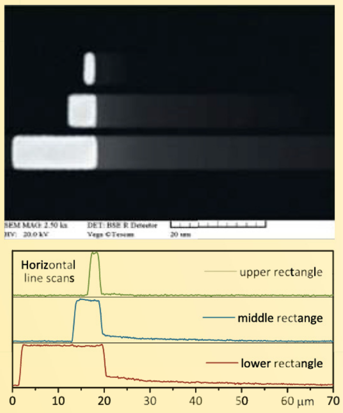
The blurring **increases with the increasing rectangle length**. This is caused by an irradiation time dependence of the afterglow (see below).

Scanning speed: **0,5 us/pixel** (fast),
No image averaging



The blurring is higher in this example - the blurring **increases with increasing scanning speed.**

Scanning speed: **0,5 us/pixel** (fast),
30x averaged

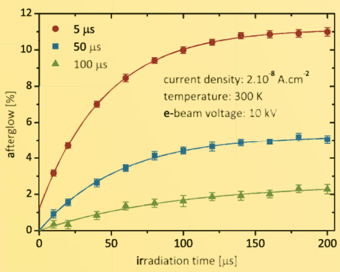


Using fast scanning and image averaging (as in this example), the afterglow cause **higher blurring**.

4. Analysis of YAG:Ce afterglow

Dependence of the afterglow on
YAG:Ce irradiation time

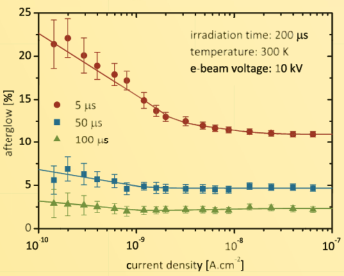
The afterglow at the defined times after the end of irradiation (5 μs, 50 μs, 100 μs) increases with increasing irradiation time.



This behaviour is interesting since the different irradiation times give different afterglow values. It can be explained on a cathodoluminescent model of YAG:Ce [4].

Dependence of the afterglow on
current density of signal electrons

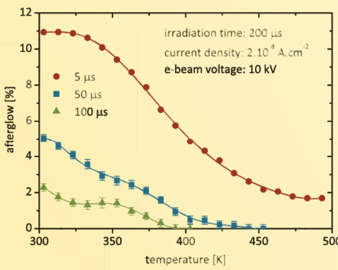
The afterglow decreases with signal electron current increasing (shown in semi-logarithmic scale).



We expected opposite tendency of this dependence. The explanation of this phenomenon is not clear yet and it is a topic of our future investigation.

Dependence of the afterglow on
YAG:Ce temperature

The temperature measurement shows that the afterglow decreases rapidly with temperature increasing above RT.



An important role in the afterglow presence play luminescent capture centres, which trap excitons. During the temperature increasing, the excitons are thermally released and the afterglow is decreased.

5. Conclusion

- The YAG:Ce afterglow causes visible blurring of contrastive images in S(T)EM.
- The afterglow increases with the increasing scintillator irradiation time - it means, the afterglow increases with increasing with higher number of adjacent bright pixels and with scanning speed.
- Since the afterglow causes the undesirable image effects, it can be reasonably reduced:
  1. Instead of using high scanning speeds with image averaging, it is better to use slower scanning speeds without averaging.
  2. Mathematical image reconstruction based on knowledge of the YAG:Ce time response could clean the presented image blurring.
  3. The YAG:Ce temperature increasing leads to the significant afterglow decreasing. Therefore, the blurring could be reduced by scintillator heating.

1. R. Autrata, P. Schauer, Scan. Microsc. 9 (1996), 1-12
2. C.W.E. van Eijk, Nucl. Instrum. Meth. A 392 (1997), 285-290
3. P. Schauer, R. Autrata, Fine Mech. Opt. 42 (1997), 340
4. V.I. Solomonov, Opt. Spectrosc. 95 (2003), 248-254