RESPONSE OF SCINTILLATING SCREENS TO FAST AND SLOW EXTRACTED ION BEAMS*

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Abstract

For FAIR (Facility for Antiproton and Ion Research) imaging properties of inorganic scintillators for high energetic heavy ion beams were studied. In order to investigate the characteristics of scintillation response and transverse beam profile, several experiments were conducted with slow (200 ms) and fast (1 µs) extracted 350 MeV/u Uranium beams from SIS18. The extracted particle number was varied between 10^5 and 10^9 particles per pulse for the irradiation of five different scintillators: Cr-doped alumina as well as two phosphors P46 and one P43. Additionally radiation resistance tests for two phosphor screens and the Cr-doped alumina screen were performed by irradiating with more than 700 pulses with 10^9 ions each.

Linear response in scintillation light output over the large range of ion intensities is observed and for each material statistical moments were calculated.

MOTIVATION

Scintillating Screens are a direct intercepting method to observe transverse beam profiles. Profile measurements are important for controlling the spatial distribution of the particle beam, as well as matching of different sections of the accelerator. Scintillating materials should fulfil several requirements [1], among them we investigated here:

- dynamic range and linearity between the incident particle flux and the light output
- radiation hardness to prevent damages
- availability in variable sizes at moderate costs

For FAIR high energy beam transport lines scintillating screens for profile measurements are foreseen at 31 different locations.

EXPERIMENTAL SETUP

All measurements were performed at GSI (Darmstadt, Germany). The results, described here, were achieved with a 350 MeV/u Uranium beam from SIS18. Before reaching the target location the ions had to cross different materials (e.g. stainless steel foil). Thus the projectile charge at the target can be estimated to have a mean value of Z_{eff}=91 and energy of 320 MeV/u for slow extraction (with 200 ms) and 340 MeV/u for fast one (within 1 µs) [2]. The number of particles per pulse (ppp) was determined in two ways:

- For slow extracted beam intensity-measurement was performed by an Ionisation Chamber for lower particle numbers and by a Secondary Electron Emission Monitor for higher number with a resolution of 5% [3].
- For fast extracted beam current-measurement was performed by a resonant transformer with a detection threshold of about 10^5 particles per pulse and a resolution of 1% [4].

In our experiment (see Fig. 1), plates of scintillating materials were inserted into the beam under an angle of 45°. The screens were observed with two standard CCD-camera-systems (AVT Marlin F033B with 8bit mode, VGA resolution, Firewire-Interface). Both cameras were mounted parallel to the scintillating screens at a distance of 40 cm. The reproduction scale was 4.1 px/mm. A remote-controlled lens system (Pentax, 16 mm focal length) as well as a 5% transmission neutral-density-filter on the second camera were used to increase the dynamic range for the experiment.

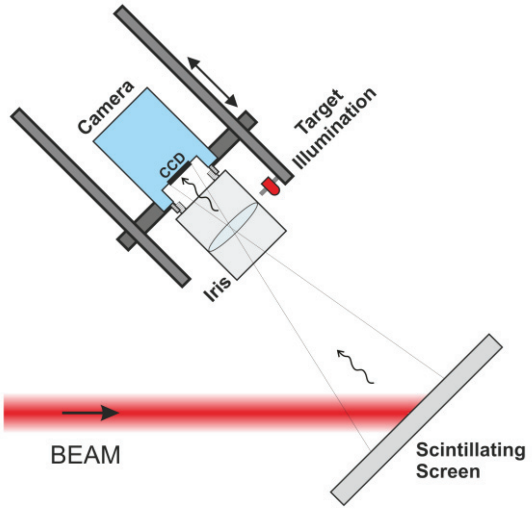

Figure 1: Principle of experimental setup. The scintillating screen target ladder is tilted by 45° with respect to the beam and is moveable perpendicular to the plane of the paper. Camera system is mounted at an angle 90° in respect to the screens.

The camera was triggered with the beam delivery. Prior to the beam delivery a background picture was recorded. The data acquisition software BeamView [5] was used to store individual images. Light recorded on CCD chip (grey-value) corresponds to light output in this publication.

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Table 1: Overview of the Investigated Screen Materials, their Layer Thickness, Initial Energy Loss and Material Phase

Material	**Supplier**	**Thickness**	**dE/dx** [2]	**Phase**
P43 (Gd_2O_2S:Tb)	ProxiVision [8]	50 µm	1.6 keV/µm	powder crystals
P46 ($Y_3Al_5O_{12}$:Ce)	ProxiVision [8]	50 µm	1.0 keV/µm	powder crystals
P46 ($Y_3Al_5O_{12}$:Ce)	Crytur [9]	20 µm	1.0 keV/µm	powder crystals
Al_2O_3	BCE [10]	0.8 mm	2.1 keV/µm	ceramics
Al_2O_3:Cr	BCE [10]	0.8 mm	2.1 keV/µm	ceramics

The results for five inorganic materials are described; an overview of the used scintillators is given in Table 1. All targets were chosen such that a part of their optical emission takes place within the working region of the used optical system, which is within 400 nm and 1000 nm.

It is important to mention that all measurements were performed in air.

Offline Analysis

To analyse the recorded images, a dedicated python code was developed. The code includes the properties of the experimental setup as well as the beam parameters (e.g. number of particles). The code performs various steps for image evaluation, including background-subtraction, image-smoothing and scaling of grey-values to the given optical setup. To minimize noise a Region Of Interest (ROI) is chosen with identical area for each target. An example of the chosen ROI is given in Fig. 2.

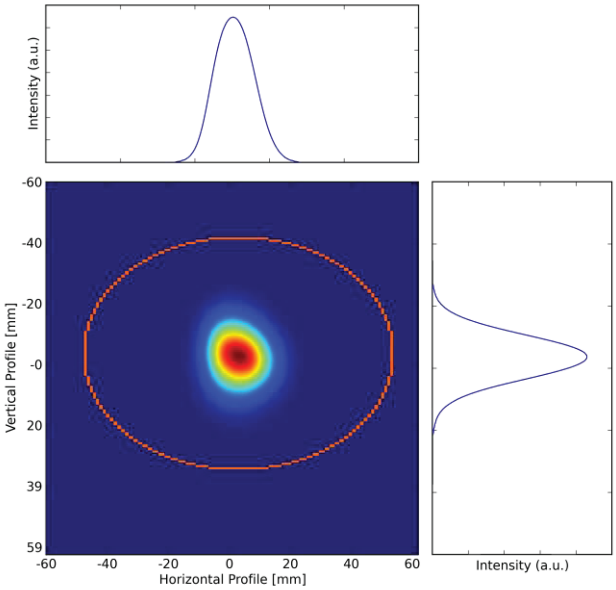

Figure 2: Processed image from recorded scintillation in false colors and the projections of the beam spot in horizontal and vertical axis with chosen ROI.

Horizontal and vertical projections as well as calculated light output and recorded beam width σ are stored into ASCII-files.

RESULTS

Light Output vs. Beam Current

For the measurements the particle number was varied between 10^5 and $2 \cdot 10^9$ppp.

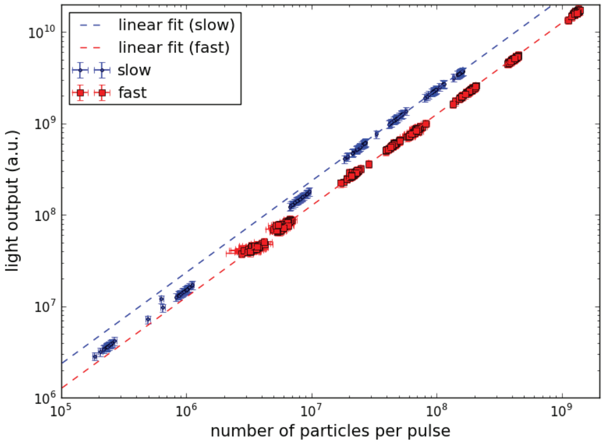

Figure 3: Light output of P43 phosphor screen vs. particle number. Each dot represents one beam pulse, the lines are linear functions. Beam parameters: 340 MeV/u (fast extraction) respectively 320 MeV/u (slow extraction) Uranium beam (Z_{eff}=91) with number of particles between 10^5 and $2 \cdot 10^9$ per pulse.

As shown in Fig. 3, the light output of the investigated scintillators shows linear response over four orders of magnitude for both, slow and fast extracted beams. Noticeable is that light output for fast extracted beams is two times lower than for slow extracted beams.

Systematic studies for different materials (Fig. 4) showed that the light output differs by two orders of magnitude between materials and rises almost linear over a large intensity range for both, slow and fast extracted beams. As expected from former studies [6], the purpose built scintillator P43 is most sensitive followed by Al_2O_3:Cr and P46 phosphor.

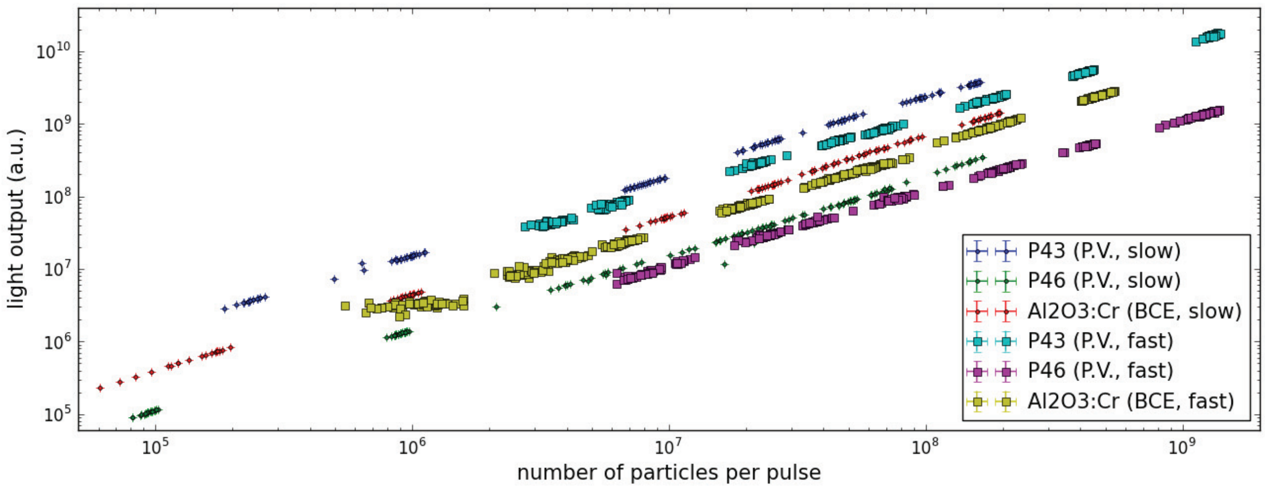

Figure 4: Light output from three scintillating screens as function of number of particles. Beam parameters: 340 MeV/u (fast extraction) respectively 320 MeV/u (slow extraction) Uranium beam (Z_{eff}=91).

Analysis of Beam Profiles

Transverse beam profiles were analysed in both, horizontal and vertical direction. An example of vertical profiles is shown in Fig. 5. A qualitative comparison of recorded beam width, by calculating the square root of the second statistical moment σ, is still under investigation. From the first data evaluation, we can see that no saturation was observed over the complete range of particle numbers. The small change in the shape of distribution was observed during irradiation with different beam currents as shown in Fig. 5. It can be due to change in the beam itself or in the material response.

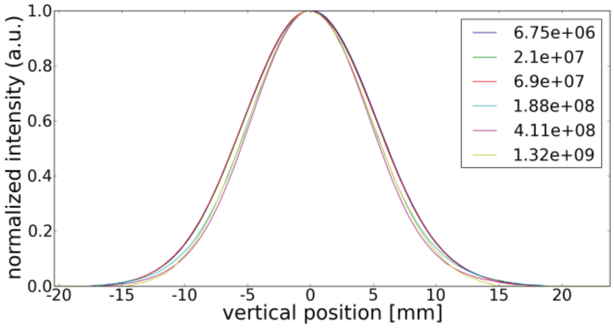

Figure 5: Normalized vertical projection of the beam spot obtained for P43 at different beam intensities with fast extracted 340 MeV/u Uranium pulses.

Radiation Stability Tests

In addition to the constant profile reproduction behaviour, the linear light output from the investigated scintillation screens enhances our interest in these materials for further studies. The radiation stability of Al_2O_3:Cr, P43 phosphor and one P46 phosphor were investigated using fast extracted $2 \cdot 10^9$ Uranium ppp with 340 MeV/u. The ion beam irradiated each target with more than 700 pulses (according to a period of 45 minutes). After a break of 10 minutes a second irradiation of 15 minutes (according to 50-100 pictures) was performed to see if any change in material response can be observed.

Among the screens, a constant light output is observed for Al_2O_3:Cr and P46 (Crytur) as presented in Fig. 6. The light output from ProxiVision sample P43 decreases slightly upon irradiation.

After the break no significant difference in light output was observed for all phosphor samples that can indicate that no thermal influence on the materials occurred during irradiation. The results are, in agreement with former investigations, on slow extracted beam [7].

The beam profile reading remains stable for all examined samples during the irradiation hardness tests.

CONCLUSION

Several inorganic materials were investigated under irradiation of high energy heavy ion beams. The light output for all studied materials is noticeably linear with respect to the number of particles and differs only by a factor of two between slow and fast extraction, even for P43 phosphor screen with a decay time 1000 times higher than spill duration of fast extraction. Also radiation hardness tests look very promising. Phosphor screens as well as common used Al_2O_3:Cr seem to be adequate for FAIR applications.

Further experiments (e.g. spectrometry) are required for a proper understanding of scintillation process and material modification due to radiation. This experimental programme will be continued for different ion species and energies to provide the necessary data required for an appropriate choice of scintillating materials keeping in mind the large variety of ion species and intensities at the FAIR facility.

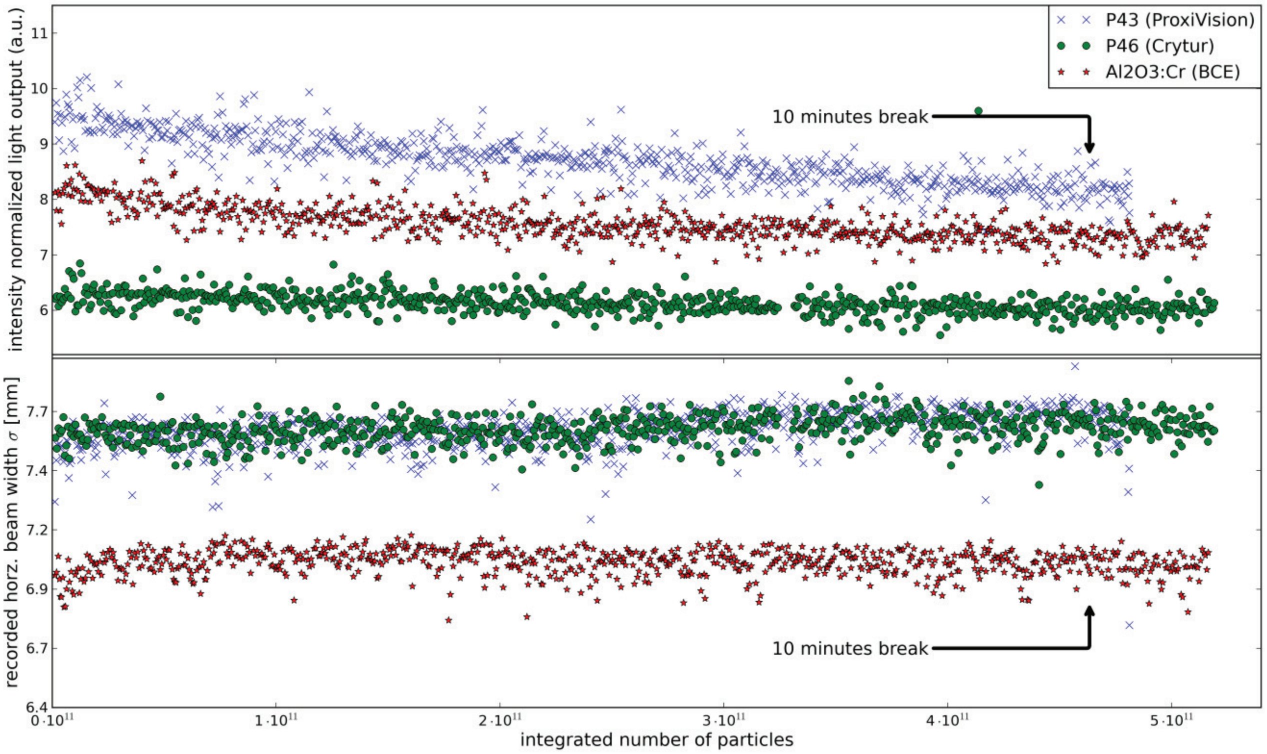

Figure 6: Light output and recorded horizontal beam width from various scintillators as function of integrated particles. After 45 minutes of irradiation a 10 minutes break was introduced to let the screen relax, followed by additional 15 minutes irradiation. The difference σ in between P43 (ProxiVision) and P46 (Crytur) to Al_2O_3:Cr indicates a modified beam setting. Beam parameters: 340 MeV/u Uranium beam (Z_{eff}=91) with $2 \cdot 10^9$ fast extracted particles per pulse.

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