TRANSVERSE BEAM PROFILE MONITORING USING SCINTILLATION SCREENS FOR HIGH ENERGY ION BEAMS*

K. Renuka, W. Ensinger, Technical University of Darmstadt, Germany
C. Andre, F. Becker, P. Forck, R. Haseitl, A. Reiter, B. Walasek-Höhne, GSI, Darmstadt, Germany

Abstract

Transverse profile measurements were carried out using scintillation screens such as single crystals (CsI:Tl, YAG:Ce), powder screens (P43, P46) and ceramics (Al_2O_3, Al_2O_3:Cr). Different ion beams such as C, Ne, Ta, and U were accelerated to energy of 300 MeV/u in the heavy ion synchrotron at GSI. The ions were extracted within 0.3 s for intensities from 10^4 to 10^9 particles per pulse and were applied to the screens. The image of each beam pulse was recorded by a CCD camera and evaluated independently. The recorded image profiles show a reproducible dependency on investigated scintillation screen. A difference in image width up to 50% is noticed between CsI:Tl and Herasil. The detailed investigation shows that the powder screens P43 and P46, ceramics Al_2O_3 and Al_2O_3:Cr reproduce the beam width within a difference of ±4 % for all the ion beam intensities used in this measurement. The light output from the screens scales linearly over 5 orders of magnitude of particle intensity. The light yield per energy deposition by a single ion was calculated for different ion beams.

INTRODUCTION

Beam diagnostics is an essential constituent of any accelerator, which let us perceive the properties of the beam at different locations. The major task of beam diagnostics is monitoring and characterizing the ion beam for successful daily operation of an accelerator facility. A number of techniques are available to measure the transverse spatial distribution of ion beams. The advantages of deploying scintillation screens for transverse profile measurements [1, 2] are its simplicity, cost and power of conviction. In the beam profile analysis using scintillation screens, a flash of light produced in the scintillation screens when struck by ionization radiation, generates a direct two dimensional beam distributions. The quantitative characterization of the beam distribution is possible via observation of photons with standard CCD sensors.

In the Facility of Antiproton and Ion Research (FAIR), the scintillation screens will be foreseen at about 40 different locations for profile measurements. In this study, a systematic beam profile investigation was carried out using various scintillation screens for the ion beams extracted from SIS18. The current investigation serves as a basic for the beam profile measurement of the ion beams at high energies using screens. In this manuscript we present, the light output and the profile reproduction behaviour of the screens for different ion beams at different particle intensities.

Since a linear light output of 3 orders of particle intensities was obtained for Carbon and Uranium ion beams of kinetic energy 300 MeV/u [3], the measurements were extended for Neon and Tantalum ions.

EXPERIMENTAL METHODS

The material selection for the current investigation is based on our previous experimental results obtained from low energy ion beams [4]. Various scintillation screens such as, single crystals, powder screens, and ceramics were used (Table 1) for the profile measurement.

Table 1: List of Investigated Materials used for the Beam Profile Measurement

Type	Material	Producers
Single crystal	CsI:Tl YAG:Ce (1 mm) YAG:Ce (0.25 mm)	Saint Gobain Crystals Saint Gobain Crystals Crytur Ltd
Ceramics	Al_2O_3 Al_2O_3:Cr	BCE Special Ceramics
Phosphor screen	P43 (Gd_2O_2S:Tb) P46 ($Y_3Al_5O_{12}$:Ce)	Proxitronics Crytur Ltd

The experimental setup used for the measurement is shown in Fig. 1. Monitoring of the scintillation screens was carried out using a standard CCD camera (AVT marlin, 8 bit ADC, VGA resolution). The larger dynamic range of particle intensity was covered with the remote controlled iris of Pentax C1614ER lens system. Due to the saturation of the first CCD camera, the measurements at higher particle intensities were carried out with a second CCD camera equipped with a grey filter of 5% transmission. A resolution of 4.0 px /mm was obtained with the installed experimental setup. The software called BeamView was used for data acquisition and storage [5]. An Ionisation Chamber and a Secondary Electron Monitor located upstream of the target were used to measure the intensity of the beam pulses for the offline analysis [6]. The light output and the statistical moments were calculated from the projected beam spot. The detailed procedure of data analysis is mentioned elsewhere in [4].

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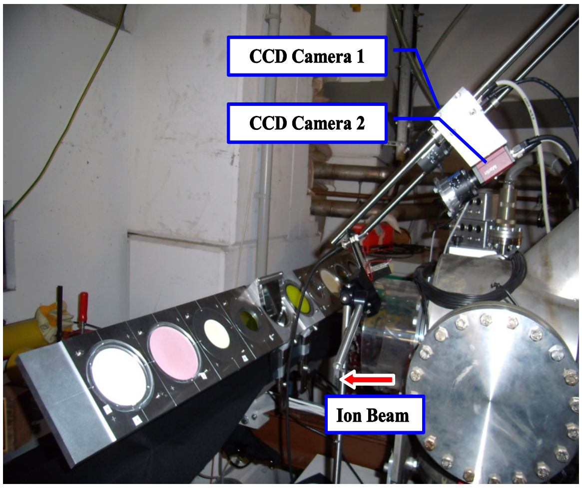

Figure 1: The experimental setup used for ion beam profile measurements. The scintillation light is captured using two CCD cameras for different intensity range.

NEON ION INVESTIGATION

The Neon ions were considered as a representative of medium weight ion in this work. About 2% of energy loss is caused by the vacuum windows in the beam line. The scintillation screens were therefore irradiated with ions of a final kinetic energy 295 MeV/u. As shown in Fig. 2 for the investigated materials, different image width was obtained for different samples. Higher standard deviations 'σ' were obtained for CsI:Tl and YAG:Ce (1 mm). The powder screens exhibit a good agreement with the image width reproduced by the aluminium oxide ceramics. The profile reproduction behaviour of the thin YAG:Ce (0.25 mm) single crystal coincide with the opaque samples within a difference of 4% as shown in Fig. 2. The light output from the scintillation materials shows a linear dependence with respect to particle intensity. For the Neon ions the light output linearly extends from 10^6 to 10^9 particles per pulse as depicted in Fig. 3. Although the

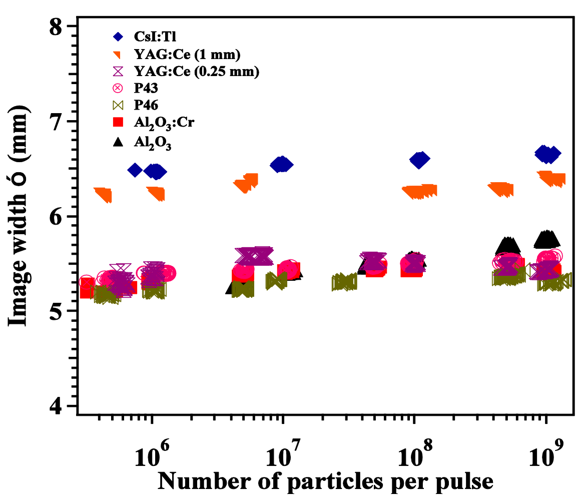

Figure 2: Image width σ obtained for different scintillation screens. Beam parameters: Neon at 295 MeV/u, 0.3 s pulse length, 0.25 Hz repetition rate and $5*10^5$ to 10^9 particles / pulse.

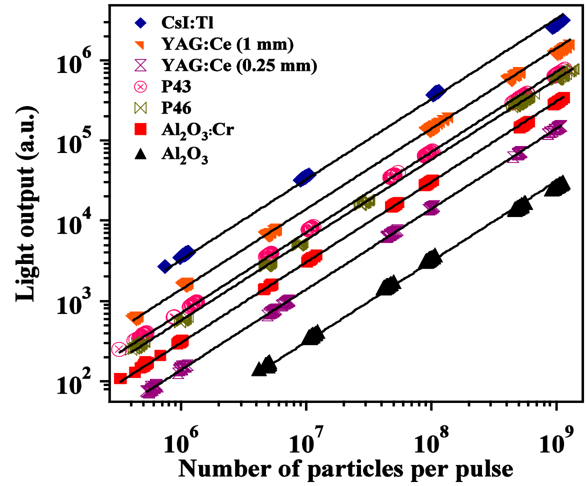

Figure 3: Light output from various scintillation screens vs. particle numbers. Beam parameters: Neon at 295 MeV/u, 0.3 s pulse length, 0.25 Hz repetition rate and $5*10^5$ to 10^9 particles / pulse.

P46 and YAG:Ce (0.25 mm) were prepared from the same source materials, P46 produces three times higher light output than YAG:Ce (0.25 mm) crystal. This reveals an enhanced sensitivity of powder crystal P46 (100 μm) compared to the single crystal (0.25mm) even at reduced thickness.

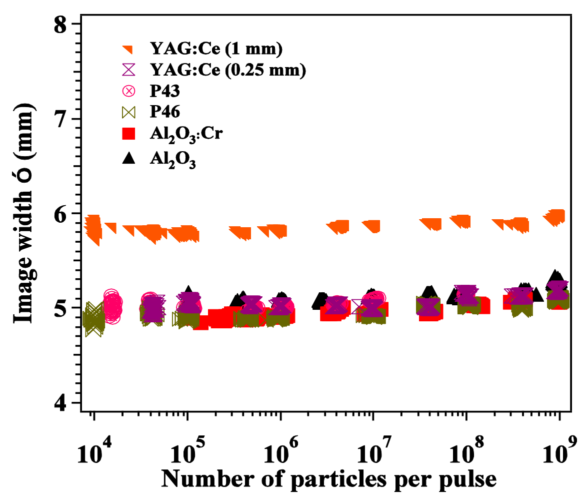

Figure 4: Image width σ obtained for different scintillation screens. Beam parameters: Tantalum at 275 MeV/u, 0.3 s pulse length, 0.25 Hz repetition rate and 10^4 to 10^9 particles / pulse.

TANTALUM ION INVESTIGATION

The Tantalum ions were considered as representative for heavy ions in relative to Neon. The scintillation screens were irradiated with ions of a final kinetic energy 275 MeV/u. The profile reproduction behaviour of the screens shown in Fig. 4 follows the similar trend as for Neon ions and YAG:Ce (1 mm) produces large image width σ. The samples show constant profile reproduction throughout the measurements, from 10^4 to 10^9 particles per pulse. For the tantalum ion, the samples show linear

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light output similar as Neon ion measurements. The linearity is extended over the whole intensity range available in the experimental area see Fig. 5.

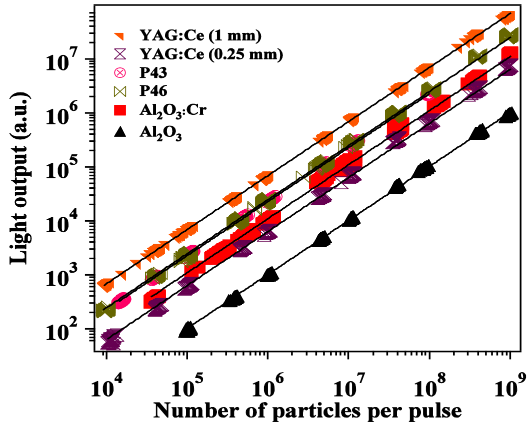

Figure 5: Light output from various scintillation screens vs. particle numbers. Beam parameters: Tantalum at 275 MeV/u, 0.3 s pulse length, 0.25 Hz repetition rate and 10^4 to 10^9 particles / pulse.

STABILITY MEASUREMENTS

In addition to the constant profile reproduction behaviour, the linear light output from aluminium oxide ceramics and the powder screens enhance our interest in these materials for further investigation. The radiation stability of these scintillation screens was investigated using Uranium beam irradiation. The ions, with intensity of $6*10^8$ particles per pulse were accelerated to 300 MeV/u and applied to the screens. For each pulse the image properties are observed, see Fig. 6. Among the screens, a constant light output and stable response is obtained from Al_2O_3:Cr screen for more than 1000 pulses. The light output from P43, Al_2O_3 and P46 samples decreases upon irradiation due to the radiation intolerance of the luminescence centres. Among the samples, P43 screen shows the most unstable behaviour in profile reproduction and light output.

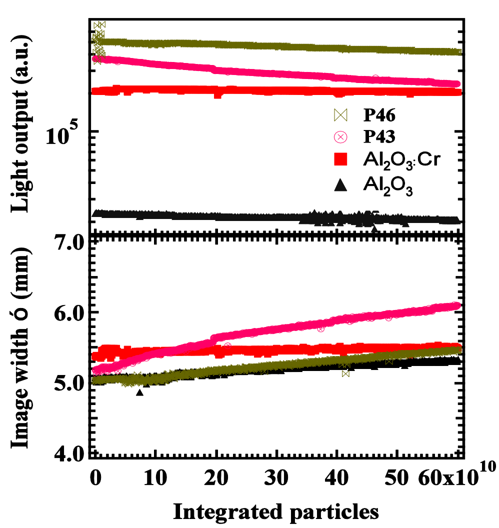

Figure 6: Light output and image width from various scintillation screens vs. integrated particle numbers for about 1000 beam pulses. Beam parameters: Uranium at 269 MeV/u, 0.3 s pulse length, and 0.25 Hz repetition rate and $6*10^8$ ions per pulse.

The average dose deposited over the thickness of the sample is calculated for the Uranium ions. The dose deposited in P46 screen by a single pulse ($6*10^8$ particles) is 1.980 kGy for $\pm 1\sigma$ area (95 mm^2), which is relatively higher compared to other samples such as Al_2O_3:Cr (1.700 kGy) and P43 (1.500 kGy). These doses deposited in the samples produced significant differences in the properties of the screen materials.

DISCUSSION

Among the investigated materials, different light outputs and image widths were recorded. A stable behaviour is noticed from Al_2O_3:Cr, which produced a linear light output and constant image width measurement with irradiation. The doped and undoped aluminium oxide samples produced a difference in light output within one order of magnitude. This difference remains constant throughout the measurements. During the measurements a significant difference in the light output from the P43 screen is noticed. The sensitivity of P43 decreases due to continuous irradiation thus results in low light output than P46. This clearly indicates the formation of radiation-induced damages in the screen material. Further investigation and material characterizations are necessary to understand the ion beam induced radiation damage in the long-standing behaviour from Al_2O_3:Cr makes it as a better choice for long term study on stability and performance.

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