SCINTILLATION SCREEN RESPONSE TO HEAVY ION IMPACT

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Abstract

For quantitative transverse ion beam profile measurement, imaging properties of scintillation screens have been investigated for the working conditions of the GSI linear accelerator. In previous studies, in the ion energy range between 4.8 and 11.4 MeV/u, the imaging properties of the screens were compared with profiles obtained using standard techniques like SEM grids and scraper. Detailed investigations with e.g. Calcium and Argon ion beams on various radiation-hard materials show that the measured beam profiles can differ from those measured with standard methods and depend on several beam and material parameters.

For the practical usage of scintillators, it is necessary to have predictions for the response of the scintillator to a given ion beam. An existing model for the light yield of scintillators for single particle irradiation has been extended to include the effect of overlapping excitation tracks.

To validate the model, dedicated measurements with homogeneous Carbon and Titanium ion beams at 11.4 MeV/u have been carried out. To understand the mechanisms, the beam flux has been varied between $5 \cdot 10^6$ and $2.6 \cdot 10^8$ particles/(ms*cm^2) and the pulse length between 5 and 0.5 ms. The results of the measurement are presented and discussed. The measured light yield can be compared to the model calculations.

INTRODUCTION

Scintillation screens are used in nearly all accelerator facilities for qualitative beam alignment, profile measurement and beam transport optimization. Further more, they will also be the first day diagnostics for the new FAIR-Project at GSI. For quantitative measurements it is necessary to understand the imaging properties of the screens in a wide range of beam conditions. One possible measurement application of scintillation screens is a pepperpot system [1]. For the conditions at the GSI universal linear accelerator UNILAC, several studies, in the energy range between 4.8 and 11.4 MeV/u, have been carried out to find a useful scintillation material which can withstand the high dose rates and to gain insight into the behaviour of the radiation-hard materials [2, 3].

As a radiation-hard material [4], ceramic Al_2O_3 showed the best performance, as a scintillator, among the investigated materials, for the conditions at the UNILAC at GSI. Further more, the studies indicated that the imaging behaviour can depend on the ion energy, ion species and observed emission wavelength [3]. Nevertheless, there are also very positive results, e.g. that the emitted scintillation light spectrum does not change significantly along the radius of the beam spot [3].

In order to have predictions for the behaviour of Al_2O_3 a model has been developed. The proposed model for the light yield of Al_2O_3 in [3] is based on model for the response of a scintillator on single charged particles [5, 6] and the radial dose distribution of the ions [7]. The model has been extended to describe an ion beam, with the overlapping excitation tracks caused by ions travelling through matter.

To validate this model, measurements of the light yield of ceramic Al_2O_3 for different beam fluxes and ion species have to be carried out. Additionally, the influence of the macro pulse length have to be investigated.

EXPERIMENTAL SETUP

In order to investigate the beam flux and pulse length dependent light yield of the Al_2O_3 screens, a new experimental setup has been build up at the materials science branch at GSI. The goal was to manipulate the arbitrary-shaped ion beam in that way, that it is possible to have a homogeneous, square-shaped ion beam on the sample.

Figure 1 shows schematically the design of the experiment. The beam comes from the right hand side, passes a current transformer, is defocussed by a quadrupole doublet and finally collimated by a slit system with horizontal and vertical plates. The fraction of the beam which hits the metal plates of the slit system is stopped inside the plate, due to the low ion energy of 11.4 MeV/u. The fraction of the beam which passes the slit system can reach the sample.

The beam flux reaching the sample is determined by the measured beam current on the metal plates of the slit system. This measurement is calibrated by inserting the Faraday-Cup into the beam line, behind the slit system. Thus, the fraction of the ion beam which passes the slit system corresponds to the current measured on the metal plates of the slit system. Additionally, the signal from the current transformer upstream the slit system can be used to cross-check the measurement with the slit system. The sample is placed on a sample holder which moves perpendicular to the ion beam and can carry 3 samples.

The scintillation light emitted by the sample is observed with a charge-coupled device (CCD) camera (AVT Stingray F033b, 8-Bit grayscale ADC) equipped with a *Linos* lens system with 25 mm focal length with a stepping-motor driven iris and focus. The camera observes the sample under a 45° angle with respect to the beam line. The optical system is able to detect light in the region be-

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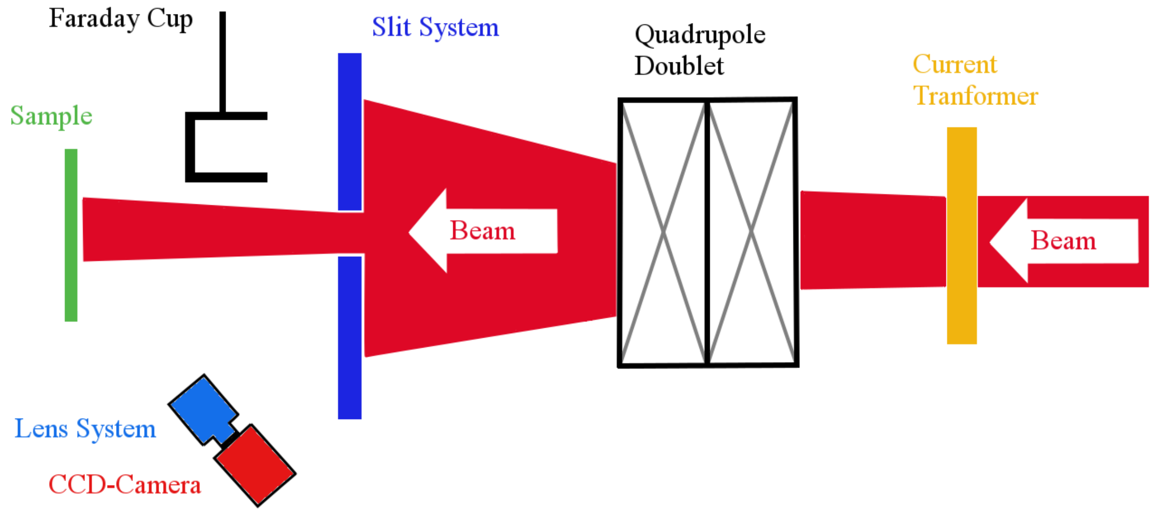

Figure 1: Schematical drawing of experimental setup, see text.

tween 380 and 700 nm. The data acquisition system allows to store the images for each macro pulse together with the number of particles which have caused the scintillation.

The sample holder is depicted in Fig. 2 with three mounted ceramic Al_2O_3 samples with 0.5 mm in thickness and 30 mm in diameter after irradiation. The samples have been produced by *BCE Special Ceramics* with a purity of better than 99.9 % (A-999). The first two samples on the left side have been irradiated with an 1 cm^2 square-shaped ^{12}C ion beam with kinetic energy of 11.4 MeV/u with varied beam flux and macro pulse length as described later. The accumulated fluence was $4.1 \cdot 10^{12}$ ions/cm^2. The third sample (Fig. 2, on the right) was used for beam alignment, the positioning of the slits and to check the homogeneity of the manipulated beam.

Thus, the setup allows to investigate three samples in one run, without breaking the vacuum. The homogeneity of the square-shaped ion beam was always better than ± 10%. The error in the determined beam flux is ± 20 %.

MEASUREMENTS WITH A HOMOGENEOUS ION BEAM

Figure 3 shows the beam flux and pulse length dependent light yield of ceramic Al_2O_3 for both ^{12}C and ^{50}Ti ion beams, with kinetic energy of 11.4 MeV/u. The ion beam was manipulated as described above, to achieve a 1 cm^2, square-shaped ion beam with a homogeneous intensity better than ± 10 %. Due to the accumulated fluence, the sample can show aging effects, which influences the light yield. To exclude the effect of ageing of the sample during the measurement in Fig. 3, separate measurements have been carried out, to determine the point of accumulated fluence were the light yield dropped by 5 % with respect to the initial value. All the measurements shown in Fig. 3 are well below this 5 % point. The accumulated fluence in Fig. 3 for Ti was $1 \cdot 10^{11}$ and for the C case $3 \cdot 10^{11}$ ions/(cm^2).

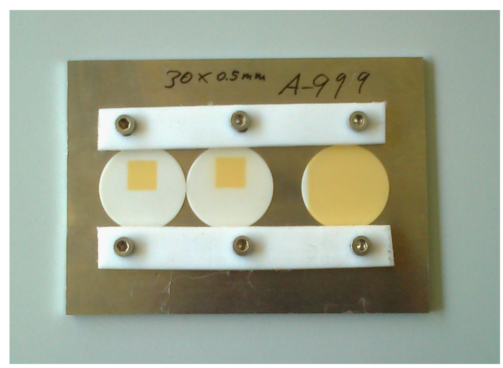

Figure 2: Sample holder with irradiated Al_2O_3 samples of 30 mm in diameter an 0.5 mm in thickness, see text.

To get a feel for the flux numbers shown in Fig. 3 one can compare them with a typical UNILAC beam. A gaussian-shaped ion beam with a sigma of 1.5 mm corresponds to about 1 cm beam diameter. Assuming that there are $5 \cdot 10^{10}$ ions within the macro pulse the maximum fluence of on macro pulse would be about $3.5 \cdot 10^9$ ions/cm^2. For a pulse length of 5 ms, the maximum flux would be $7 \cdot 10^8$ ions/(ms*cm^2). Due to the defocussing with the quadrupole doublet and the consequential beam loss on the slit system, the flux values in this experiment are lower.

The best possible result would be, when the measured points in Fig. 3 are aligned on a straight horizontal line. This would indicate that the light yield is independent of the beam flux and the pulse length. Although, it would be

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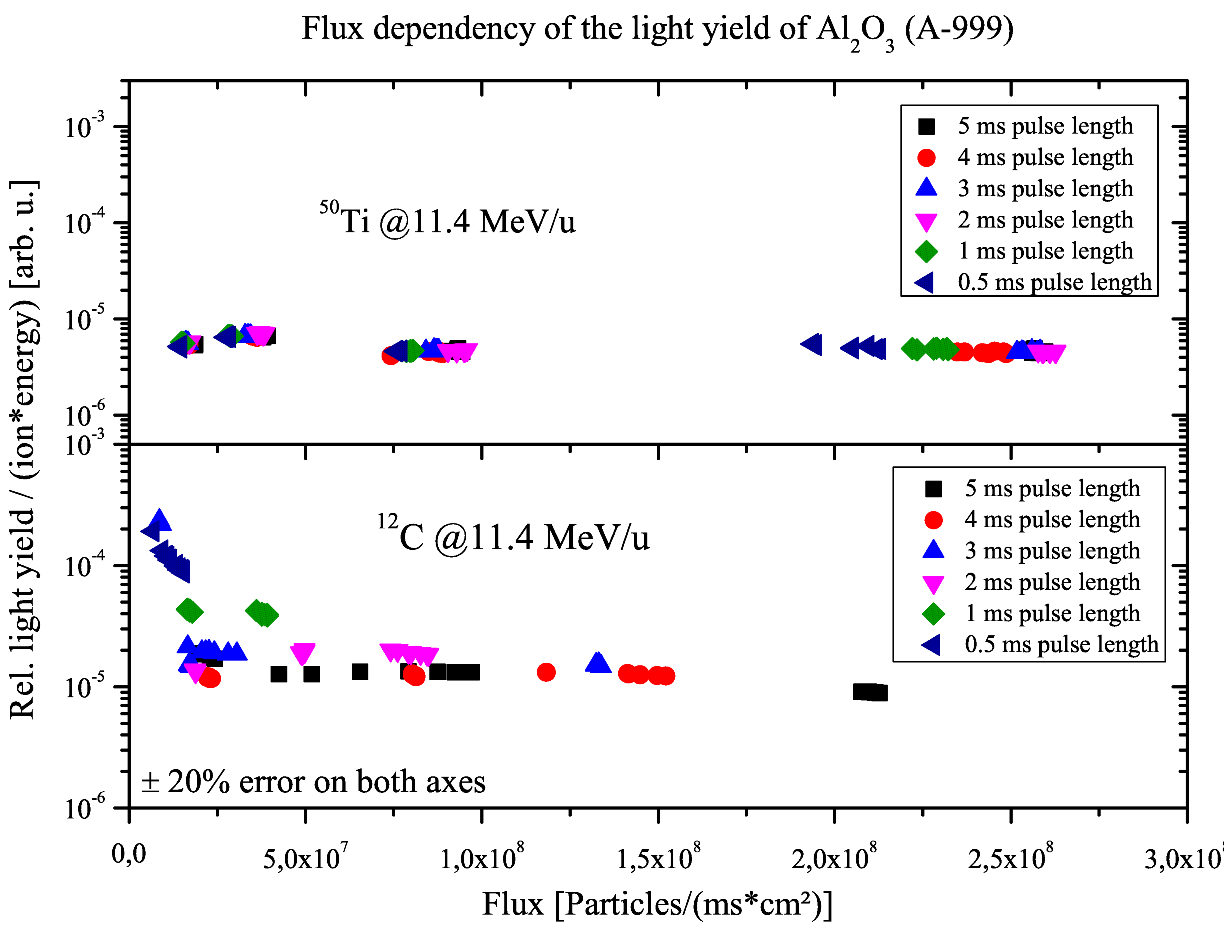

Figure 3: Flux and pulse length dependency of the light yield of Al_2O_3 ceramic screens for ^{50}Ti and ^{12}C ion beams with 11.4 MeV/u kinetic energy, macro pulse length between 5 and 0.5 ms and beam fluxes between $5 \cdot 10^6$ and $2.6 \cdot 10^8$ particles/(ms*cm^2).

expected, that there is less light yield for ions with higher nuclear charge (Z), due to the difference in the radial dose distribution along the ions path [6]. The higher Z ions have a higher stopping power (dE/dx). Due to the give ion velocity, which is the same for both Ti and C, the radial dose distribution is higher vor higher Z ions [7]. Given a higher radial dose distribution, the ligth yield should be less [6].

In the case of the Ti ion beam, one can see that the measurement indicates no significant dependency of the light yield on the beam flux or the macro pulse length, within the error.

In the case of the C ion beam, there is a tendency to higher light yield at shorter macro pulses and beam fluxes. This is behaviour not jet understood and part of current studies. Nevertheless, the slightly lower light yield for C ions with respect to Ti ions can be explained, as mentioned above, by the difference in radial dose distribution. In [6] it is proposed to use a threshold for the dose, in the radial dose distribution, which can be converted into light. All the deposited energy above this limit, would be lost in quenching processes. This results in a lower light yield for higher Z ions.

This results have to be verified by the calculated light yields from the model. The behaviour for C ions is not understood by now and has to be clarified. Further more, it would be interesting to have experimental results for the flux region which is typically used at the UNILAC, which is of the order of $7 \cdot 10^8$ particles/(ms*cm^2). This was not possible in the experiment, due to the high degree of defocussing, in order to achieve a homogeneous ion beam.

CONCLUSIONS AND OUTLOOK

The presented results for the measurements of the dependency of the light yield of ceramic Al_2O_3 on the beam flux and pulse length are the fundamental bases to understand the imaging properties of the material for the conditions at the UNILAC at GSI. Based on this measurements the proposed model in [3] can be further investigated which would be of high practical usage.

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