HIGH CURRENT ION BEAM INVESTIGATIONS ON INORGANIC SCINTILLATION SCREENS

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Abstract

At the GSI heavy ion LINAC, the properties of scintillating screens irradiated by the ion beam were studied. Different ion beams from H^+ to U^{28+} in the energy range from 4.8 to 11.4 MeV/u were used with currents up to some mA. The investigations were focused on ceramic materials. Their properties (light yield, beam width and higher statistical moments) were compared with different quartz glasses. The image of each ion beam pulse was recorded by a digital CCD camera and individually evaluated. The recorded beam width shows dependence on the used scintillator material. Additionally, the light yield and beam width depend significantly on the screen temperature. For ZrO_2 the influence of the screen temperature on the statistical moments was investigated. Furthermore, the spectra of the scintillation screens were studied in the UV-VIS region with different ion species.

INTRODUCTION

Since decades, scintillation screens are widely used for beam profile measurement in nearly all accelerator facilities. Moreover, these screens are an essential part of a pepper-pot ermittance system. The realization at GSI, as used for the high current operation of the LINAC, is described in [1]. However, there had been doubts concerning the accuracy of the pepper-pot method [2], which might be related to a possible image deformation by the scintillating screen as reported in [3, 4, 5]. The properties of the luminescent materials (see Table 1) were investigated with ion beams of H^+, C^{2+}, Ar^{10+}, Ni^{9+}, Ta^{24+} and U^{28+} at energies between 4.8 and 11.4 MeV/u and different beam currents as delivered by the LINAC. The typical size of the ion beam was σ = 2 mm. Sensitive scintillation screens, like the single crystal $YAG{:}Ce$ or $ZnS{:}Ag$, were irradiated with lower currents [4]. The ceramic materials with less light yield, like BN, ZrO_2, $ZrO_2{:}Mg$, pure Al_2O_3 and $Al_2O_3{:}Cr$ (Chromox), were investigated and compared to Quartz-glass (Herasil 102) and Quartz-glass doped with Ce (M382). The realised experimental setup and the data aquisition system are described in [4, 6]. The original image of the beam spot was projected to the horizontal and vertical plane of the beam. In this work the results for the horizontal projection are presented, but comparable results were also obtained for the vertical one. For the characterization of the distribution $p_i(x_i)$ not only the centre μ (1st moment) and standard deviation σ (2nd moment) were used, but also the skewness γ (3rd moment, parameter of the asymmetry) and the kurtosis κ (4th moment, the peakedness) [7].

Table 1: Compilation of Investigated Materials

Type	Material	Supplier
Ceramic	ZrO_2 (Z700-20A), $ZrO_2{:}Mg$ (Z507), BN, Al_2O_3, $Al_2O_3{:}Cr$,	BCE Special Ceramics
Quartz glass	Quartz ($Herasil$ 102), Quartz:Ce ($M382$)	Heraeus Quarzglas

SCREEN INVESTIGATION

The interest of pepper-pot emittance measurements arises from the UNILAC high current operation with several mA. As reported in [3, 4, 5], the imaged beam width depends significantly on the temperature of the scintillating screen. An example for high current measurement is shown in Fig.1 where the screens were irradiated by Ar^{10+} with a current of 310 μA within 100 μs delivery time corresponding to $2 \cdot 10^{10}$ ppp. The peak power was 14 kW while the average power was 3.8 W. As expected the light yield of the various materials differs by several orders of magnitude. For the four materials $Quartz{:}Ce$, $ZrO_2{:}Mg$, BN and $Herasil$ the yields dropp significantly during the irradiation. The determined beam width varies within a factor of two. The light yield decreases coincidently with the imaged beam width, but with a slightly different time constant. Since it is known that the light yield reduction is correlated with the screen temperature [3, 4, 5], a break in the beam delivery of 3 minutes was scheduled to let the screens cool down. For $Herasil$, Al_2O_3, $Al_2O_3{:}Cr$ and $ZrO_2{:}Mg$ the light yield and the beam width show reproducible time behaviour and reach a constant value. For Al_2O_3 the light yield is constant whereas for $Al_2O_3{:}Cr$ the yield even increase. In both cases, a broadening of the image width occurr in a reproducible manner. Using a PT100 temperature sensor at the backside of $ZrO_2{:}Mg$ screen the average temperature of 240°C was determined for comparable beam parameters with an average power of 2.3 W (respectively to 3.8 W for the measurements shown in Fig.1). The interpretation of the temperature behaviour is challenging. As reviewed in [8] and [9] the light yield of crystal scintillators like $NaI{:}Tl$, BGO and $CdWO_4$

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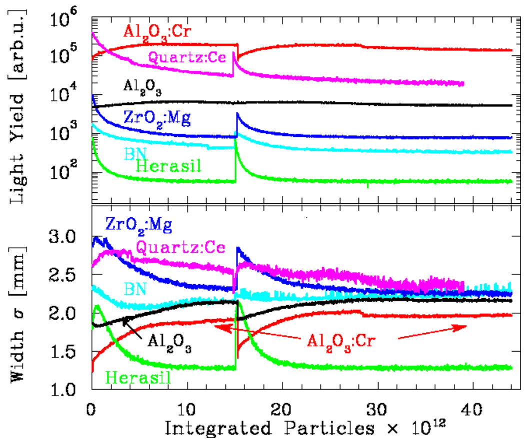

Figure 1: Light yield and beam width for different materials irradiated by 2200 macro-pulses of Ar^{10+} ions with $2 \cdot 10^{10}$ ppp, in 100 μs pulse lenght with 2.6 Hz repetition rate at 11.4 MeV/u (~300 μA). After 5 min. of irradiation, a 3 min. break was introduced to let the screen cool down, followed by 10 min. irradiation.

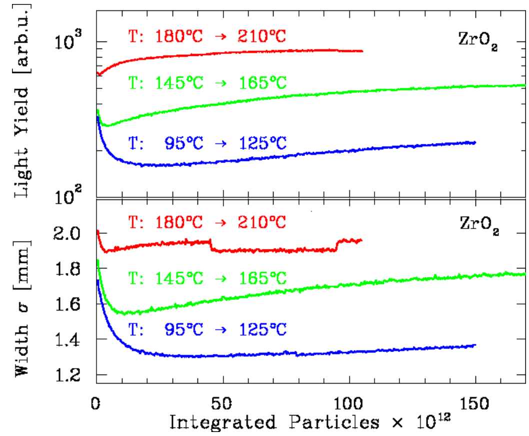

Figure 2: Light yield and beam width for ZrO_2 irradiated by 300-500 macro-pulses of 2 Hz repetition rate with $3.9 \cdot 10^{11}$ ppp H^+ in 4 ms pulse lenght at 4.8 MeV/u.

depends significantly on the temperature. After a certain (material dependent) irradiation time, a steady-state temperature distribution is reached leading in a constant yield and width reading. The equilibrium width reading differs.

For the investigation of the temperature dependence, a Ni layer (heating loop) was sputtered on the backside of ZrO_2 screen to heat the sample up to 300°C. The light yield and the beam width for ZrO_2 with three different heating levels are shown in Fig.2. The sample was irradiated by a proton beam with $3.9 \cdot 10^{11}$ ppp within 4 ms beam delivery and a repetition rate of 2 Hz, corresponding to a peak power of 75 W and an average power of 600 mW. The heating power was kept constant for each curve but the sample was additionally heated by the ion beam. Thus, the temperature on the backside of the sample increases during the irradiation. Beside an initial phase, which is difficult to interpret, one can clearly see that the equilibrium light yied and the imaged beam width increase with the temperature. By heating up the ZrO_2 screen from room temperature to 274°C, the light yield increases by one order of magnitude. In Fig.2 the light yield is increases by a factor of 4 and the imaged beam width increases by a factor of 1.5 in the temperature range from 125°C to 210°C. These results clearly point out that the temperature of the ceramic scintillaton screens could be a critical issue, especially for high current ion beams. Further experimental results are reported in [3, 4, 5].

SPECTROSCOPIC STUDIES

The spectroscopic studies on the scintillation screens were performed with the Jobin Yvon Horiba CP140-202 spectrograph [10] and an Image Intensifier CCD Camera (ICCD). The spectra of six different scintillation screens irradiated with a Ta^{24+} and a H^+ ion beam are presented in Fig.3. The spectra are not corrected by the photocathode and the spectrometer efficiency. By comparing the luminescence spectra for the two ion species Ta^{24+} and H^+, some significant differences were observed for Al_2O_3, Al_2O_3:Cr, BN, $Herasil$ and ZrO_2. There is no change in the spectrum of ZrO_2:Mg. By comparing the spetra of pure Al_2O_3 and Al_2O_3:Cr, one can clearly see the influence of the host lattice on the band around 490 nm. The absence of the known line at about 695 nm for Al_2O_3:Cr is not explained till now. The screen temperatures are different for Ta^{24+} and H^+ during the irradiation process, which could cause a slight shift in the spectra. To investigate the influence of the screen temperature on the spectrum, temperature studies were performed, like the one for Fig.2. In Fig.4 three different heating levels were applied on the ZrO_2 scintillation screen. Starting from room temperature with no additional heating to a temperature of ~250°C. For the broad bands, a slight shift into higher wavelength during the heating process was observed. Further more, the bands around 400 nm and 725 nm are strongly effected by the increased temperature. An additional interesting observation is that there is no change in the position for the sharp line around 515 nm in the ZrO_2 spectra with H^+ ions. It turns out that the influence of the screen temperature is bigger for irradiation with H^+ than for Ta^{24+}.

MEASUREMENT RESULTS

Several scintillation materials were investigated under various beam conditions. Different readings of the imaged beam width for various materials were determined even for purpose built crystalline scintillators. These results were obtained with H^+ ions, as well as heavier elements up to U^{28+}. The observed behaviours were reproducible under different beam conditions. The influence of a chromatic abberation of the lens, as well as the light intensity on the CCD-Chip could be excluded to explain the results. Due

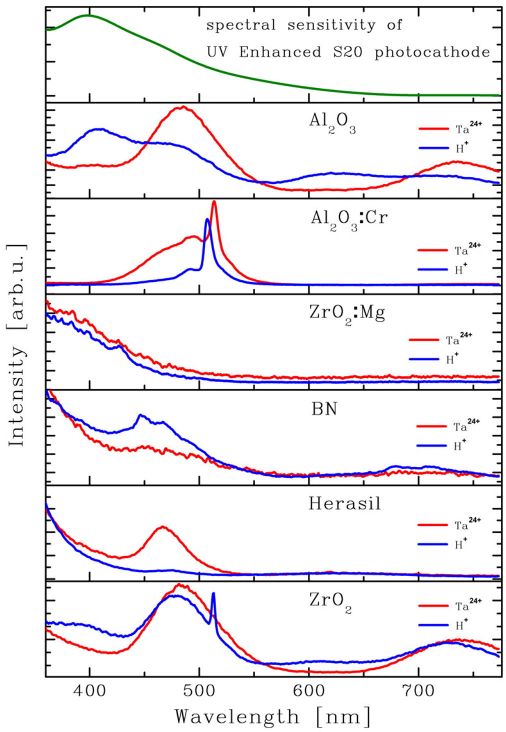

Figure 3: Spectra of the scintillators for Ta^{24+} (in red) and H^+ ions (in blue). Beam parameters for H^+: $4.1 \cdot 10^{11}$ ppp at 4.8 MeV/u, 2 ms pulse lenght, 2 Hz repetition rate. Beam parameters for Ta^{24+}: $8.8 \cdot 10^9$ ppp at 11.4 MeV/u, 100 μs pulse lenght, 1 Hz repetition rate. The spectra are averaged over about 1000 images and they are not corrected by photocathode (top) and spectrometer efficiency.

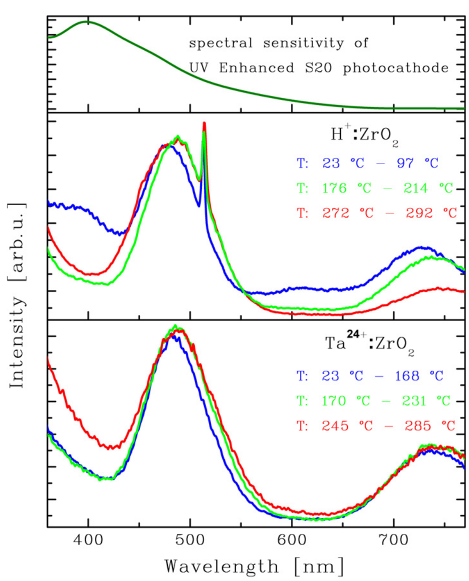

Figure 4: Spectra of ZrO_2 for irradiation with Ta^{24+} and H^+ ions for different heating levels. The beam parameters and the evaluation are the same as in Fig.3.

to the possibly high surface temperature, it is intended to introduce a filter in front of the lens, to avoid image deformation due to IR-radiation. The influence of the surface roughness and grain size has to be investigated for the ceramics. Additionally, the linearity of the investigated scintillating materials has to be determined. Further data analysis are in progress to discriminate between saturation, diffuse refraction and self-absorbtion of scintillation light using the higher statistcal moments. Additional beam-based experiments are required to distinguish between these effects.

For high current applications, the properties are influenced by the temperature of the screens, which is significantly increased during irradiation. This knowledge is essential for choosing a well-suited material for the pepper-pot emittance device. Following the high current investigations at least BN and $Quartz$:Ce can not be used due to the permanent degradation [5]. It seems that ZrO_2:Mg and $Herasil$ are good candidates for a high current application. ZrO_2:Mg has a high light yield, it does not show a significant surface modification and its spectrum shows almost no dependence on the ion species. $Herasil$ showed a narrow imaged beam width and being a transparent material the diffuse reflections at the grain boundaries are avoided, but its spectrum shows a significant change for Ta^{24+} compared to H^+. The influence of different ion energies and species on the scintillation process has to be investigated for $Herasil$, because of its transparency. In addition ion beam analysis will be carried out to clarify the open questions.

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