SCINTILLATING SCREENS STUDY FOR LEIR/LHC HEAVY ION BEAMS

C. Bal, E. Bravin, T. Lefèvre*, R. Scrivens and M. Taborelli, CERN, Geneva, Switzerland

Abstract

It has been observed on different machines that scintillating ceramic screens (like chromium doped alumina) are quickly damaged by low energy ion beams. These particles are completely stopped on the surface of the screens, inducing both a high local temperature increase and the electrical charging of the material. A study has been initiated to understand the limiting factors and the damage mechanisms. Several materials, ZrO_2, BN and Al_2O_3, have been tested at CERN on LINAC3 with 4.2MeV/u lead ions. Alumina (Al_2O_3) is used as the reference material as it is extensively used in beam imaging systems. Boron nitride (BN) has better thermal properties than Alumina and Zirconium oxide (ZrO_2). BN has in fact the advantage of increasing its electrical conductivity when heated. This contribution presents the results of the beam tests, including the post-mortem analysis of the screens and the outlook for further measurements. The strategy for the choice of the screens for the Low Energy Ion Ring (LEIR), currently under construction at CERN, is also explained.

INTRODUCTION

Luminescent screens, ceramics or crystals, have been used widely for the past 25 years for beam observation [1]. Radiation hardness was a major concern and experimental studies led to the development of special Al_2O_3 with Cr_2O_3 as a doping material, known as Chromox 6 [2]. Thermal quenching of fluorescence and the dependence of lifetime on temperature have been studied using a 30keV electron beams [3]. These effects are due to competing radiative and non-radiative decay processes, the latter increasing in probability with temperature. At CERN screens have withstood integrated proton fluxes of up to 10^{20} p/cm^2 at flux levels up to 7 10^{14} p/cm^2/pulse (~500ns). In the SLC linac [4], a phosphorescent deposition ($Gd_2O_2S:Tb$ known as P43) on a thin aluminium foil was used as a screen without any sign of damage after bombardment with 4 10^{18} e/cm^2. Chromium doped alumina has been also successfully used on 10 and 100GeV/u low intensity oxygen ion beams in injection and extraction lines of the SPS machine at CERN [5]. Some investigations were done in the following years in order to find a luminescent material with a better sensitivity [6]. Thallium doped caesium iodide was found to have a 30 times better sensitivity than chromium doped alumina. In low energy ions accelerator, profile monitoring is most of the time done using SEM grids or wire scanners. Some tests were done on low energy lead ions using Chromox [6] screens but their performances were very poor with a strong reduction of the light intensity limiting the life time of the screen to very short time periods [7]. The range of low energy ions in matter is very small, (few tens of µm), so that the ions are stopped in the screen inducing a local charging of the material and the high thermal load.

The Low Energy Ion Ring (LEIR) [8] will start operation at CERN by the end of 2005. Its main task is to prepare the ion beams to reach the required brilliance for LHC. In LEIR 4.2MeV/u ions from the LINAC3 [9] are accumulated, cooled and pre-accelerated up to 72MeV/u. They are then injected into the consecutives accelerator rings PS, SPS and finally LHC.

In 2004 a new study has been initiated with the aim of understanding the degradation mechanism of the screen and finding an alternative for the imaging system needed for the LEIR instrumentation. In this paper we present the test of different luminescent materials irradiated by 4.2MeV/u lead ions.

SETUP AT LINAC3

A sketch of the experimental set-up in LINAC3 at CERN is given in Figure 1.

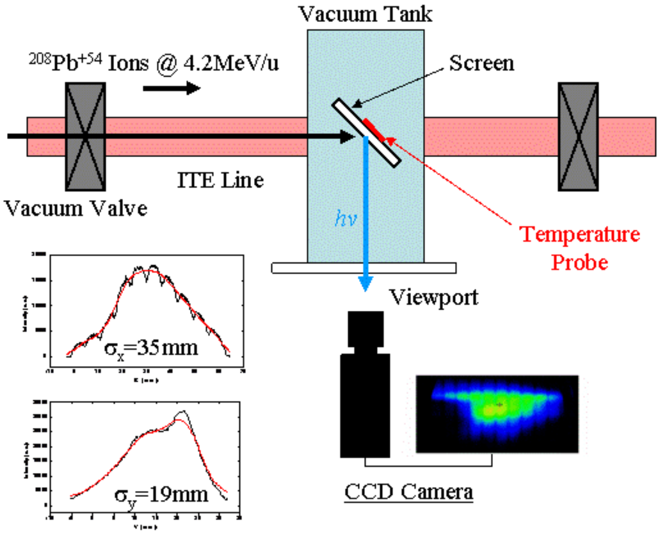

Figure 1: Set-up for the screen test in the LINAC3

The irradiation tests have been carried out in the ITE bypass line with a 100µA, 600µs lead ions beam every 1.2s. This line, normally used for emittance measurements is already equipped with a TV observation tank. The system was slightly modified in order to install 1mm thick and 50mm diameter screens. Mounted on an aluminium support the screen was tilted by 45 degrees with respect to the beam trajectory. The screen was then imaged onto a normal CCD camera using a 50mm focal length camera lens. A temperature probe was installed on the back of the screen through a hole in the support in order to monitor the temperature variations due to the beam impact.

Images were recorded digitally on a near by PC for periods spanning from a few hours to a whole night at more or less regular intervals.

The characteristic of the screens used in the test are summarized in Table 1. They were all bought from the BCE GmbH special-ceramics company in Germany [10]. Alumina was used as the reference material. The two other ceramics were chosen because they were presenting somehow better characteristics either from the thermal or electrical point of view. Boron Nitride (BN) has higher heat conductivity (k) and can be used up to 2400 ºC. Moreover with a higher specific heat (c_p), the local temperature rise would be less. On the other hand Zirconium oxide, actually worse than alumina for thermal properties, was chosen because of its electrical properties. All the ceramics are in general very good insulators at ambient temperature with resistivity (R) between 10^9 - 10^{14} Ω.cm. The resisitivity of ZrO_2 has the interesting feature of decreasing strongly with temperature. At 400 ºC, it has dropped by 5 orders of magnitude.

Table 1: Characteristics of the luminescent screens

Material	ρ (g/cm^3)	c_p at 20ºC (J/g.K)	k at 100ºC (W/m.K)	Tmax (ºC)	R at 400ºC (Ω.cm)
Al_2O_3	3.9	0.9	30	1600	10^{12}
ZrO_2	6	0.4	2	1200	10^4
BN	2	1.6	35	2400	10^9

Four different screens have been tested consecutively, one Al_2O_3, one BN and two ZrO_2 namely the Z700-20A particle reinforced and the Z500 which were corresponding to materials with two different doping and grain sizes, respectively Y_2O_3-0.7µm and MgO-50µm.

EXPERIMENTAL RESULT

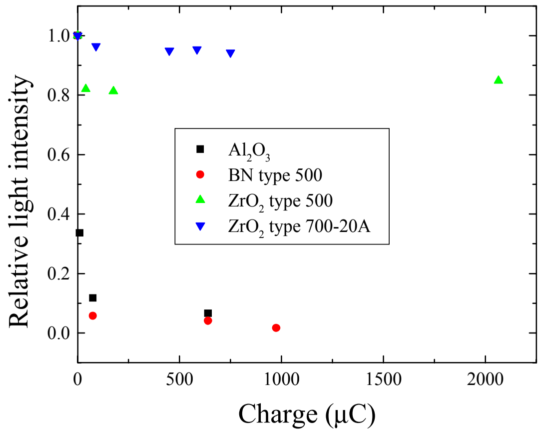

Figure 2: Luminescence yield of the different material as a function of the integrated beam charge

At the screen position, typical horizontal and vertical beam sizes were measured to be respectively 35mm and 19mm as shown in Figure 1. The relative luminescence yield was computed by integrating the pixel amplitudes over the full image. Unfortunately no absolute measurements of the light intensity were performed during this test so that the relative luminescent yield of one material with respect to the others could not be extracted from these data.

The results are depicted shown on Figure 2, plotting the light intensity as a function of the integrated beam charge irradiating the screen. In some cases, the iris of the camera lens was re-opened during the test in order to follow the decrease of the light intensity. For BN and Al_2O_3, the luminescence yield in the irradiated zone dropped rapidly to levels not observable anymore with the set-up used. For ZrO_2, it decreased only by a small fraction (10-20%) in the first minutes and remained constant at least till the end of our test.

When the screens were taking out of the vacuum tank after irradiation, the surface exposed to the beam has turned to a dark-brown coloration. This was the case for all the screens as depicted in Figure 3 with as examples BN and Z500. The coloration seemed to be even stronger for ZrO_2. This could come from the difference in the integrated irradiation time or in the temperature rise of the screen. Since ZrO_2 was performing well, it was tested twice longer than BN. Maximum temperature measured with ZrO_2 was 46°C and only 30°C with BN. Exposed to the same beam conditions, the thermal load on ZrO_2 would be higher than on BN because it has a four times lower specific heat. Moreover ZrO_2 has a factor 17.5 worse heat conductivity. It is important to remind here that the thermal probe, installed on the back side of the screen, was measuring a much lower value than the local temperature on the irradiated screen surface.

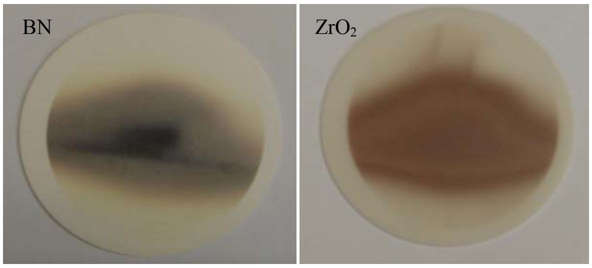

Figure 3: Pictures of the BN and Z700-20A screen after the beam irradiation

For BN heating in ultra-high-vacuum at 350°C during 1hour did not change the colour of the dark area. On the opposite side, Al_2O_3 and ZrO_2 screens were recovering their initial colour by heating the samples in air (some 100-200°C).

As a second step of the test, the screens have been analyzed using x-ray photo-electron spectroscopy (XPS) in order to check if there is any radiation induced surface modification. Both the irradiated and the non irradiated part of the screens were analyzed by the same method. The results are presented in Figure 4. Non-irradiated sides were, in general, more polluted with C and showed a higher amount of "other" contaminants than irradiated sides. The ion beam irradiation had a surface cleaning effect.

For BN, a large amount of O was found on the irradiated area. In the non-irradiated area the ratio of B to N concentration corresponds to the correct stochiometry of the compound BN, whereas in the irradiated area N has been partially replaced by O. For Al_2O_3 and ZrO_2, no noticeable difference was observed that could explain the colour of the exposed side.

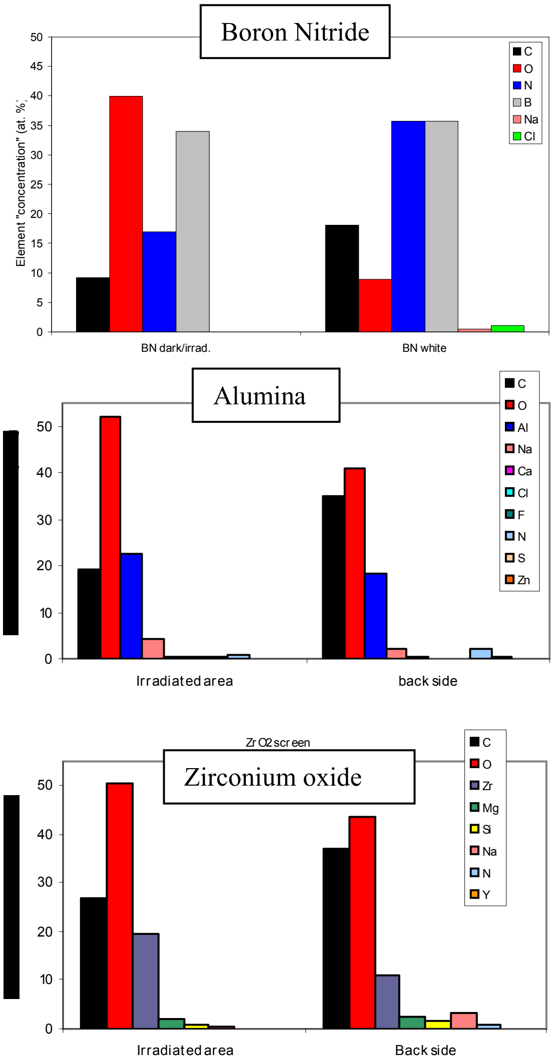

Figure 4: Analysis of the screens composition done by X-ray photo-electron spectroscopy

CONCLUSION AND PERSECTIVES

BN, Al_2O_3 and ZrO_2 screens have been irradiated by 4.2MeV/u Pb^{54+} ions (~ 3 10^{11} ions/s). The screen was imaged by a CCD camera (visible light) and the evolution of the fluorescence light intensity measured as a function of the irradiation time. For BN and Al_2O_3 the light intensity decreased rapidly to very low level making beam profiles measurement impossible. For ZrO_2 the light intensity was just reduced by 10-20% in the first minutes of the test and then remained constant. Beam profiles measurements were not altered at least during 24h conserving the same spatial resolution. The screen surface has been then characterized by XPS. After irradiation the colour of all the materials had turned to a dark-brown colour. For Al_2O_3 and ZrO_2 screens, the modifications induced by the beam were probably a chemical reduction of the oxides at a level which cannot be detected by XPS and were reversible by heating the samples in air (some 100-200°C). No mechanism has been identified so far in order to explain this colour change and the fluctuations of the luminescent yield for alumina. For BN, the colour comes from the large amount of O which has partially replaced N. The re-crystallization of BN have been already observed by others under irradiation with 8MeV protons [11] and was irreversible.

In the context of the ions program for LHC, 10 imaging systems, named MTV, will be installed in the injection line from the LINAC3 to LEIR and in the extraction line from LEIR to the PS accelerator. All the systems will be equipped with 2mm thick 80mm diameter ZrO_2 screens (Z700-20A particle reinforced). Outgasing tests have been performed and they have confirmed that ZrO_2 could be used in a high quality vacuum as foreseen on LEIR (10^{-12} Torr).

Some other tests have been already planned in parallel to the LEIR operation in order to understand the degradation mechanism. High power excimer laser irradiations will be performed with the aim of verifying the influence of a high local temperature increase on the degradation mechanism.

ACKNOWLEDGMENT

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