

PRODUCTION OF INORGANIC THIN SCINTILLATING FILMS FOR ION BEAM MONITORING DEVICES

M. Re, G.A.P. Cirrone, L. Cosentino, G. Cuttone, P. Finocchiaro, P.A. Lojaco, INFN-LNS, Via s. Sofia, 62, Catania, Italy

Y.J. Ma, CIAE, P.O.Box 275(27), Beijing, P.R. of China

P. Vynck, B. Volckaerts, M. Vervaeke, J. Van Erps, A. Hermanne, H. Thienpont, TW-TONA VUB, Pleinlaan 2, Brussels, Belgium

Abstract

In this work we present the development of beam monitoring devices consisting of thin CsI(Tl) films deposited on Aluminium support layers. The light emitted by the scintillating layer during the beam irradiation is measured by a CCD-camera. In a first prototype a thin Aluminium support layer of 6 micron allows the ion beam to easily pass through without significant energy loss and scattering effects. Therefore it turns out to be a non-destructive monitoring device to characterize on-line beam shape and beam position without interfering with the rest of the irradiation process. A second device consists of an Aluminium support layer which is thick enough to completely stop the impinging ions allowing to monitor at the same time the beam profile and the beam current intensity. Some samples have been coated by a 100 Å protective layer to prevent the film damage by atmosphere exposition. In this contribution we present our experimental results obtained by irradiating the samples with proton beams at 8.3 and 62 MeV. We also propose some innovative applications of these beam monitoring devices in different nuclear sectors such as cancer proton therapy and high intensity beam accelerators.

INTRODUCTION

Accurate beam diagnostics is one of the crucial point in many beam application facilities. The development of simple, reliable, flexible, and low cost beam monitoring devices is the appealing perspective of this research activity which was triggered by the outstanding results obtained at INFN-LNS in beam diagnostics with thick CsI:Tl plates [1]. The main advantage of beam monitoring devices based on thin scintillating films lies in the opportunity of a quick and remote readout of the basic beam parameters: intensity and shape. In addition, if the thin scintillating film is deposited on a thin support, the beam will easily pass through without significant energy loss, heat dissipation or scattering effects, therefore this device could not need to be moved off-beam during the usual beam operation. Furthermore, thin scintillating films are not affected by the electrostatic surface charge that usually occurs with thick scintillating layers during the beam irradiation.

In-situ diagnostics of the intensity, the spatial distribution and the pointing stability of high density light ion beams are appealing issues at the VUB cyclotron laboratory in Brussels [2], from the production of short-lived radio-nuclides in biomedical applications to the

fabrication of micro-optical and micro-mechanical components using Deep Lithography with Protons [3].

The EXCYT (EXotics with Cyclotron and Tandem) facility at INFN-LNS is designed to produce radioactive ion beams [4]. The diagnostic element located near the Target Ion Source will operate at 50 kV with respect to the platform, in a high-activity and high-temperature region. The installation of moving parts and/or electro-mechanically controlled devices is not recommended, and therefore the installation of passive devices, like the ones proposed here, seems to be the best solution for this application.

Low current density of 62 MeV proton beams are used in the CATANA (Centro di AdroTerapia ed Applicazioni Nucleari Avanzate) facility at INFN-LNS for the radio-therapeutic treatment of some kinds of ocular tumors, like choroidal and iris melanoma [5]. In this work we also propose a very thin scintillating device that, placed along the beam direction, allows a complete 2D reconstruction of the irradiation field during the beam treatment.

PREPARATION OF SAMPLES

The CsI:Tl film was either deposited by thermal evaporation or electron-gun bombardment at about 10^{-6} mbar. The evaporating material is prepared by compression in tablets of CsI powder doped with 0.1 to 0.3 molar % of Tl powder [6]. The employment of metallic Tl powder is to prefer compared to TII salt because of its lower vapour pressure (as compared to the CsI) that would produce unpredictable Tl concentration in the CsI:Tl films [7]. The evaporation rate of about 10 Å/s was controlled by a quartz balance. The CsI:Tl salt is simultaneously deposited on 4 different kinds of support (1 glass, 2 mirror-like Al of 1.5 mm, 1 Al layer of 6 µm) placed in a rotating carousel to ensure thickness uniformity. Supports are previously degassed at 300 °C, while the deposition process was carried out either at 300 °C or at room temperature (RT). Before starting the CsI:Tl evaporation a 400 Å fresh Al layer was deposited.

Since CsI is strongly hygroscopic, the thin scintillating layer quickly becomes opaque when exposed to the atmosphere, while its scintillating efficiency is only slightly compromised. To improve the humidity proof, a few samples have been coated by a thin protective layer of 100 Å of Si or Al, which does not affect the light transmission efficiency [8]. These layers when exposed to the atmosphere are quickly passivated by a 20 to 50 Å thin films of respectively SiO₂ and Al₂O₃ which are able

to prevent any further CsI:Tl damaging. From preliminary tests the Si coating seems to be more effective than the Al one. This is mainly due to the fact that Al_2O_3 is partially soluble in water, while SiO_2 is insoluble.

EXPERIMENTS AND RESULTS

$^1\text{H}^+$ 8.3 MeV Ion Beam Irradiation

Samples of 2 μm CsI:(0.1%)Tl layers deposited on Al support have been irradiated by an 8.3 MeV proton beam at the VUB cyclotron laboratory in Brussels. Results and comparisons with Al_2O_3 :Cr layers have been presented elsewhere [9].

The emitted light signals, originating from a scintillation film, are measured by means of a 0.5 lux sensitive CCD-camera from jAi (CV-M50) and reported in figure 1. To avoid the CCD saturation optical diaphragms were interposed, the related attenuation factors σ are reported on the figure itself.

The minimum detectable beam flux was 140 pA/mm^2 related to a released beam power density in the film of 3.2 $\mu\text{W}/\text{mm}^2$, the stopping power for this beam in CsI is 11.2 $\text{keV}/\mu\text{m}$. Light emission is quite linear up to a beam flux of about 60 nA/mm^2

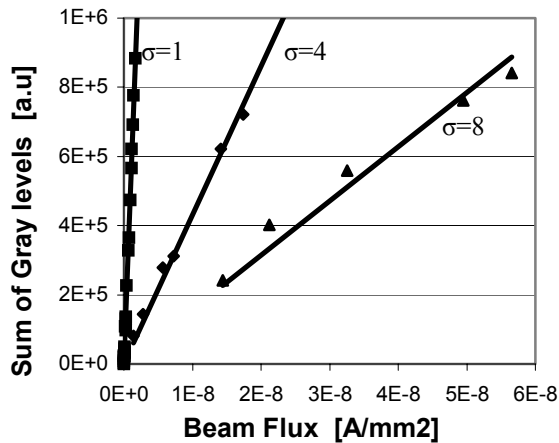


Figure 1: Light emission from a sample grown at 200°C (CsI04:(0.1%)Tl, 2 μm) versus beam flux for different optical diaphragm apertures of attenuation factor σ .

$^1\text{H}^+$ 62 MeV Ion Beam Irradiation

Some samples (as reported in table 1) have been irradiated with a 62 MeV proton beam at INFN-LNS. The emitted light was measured by means of a 0.003 lux sensitive CCD-camera from Watec (WAT-535EX).

All samples show a systematic effect of the growing temperature on the light emission yield. Literature data [10] suggest that the higher the growing temperature of the scintillating film, the higher the scintillating efficiency. On the contrary, from our experiment we can conclude that samples grown at room temperature (RT) exhibit a higher beam sensitivity in terms of light emission yield. Table 1 reports the lowest detectable beam flux and the related released energy flux in the film. A systematic behavior is recognizable: samples grown at

RT show a higher beam sensitivity up to a factor 4 - 5. The stopping power for this beam in CsI is 2.62 $\text{keV}/\mu\text{m}$.

Table 1: Lowest detectable beam flux and released energy flux for 2 μm thick samples irradiated by a 62 MeV proton beam. (Sample CsI14 is 1 μm thick)

Samples	Growing Temp. [°C]	Beam Flux [pA/mm^2]	Energy Flux [nW/mm^2]
CsI02:0.1%Tl	RT	4.2	22
CsI03:0.1%Tl	200	21	107
CsI11:0.2%Tl	300	57	297
CsI12:0.25%Tl	RT	14	74
CsI13:0.2%Tl	300	47	248
CsI14:0.2%Tl	RT	12	32
CsI15:0.3%Tl	RT	6.7	35

The irradiation process was carried out in the same conditions used in the CATANA facility for the radiotherapeutic treatment of some kinds of ocular tumors.

Before each treatment session it is necessary to check the lateral and the depth dose distribution of the proton beam in the position where the patient is located. This measurement is usually performed by means of silicon diodes that scan the proton beam in two directions. This technique, even if very practical, is very time consuming (1 to 3 minutes). In order to reduce the acquisition time a few of us [11] realized a new system based on a scintillating screen and a CCD camera. This technique is able to reconstruct a 2D dose distribution of the proton beam.

A further improvement in the proton therapy field should be the "on-line" monitoring and control of the dose distribution during the patient irradiation.

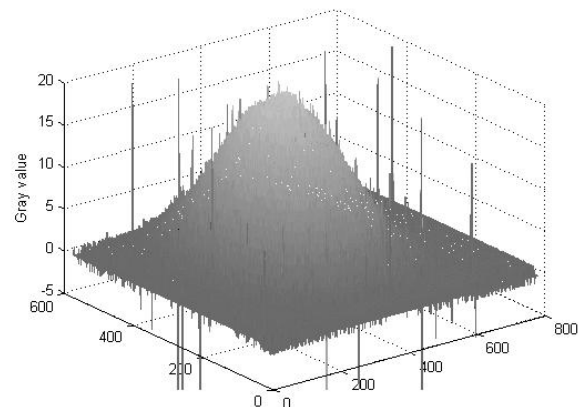


Figure 2: CCD-image of a gaussian 62 MeV beam spot (FWHM= 12 mm) on a CsI15:(0.3%)Tl 2 μm thick sample. Lateral pixel size is 37.5 μm . Background was digitally subtracted.

In figure 2 is reported the lowest detectable spot of a CsI15:(0.3%)Tl 2 μ m sample irradiated by a gaussian 62 MeV beam (FWHM= 12 mm). The average beam flux is 7 pA/mm² and the released power flux in the film is 35 nW/mm². All samples exhibit a very low light yield for the typical beam current suitable for the proton therapy (1-2 pA/mm²). Due to the very low current flux, a 20 μ m thick CsI16:(0.3%)Tl scintillating layer was deposited on Al support at RT.

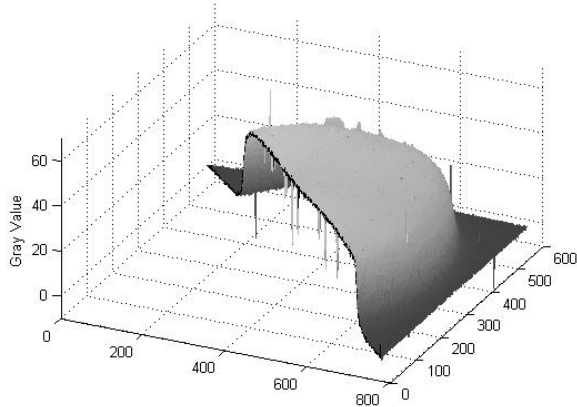


Figure 3: CCD-image of a quasi-uniform 62 MeV beam spot (\varnothing = 25 mm) on a CsI16:(0.3%)Tl 20 μ m thick sample. Lateral pixel size is 37.5 μ m. Background was digitally subtracted.

The beam suitable for the proton therapy is conformed by a stopper and a first collimator to exhibit a flat beam density profile within a diameter of 25 mm, a second collimator then is able to cut the correct shape that matches the tumour mass projection. Typical current density for the treatment is about 1.6 pA/mm². In the picture of figure 3 we show the 2D reconstruction of the light signal from the 20 μ m thick sample named CsI16:(0.3%)Tl. The beam flux is 1.63 pA/mm² and the released power flux in the film is 85 nW/mm².

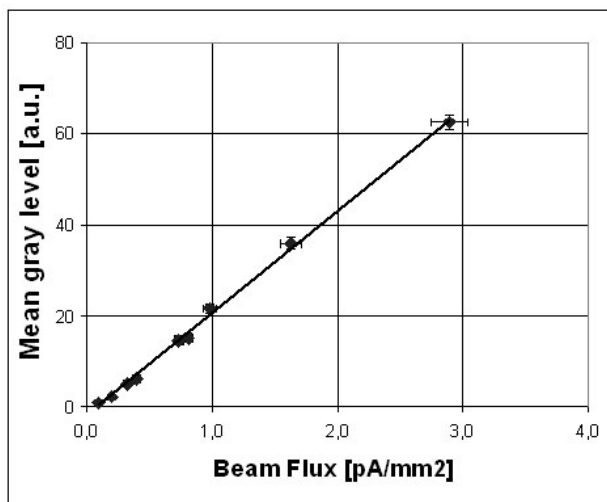


Figure 4: Average grey level from sample CsI16 with respect to the beam flux. Background was subtracted.

The profile was cut in order to highlight its cross section view. In this picture the beam uniformity was not completely achieved.

The light yield from the scintillating layer exhibits a good linear behaviour with respect to the beam flux as reported in the figure 4. The threshold for scintillation, using this light detection configuration, corresponds to a beam flux of 0.087 pA/mm², while the lowest beam flux able to generate a light signal suitable for beam characterisation is 0.200 pA/mm².

CONCLUSIONS

In this contribution we propose some application of thin scintillating films that can be produced to match the diagnostic requirements, either for low or high intensity beam and on thick or thin supports. Experiments show a good linear response with respect to the beam flux and from preliminary measurements a good lateral resolution of the order of hundreds of microns. Further investigation is needed to clarify the role of the growing temperature on the scintillating efficiency and a more accurate chemical and morphological characterisation of the grown layers. Furthermore we need absolute luminescence calibration for quantum efficiency determination.

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