EXPERIMENTAL COMPARISON OF PERFORMANCE OF VARIOUS FLUORESCENT SCREENS APPLIED FOR RELATIVISTIC ELECTRON/POSITRON BEAM IMAGING

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Abstract

Fluorescent screens are widely used for single-pass measurements of transverse beam profile at most of accelerator facilities. Great number of materials is now used for manufacture of fluorescent screens. The linearity, sensitivity and spatial resolution of the diagnostics depend on the choice of screen substance. We made an attempt to compare a linearity and relative light yield for few types of the fluorescent materials applied for screen manufacturing. A CCD-camera and photomultiplier tube record the light flux and 2D profile of the electron/positron beam image on the screen. Experiments were carried out with the electron/positron beam energy of 350 MeV and the beam charge of 0.1 – 100 pC.

INTRODUCTION

This paper was motivated by necessity to create a diagnostic system for the booster of NSLS-II SR source (Brookhaven, USA). Booster diagnostics [1] contains 6 fluorescent screens, which are used to close the first beam turn and to monitor the transversal dimensions and position of a beam during injection and extraction. We have chosen YAG:Ce as a material for the screens because it was used previously for the same diagnostics at NSLS [2].

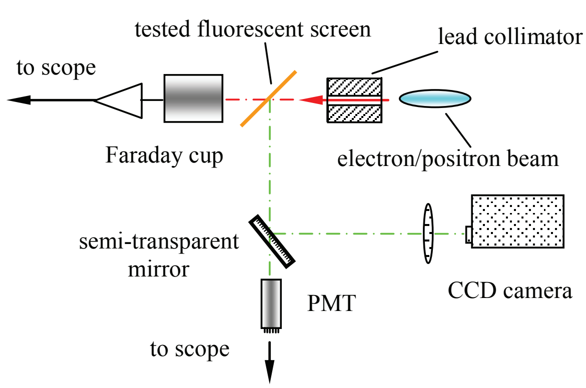

Figure 1: Experimental setup.

The thickness of the screens has been chosen to be 0.1 mm to improve spatial resolution of the diagnostics. As the light yield of the fluorescent screen is propotional to the thickness, we decided to measure this value directly, and, besides it, to compare YAG:Ce with other types of phosphors and crystals, which could be applied for the screens. At this stage of the experiments we were not interested in spatial resolution of the screens.

The measurements were done at the electron and positron beam extracted from synchrobetatron B-4M [3]. Beam energy was E=354 MeV, and duration – of about 5 nsec. The beam was extracted from B-4M through separation foil into atmosphere, passed through the examined fluorescent screen and was absorbed in Faraday cap The distance between the foil and the cup was about 30 cm. The light, emitted by the screen, was distributed by the semi-transparent mirror between the photomultiplier tube (S20 photocathode) and the triggered CCD camera (Fig. 1) equipped with SONY IAX84AL matrix.

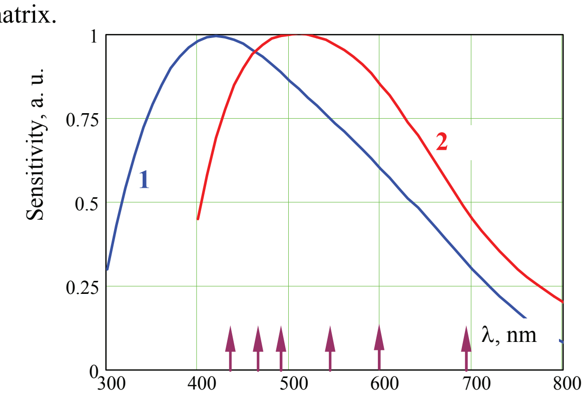

Figure 2: Spectral response of PMT (1, blue) and CCD camera (2, red). Arrows indicate wavelength of luminescence maximum of the studied materials.

Figure 2 represents spectral sensitivity of these devices. The beam diameter was cut down to 4 mm by lead collimator. Typical beam image from the CCD camera is presented in Fig. 3.

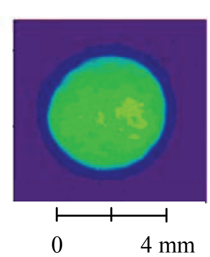

Figure 3: Typical beam image registered with CCD camera. Light intensity is represented by the colored scale

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EXPERIMENTS

Absolute Calibration of the Diagnostics

Absolute calibration of the CCD camera was done using a laser diode with a 532-nm wavelength. The laser power of 30 ± 3 mW was determined with a calorimeter. For calibration the light power was decreased by a set of certified neutral filters. The resulting light power measured by CCD was (7±3) μW. It corresponds to the total flux of $(9\pm4)\cdot10^9$ photons. These data were used to estimate light yield of the screens, but only transparency of the mirror was taken into account. The reduction of light by the lens and solid angle of light collection were not included into consideration. The latter was less than the angle of total internal reflection in crystals, aperture ratio of the lens was about 1:17.

All the following values of light yield normalized to the absolute calibration data and relates to photons with the wavelength of 532 nm

Study of the light Yield of the Phosphors

We have tested 5 types of phosphor screens (Table 1). The screens were covered with phosphor using the same technique: precipitation of powder mixed with acetone solution of silicate glue. 1-mm aluminium plates were used as a substrate. Grain size of the phosphors was about 2-3 μm.

Table 1: Phosphors, Studied in the Experiments

Phosphor	Light output colour	Timing (10%), mks
1: ZnS	Green	1250
2: Gd_2O_2S:Tb	Green	750
3: (ZnS, CdS):Ag	Green	1250
4: Y_2O_2S:Tb	Blue	1000
5: Gd_2O_2S:Eu	Red	250

Thickness of the phosphor layer was about 0.2 mm. The measurements were carried out with two specimens of each type of phosphors and the results were the same for both samples within the accuracy of the measurements. The decay curves of the phosphors are presented in Fig. 4

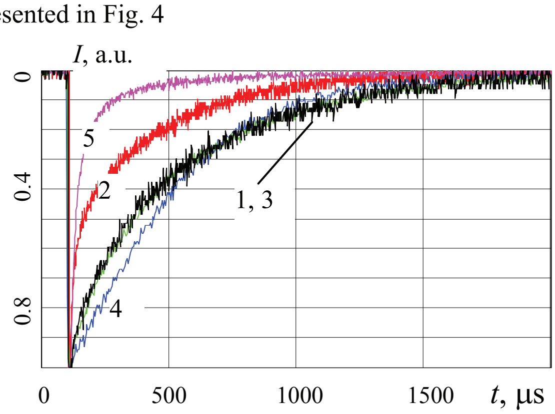

Figure 4: Temporal response of the phosphors under influence of electron beam.

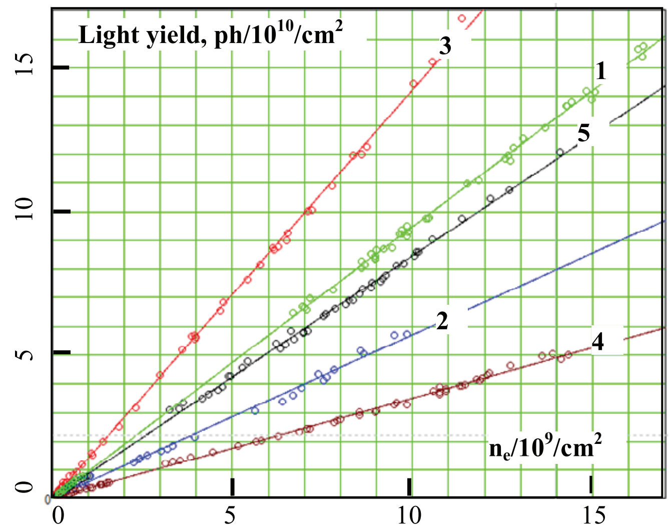

Figure 5: Light yield of the phosphors vs beam charge (CCD data). See Table 1 for key.

The best sensitivity to the influence of electron beam was demonstrated by the (ZnS, CdS):Ag screen (Fig. 5). It relates as to CCD as to PMT data. The light yield of all the phosphors was linear up to the beam density about $2\cdot10^{10}$ e^-/cm^2. We used data of PMT and CCD at low beam intensity for control of linearity and dynamic range of both devices. During increasing of beam current we decreased the light for CCD camera by neutral filters.

Study of the Light Yield of the Crystals

We have also measured the light yield of the crystals listed in Table 2. The BGO, ZWO ($ZnW0_4$), CWO ($CdWO_4$) crystals were grown in Nikolayev Institute of inorganic chemistry (Novosibirsk, Russia) [3].

Table 2: Crystals, Studied in the Experiments

Crystal	Refr. index	Hydro-scopic	Mech. properties
1: Al_2O_3:Cr	1.57 (589 nm)	No	Excellent
2: BGO	2.15	No	Good
3: $CdWO_4$	2.25	No	Satisfactory
4: $ZnW0_4$	2.1-2.2	No	Satisfactory
5: YAG:Ce	1.82	No	Excellent

Only data obtained from the CCD camera are presented in Fig. 6, because short timing of crystals did not allow distinguishing the true light registered by PMT from the bremsstrahlung influencing the signals. The presented data of light yield are normalized to 0.2 mm thickness of Al_2O_3:Cr crystal. Comparison of light yield of most bright phosphors and 3 crystals against the density of a beam charge is presented in Fig. 7. Apparently, this dependence for all samples is linear up to the density of 3 nC/cm^2 .

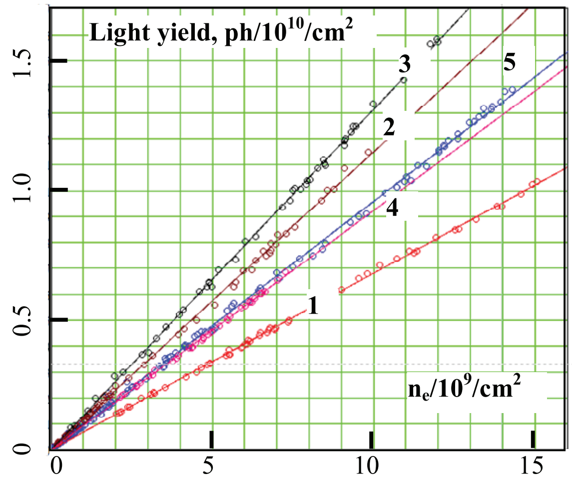

Figure 6: Light yield of the crystals vs beam charge. See Table 2 for key.

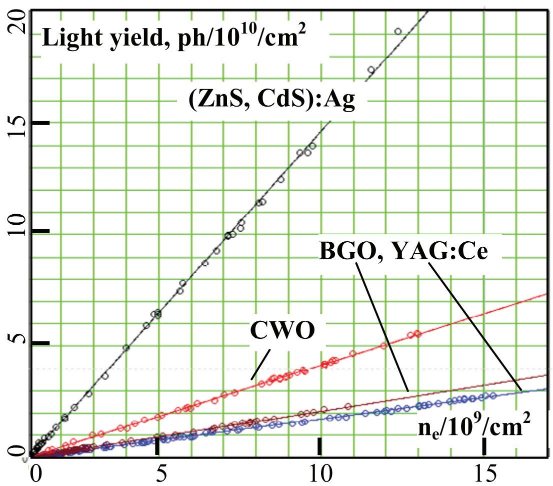

Figure 7: Comparison of the phosphors and crystals light yield.

Light Yield of Phosphor Under Positron Impact

We have also measured the light yield of the most sensitive phosphor (ZnS, CdS):Ag under the influence of positron beam (Fig. 8). Expectedly, no difference within the accuracy of the experiment was found.

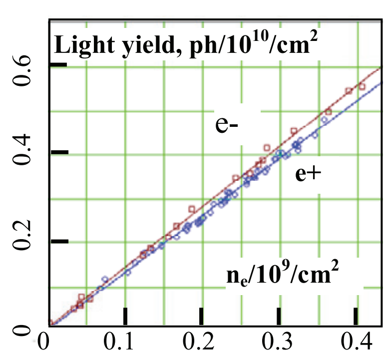

Figure 8: Comparison of light yield of phosphor under electron and positron impact.

At least, light yield of YAG:Ce and (ZnS, CdS):Ag screens was measured under electron beam extracted from VEPP-3 accelerator [4]. Beam energy was E = 1852 MeV and number of particles in bunch varied between $7{\cdot}10^9$ and $1.2{\cdot}10^{11}$. These data are presented in Fig. 9.

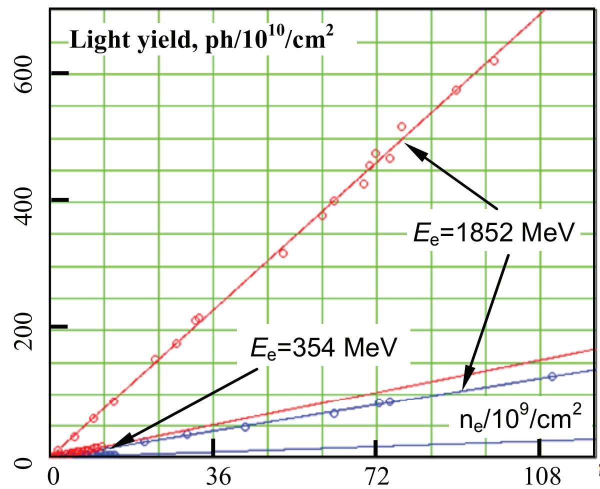

Figure 9: Light yield of (ZnS, CdS):Ag phosphor and YAG:Ce crystals under influence of electron beam with different energies.

CONCLUSION

The comparison of light yield for 5 kinds of phosphors and 5 kinds of crystals under influence of electron beam were done. The light yield of all tested materials was linear up to the beam density about 10^{11} e^-/cm^2. No signs of saturation of light yield were found.

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