INORGANIC SCINTILLATORS FOR PARTICLE BEAM PROFILE DIAGNOSTICS OF HIGHLY BRILLIANT AND HIGHLY ENERGETIC ELECTRON BEAMS

G. Kube, C. Behrens, C. Gerth, B. Schmidt, M. Yan, DESY, Hamburg, Germany
W. Lauth, Institut für Kernphysik, Mainz, Germany

Abstract

Scintillating screens are widely used for particle beam diagnostics, especially in transverse profile measurements at hadron machines and low energy electron machines where the intensity of optical transition radiation (OTR) is rather low. Their usage may serve as an alternative way to overcome limitations in OTR based beam diagnostics imposed by the influence of coherent emission. However, there is only little information about scintillator properties for applications with highly energetic electrons. Therefore, test experiments have been performed at the Mainz Microtron MAMI in order to study the screen applicability. The status of these experiments is presented and the results are discussed in view of scintillator material properties and observation geometry.

INTRODUCTION

Transverse beam profile diagnostics in electron linacs is widely based on optical transition radiation (OTR) as standard technique which is observed in backward direction when a charged particle beam crosses the boundary between two media with different dielectric properties. Unfortunately, microbunching instabilities in high–brightness electron beams of modern linac–driven free–electron lasers (FELs) can lead to coherence effects in the emission of OTR, thus rendering it impossible to obtain a direct image of the particle beam and compromising the use of OTR monitors as reliable diagnostics for transverse beam profiles. The observation of coherent OTR (COTR) has been reported in the meantime by several facilities [1, 2]. In order to allow beam profile measurements in the presence of microbunching instabilities, different monitor concepts are under consideration. One option to suppress coherence effects is to measure at smaller observation wavelengths. While Ref. [3] reports about the first beam profile imaging with transition radiation in the EUV region, possibilities to measure beam profiles with parametric X–ray radiation are discussed in Ref. [4]. An alternative concept is to use scintillation screens instead of transition radiation, especially inorganic scintillators because of their good radiation resistance, high stopping power for high light yield, and short decay times of the excited atomic levels. A comprehensive overview over scintillating screen applications in particle beam diagnostics is given in Refs. [5, 6]. While the use of screens at hadron machines is widespread, there is little information for high energy electron beam diagnostics. In order to study scintillator properties in view of high resolution beam profile monitoring, a set of test experiments has been performed at the 855 MeV beam of the Mainz Microtron MAMI (University of Mainz, Germany). First results were presented in Ref. [7], this article summarizes latest results from a measurement campaign in spring 2011.

It should be mentioned that simply the use of scintillators does not avoid contributions of COTR in beam profile monitoring. However, the description of COTR suppression schemes is beyond the scope of this article and can be studied e.g. in Refs. [8, 9].

EXPERIMENTAL SETUP

The experiment was performed at the 855 MeV electron beam of MAMI. A target holder with 6 scintillators and an OTR screen was mounted onto a goniometric stage in the test vacuum chamber. The screens were irradiated with a cw electron beam with currents between 10 pA and 50 nA. The resulting beam profiles were observed with a standard CCD camera (JAI BM-141 GE) collecting the light emitted in backward direction. Two camera positions were used for studying the influence of the observation geometry on the resolution: in geometry $\mathcal{A}$ the CCD was mounted at an angle of 22.5° with respect to the beam axis, in geometry $\mathcal{B}$ the angle amounted 90°, c.f. Fig.3. Table 1 summarizes the screen materials under investigation together with their thicknesses.

Table 1: Screen Materials and their Thicknesses

material	thickness / mm
YAG:Ce ($Y_3Al_5O_{12}$:Ce)	0.3
LuAG:Ce ($Lu_3Al_5O_{12}$:Ce)	0.3
LYSO:Ce ($Lu_{2-x}Y_xSiO_5$:Ce)	0.8; 0.5; 0.3
BGO ($Bi_4Ge_3O_{12}$)	0.3
CRY019	0.3
CRY018	0.3

CRY018 and CRY019 are scintillator trade names from Crytur [10], their chemical compositions are not published. However, according to the physical parameters CRY019 is expected to have similar properties to LYSO:Ce.

DATA TAKING AND ANALYSIS

Three series of measurements were performed: In the first measurement the spatial resolution was investigated as function of the scintillator material for 0.3 mm thick screens and observation geometry $\mathcal{A}$. The scintillators were oriented such that their surface normals coincided with the

ISBN 978-3-95450-115-1

electron beam axis, i.e. $\theta = 0°$ according to Fig. 3. The second measurement was dedicated to a study of the observation geometry influence, i.e. for selected scintillator materials, beam profiles were recorded in geometry $\mathcal{A}$ and $\mathcal{B}$. In the last measurement the influence of the scintillator thickness on the resolution was studied using LYSO screens in geometry $\mathcal{A}$ with $\theta = 0°$.

For each individual measurement 20 images were taken, with and without beam each. The mean background image was subtracted from the corresponding mean signal image to determine the background corrected profile. The projections of the resulting images were fitted in a pre–defined range with a normal distribution, and the resulting (1σ) beam sizes were taken as measure of the resolution.

RESULTS

In Fig. 1 the result of the comparative resolution study for different scintillator materials is shown. The fitted beam sizes from the scintillators are compared to each other and to the profile measured with the OTR screen. As can be

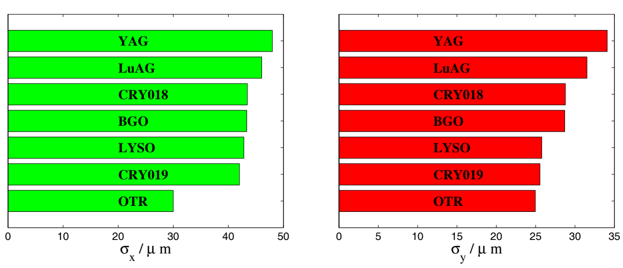

Figure 1: Horizontal (left) and vertical (right) 1σ beam sizes as measured with the 0.3 mm thick scintillators from Tab. 1 and the OTR screen in observation geometry $\mathcal{A}$.

seen the best resolution is achieved with the OTR screen followed by the CRY019/LYSO one, while YAG shows significant resolution broadening. This result confirms the measurements reported in Ref. [7] that (i) LYSO is a suitable material for beam profile measurements, and that (ii) a profile monitor with a YAG screen – even it is very popular for beam diagnostics – has only a moderate resolution. It is obvious that the horizontal resolution broadening from the scintillators with respect to the OTR screen is more pronounced than for the vertical one. This discrepancy reflects the dependency of the resolution on the observation geometry. While the OTR generation is a pure surface effect in the sense that the incoming particle field is reflected at the metallic screen surface, the generation of scintillation light is a volume effect, i.e. in first order the light source inside the scintillator can be represented by an isotropically emitting line source with an axis determined by the electron beam axis. The increased horizontal resolution reflects the fact that the observation axis has an inclination angle of 22.5° in the horizontal plane for geometry $\mathcal{A}$ with respect to the axis of the light source.

In the next step the influence of the observation geometry on the horizontal resolution was investigated in detail. As

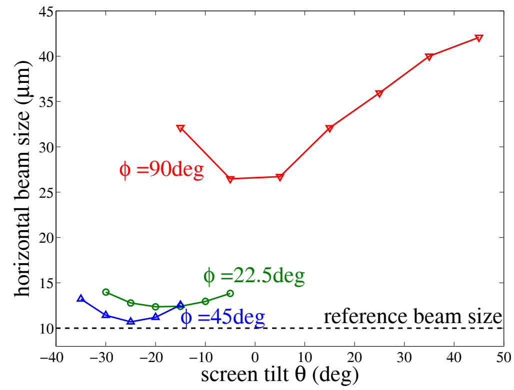

Figure 2: Simulated horizontal beam sizes as measured from a BGO scintillator for different observation geometries [11]. $\Phi = 22.5°$ corresponds to observation geometry $\mathcal{A}$, 90° to geometry $\mathcal{B}$, and 45° to a geometry which will be used for the screen stations of the European XFEL (E–XFEL). The real beam size was assumed to $\sigma_x = 10\ \mu$m.

pointed out in Ref. [7], for a given observation geometry there exist an optimum tilt angle θ of the scintillator surface normal with respect to the beam axis. This behavior was tested and reproduced again during this measurement campaign. Another aspect was to compare the results of different observation geometries. According to the model in Ref. [7] which is based on the light emitting process as described by a line source inside the scintillator host ma-

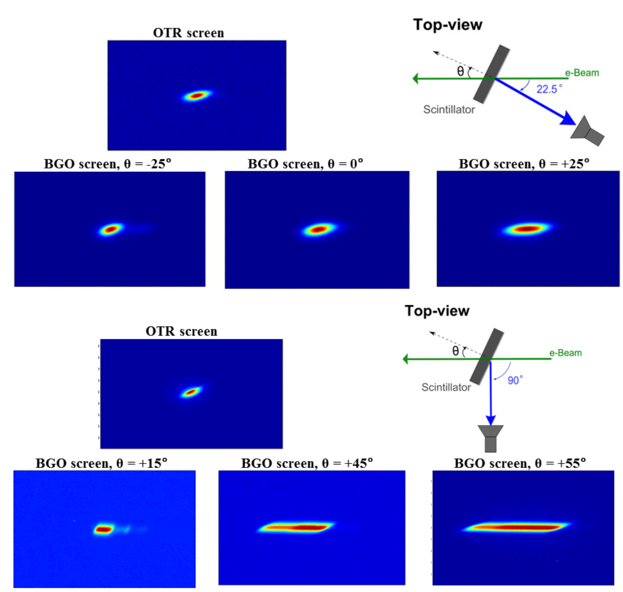

Figure 3: Beam images measured for observation geometry $\mathcal{A}$ (top) and $\mathcal{B}$ (bottom). For each geometry the beam spot from the OTR screen is shown together with 3 measured spots from the BGO scintillator. In geometry $\mathcal{A}$ the scintillator was tilted by θ = -25°, 0°, +25° (from left to right), in geometry $\mathcal{B}$ by θ = +15°, +45°, +55°.

terial (cf. previous passage), simulations have been performed with the optical ray–tracing code ZEMAX© [12] which are shown in Fig. 2. As can be seen from this figure, a drastic resolution broadening is expected for geometry $\mathcal{B}$. Fig. 3 compares measured beam spots for observation geometry $\mathcal{A}$ and $\mathcal{B}$. As can be seen from these examples, the expected resolution broadening is indeed clearly visible. It is worth noting that it will be difficult to resolve a micro–focussed beam spot in geometry $\mathcal{B}$, even it is a popular arrangement in beam diagnostics.

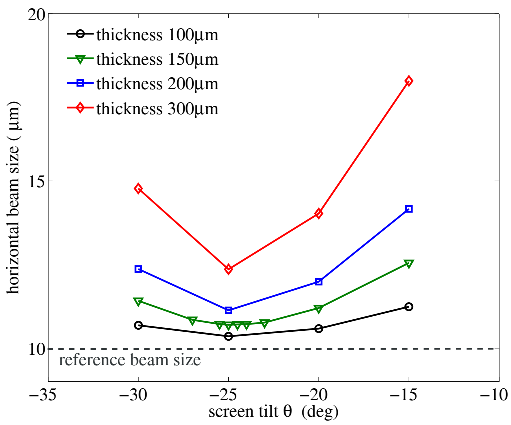

Figure 4: Simulation of the horizontal beam size as function of the screen tilt angle θ for BGO scintillators with different thicknesses in geometry $\mathcal{A}$. The real beam size was assumed to σ_x = 10 μm.

The last point of investigation was devoted to a study of the scintillator thickness influence on the achievable resolution. Fig. 4 shows the results from a simulation for horizontal beam sizes expected for BGO scintillators with thicknesses between 100 μm and 300 μm. According to this simulation the resolution strongly depends on the material thickness. However, it is interesting to note that the optimum screen tilt angle θ remains the same for a given scintillator material. For the measurement 3 LYSO screens with thicknesses between 300 μm and 800 μm were used in observation geometry $\mathcal{A}$ with $\theta = 0°$. Fig. 5 summarizes the results of this investigation. As expected, the best resolution in horizontal and vertical plane is achieved with the thinnest scintillator.

CONCLUSION

A series of test experiments has been performed to study different scintillator materials in view of high resolution profile monitoring for high energy and high brilliance electron beams. It is shown that there exist suitable materials like LYSO that experience a rather small resolution broadening similar to profile measurements with an OTR screen. However, it is not only the scintillator material but also the observation geometry which strongly influences the measured profile width. Care has to be taken to observe the scintillator surface under an angle without deteriorating

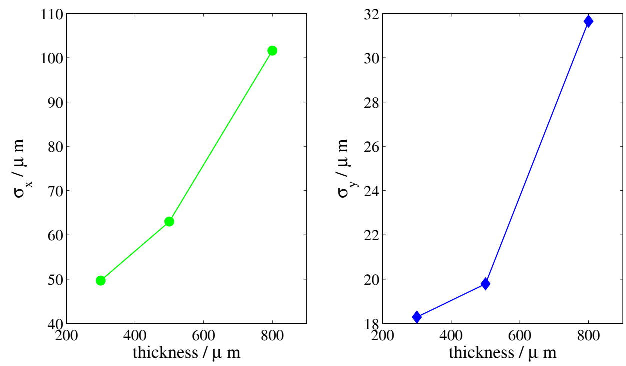

Figure 5: Measured horizontal (left) and vertical (right) beam size as function of the LYSO scintillator thickness for geometry $\mathcal{A}$ with $\theta = 0°$.

drastically the spatial resolution. In addition, the scintillator thickness affects the achievable resolution such that for high resolution measurements the scintillator should be as thin as possible.

The results of these experiments directly influenced the design of the screen stations for the European XFEL which is presently under construction at DESY. The E–XFEL will be equipped with 200 μm thick LYSO screens observed under an angle of $\Phi = 45°$ in backward direction. The scintillator surface normal is collinear to the beam axis, i.e. $\theta = 0°$ which should lead to a spatial separation from COTR eventually generated at the crystal surface. In addition, the CCD will be operated in Scheimpflug geometry to compensate the non–parallel orientation of object and image plane.

REFERENCES

[1] H. Loos *et al.*, Proc. FEL'08, Gyeongju, Korea, August 2008, THBAU01, p.485 (2008).

[2] S. Wesch and B. Schmidt, Proc. DIPAC'11, Hamburg, Germany, May 2011, WEOA01, p.539 (2011).

[3] L.G. Sukhikh, S. Bajt, G. Kube *et al.*, these proceedings, MOPPR019.

[4] A. Gogolev, A. Potylitsyn, G. Kube, J. Phys. Conference Series **357** (2011) 012018.

[5] B. Walasek–Höhne, G. Kube, Proc. DIPAC'11, Hamburg, Germany, May 2011, WEOB01, p.553 (2011).

[6] B. Walasek–Höhne *et al.*, accepted for publication in IEEE Trans. Nucl. Sci.

[7] G. Kube, C. Behrens, W. Lauth, Proc. IPAC'10, Kyoto, Japan, May 2010, MOPD088, p.906 (2010).

[8] M. Yan *et al.*, Proc. FEL'11, Shanghai, China, August 2011, THPB16 (2011).

[9] C. Behrens *et al.*, submitted to Phys. Rev. ST Accel. Beams and `http://arxiv.org/abs/1203.1169`.

[10] `http://www.crytur.cz/`

[11] M. Yan *et al.*, Proc. DIPAC'11, Hamburg, Germany, May 2011, TUPD59, p.440 (2011).

[12] `http://www.zemax.com`