Beam Profile Measurements of Intense Heavy-Ion Beams

W. Laux, P. Spiller, M. Dornik and D.H.H. Hoffmann
GSI Darmstadt and Max-Planck-Institut für Quantenoptik, Garching

Abstract

Beam profile measurements by scintillation diagnostics offer advantages in spatial and temporal resolution compared to conventional techniques like profile grids. The use of plastic scintillators offers excellent temporal resolution, but the applicability at high beam intensities is limited due to nonlinearities and radiation damage. A very promising alternative scintillation material is cerium-doped quartz glass. The scintillation efficiency is linear up to intensities of $6 \cdot 10^9$ Ne-ions/mm^2 and higher. The decay time of the light output with heavy ions was determined to 95±5 ns.

1 INTRODUCTION

The goal of our research project at GSI is the creation and diagnosis of plasmas produced by intense heavy-ion beams [1]. The high-energy heavy-ions from the synchrotron (SIS) offers unique possibilities to create plasmas with extreme densities. The potential of heavy-ions to heat matter is given by the specific energy E_s deposited in the target material. It can be calculated by

$$E_s = \frac{dE}{dx} \cdot \frac{N}{\pi\, {r_0}^2} \tag{1}$$

with $\frac{dE}{dx}$ the stopping power, N the number of ions in the pulse and $\pi\, {r_0}^2$ the sectional area of the beam at target position.

The stopping power is given by ion species, energy and target material. At a given number of ions in the synchrotron the specific energy is maximized by focusing the beam to a small spot size on the target. Currently the beam is focused with a fine focus system by conventional quadrupoles [2] down to focal spot radii of $350\,\mu$m typically. The focusing power will be further increased in near future by a plasma lens [3]. The adjustment of the fine focus system requires accurate measurements of the beam profiles at several positions upstream.

2 SCINTILLATION DIAGNOSTICS

The principle of beam profile measurements with scintillation diagnostics is simple. A scintillator is positioned in the beam and its light output is observed by a camera. The flexibility of the arrangement of scintillator and camera enables several measurements.

The transverse intensity distribution (x-y-plane) of the beam is obtained by a thin plate of scintillator. For high-energy beams it is not possible to position the camera behind the scintillator. If the scintillator plate is tilted by half of the angle camera-beam the image gives the distribution in the x-y-plane free from distortion. However, tilting the scintillator limits the spatial resolution in this dimension to $2d \sin\Theta$ with d the thickness of the scintillator and Θ the tilting angle.

The use of an thick block of scintillator observed perpendicular to the beam axis gives the beam profiles in the x-z- and y-z-plane. This measurement requires an sufficiently long range of the ions in the scintillation material. The energy loss of the ions in the scintillator has no effect on the beam envelope, because the diagnostics takes place in drift regions. The only problem of this measurement is transverse straggling. Normally this can be neglected for high-energy ions as demonstrated experimentally (s. Fig. 2).

These two measurements can also be mixed by taking simultaneously several x-y-profiles with tilted thin scintillator-plates at distinct z-positions. Here accurate measurements of the transverse beam profile are combined with informations of the beam envelope in a one-shot measurement.

3 SCINTILLATORS

In beam profile measurements the scintillator should fulfill several requirements. To enable high spatial resolution the light production should be locally and the scintillator should be free of optical scattering centers. The scintillation efficiency should remain constant up to the highest areal densities of the ions and should not decrease by radiation damage and aging. In many cases a high temporal resolution is required, this can be achieved by a scintillator with fast decay of the light output in connection with a fast gated camera.

Plastic scintillators like NE 102A offer excellent temporal resolution. But at high intensities problems arise as nonlinear light output and radiation damage by decomposition of the plastics.

In cases with somewhat relaxed requirements in temporal resolution we propose the use of cerium-doped quartz glass. The Ce^{3+} in the amorphous SiO_2-matrix exhibits intensive fluorescence at an emission wavelength of 395 nm. The material is stable up to temperatures of 1300°C and is absolutely insensitive to radiation damage because of its simple chemical structure.

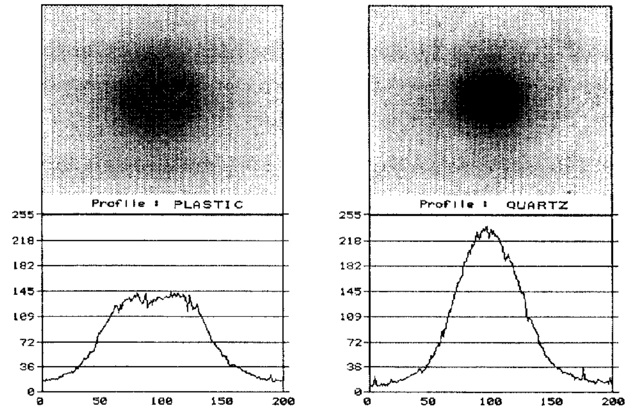

Figure 1: Transversal beam distribution in the focus of an 300 MeV/amu Ne^{10+}-beam diagnosed by plastic scintillator NE 102A (left part) and cerium-doped quartz glass (right part). The particle areal density in the center of the focal spot amounts to $6 \cdot 10^9\,\mathrm{mm}^{-2}$.

4 EXPERIMENTAL RESULTS

We tested different scintillation materials by using a focused heavy-ion beam with typical energies of 300 MeV/amu. Figure 1 shows the transversal beam distribution in the focus measured by plastic scintillator and cerium-doped quartz glass.

Evidently the plastic scintillator exhibits strong saturation of the light output at high beam intensities. The cerium-doped quartz glass shows the undistorted gaussian beam profile.

The scintillation efficiency of cerium-doped quartz glass was directly compared with plastic scintillator with an low-intensity beam of 300 MeV/amu Ne-ions. It amounts to 20 % of NE 102A.

An example of a measurement of the beam profile in the y-z-plane by scintillating glass is shown in Figure 2. Remarkable is the very low transversal scattering of the heavy ions during the decelerating process. The transversal integrated light emission (lower part of Figure 2 shows an increased scintillation efficiency with lower beam energy. The energy dependence of the scintillation efficiency is given mainly by the stopping power $\frac{dE}{dx}$. Therefore the well-known bragg peak is formed.

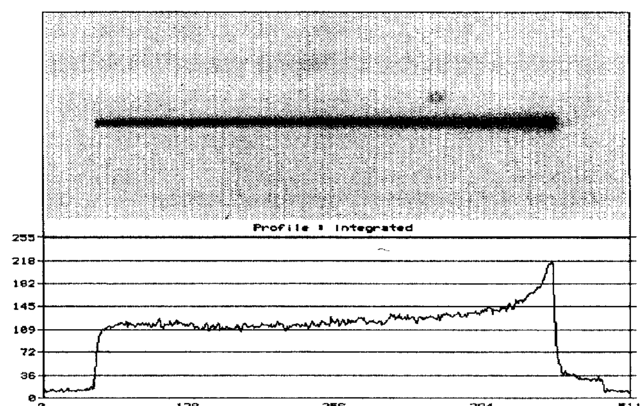

Figure 2: Focused beam of a 300 MeV/amu Ne^{10+} penetrating a block of scintillating glass and stopped after a distance of 49.5 mm.
The upper part shows the beam profile in the y-z-plane. The lower part is the transversally integrated light emission.

We determined the time-constant of the light output of cerium-doped quartz glass by measuring the spatially integrated light output at various times by a gated CCD-camera synchronized to the time structure of the bunches (jitter $< 10\,\mathrm{ns}$). These data points are fitted by the time structure of the bunches measured by a fast beam current transformer [3] and numerically filtered with a single time constant. The result is shown in Figure 3.

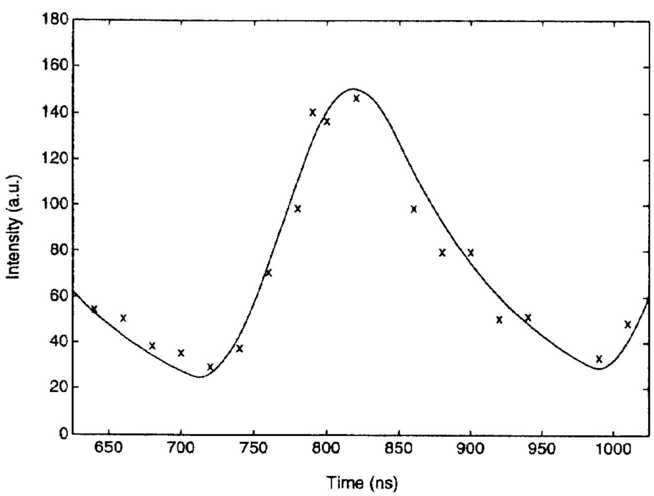

Figure 3: Spatially integrated light output of cerium-doped quartz glass irradiated by the fast extracted bunches of 300 MeV/amu Ne^{10+} (data points). The solid line shows the beam current low-pass filtered with a single time constant $\tau = 95\,\mathrm{ns}$.

The light intensity variation of the quartz glass scintillator is well fitted by a time constant of $\tau = 95\,(\pm 5)\,\mathrm{ns}$.

5 CONCLUSIONS

The temporal resolution of cerium-doped quartz glass is inferior to plastic scintillators, but still sufficient to discriminate the different SIS bunches typically 250 ns apart. The advantages of scintillation diagnostics with cerium-doped quartz glass are excellent spatial resolution, resistance to radiation damage and linear response up to highest intensities. Because of its relatively high scintillation efficiency cerium-doped quartz glass is also well suited to low-intensity beam diagnostics and should replace ceramic scintillators if high spatial resolution is required.

6 REFERENCES

[1] J. Meyer-ter-Vehn, S. Witkowski, R. Bock, D.H.H. Hoffmann, I. Hofmann, R.W. Müller, R. Arnold and P. Mulser, Phys. Fluids B **2**, 1313 (1990)

[2] B. Heimrich, H. Nestle, M. Winkler, D.H.H. Hoffmann and H. Wollnik, Nucl. Instr. and Meth. A **294**, 602 (1990)

[3] E. Boggasch, A. Tauschwitz, H. Wahl, K.-G. Dietrich, D.H.H. Hoffmann, W. Laux, M. Stetter and R. Tkotz, Appl. Phys. Lett. **60**, 2475 (1992)