PILOT STUDIES ON OPTICAL TRANSITION RADIATION IMAGING OF NON-RELATIVISTIC IONS AT GSI

B. Walasek-Höhne, C. Andre, F. Becker, P. Forck, A. Reiter, M. Schwickert
GSI Helmholtz Centre for Heavy Ion Research GmbH, Darmstadt, Germany
A. Lumpkin, Fermi National Accelerator Laboratory, USA

Abstract

The characterization of transverse ion beam profiles is an ongoing research field at GSI. Presently, beam profiles are measured with Secondary Electron eMission Grids (SEM-Grid), scintillating screens or Beam Induced Fluorescence (BIF) monitors [1]. As an alternative, the feasibility of Optical Transition Radiation (OTR) has been evaluated in this pilot study with an 11.4 MeV/u ($\beta = 0.16$) Uranium beam at GSI. The present experiment was prompted by successful measurements at the CLIC Test Facility 3 with 80 keV electrons and the feasibility study for UNILAC and SIS18 energies at GSI [2].

This pilot study aimed to find a suitable OTR target for highly-charged heavy-ions and to detect useful transverse beam profiles for the first time, taking advantage of the large ion charge.

INTRODUCTION

Optical Transition Radiation (OTR) is a classical electro-dynamic process: An ion of charge q and velocity β generates optical photons when it crosses the boundary between two media of different dielectric constants. OTR has become a popular method of beam imaging since it was first introduced in beam diagnostics applications forty years ago by Wartski [3]. There are extensive experiences with OTR imaging of relativistic electron and proton beams [4]. In these cases $\gamma >> 1$ and $\beta \sim 1$ were hold. Recent experiments on the 80 keV ($\beta = 0.63$) electron beam in the CLIC Test Facility 3 with about 10^{11} electrons in 4 ns were successful. Using an intensified CCD camera (ICCD) to acquire images of the beam spot a good linearity over a charge range from 20 to 60 nC was obtained.

Table 1: Comparison of Various Particle Beam Cases with Estimated Photon Number [2]

Particle	*E (MeV)*	*q*	*β*	*N*	*Photon number*
e	0.08	1	0.63	$4{\cdot}10^{11}$	$7{\cdot}10^{5}$
e	150	1	0.99	$6{\cdot}10^{9}$	$1.2{\cdot}10^{7}$
p	$1.2{\cdot}10^{5}$	1	0.99	$1{\cdot}10^{11}$	$1{\cdot}10^{8}$
U	$2.6{\cdot}10^{3}$	28	0.16	$1{\cdot}10^{11}$	$4{\cdot}10^{6}$

Ginzburg et al. [6] considered a non-relativistic charge q moving from vacuum to an ideal conductor with $v << c$.

For the number of emitted photons I, theory predicts the proportionality $I \propto q^2{\cdot}\beta^2{\cdot}N$ where N is the number of particles. The OTR signal of a non-relativistic ion beam has been evaluated for the first time by Lumpkin [2]. A comparison with successful non-relativistic [5] and relativistic [6] electron and proton [4] measurements is shown in Table 1. Since the ion charge state $q >> 1$ for heavy ions like U^{28+} seems to compensate for the low value β, a pilot OTR experiment was carried out at the UNILAC.

EXPERIMENTAL SETUP

The GSI linear accelerator UNILAC is designed to accelerate ions from protons to Uranium with energies up to 11.4 MeV/u. The diagnostics test bench, beam line X2, was used for OTR tests with Uranium ions.

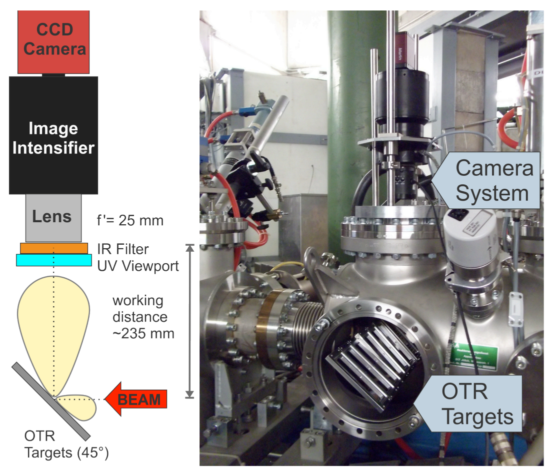

Figure 1: Scheme (left) and photo (right) of the OTR experiment at the X2 area with the OTR screen tilted 45° to the beam direction and the ICCD.

Figure 1 shows a scheme of the experimental setup consisting of the OTR targets (500 µm stainless steel and 10 µm aluminized Kapton) and imaging system.

In order to detect single photons an image intensified camera system (Proxitronic) was used. In this device the photon is converted into an electron by a Bialkali photocathode and accelerated to a double Multi Channel Plate with 10^6 fold amplification. The electrons then hit a phosphor screen to create photons again which are finally observed by a standard CCD camera (Marlin F-033b, in 8 bit b/w mode). The ICCD gating feature (down to 100 ns) was used to select preferentially the prompt OTR signal versus any background sources in the screen with a longer emission time constant e.g. blackbody radiation from the heated up screen. To image the spot on the photocathode a standard lens Pentax B2514ER with focal length f = 25 mm was used with an infrared filter KG5 to suppress signals above 850 nm.

ISBN 978-3-95450-121-2

Since the number of photons from the OTR process depends on the square of the ion charge state. A moveable 570 μg/cm^2 carbon stripping foil upstream of the target has been installed to increase the mean charge state from q = 28 to q ~ 73 and hence the expected OTR signal.

FIRST RESULTS

Signal Strength and Profile Comparison

Measurements were performed for OTR signals generated by 11.4 MeV/u Uranium beams with intensities up to $1\cdot10^{10}$ particles per pulse (ppp) for both stainless steel and aluminum foil. During initial tests, a stainless steel target showed superior thermal behavior compared to the thin aluminized Kapton target. Since measurements with a high intensity showed fast target degradation and heating problems, we reduced the beam intensity below $2\cdot10^9$ ppp to observe the OTR signal without thermal effects.

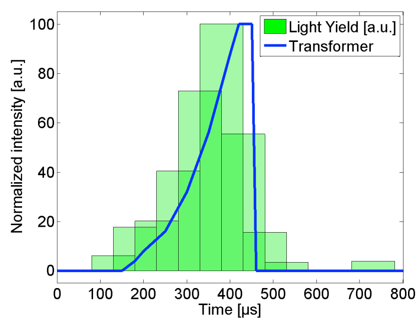

Figure 2: Time response of OTR (green) and transformer signal (blue) of a U$^{\sim73+}$ ion beam with 300 μs pulse duration. Every bar shows the OTR signal strength in a shifted 100 μs time window.

Taking advantage of prompt OTR emission and of the ICCD gating features, we could measure the OTR signal strength as a function of time and exclude possible background sources with a longer emission time as presented in Figure 2.

Figure 3 shows a typical pseudo-colour image of backward OTR from $9\cdot10^8$ U$^{\sim73+}$ ions impinging onto the stainless steel target and the chosen Region Of Interest (ROI) for future data evaluation.

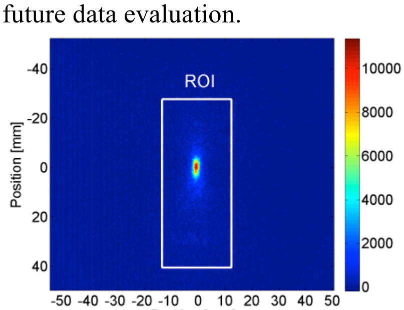

Figure 3: Pseudo-colour image of $9\cdot10^8$ non-relativistic U$^{\sim73+}$ ions averaged over 113 shots with ROI. Beam energy is 11.4 MeV/u and pulse length 300 μs.

In comparison to scintillating screens, OTR has other advantages for beam imaging. OTR has linearresponse to the incident particles without risk of saturation. In Figure 4 the integral OTR signal inside the chosen ROI, for different particle numbers per pulse is displayed. In our UNILAC studies the OTR signal shows linear behaviour with respect to the incident particle number.

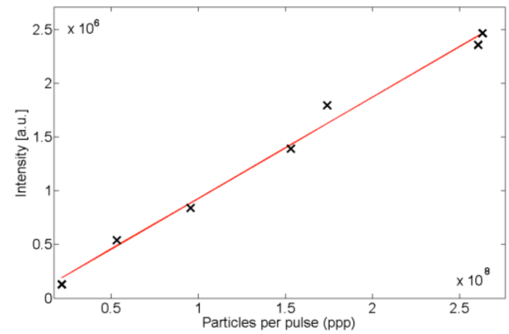

Figure 4: The OTR signal strength as a function of the particle number for the U$^{\sim73+}$ beam.

By inserting the stripping foil in front of the OTR screen, the charge state can be modified. Figure 5 shows beam distributions for two different charge states but same beam intensity of $6.7\cdot10^8$ ppp.

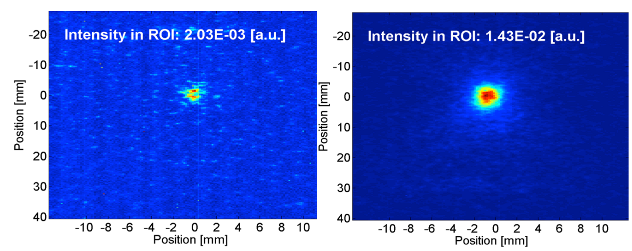

Figure 5: The OTR signal during irradiation with $6.7\cdot10^8$ Uranium ions, without stripping foil (left, U^{28+}) and with 570 μg/cm^2 carbon stripping foil (right, U$^{\sim73+}$).

The significant influence of the higher charge state is evident and the ratio of the ICCD intensities roughly supports the predicted q^2 dependence. But, one has to take into account that due to low signal strength this result is sensitive to the background level and chosen ROI.

For U$^{\sim73+}$ ions reasonable beam distributions were obtained by averaging over ~ 100 pulses down to ~$2\cdot10^7$ ppp. The resulting beam profiles for different ion beam currents are displayed in Figure 6.

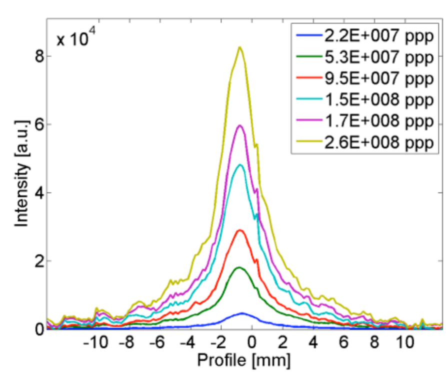

Figure 6: The horizontal projection of OTR screen images for different particles numbers.

ISBN 978-3-95450-121-2

To determine the imaging qualities of the OTR method, additional profile measurements with a SEM-Grid have been applied. As an example, the horizontal profile acquired by the OTR method compared to the SEM-Grid is presented in Figure 7. The profiles show good agreement, but the origin of the observed shoulder in the OTR profile is not yet clear and will be studied in details later.

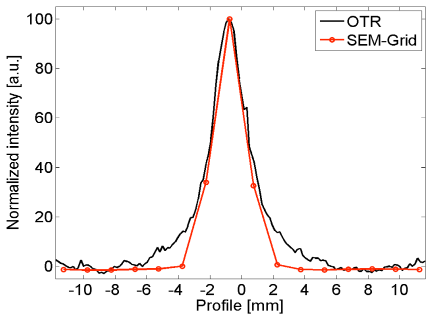

Figure 7: Comparison of the beam profile for two methods: OTR (black) and SEM-Grid (red).

Spectroscopic Studies

To clearly distinguish the OTR signal from blackbody radiation an advanced experimental setup for spectroscopic investigations has been used with the Jobin Yvon Horiba CP140-202 spectrograph and an ICCD camera system in photon counting mode.

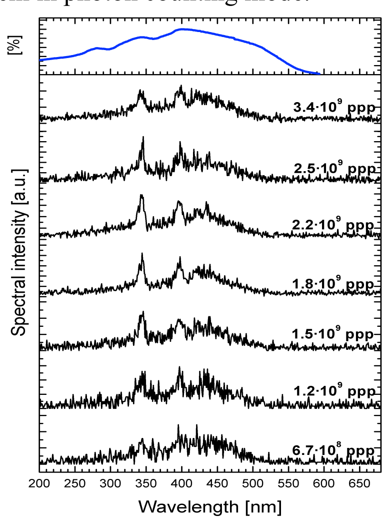

Figure 8: OTR spectra obtained for different $U^{\sim 73+}$ ion intensities, not normalized or corrected. The spectral efficiency of the Bialkali photocathode is shown on the upper graph (blue line). The spectra were recorded during ~ 500 beam pulses.

All spectra were first calibrated to a Hg-Ar standard lamp. The spectra presented in Figure 8 have not been normalized to the spectral efficiency of the optical components, which is partly given in Figure 8 as well (upper plot). The measured spectra show a broad continuum which roughly follows in intensity the efficiency of the Bialkali photocathode. The photocathode introduces also peak structures around 340 and 400 nm. As shown in Figure 8, the obtained spectra are not changing with particle number and the usage of the infrared filter as well as the photocathode significantly suppresses all wavelengths above 550 nm.

SUMMARY

Usability of the OTR method to obtain profiles of non-relativistic ion beams in the UNILAC was successfully demonstrated and first images were taken. Measurements indicate that OTR signal levels are sufficient to allow imaging at particle intensities as low as $2\cdot 10^7$ ppp. As OTR is instantaneously formed, we could measure the OTR signal strength as a function of time to exclude long emission time background sources. Additionally, we showed that the OTR signal has a linear dependency to the incident particle number. The beam profiles of SEM-Grid and OTR are in agreement with the advantage of directly obtaining a two dimensional beam shape with the OTR. By spectroscopic studies a significant contribution by blackbody radiation could be ruled out. The spectral response does not change with particle number

The next steps are to perform advanced studies on the OTR polarization effects and q^2 dependence. Additional observed shoulders in the beam profiles have to be investigated in more detail. The installation of an OTR monitor in the high energy beam transport lines is in preparation to provide the necessary data required for more intense and energetic ion beams as planned for the Facility for Antiproton and Ion Research (FAIR). The usage of OTR monitoring as a minimally intercepting method can be considered as an alternative to scintillators or BIF monitors. Since OTR is a surface phenomenon, one can use very thin aluminized Kapton (e.g. 0.1 µm Al on 6 µm Kapton), Ti foils or Al foils to reduce the ion energy loss in the OTR screen.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge members of the GSI operating team, beam diagnostic group, target and detector laboratories for their support and help before and during the experiment.

REFERENCES

[1] P. Forck, “Lecture notes on Beam Instrumentation and Diagnostics”, Joint Universities Accelerator School (JUAS 2010), http://www-bd.gsi.de.
[2] A. Lumpkin, “Feasibility of OTR imaging of non-relativistic ions at GSI”, http://www-bd.gsi.de/ssabd.
[3] L. Wartski et al., “Detection of optical transition radiation and its application to beam diagnostics” IEEE Trans. Nucl. Sci., 1973.
[4] V. E. Scarpine et al., “OTR imaging of intense 120 GeV protons in the NuMI beamline at FNAL” Proceeding of PAC 2007.
[5] C. Bal et al., “OTR from Non-relativistic Electrons” Proceeding of DIPAC 2003.
[6] V. L. Ginzburg et al., “Transition Radiation and Transition Scattering”, Adam Hilger Series on Plasma Physics, 1984.

ISBN 978-3-95450-121-2