

OPTICAL TRANSITION RADIATION FOR NON-RELATIVISTIC ION BEAMS

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Abstract

The precise transverse ion beam profile measurement is an ongoing research field at GSI. Usually 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 investigated using an 11.4 MeV/u ($\beta = 0.16$) Uranium beam at the GSI UNiversal Linear ACcelerator (UNILAC). The experiment was prompted by successful measurements at the CLIC Test Facility 3 with 80 keV electrons and a feasibility study for UNILAC and SIS18 energies at GSI.

OTR is a classical electro-dynamic process where the emitted photon number depends on the square of the ion charge state. Usage of a stripping foil during the experiment increased the mean charge state of ions, compensated the low β and allowed imaging the ion beam with an Image Intensified CCD camera (ICCD). Various experiments, using a non-relativistic beam, have been performed to estimate signal strength and evaluate the working regime of the OTR technique. The precise ICCD gating feature, as well as the emitted light spectrum, was used to distinguish the prompt OTR signal from any background sources with longer emission time constant e.g. blackbody radiation. In this contribution, the results of applying the OTR beam profile monitor technique to a non-relativistic ion beam are presented.

INTRODUCTION

Optical Transition radiation is produced by the ions of charge q and velocity β when they cross the interface of 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 [2]. There are extensive experiences with OTR imaging of relativistic electron and proton beams [3]. In these cases $\gamma \gg 1$ and $\beta \sim 1$ were hold.

Ginzburg et al. [4] considered a non-relativistic charge q moving from vacuum to an ideal conductor with $v \ll c$. 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 [5]. A comparison with successful non-relativistic [6] and relativistic [4] electron and proton [3] measurements is shown in Table 1. Since the charge state $q \gg 1$ for heavy ions like

U^{28+} seems to compensate the low value β , a pilot OTR experiment was carried out at the UNILAC.

Table 1: Comparison of Various Particle Beam Cases with Estimated Photon Number [5]

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	$1 \cdot 10^{11}$	$4 \cdot 10^6$

EXPERIMENTAL SETUP

The GSI linear accelerator UNILAC is designed to accelerate all ions from protons to Uranium with energies up to 11.4 MeV/u. For OTR tests the diagnostics test bench (beam line X2), equipped with different profile and current measurement methods, was used.

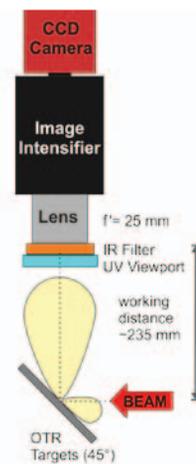


Figure 1: Scheme of the OTR experiment at the X2 area with the OTR screen tilted 45° to the beam direction and the ICCD.

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

In order to detect even single photons an image intensified camera system (ICCD from ProxiVision Company) was used where the photons are converted into electrons by a Bi-alkali 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 precise 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. To image the OTR 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.

Since the number of photons from the OTR process scales with the square of the ion charge state, a moveable $570 \mu\text{g}/\text{cm}^2$ carbon stripping foil upstream of the target has been installed to increase the Uranium ions mean charge state from $q = 28$ to $q \sim 73$ and hence the expected OTR signal.

RESULTS

Signal Strength and Profile Comparison

Measurements were performed for OTR signals generated by 11.4 MeV/u Uranium beams with intensities up to $1 \cdot 10^{10}$ particles per pulse (ppp) for both OTR targets: stainless steel and aluminized foil. During initial tests, a stainless steel target showed superior thermal stability compared to the thin aluminized Kapton target as shown in Figure 2.



Figure 2: Thin aluminized Kapton target (left) and stainless steel target (right) after irradiation with 10^{10} Uranium ions per pulse. Visible target modifications due to heating-up are observed.

Since measurements with a high intensity beam showed target degradation and heating problems, the beam intensity was reduced below $2 \cdot 10^9$ ppp to observe the OTR signal without any thermal effects.

To exclude possible background sources with a longer emission time, the ICCD was gated with 100 μs time window and shifted over whole macro-pulse. The measured OTR signal proves that only prompt emission was acquired Figure 3.

In comparison to scintillating screens, OTR has the advantage for beam imaging that it is expected to show perfect linearity to the number of 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.

By inserting a stripping foil upstream of the OTR screen, the charge state can be modified. Figure 5 shows

beam distributions for two different charge states but for the same beam intensity of $6.7 \cdot 10^8$ ppp.

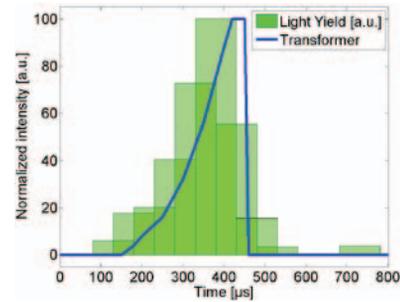


Figure 3: Time response of OTR (green) and transformer signal (blue) of an U^{-73+} ion beam with 300 μs pulse duration. Every bar shows the OTR signal strength in a shifted 100 μs time window.

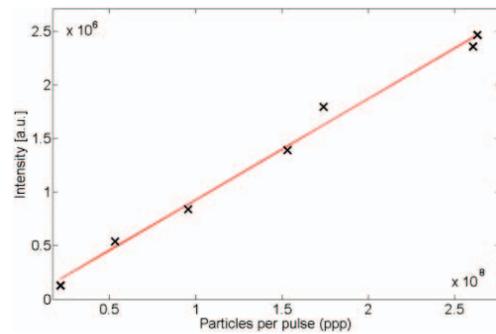


Figure 4: The OTR signal strength as a function of the particle number for the U^{-73+} beam.

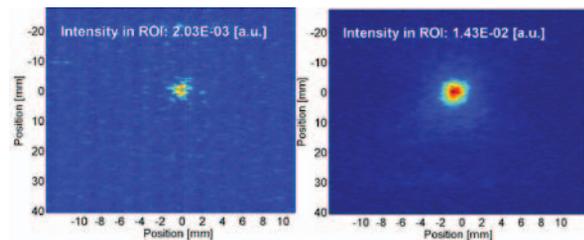


Figure 5: False colour OTR images during irradiation with $6.7 \cdot 10^8$ Uranium ions, without stripping foil (left, U^{28+}) and with $570 \mu\text{g}/\text{cm}^2$ carbon stripping foil (right, U^{-73+}). Beam energy is 11.4 MeV/u and pulse length 300 μs .

The influence of the higher charge state is significant 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.

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 6. 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.

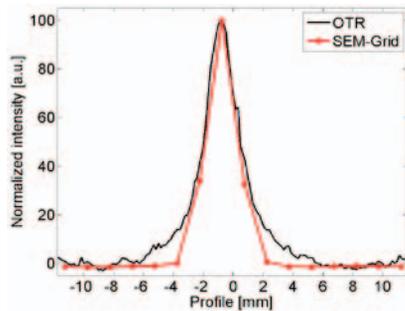


Figure 6: Comparison of the beam profile for two methods: OTR (black) and SEM-Grid (red).

Spectroscopic Studies

To clearly distinguish the OTR signal from blackbody radiation spectroscopic investigations have been performed with a Jobin Yvon Horiba CP140-202 spectrograph and an ICCD camera system in photon counting mode (Figure 7).

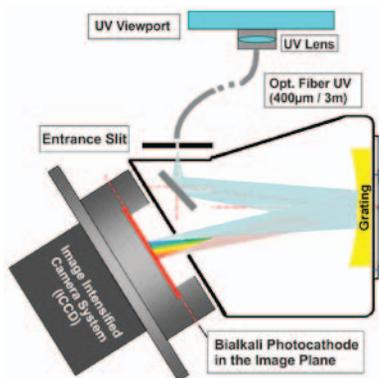


Figure 7: Scheme of the spectroscopic setup.

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 (upper plot).

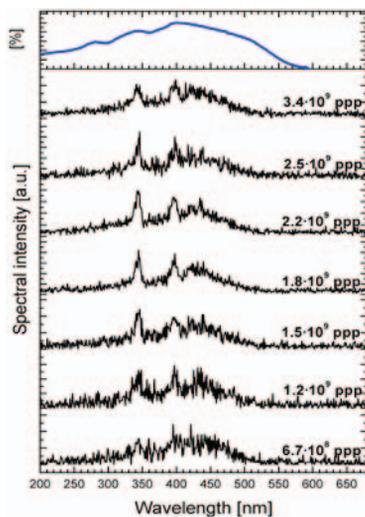


Figure 8: OTR spectra obtained for different U^{-73+} ion intensities, not normalized or corrected. The spectral efficiency of the Bialkali photocathode is shown in the upper graph (blue line). The spectra were recorded during ~ 500 beam pulses.

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 data 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 from any 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 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).

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