OTR MEASUREMENTS OF THE 10 KEV ELECTRON BEAM AT THE UNIVERSITY OF MARYLAND ELECTRON RING (UMER)*

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Abstract

We present strong evidence of the observation of optical transition radiation (OTR) from aluminized silicon targets intercepting the UMER 10 keV, 100 ns pulsed electron beam, using fast (300ps and 1ns rise time) photomultiplier tubes. An intensified gated (3ns-1ms) intensified CCD camera is used to image the beam using OTR and to study its time evolution throughout the beam pulse. A comparison of wave forms and time resolved OTR images is presented along with time integrated images obtained with phosphor screens for different initial conditions, i.e. beam currents and gun bias voltages.

INTRODUCTION

OTR is a well known diagnostic tool for high energy beams, where its directivity, promptness and sensitivity to energy and trajectory angle are exploited to measure the spatial profile, divergence and energy [1]. Although the observation of OTR at non relativistic particle energies was first reported almost 50 years ago - the first experimental confirmation of its existence [2] - it has not been widely used as a diagnostic for non relativistic particle beams. This is due to the low light yield and large angular distribution of the radiation at low energy. Nevertheless, the characteristics of OTR at non relativistic energies has been well studied and OTR imaging of an 80 keV electron beam has recently beam reported [3].

We present here experimental results which verify the observation of OTR at the 10 keV UMER facility and describe how we use OTR to produce time resolved images of the beam within the 100 ns beam pulse. We are employing OTR to study the evolution of the beam at injection and as it evolves in the ring [4].

EXPERIMENTAL METHOD

For an imaging target we employ a rotatable Silicon screen which has a 1000 angstrom Al coating on one side and a P43 phosphor deposited on the opposite side. The purpose of this dual target is to provide a basis for comparison of the standard UMER images which traditionally use slow phosphors (1.5 ms decay time) with OTR which has a sub ps response time.

Our experimental configuration is shown in Figure 1. We have the capability of observing the radiation emitted from the screen with a fast photomultiplier tube as well as a gated micro channel plate intensified CCD camera (PIMAX2).

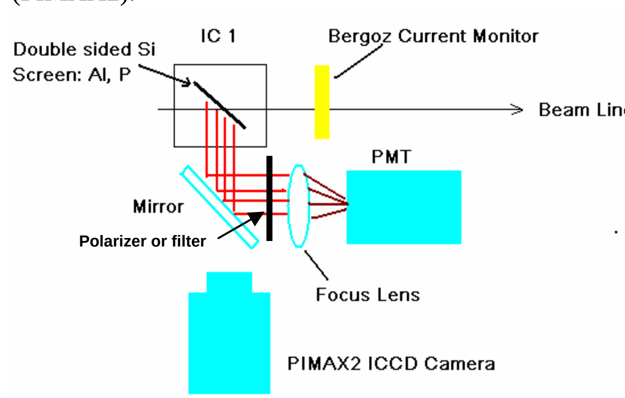

Figure 1: Experimental setup.

We image the radiation from the target with either a single lens to image the beam on the PMT or a standard macro camera lens on the ICCD camera; the focal length of both lenses is 60mm. We have the capability of introducing band pass filters or a polarizer in front of the PMT. A Bergoz current transformer, which has a response time of about 1ns, monitors the beam current when the target is removed from the system via a linear actuator.

RESULTS

OTR Verification Measurements

To verify the radiation from the Al target is OTR, we observed the radiation's, time duration, absolute yield, wavelength dependence and polarization, in much the same manner as the earliest reported studies of OTR [2].

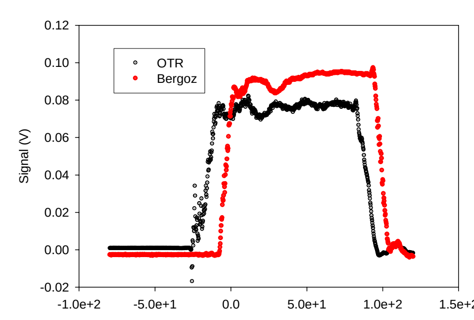

Figure 2: Comparison of PMT and Bergoz signals.

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The time histories of the current and the PMT signal are shown in Figure 2. The entire beam image is focused on the PMT's 1cm diameter photocathode. There is good agreement between the signal rise/fall times, width and shape.

The PMT signal measured as a function of charge in the UMER pulse is shown in Figure 3. The signal is very linear with the current which is exactly what OTR theory predicts in the incoherent wavelength regime, i.e. when $\lambda << \Delta\tau$, the bunch length.

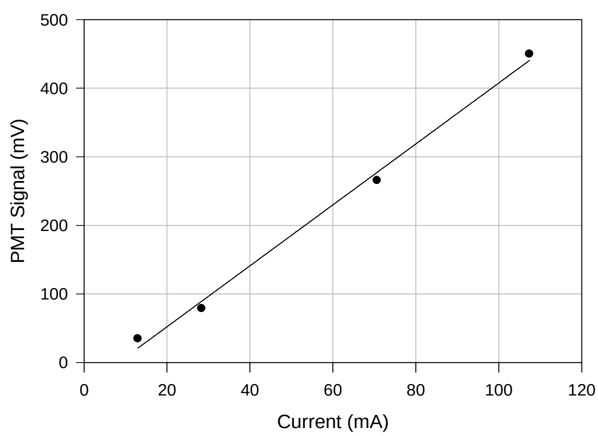

Figure 3: PMT signal as a function of beam current.

The angular distribution of OTR observed from an electron with any energy incident on an inclined perfect conductor has the following form [5]:

$$\frac{d^2W}{d\omega d\Omega}=\frac{e^2\beta^2}{4\pi^2 c}\left(\frac{\sin(\theta-2\psi)}{1+\beta\cos(\theta-2\psi)}+\frac{\sin\theta}{1-\beta\cos\theta}\right)^2 \qquad (1).$$

Here W is the energy of the radiation, ω is the angular frequency of the radiation, Ω is the solid angle, e is the charge of the electron, β is the velocity of the particle divided by c, the speed of light, θ is the observation angle in the horizontal plane formed by the velocity of the electron $\boldsymbol{V}$ and $\boldsymbol{n}$, the normal to the screen and ψ is the angle between $\boldsymbol{V}$ and $\boldsymbol{n}$.

The angular distribution is plotted in Figure 4. for the UMER beam incident on the screen for $\psi = 35$ degrees. The radiation is observed by the lens in the direction of 270 degrees. The angular field of view (FOV) subtended by the lens is ~20 degrees, which is determined by the size of the lens (60 mm) and the distance of the lens from the source (180 mm). Over this FOV the OTR intensity changes by about 30%. The polarization of the OTR will be approximately linearly within this narrow FOV and the intensity as a function of the polarizer angle will follow a squared cosine law. Figure 5. shows the measured intensity as a function of polarizer angle; the predicted squared cosine distribution is clearly observed.

Eq. 1. predicts that ΔN the number of OTR photons observed in a fractional bandwidth Δλ/λ is just proportional to this quantity. We measured the OTR intensity for five different filter band passes in the range 352-610 nm. The measured and calculated values of ΔN

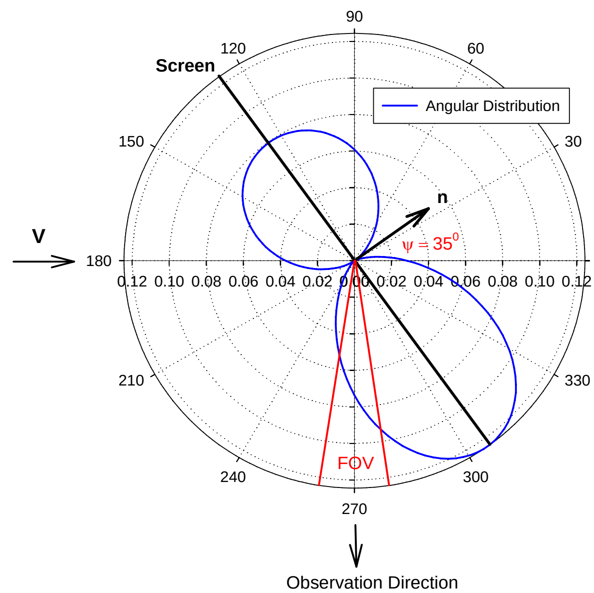

Figure 4: Theoretical angular distribution of OTR for a 10 keV (β =0.139) electron beam.

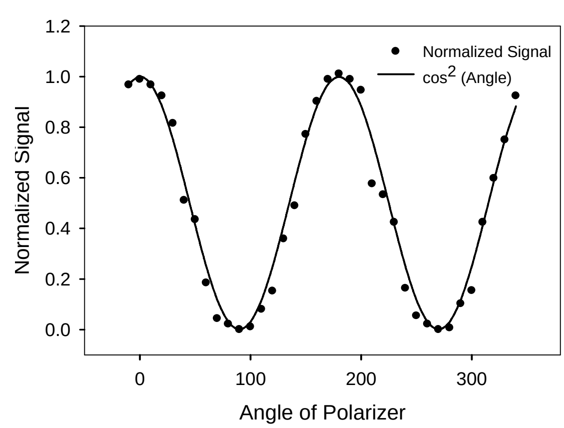

Figure 5: Radiation intensity measured as a function of polarizer angle with fit to a squared cosine distribution.

agree within factors of 2-5 over this range. In view of the uncertainties in the quantum efficiency of the PMT, the transmission and reflection coefficients of the optics and the effect of the finite large beam size (d ~ 10mm), which was not been taken into account in the theoretical calculations, the agreement between theory and experiment is quite good.

OTR - Phosphor Screen Imaging

We imaged the UMER beam using both OTR and phosphor screens. The results of our experiments are shown for a full 100ns UMER beam pulse in Figure 6.

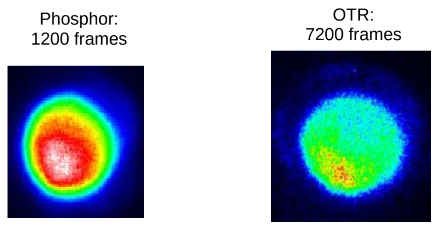

Figure 6: Comparison of phosphor screen and OTR images for a full 100 ns beam pulse; 100ns gate.

Note the factor of six increase in integration time required with the OTR screen for the same gate width (100ns).

Figure 7. shows progressive 10ns gated pictures, throughout the 100ns UMER beam pulse taken just after injection of the beam into the ring. The current was 22mA with a 30V bias on the gun grid. The pulse repetition rate is 60 Hz. The results show that the beam continuously evolves throughout the 100 ns UMER pulse. Figure 8 shows the beam evolution for a 45 V grid bias; in this case the beam exhibits a distinct halo.

CONCLUSIONS

We have shown that OTR has been observed from 10 keV electrons interacting with an Aluminized Silicon target on UMER by measuring the time history, absolute intensity as a function of wavelength, polarization within a narrow field of view and the linearity of the intensity with beam charge. The OTR observed is useful for producing fast (3-10ns) snapshots of the beam and can be used to study the evolution of the UMER beam in time and distance around the ring. However, the low light yield requires long integration times, e.g. 120 secs to capture a 10ns image of the beam using a gated intensified CCD camera.

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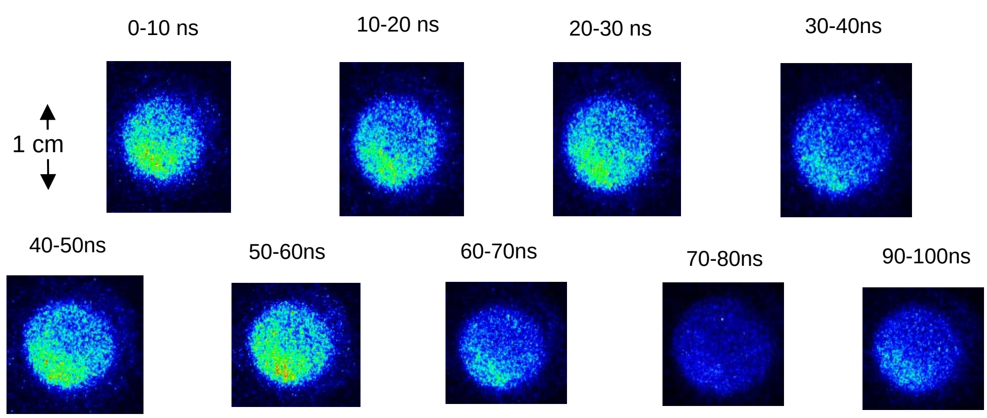

Figure 7: OTR images each taken with 7200 frames of 10ns gate duration, in progressive 10ns steps from the beginning to the end of UMER’s 100 ns pulse.

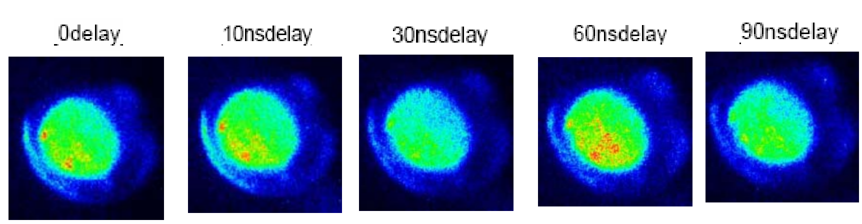

Figure 8: OTR 10ns gated images with 45 V grid bias.