

emitted by an energetic electron bunch accelerated in a laser-driven plasma wakefield

C. Palmer, L. Schaper, Plasma Accelerator Group, DESY, Hamburg, Germany (November 2013)

Introduction

Acceleration of electrons within a laser-driven plasma wakefield is a rapidly developing area of accelerator research. In this process a short duration high intensity laser is used to ionise a gaseous target. As the laser pulse propagates through the subsequent plasma electrons are displaced by the ponderomotive force, light pressure, of the laser and oscillate around their original position once the laser pulse has propagated further. This creates a perturbation in charge and therefore an electric field forming a traveling wave with phase velocity close to the speed of light, the wakefield. Here the accelerating fields are not limited by the breakdown of the vacuum as in the case of radio-frequency based accelerators because the plasma itself is used as the source of the acceleration, achieving accelerating gradients several orders of magnitude greater than accelerators depending on conventional technology. The electron bunches accelerated in this manner are characteristically short in duration (~10s fs) with charges of 10s pC, and peak energies in excess of 1 GeV (more typically 100 s MeV).

Various methods are used to characterise the electron bunches but fluctuations in experimental parameters from shot to shot mean obtaining as much information as possible within a single shot is extremely important. Transition radiation is one of the most promising diagnostics under development with this respect.

Transition radiation is emitted whenever a charged particle, or bunch of particles, transitions between regions with different dielectric constants, e.g. at the interface between two materials. The radiation is instantaneous with the same duration as the charge bunch and has a broad spectrum. For wavelength shorter than the bunch duration the radiation adds incoherently scaling in number of photons with the number of electrons within the bunch. For wavelengths longer than the bunch duration the radiation adds coherently leading to a bright signal with number of photons per wavelength interval dependent upon the form factor of the bunch, the Fourier transform of the longitudinal profile of the bunch, as well as the square of the number of accelerated electrons. Measurement of this radiation can reveal many characteristics of the particle bunch including transverse spatial profile and integrated charge, as well as, longitudinal structure and bunch duration.

Application Note

Experiment

A recent experiment, based at the Astra GEMINI facility of the Rutherford Appleton Laboratory, attempted to employ this technique to diagnose information about the energetic electron bunches accelerated from a hydrogen gas jet in collaboration with the team from Imperial College London. The dual beam Ti:sapphire laser system achieves energies of 15 J after compression to pulse lengths of 40 fs FWHM. The pulse was focused with an off-axis f/20 parabolic mirror to a focal spot of 22 microns (FWHM), leading to intensities of 1020 W/cm².

The aim of the transition radiation diagnostic was to simultaneously measure the transverse bunch profile and the spectrum of the emitted radiation. To generate the radiation a 40 micron thick piece of Aluminum foil was placed in the beam path. In addition this foil acted as a light block to prevent laser light from traveling directly down the optical path. The beam was directed to a focus at the entry slit of a spectrometer and imaged into an ICCD with x1 magnification.

For the spectroscopy a Shamrock SR-303i-A spectrograph using a 150 lines/mm grating blazed at 300 nm was employed together with a Newton CCD detector DU920N-BU2 with Back Illuminated "BU2" chip. The spectrometer covered the range 300 – 900 nm and imaged in the vertical plane. The analysis of the data is in the preliminary stages but qualitative assessment shows exciting results.

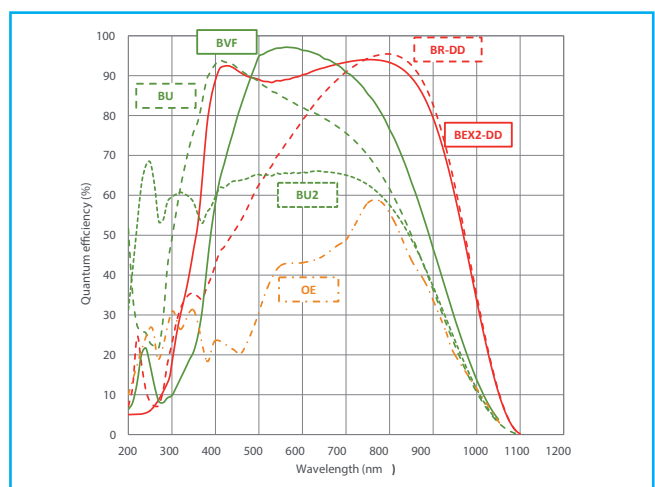


Figure 1: Quantum efficiency of the Newton CCD detector with back illuminated "BU2" sensor at +25 °C.



Spatial and spectral measurements of transition radiation

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During a laser shot on target many different sources of radiation are present. These include the laser light itself scattered from the target and vacuum chamber walls, betatron radiation from the oscillation of the electrons during acceleration, broadband self-emission from the plasma target and fluorescence from phosphor screens used in other diagnostics. Some of these sources are outside the sensitivity of the detector and can therefore be disregarded. However, others present a problem when attempting to measure the low intensity signal of transition radiation. The gating option of the Andor iStar allowed the exposure to be limited minimizing the integration of the long timescale self-emission of the plasma, and the fluorescence of the phosphor screens. Additionally the internal delay was used to allow for the camera to be simply triggered with the other long exposure diagnostics and then delayed internally until 30 microseconds before the arrival of the laser at the gaseous target.

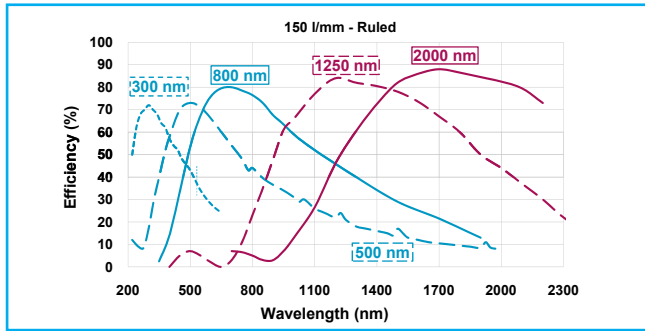


Figure 2: Efficiency of the grating 150 l/mm blazed at 300 nm within the Shamrock spectrometer.

For the imaging line an Andor iStar ICCD detector DH334T-18U-03 was employed. Since the expected ~ 10 fs bunch durations of laser-plasma acceleration would lead to the optical wavelength falling in the transitional region of the spectrum it was unknown whether the signal would be incoherent or coherent within the optical wavelength. Therefore it was possible that the signal level could have been very low. Consequently a high sensitivity detector was required. The Andor iStar provided a perfect fit for the requirements as well as a quantum efficiency increasing towards the shorter wavelength, the region in which lower signal is expected due to incoherence within the radiation and reduced transmission through the optical path. The gating options of the iStar allowed short exposure times (shortest gate width 2 ns).

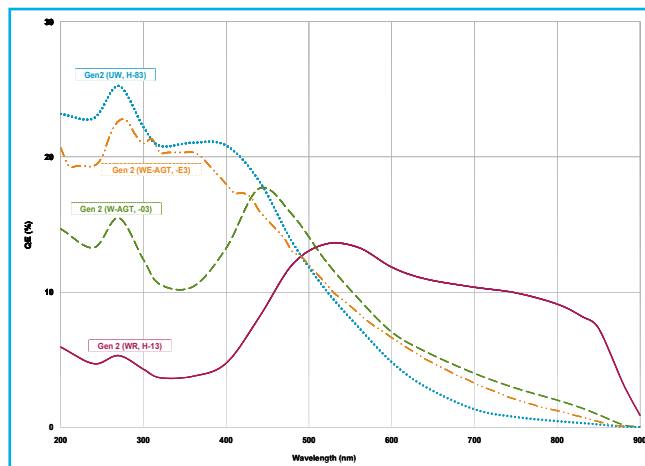


Figure 3: Quantum efficiency of the iStar ICCD detector with Generation 2 "W-AGT" photocathode.

Results

The data analysis is in the early stages of analysis and it is hoped that information about the temporal structure of the bunch and its profile can be obtained and used to learn more about the process of wakefield acceleration.

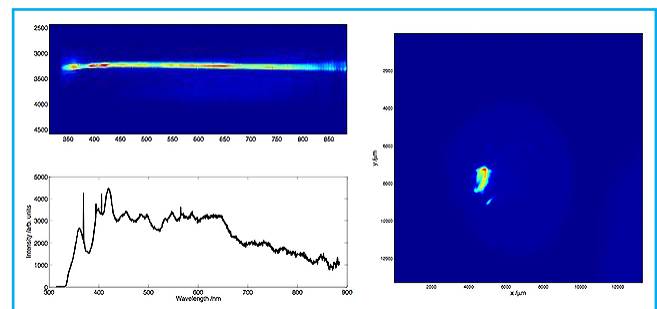


Figure 4: (Left top) Spectrum of the transition radiation dispersed horizontally, imaging in the vertical direction. (Left bottom) A horizontal lineout along the spectrum illustrating wavelength dependent intensity modulations. (Right) An image of the radiation source corresponding to the longitudinally integrated transverse electron bunch profile. The colour scale in both images is arbitrary with red regions representing high counts and blue low signal.

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