A demonstration of ultra-high time resolution with a pulse-dilation photo-multiplier

J D Hares\textsuperscript{1}, A K L Dymoke-Bradshaw\textsuperscript{1}, T J Hilsabeck\textsuperscript{2}, J D Kilkenny\textsuperscript{2}, D Morris\textsuperscript{2}, C J Horsfield\textsuperscript{3}, S G Gales\textsuperscript{3}, J Milnes\textsuperscript{4}, H W Herrmann\textsuperscript{5} and C McFee\textsuperscript{6}

\textsuperscript{1}Kentech Instruments Ltd., Wallingford, United Kingdom\textsuperscript{2}General Atomics, San Diego, California, USA\textsuperscript{3}Atomic Weapons Establishment, Aldermaston, United Kingdom\textsuperscript{4}Photek Ltd, St Leonards on Sea, United Kingdom\textsuperscript{5}Los Alamos National Laboratory, Los Alamos, NM, USA\textsuperscript{6}Sydor Instruments LLC, Rochester, New York, USA

E-mail: jdh@kentech.co.uk

Abstract. A novel microchannel plate (MCP) intensified high-speed photo-multiplier tube making use of pulse-dilation\cite{1} has been tested. A ramped photo-cathode voltage followed by a relatively long drift region results in a transit time which is dependent on the photo-electron birth time. This leads to temporal magnification or dilation, so providing an enhancement in time resolution of the optical signal with respect to the electrical signal at the output anode. By this means a time resolution on the order of picoseconds may be realized with a substantially slower oscilloscope. The photo-electron signal is guided from a photo-cathode to an MCP by an axial magnetic field and a short input record length is stretched by a factor up to 40X to yield significantly improved time resolution at the photo-cathode. Results of the first measurements are presented.

1. Motivation

Diagnosing the evolution of plasma conditions during inertial confinement fusion reactions is challenging due to the short duration of the burn. At the National Ignition Facility (NIF), implosion burn widths are typically 150 ps and are expected to drop as performance improves. For adequate characterization of the dynamics near stagnation, detectors with temporal response on the order of 10 ps are required. There are several diagnostic techniques which record optical signals derived from the imploding core plasmas. These optical signals can be recorded with traditional photo-multiplier tubes but temporal resolution is limited to around 100 ps. Streak cameras can provide the required 10 ps response time, but they suffer from poor signal-to-noise performance in the harsh radiation environment surrounding the NIF implosion.

2. Electron Pulse-dilation

The pulse-dilation technique is a method for slowing down an electronic signal using velocity dispersion of electrons in a vacuum drift tube. The technique was first demonstrated by Prosser\cite{1} in a device that was intended to slow down electrical signals so they could be recorded accurately using low bandwidth oscilloscopes. The electron velocity dispersion was created by
ramping the potential difference between the electron emitting thermionic cathode and an anode mesh. More recently, the electron dispersion tube was coupled to a photo-cathode and a gated MCP detector to achieve 5 ps gating of 2D images[2] and an x-ray imager for the NIF was developed based upon this work known as DIXI[3]. Here, we employ pulse-dilation to create a photo-multiplier tube with reduced requirements on the bandwidth of the collection anode and recording oscilloscope.

Figure 1 shows a basic layout of the device which consists of a vacuum vessel containing a transmission photocathode, anode mesh, field free drift region, microchannel plate and collection anode. The photocathode - anode mesh gap is excited by a high voltage pulser which produces the birth time dependent velocity of the photoelectrons. The microchannel plate is biased DC and provides gain for the photoelectron signal. The microchannel plate output is collected near the end of the tube and coupled to a transmission line output. An energized coil wound around the vacuum vessel produces a weak magnetic field which guides the electrons down the tube.

3. Photoelectron Accelerating Field

For a reasonably compact device, the time varying potential applied to the anode-photocathode gap must have a ramp rate of 1 kV/ns or greater. The spatial gradient associated with these short duration ramps induces a discrepancy in the transit times of photoelectrons born at the same time but at different locations on the photocathode. This effect will significantly limit the minimum achievable temporal resolution unless it is corrected. One solution for mitigating this effect is to fashion the anode-photocathode gap into a microstrip transmission line structure and launch traveling waves from opposing directions along the line. For linearly varying waves, the spatial gradients exactly cancel and the transit time discrepancy for simultaneous photoelectrons vanishes.

Unfortunately, a linear potential ramp does not produce a uniform temporal magnification of the signal and accurate reconstruction of the input signal requires precise knowledge of the relative timing between the photocathode pulse and the output signal. For example, a linear ramp which produces a temporal magnification varying between 40 and 100 over a 100 ps input interval requires timing control of 5 ps to achieve a reconstructed signal error of less than 10%. To lessen this strict timing requirement, a shaped photocathode pulse can be driven which results in a uniform temporal magnification over the recording interval. In this case, the input signal can
Figure 2. Ramp potentials applied to the anode-cathode gap. To achieve uniform temporal magnification, a shaped ramp is needed. In this experiment, a linear ramp was used which results in the temporal magnification increasing during the measurement.

be constructed by simply contracting the time axis of the output signal. However, the shaped pulse will have a spatial gradient which limits the temporal resolution to some extent. For 40X magnification, effective temporal spreads of 1, 4 and 9 ps are encountered for simultaneous photoelectrons born 10, 20 and 30 mm apart from one another. Therefore, a 10 mm diameter active area device with uniform temporal magnification and a 10 ps temporal resolution goal is achievable. A comparison of a linear and a shaped ramp is given in Figure 2.

4. Experimental Demonstration
The DIXI x-ray framing camera was modified in order to demonstrate an electron pulse-dilation photomultiplier tube. The phosphor window and CCD camera at the back end of DIXI were replaced with a simple 10 mm diameter anode which was coupled to a coaxial transmission line. A bias Tee was used to maintain the anode potential above that of the microchannel plate output in order to collect the electron signal. An input signal was derived from an EKSPLA PL2251A mode locked Nd:YAG laser operating at its fourth harmonic. A single 80 ps FWHM 266 nm laser pulse was divided with a beam splitter and each pulse was directed on to the photocathode. The pulses were spaced temporally by 160 ps by adjusting the beam paths and this temporal spacing was verified using DIXI in streak camera mode. Figure 3 shows the output signal measured on an Agilent DSO9104A 1 GHz bandwidth oscilloscope. Two pulses are clearly shown in the data with a relative temporal spacing of approximately 4 ns which demonstrates a temporal magnification of 25X. The pulse shapes in Figure 3 differ in height and width due to the non-uniform temporal magnification caused by the linear DIXI photocathode ramp.

5. Future Devices
Efforts are underway to produce a visible light sensitive device which is capable of 10 ps temporal resolution over a recording interval of 1 ns. This new tube has a 35 cm drift length and its S25 photocathode has an active diameter of 10 mm. The accelerating potential ramp is generated by a programmable waveform avalanche pulser which can be tuned to produce a uniform temporal magnification. The stretched electron signal exits the tube through a high speed anode output feed with 100 ps response time. Unlike an imaging system, only a modest magnetic field is required to prevent the drifting electrons from hitting the wall. Therefore, a DC solenoid is used which allows for repetitive operation.

A model for a 40 cm visible light sensitive pulse-dilation photo-multiplier tube is shown in
Figure 3. Oscilloscope trace clearly showing two independent pulses separated by 4 ns. The injected light pulses were spaced by 160 ps and the temporal magnification is 25.

Figure 4. Visible light sensitive pulse-dilation photo-multiplier tube. The 40 cm tube length provides 10 ps resolution over a 1 ns recording interval.

Figure 4. The main tube is stainless steel which is welded at its ends to Kovar flanges and the various tube sections are joined together with brazed ceramic insulators. We have confirmed that the disturbance to the magnetic field from Kovar joints is not a problem. Screening is used to prevent the photocathode fast ramp from coupling to the output end of the tube. The device illustrated in Figure 4 is a prototype that will be used to demonstrate the potential of high speed pulse-dilation light sensing. Future devices based on this design will be constructed for specific applications. It is envisioned that pulse-dilation photo-multiplier tubes will provide a single channel alternative to streak cameras for light detection at the picosecond time scale.

References
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