

These results apply not only for the TICM II imager: the Barr and Stroud IR18 imager uses the same SPRITE detector and analogous scanning optics, and other imagers use SPRITE and other HgCdTe detectors of various types. Thus these results are of general significance in the thermal imaging field.

The large NPL Primary Standard Blackbody covering ambient to 200 °C appears to be extremely uniform in radiance for the range of temperatures tested so far. Some faint structure may be discerned but it corresponds to an internal range of temperatures of less than 0.1 °C, within its stability, precision of setting and calibration uncertainty.

#### Acknowledgments

The authors are indebted to Mr A S Lovering for his help with the electronic modifications and to Mr O E D Josephs for working out and starting the experimental and computational work whilst he was a vacation student employee at NPL. The authors are also indebted to Messrs T R D Chandler and J W Andrews of the NPL Temperature Standards Section for the development and calibration of the Primary Standard Blackbody.

#### References

- Clarke F J J 1986 A deep focus attachment for a far-focus thermal imager system  
*Proc. SPIE* **590** 40–6
- Clarke F J J, Boyd N A and Leonard J K 1988 Design of a sample chamber for spatial emissivity measurements using thermal imaging  
*Proc. SPIE* **916** 76–82
- Clarke F J J and Larkin J A 1985 Emissivity determined from hemispherical reflectance and transmittance throughout the thermal infrared spectrum  
*High Temp.–High Pressures* **17** 89–96
- Clarke F J J and Larkin J A 1986 A thermal imaging facility for measuring the spatial distribution of the emissivity of materials *Advanced Infrared Detectors and Systems* (IEE Conf. Publ. 263) pp 60–4
- Clarke F J J and Larkin J A 1988 Improved techniques for the NPL hemispherical reflectometer  
*Proc. SPIE* **917** 7–14
- Clarke F J J and Leonard J K 1988 Development and use of a thermal imaging facility for measuring the spatial distribution of emissivity of non-uniform materials *Proc. Workshop on Optical Property Measurement Techniques* EUR 11607 EN 175–181 (Luxembourg: Commission of the European Communities)
- Cuthbertson G M and MacGregor A D 1981 High performance thermal imagers with automated display *Advanced Infrared Detectors and Systems* (IEE Conf. Publ. 204) pp 30–5
- Elliott C T 1981 The SPRITE detector *Advanced Infrared Detectors and Systems* (IEE Conf. Publ. 204) pp 1–6
- Moore W T and Reeves T C 1979 A 625 line CCIR compatible thermal imaging system *Low Light and Thermal Imaging* (IEE Conf. Publ. 173) pp 63–4

## Fast gating of a windowless dual-multichannel-plate-intensified array detector

M C Marconi<sup>†</sup>, J J Rocca<sup>†</sup> and G J Krause<sup>‡</sup>

<sup>†</sup>Electrical Engineering Department, Colorado State University, Fort Collins, CO 80523, USA

<sup>‡</sup>Directed Energy Inc., Fort Collins, CO 80526, USA

Received 17 January 1989, in final form and accepted for publication 27 April 1989

**Abstract.** Abstract. A technique for rapid gating of the gain of a windowless dual-multichannel-plate-intensified array detector is described. A DC bias applied to the plates allows effective switching of the gain with a relatively low-voltage (500 V) pulse. The pulse is generated by discharging 50 Ω transmission lines through a single fast MOSFET. The pulser characteristics and the dependence of the intensifier sensitivity on the applied voltage are discussed. The apparatus was used to obtain time-resolved extreme ultraviolet spectra with an optical aperture time of about 5 ns.

Multichannel plates (MCP) were originally developed as amplifiers for image-intensification devices and have extended their usefulness to fields like mass spectrometry, electron microscopy and spectroscopy. Their main features: high gain, low dark noise, large dynamic range and high spatial resolution, make MCP very useful devices to be used as intensifiers for solid-state array detectors. A single-multichannel-plate intensifier can achieve gains as high as  $10^4$  and this value can be increased to more than  $10^7$  with a double-plate Chevron configuration as described by Wiza (1979). Optical multichannel detectors intensified with MCP have demonstrated themselves to be a powerful tool which amalgamate the advantages of the broad spectral coverage of film spectrographs and the high sensitivity and time-resolved capability of photomultipliers. These features greatly increase the spectrographs capabilities, more significantly in experiments where low-light collection or low-intensity sources are used, or when the emission of an entire spectral region must be recorded in a single-shot experiment.

The spectroscopic study of the light emitted by a plasma permits its characterisation, allowing in many cases the determination of parameters, e.g. density, temperature and composition. The recording of time-resolved spectra permits the study of the temporal evolution of these parameters which gives information about the plasma dynamics. A convenient way to obtain such spectra is by using a multichannel-plate-intensified array detector and to gate the gain of the MCP by applying a short high-voltage pulse across the plate (Luppi *et al* 1984). This pulse switches the intensifier gain, acting as a fast shutter. Fast high-voltage pulsers for switching multichannel plates have been implemented with thyatron and spark-gap switches (Nahrath *et al* 1976) or constructing a Marx bank with transistors in avalanche (Pfeiffer and Wittmer 1982).

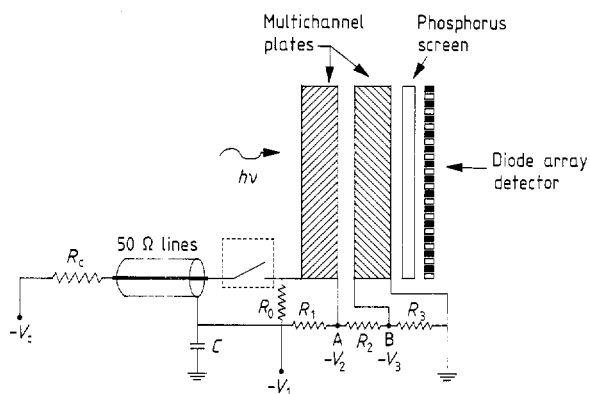
This paper discusses a simple technique and the circuit implementation that allow rapid gating of the gain of a

windowless dual-multichannel-plate array detector with relatively low-voltage (500 V) pulses. The apparatus was used to record time-resolved extreme ultraviolet (XUV) spectra with a resolution of 5 ns. The detector is similar to others previously described in the literature by Fonck *et al* (1982) and Register *et al* (1984), but with the difference that it has two stacked multichannel plates to increase the sensitivity. Our detection system is composed of two 1 inch (2.54 cm) diameter intensifier multichannel plates stacked in a Chevron configuration from Galileo Electro Optics and a 1024 diode array detector from Princeton Instruments. The front plate is funnelled and coated with copper iodide to extend the sensitivity in the VUV and XUV regions (Richards 1979). The detector is connected to a personal computer which digitises and stores the acquired data. The array detector was used in combination with a 1 m normal incidence vacuum spectrograph to study the XUV emission of dense pulsed capillary plasmas. The set-up allows the simultaneous recording of spectra within the window of the spectrograph, which for a gating of 600 lines per mm is 42 nm.

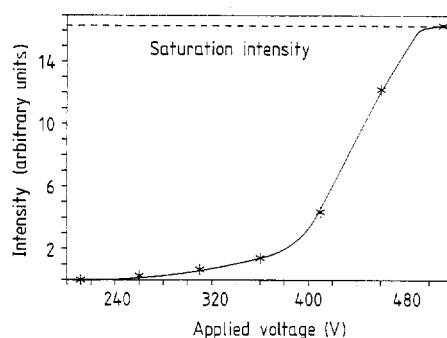
The electrical configuration used to bias the detector multichannel plates is shown in figure 1. The back face of the second plate which faces the phosphorus screen is grounded and the screen is biased to 4 kV by a positive DC power supply. The front face of this plate is negatively biased. Larger negative voltages are applied to the first multichannel plate. A potential difference of a few tens of volts is maintained between the plates. This small interplate bias accelerates and collimates the electrons in the interplate gap, improving the spatial resolution of the detector. A second DC power supply is used to provide the three negative bias voltages through a resistor divider composed of resistors  $R_1$ ,  $R_2$  and  $R_3$ . In this way all the bias voltages are applied simultaneously and the potential difference between the adjacent faces of the two closely spaced plates is guaranteed not to exceed several tens of volts at all times.

Figure 2 shows the recorded intensity of the emission of the 83.3 nm line of O II produced with a DC low pressure (13 mPa) capillary discharge as a function of the applied voltage across the first plate. The second plate was maintained at a fixed potential of 800 V and the interplate bias was 40 V. The intensity grows from the background noise to saturate the detector when the voltage in the first plate is increased from 200 to 520 V. These data were obtained in a time integrated recording, and indicates that with an adequate biasing of the MCP an effective switch of the gain can be achieved by applying a relatively low voltage increment.

To obtain time-resolved spectra with our detector we initially DC biased the intensifier plates to levels where the gain is small such that no significant signal is recorded for a given light intensity. This low-level gain can be easily adjusted by



**Figure 1.** Electrical configuration used to gate a dual-plate-intensified array detector. The broken square represents the 1000 V MOSFET pulser circuit.



**Figure 2.** Intensity of the 83.3 nm line of O II as a function of the applied DC voltage in the first MCP. The second plate was maintained at  $-800$  V. The interplate bias was 40 V.

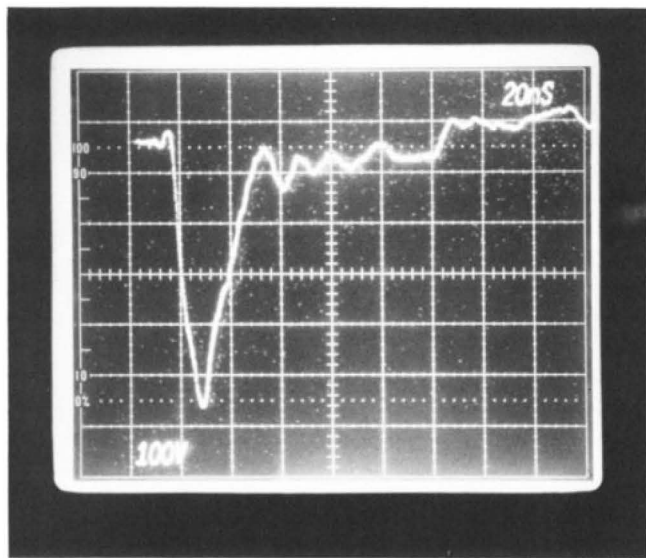
changing the values  $V_1$ ,  $V_2$  and  $V_3$ , depending on the light intensity. Once the DC bias voltage is fixed, the gain switch is obtained by applying an additional short negative voltage pulse to the front face of the first plate. The capacitor  $C$  fixes the base voltage  $V_1$  over which the pulse is added to gate the plate. This scheme has the advantage of reducing the voltage requirement of the fast pulser circuit to less than 500 V, allowing its implementation with a commercially available single MOSFET switch as discussed below.

The negative short pulse used to gate the gain is obtained by discharging four  $50 \Omega$  transmission lines constructed with coaxial cable initially charged up to  $V_c = 1000$  V. The resistor  $R_0$  is connected at the output of the transmission line in order to match the output impedance with the MCP. Four  $50 \Omega$  lines were used to provide the charge required to polarise the MCP, which has a capacitance of approximately 200 pF (Wiza 1979). Although  $Z_0$  for four lines should be  $12.5 \Omega$ , a  $27 \Omega$  carbon resistor ( $R_0$  in figure 1) was found to be the optimum to obtain a good termination and to minimise overshooting and reflection of the gating pulse.

To drive the discharge of the transmission lines we used a MOSFET based commercially available switch†. This switch has a rise time of 2.8 ns and is designed for applications using charge line pulse-forming techniques. The switch has a jitter of less than 800 ps when the trigger voltage is varied between 5 and 150 V and is designed to accommodate up to four input charge lines in parallel. These lines can be varied in impedance and number to provide the best match to the load. This device is used as the high-speed, high-voltage switch in figure 1. When the switch is closed, a negative edge is developed across  $R_0$  since nodes A and B are at AC ground. At the same time a positive wavefront  $V_c/2$  in high is launched back down the  $50 \Omega$  lines in the direction of  $R_c$ . When the front wave reaches the physical end of the lines, it inverts and is reflected back to the switch end where, on its arrival, the negative pulse at  $R_0$  returns to its  $-V_1$  reference point. Therefore, the pulse across  $R_0$  is the two-way transit time of the line and the pulse width can be controlled by changing the line length which, in our case, was selected to obtain a 18 ns voltage pulse. The output of the pulse is directly connected to the output of the multichannel plate through a coaxial high-voltage MHV feedthrough. A 500 V negative pulse generated by the circuit described above is illustrated in figure 3. The pulse was measured directly in the MOSFET drain with the pulser circuit connected to the MCP using a 100X P6057 Tektronix probe through a decoupling capacitor to isolate the pulser bias.

To obtain a stable output voltage working at 500 V pulses it

† FPS 3n power switch available from Directed Energy Inc., 2301 Research Blvd, Fort Collins, CO 80526, USA.

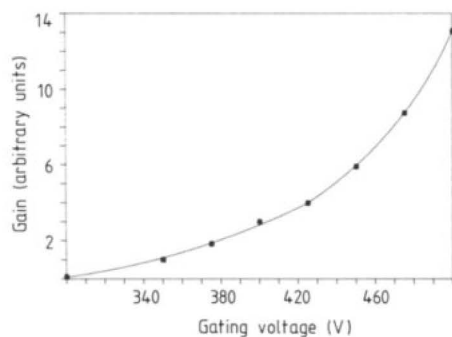


**Figure 3.** High-voltage pulse generated by discharging four 50  $\Omega$  lines initially charged at  $-1000$  V when the pulser is connected to the multichannel plate. This 18 ns FWHM pulse is applied in the first plate to switch on the detector gain.

was necessary to cool the MOSFET. Failure to do so produces a decrease in the peak value of the pulse after about ten minutes of operation because of the increase in the leak current in the MOSFET as the temperature rises. By cooling the MOSFET, the pulse voltage remains constant for more than 30 minutes of continuous operation. The cooling was accomplished by adding a water-cooled copper cold finger in contact with the MOSFET.

Figure 4 displays the dependence of the relative gain of the detector on the amplitude of the gating voltage pulses, for the case in which  $V_1$  in figure 1 is 950 V. The data was obtained by monitoring the 164 nm He II 3-2 line emission from a 100 ns FWHM high current-density helium capillary discharge. As noticed by Luppi *et al* (1984), the optical aperture time of the multichannel plate is shorter than the applied pulse due to the strong non-linear dependence of the gain upon the applied voltage. At the typical conditions under which the apparatus is operated ( $V_1 = 950$  V), it was found to be about 5 ns FWHM by convolving the voltage pulse of figure 3 with the gain curve of figure 4.

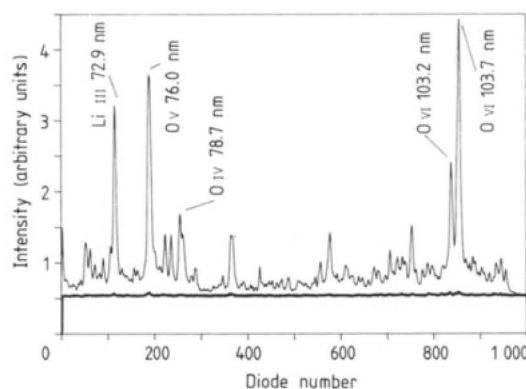
This apparatus was used to obtain time-resolved spectra from short pulsed capillary discharges at wavelengths between 40 and 200 nm. In our experiment the pulser is triggered by the signal of a current probe which senses the initiation of a capillary discharge, synchronising the detector gating with the pulsed discharge. Different delays for the detection window



**Figure 4.** Gain dependence on the amplitude of the applied gating voltage pulse for  $V_1 = 950$  V.

were obtained by changing the length of the coaxial cable which carries the trigger signal. The intrinsic delay of the pulsing circuit was found to be 30 ns. Figure 5 shows a time-resolved spectrum of the axial emission of a 50 ns FWHM LiH pulsed capillary discharge, obtained with an optical aperture time of 5 ns along with the background signal recorded under the same DC bias conditions but when no pulse is applied in the multichannel intensifier. The time-integrated background signal which appears when no pulse is applied is less than 1% of the signal obtained in the time-resolved spectra as illustrated in the figure. Obviously this number depends on the ratio of the radiation emitted by the source during the selected time window and the total emitted radiation, and consequently it will vary depending on the pulse width of the radiation and the selected optical aperture time.

In summary, an easily implemented circuit used to gate the gain in a MCP is presented. The DC biasing scheme used reduces the voltage requirements of the HV pulser. With gating pulses of 500 V, time-resolved XUV spectra with an optical window of about 5 ns FWHM and contrast ratio of more than 1:100 were obtained.



**Figure 5.** Time-resolved XUV spectrum of the axial emission of a 50 ns FWHM capillary LiH discharge obtained with a temporal resolution of 5 ns. The biasing voltages were 780 V across the second plate, 40 V interplate and 180 V across the first plate where the  $-500$  V pulse is applied. The optical window is centred at 3 ns after the peak of the current pulse. The bottom line is the spectrum recorded under the same conditions but when the HV pulse is not applied and represents a background signal of less than 1% of the time-resolved spectrum signal.

#### Acknowledgments

The authors want to acknowledge the fruitful discussions with Yair Talmi from Princeton Instruments. This work was supported by NSF grant ECS 8606226 and by a NSF Presidential Young Investigator Award (to J J Rocca). M C Marconi was supported by a fellowship from Universidad Nacional de Buenos Aires and Consejo Nacional de Investigaciones Científicas y Técnicas de la República Argentina.

#### References

- Fonck J, Ramsey A T and Yelle R V 1982 Multichannel grazing incidence spectrometer for plasma impurity diagnosis: SPRED *Appl. Opt.* **21** 2115
- Luppi R, Pecorella F and Cerioni I 1984 Pulsed microchannel-plate mounting for subnanosecond x-ray image intensifiers *Rev. Sci. Instrum.* **55** 2034-6
- Nahrath B, Shakhatre M and Decker G 1976 Nanosecond x-ray pictures recorded with a pulsed channel plate *Rev. Sci. Instrum.* **42** 88-9

- Pfeiffer W and Wittmer D 1982 High resolution nanosecond gated image intensifier diode *15th Int. Congr. High Speed Photography and Photonics (San Diego, CA)* pp 260–6
- Register D F, Jackson G L and Walker S E 1984 A one meter normal incidence UV spectrometer for plasma measurements *5th Topical Conf. on High Temperature Plasma Diagnostics (Tahoe City)*
- Richards R K 1979 Broad band stable detector for ultraviolet (300–1700 Å) plasma spectroscopy *Rev. Sci. Instrum.* **49** 1210
- Wiza J L 1979 Micro-channel plate detectors *Nucl. Instrum. Methods* **162** 587

---

## Method for narrowing energy width of $e^+$ and $e^-$ beams in a TOF system

O Sueoka† and M Yamazaki

Institute of Physics, College of Arts and Sciences, University of Tokyo, 3-8-1 Komaba, Meguro-ku, Tokyo, 153 Japan

Received 20 June 1988, in final form 29 March 1989, accepted for publication 27 April 1989

**Abstract.** Abstract. A method for narrowing the energy width of  $e^+$  and  $e^-$  beams using a  $^{22}\text{Na}$  radio-isotope and a W moderator is developed. The method provides a width of about 1 eV for 10–20 eV beams, and is applied to inelastic scattering measurements on the Schumann–Runge excitation of an  $\text{O}_2$  molecule by  $e^+$  and  $e^-$  impact. The ratio of the excitation cross section in  $\text{O}_2$  by  $e^+$  impact to that by  $e^-$  is about 1.2 for impact energies in the range 13–22 eV.

### 1. Introduction

A number of total cross-section studies in a positron–gas system have been performed by a time-of-flight (TOF) method using a radio-isotope source and a moderator (Charlton 1985). A similar method has been applied in inelastic-collision experiments (Coleman *et al* 1982) where beams wider than 2 eV (FWHM) were used. Although the energy resolution in inelastic-collision experiments is poor when the beam has a wide energy width, the conventional energy analyser used in electron-beam experiments is not used because of the weak intensity of positron beams. In this report, a new method of energy-width narrowing for  $e^+$  and  $e^-$  beams is attempted in a TOF system using a radio-isotope as the beam source. Using this method an energy width of about 1 eV is achieved for 10–20 eV beams.

Using the TOF method with a radio-isotope source, we have carried out an inelastic cross-section experiment on the Schumann–Runge (SR) excitation in an  $\text{O}_2$  molecule by  $e^+$  impact (Katayama *et al* 1987). However, we could not apply this technique to  $e^-$  impact excitation, because the long tail of the  $e^-$  beam profile (Sueoka and Mori 1986) smeared out the inelastically scattered electron spectrum. This  $e^-$  beam is composed of secondary-emission electron beams emitted from the same W ribbon used as the moderator for positron beams. The purpose of this work is also to perform measurements of SR excitation using the narrowed  $e^-$  beams with the long tail cut off. The results of SR excitation by  $e^-$  impact are compared with those by  $e^+$  impact which are newly measured separately using the energy-width narrowing method.

Part of this study was presented at the 4th Positron Workshop 'Atomic Physics with Positrons' (Sueoka 1987).

### 2. Apparatus

Apparatus for the energy-width narrowing method was built up by remodelling the apparatus used for total cross-section measurements of low and intermediate energy positrons and electrons (Sueoka and Mori 1984) as follows.

† Present address: Faculty of Engineering, Yamaguchi University, 2557 Tokiwadai, Ube, Yamaguchi, 755 Japan.