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Nuclear Instruments and Methods in Physics Research A 387 (1997) 86–87

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Detector for multichannel spectroscopy and fluorescence lifetime imaging on the picosecond timescale

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Abstract

Simultaneous acquisition of time- and space-information on the picosecond timescale became feasible by a recent advance in microchannel-plate photomultiplier-tube (MCP-PMT) technology: we present two novel MCP-PMT detectors for time- and space-correlated single photon counting (TSCSPC), featuring a space-sensitive delay-line (DL) anode and quadrant-anode (QA), respectively. The linear DL-MCP-PMT is characterised by a spatial instrument response function (IRF) of 100 μm FWHM, resulting in 200 space channels, whereas the QA-MCP-PMT is a 2D imager with 400×400 pixel of 40 μm space resolution. The detectors have a temporal IRF of 75 ps (DL) and 80 ps (QA) FWHM, sufficient for 10 ps time resolution, at a dynamic range of 10^5 of the uncooled detector. By employing a 2D multichannel analyser based on transputer technology, 100 000 cps through-put or higher is possible. In imaging mode without timing, the QA-detector can achieve 10^6 cps. A gain of 5×10^6 is achieved at only minus 2400 V.

Applications for the novel imaging detectors will be found in microscopic structural biology, astronomy, and nuclear research.

1. Introduction

Simultaneous time- and space-correlated single photon counting (TSCSPC) spectroscopy, based on novel microchannel plate (MCP) photomultiplier tubes (PMT), had been introduced recently [1]. By replacing the disk anode of a standard MCP-PMT with a delay-line (DL) or quadrant anode (QA), we gain access to space information along *x*- and *xy*-directions, respectively. TSCSPC is a variant of TCSPC [2], a well established method for the acquisition of fluorescence dynamics on the picosecond timescale of very weakly emitting sources that is distinguished by its unsurpassed dynamic range. IRFs as narrow as 16 ps can be achieved in single-channel detectors, resulting in an effective time-resolution of about 2 ps after deconvolution, and indicating the ultimate time resolution of this technology.

2. TSCSPC spectroscopy systems

Standard MCP-PMT and the novel DL- and QA-detectors for time- and space-resolved single photon counting are of identical construction, with exception of the anode.

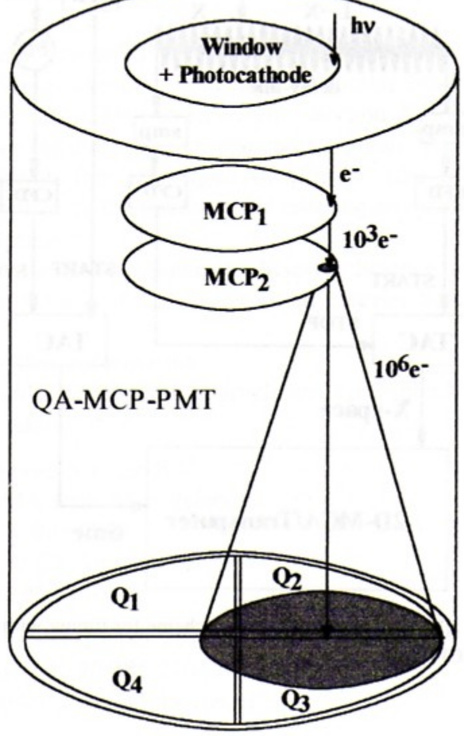

Fig. 1. Schematic view of QA-MCP-PMT detector.

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PII S0168-9002(96)00967-9

The determination of the x-space coordinate in the DL system is based on a measurement of travel time difference [1,3]; the xy-space in the QA-system, in contrast, by measuring charges. In both detectors the incident photon produces a cone-shaped cloud of electrons at the output face of the second MCP that hits DL- or quadrant-anode at a spatial position identical to that of the photon. The electric pulse is split in two or four portions, by DL- and QA-system, respectively. The two pulses of the DL-system are amplified, discriminated and used as start and stop pulse in a TAC. The four charge packets (Q_1–Q_4) of the QA-system (Fig. 1) are amplified, discriminated, and, after AD-conversion a fast algorithm calculates the xy-coordinates [4].

There are two possibilities to gain the time information: (a) a 2D-MCA, equipped with transputer and local memory, calculates time- and space-coordinate from sum and difference, respectively, of both TAC outputs in a convolved scheme (DL) [1], (b) both TACs are independent and sum/difference calculation is not necessary [1], the timing information is derived from an auxiliary pulse, drawn from the 2nd MCP, that is inverted, amplified, discriminated, and then fed as start pulse into a TAC, together with a stop pulse from a photo-diode as in standard TCSPC (DL and QA, Fig. 2).

Best field data so far: (a) DL-system: FWHM(t) = 75 ps, FWHM(x) = 100 μm, 200 space channels, dynamic range = 10^5, lifetime separability 20% [1,6], (b) QA-system: FWHM(t) = 80 ps, FWHM(xy) = 40 μm, 400 × 400 space channels, and 10^5 cps through-put [5].

In imaging mode without time-resolution 10^6 cps can be achieved with the QA-system.

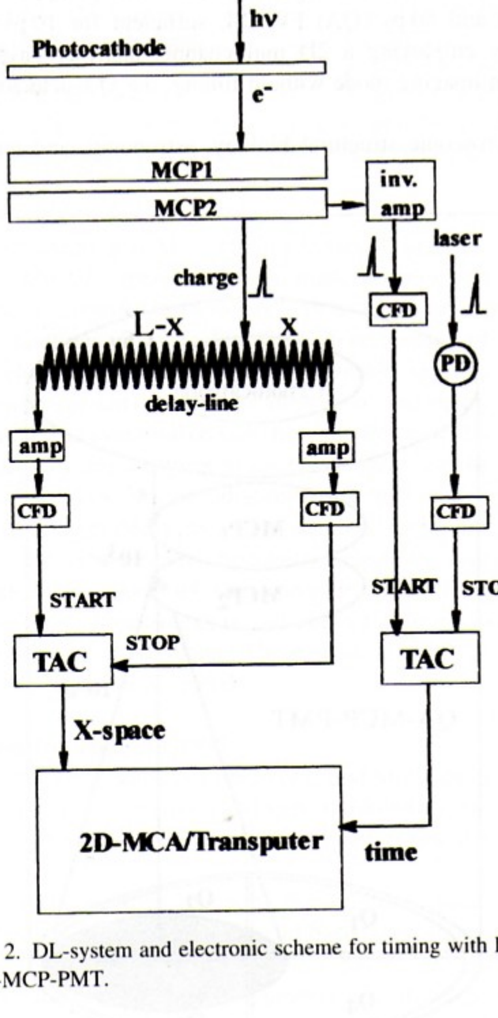

Fig. 2. DL-system and electronic scheme for timing with DL- and QA-MCP-PMT.

3. Results

There are currently three systems in operation: (a) DL-polychromator system for basic spectroscopy studies, (b) DL-microscope system for line imaging of high time resolution, and (c) a QA-microscope system for xy-imaging on the picosecond timescale. Picosecond time resolution is indispensible for dynamic stray-light rejection in the microscope: stray light can be recognised by the risetime of 140 ps in our particular system [6]. Kinetic discrimination of probe-protein (50–200 ps) and probe-DNA (0.4–4 ns) complexes in biological samples requires 50 ps time resolution in imaging mode [6].

Acknowledgement

This work was supported by INTAS-94-4461 and by the EC Preparatory Award for a Demonstration Project BIO4-CT95-9253.

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