INTELLIGENT LINEAR IMAGER
AS DETECTOR ARRAY IN A COMPACT MASS-SPECTROMETER

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Abstract

This is a feasibility study on the use of a new type of intelligent imagers as detector back-end of a mass spectrometer. The integration of digital position-encoding intelligence on chip allowed to increase the detection frequency in single-ion detection mode and to reduce significantly the number of peripheral circuits.

Keywords: *Intelligent imager; mass spectrometer; single ion detection.*

INTRODUCTION

Mass spectrometer

Mass-spectrometers are used in aeronomy for monitoring minute concentrations of gases in the upper atmosphere. These spectrometers are contained in balloon payloads. Consequently they have to be lightweight, and operate autonomously for a few hours.
Actual magnetic mass-spectrometers are based on a classical accelerator-separator section, a micro-channel plate, and a phosphorescent screen for final electron to photon conversion (fig. 1). The light spot representing a detected ion, is read-out by a photo diode array. These photo diode arrays require a significant amount of driving and processing electronics, furthermore, their data output is sequential, and thus relatively slow.

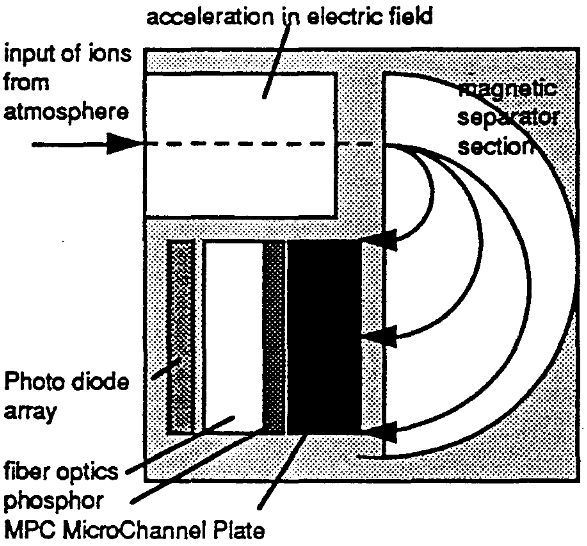

Fig.1 Schematic respresentation of a mass spectrometer.

Smart detector array

The present development uses the FUGA10b "smart photo diode array". Its has [for the present application] 256 pixels on a 40 µm pitch. Every pixel contains a separate charge amplifier and a certain amount of logic, which performs binarisation (i.e. black/white thresholding), neighbourhood operations (erosion or dilation), and the detection and encoding of the positions of edges in the image line. The actual device outputs the leftmost and rightmost edges in the image, in a parallel digital format Unlike the familiar CCD's or photo diode arrays, the device does not yield a sequential video like signal, as it processes each frame ("scanned line") internally. The number of data output is therefore small; the device can operate at very high "image" frequencies. For the envisaged application, *single ion detection* can be done at speeds of more than 100 kHz.

The FUGA10β is a successor of the reported XYW event detector chip [1-2].

Each clock cycle the FUGA10β yields two digital output words: the pixel numbers of the leftmost resp. rightmost transition from dark to light in the pixel array. The discrimination between dark and light is done inside the charge amplifiers, and depends on an externally adjustable threshold. The device is fabricated in a CMOS technology, operates on a 5 V supply, and interacts in a purely digital way with the outside world.

FEASIBILITY STUDY

A set-up has been built to demonstrate the feasibility of a compact, light and inexpensive mass-spectrometer back-end (fig. 2). The light spots emerging from the spectrometer's screen are emulated by a L.E.D. mounted in a microscope objective. The L.E.D. is pulsed by an oscillator running asynchronously with the FUGA10β clock. The number of photons in a pulse is controlled by the electrical pulse length and the current amplitude through the L.E.D. Although the intensities of light pulses on the detector can vary within a wide range, the impact mid-points must be very reproducible. The sensitive area of the actual FUGA10β imager chip is 10.24 mm by 450 µm. In a production device the sensitive length should be increased to 24 mm.

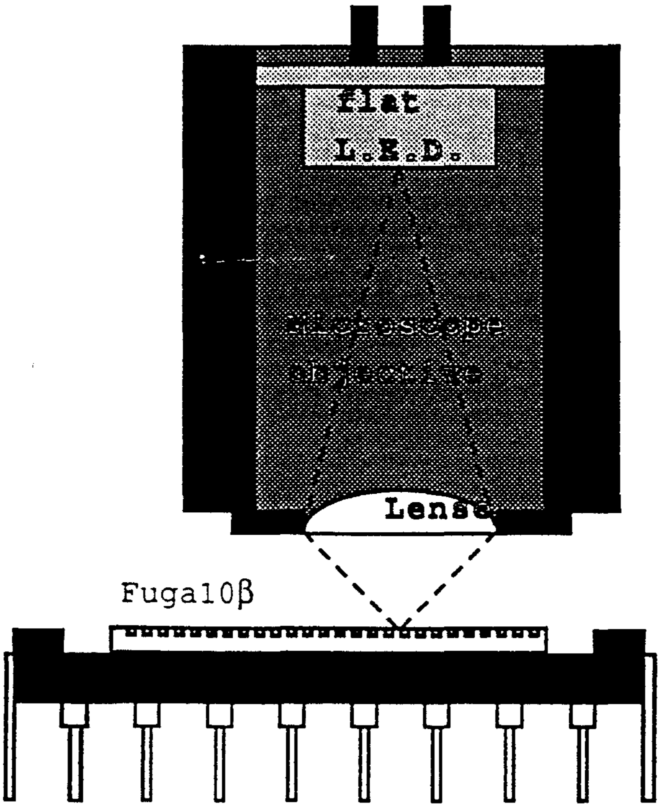

Fig.2 Demonstration set-up for the back-end of a mass spectrometer based on the FUGA10β. A flat yellow (λ = 650 nm) L.E.D. is mounted in a microscope objective so as to project a small image of the light emitting surface on the FUGA10β detector array. The shape of the spot is about Gaussian, with a 2σ diameter of 80 µm, which is representative for a real spectrometer. Multiple spots can be realized with multiple independently driven L.E.D.s.

EXPERIMENTAL RESULTS

The maximum detection rate is 150 kHz. The following results are obtained at 25 kHz; the integration time of the charge amplifiers was 20 µs.

Position resolution

The spot position is determined as the average of left and right edge position. Although the spot width may vary widely, one sees that the average position is quite reproducible (Fig. 3).

For low and medium intensities, the number of positions that deviate from the median position is a few percents (Fig. 4); i.e. the spot position is reproducible within 20 µm (= 1/2 pixel).

Lower detection threshold

Figure 3 shows the detection results as a function of the total number of photons in a pulse that arraive on the detector surface. These numbers were calibrated versus L.E.D. current and pulse duration. A lower reliable detection threshold was determined at about 200000 photons per pulse. This is equivalent to about 40000 electrons accumulated per pixel in one period (due to the fact that the spots are smeared out over several pixels, and due to a non-100% quantum-efficiency, the number of photons is significantly higher). This limit is mainly determined by the technology dependent MOSFET Vth non-uniformity.

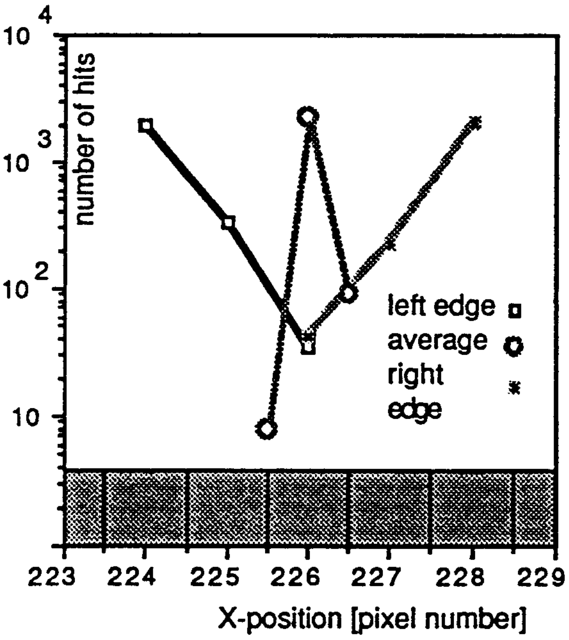

Fig.3 example of the statistical distribution of the positions of a large number of detected spots, for a fixed spot position and fixed pulse conditions. X-axis: pixel number (in a row of 256 pixels of 40 µm wide). Y-axis: the number of hits accumulated in each position during one second. The central positions are calculated as the "average" of left and right

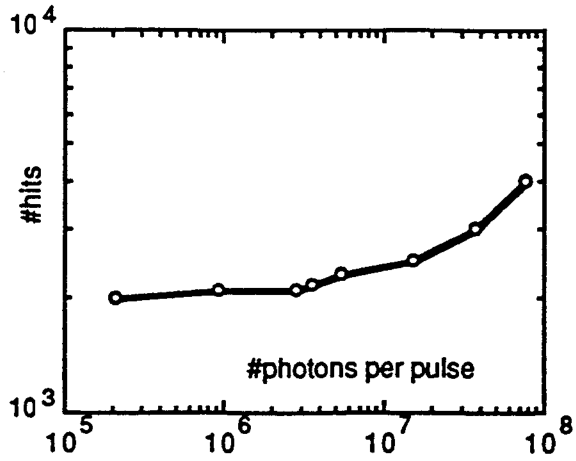

Fig.4 X-axis: total number of photons in a pulse. Y-axis: The number of detected hits on a total of 3000 pulses sent. (the anomalous results are due to the dead-time between integration periods, and to overlapping of the longer pulser lenght on two detection periods)

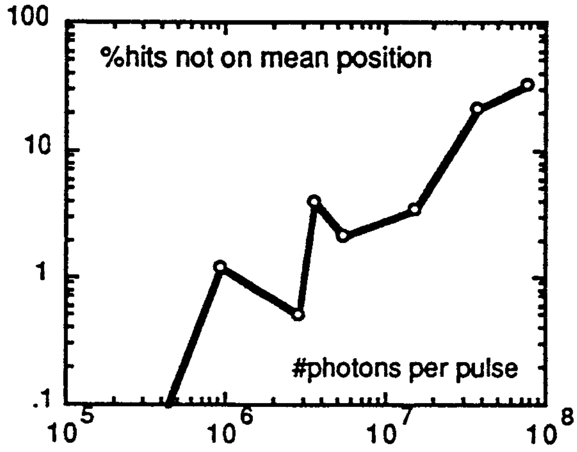

Fig.5 The percentage of measured spot positions that deviates (by 1/2 pixels or more) from the mean position, as a function of spot intensity.

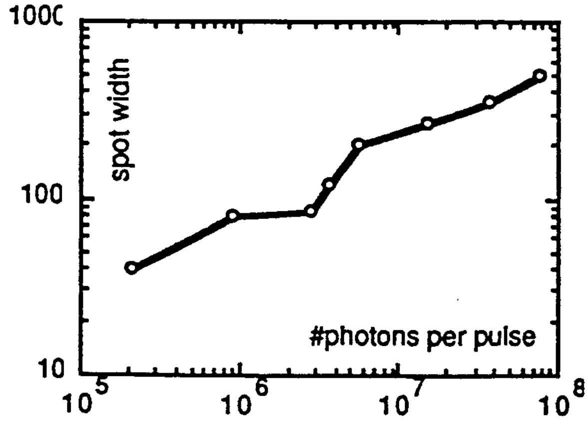

Fig.6 Average spot width (= the difference between left and right edge positions) as a function of spot intensity.

CONCLUSIONS

The feasibility of the proposed approach to develop an intelligent and compact mass spectrometer back-end was demonstrated.

There remains room for technical improvement:

In terms of position resolution, the required system resulution can be matched, as imposed by the MCP resolution. A present a successor array of the FUGA10 with 6μm pixel resolution and 1MHz frame rate has been demonstrated.

In terms of sensitivity, the 200000 photons/pulse/spot detection limit is adequate for the $10^5..10^6$ photons/ expected from actual front-ends. By an improved charge amplifier design, and smaller pixels, one will enhance the sensitivity to 1000 electrons/pixel/pulse. But as the total spot area has an externally imposed 80μmϕ size, the minimal number of photons per pulse will decrease at a lesser pace to about 50000.

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