Microelectronic Engineering 19 (1992) 639-642
Elsevier

Smart imager for fast and inexpensive mass-spectrometer back-ends

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Abstract

A new "smart" type of detector array is presented that is suited for application in the 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.

1. INTRODUCTION

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. The light spot representing a detected ion, is read-out by a photo diode array.

2. SMART DETECTOR ARRAY

The present development uses the FUGA10β "smart photo diode array". Its 1024 photo diodes are operated as 256 pixels. Unlike linear CCD's or classical photo diode arrays, it does not yield a sequential video like signal, but 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*

0167-9317/92/$05.00

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].

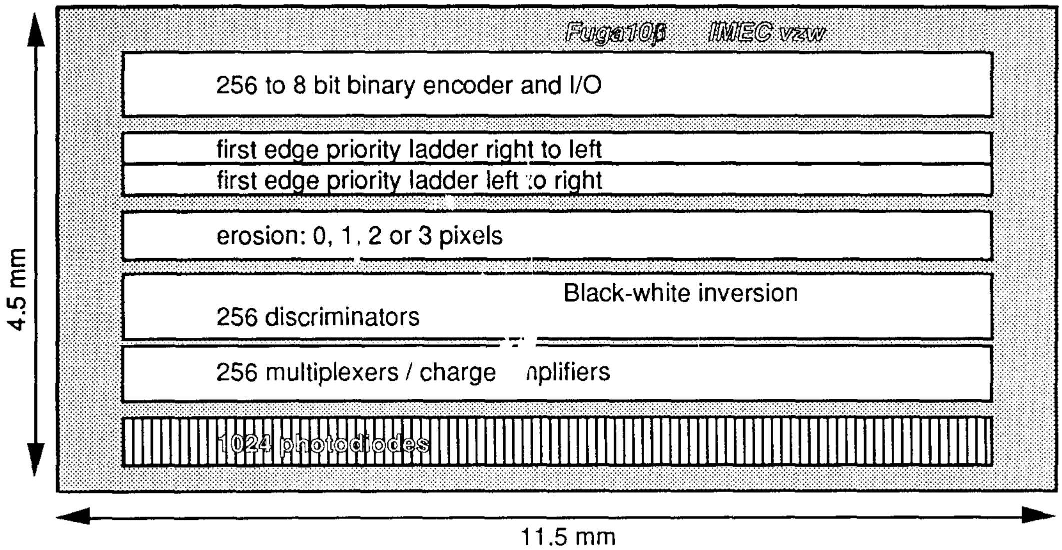

Fig.1. Floor plan of the FUGA10β. 1024 photo diodes are connected in groups of 4 to 256 integrating charge amplifiers and discriminators, yielding 0 (=dark) or 1 (=light). Two parallel priority ladders determine the leftmost and rightmost extent of the 'light spot'. The 4 diodes per amplifier, black-white inversion, and erosion are not of interest for the present application.

After 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 processed in a CMOS technology, operates on a 5 V supply, and interacts in a purely digital way with the outside world.

3. 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 is 10240 μm by 450 μm. In a production device the length must be increased to 24 mm (1000 pixels on a 24 μm pitch)

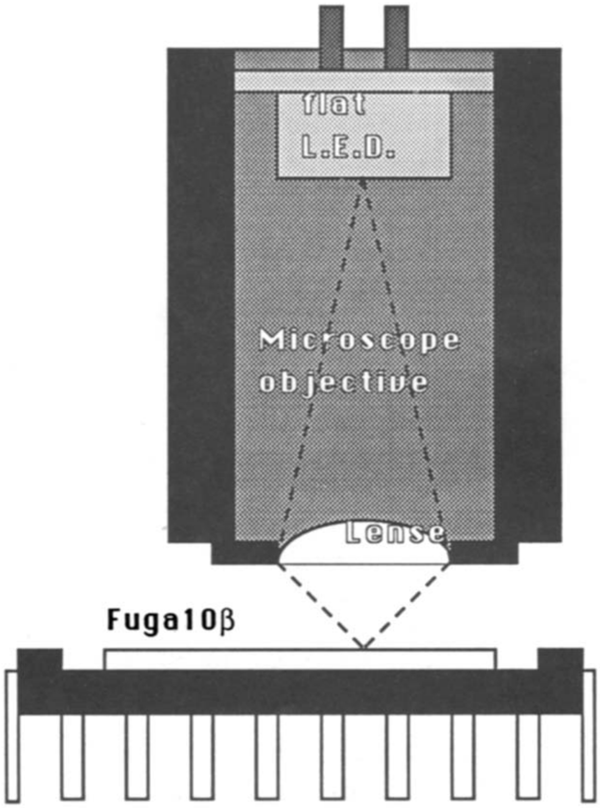

Fig. 2 Demonstration set-up for the back-end of a mass spectrometer based on the FUGA10β. A flat yellow (λ = 650 nm) L.E.D. is mounted in a microscope objective so as to project a small image of the light emitting surface on the FUGA10β detector array. The shape of the spot is about Gaussian, with a 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.

4. EXPERIMENTAL RESULTS

The maximum detection rate is 100 to 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 4 shows the detection results as a function of the total number of photons in a pulse. 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.

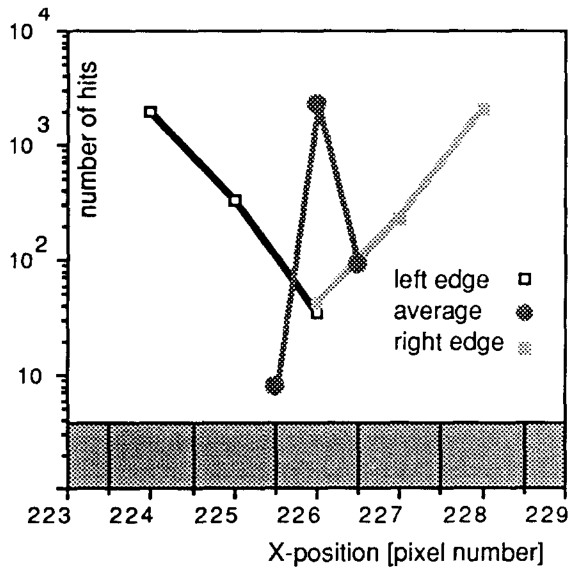

Fig.3 example of the statistical distribution of the positions of a large number of detected spots, for a fixed spot position and fixed pulse conditions. X-axis: pixel number (in a row of 256 pixels of 40 μm wide). Y-axis: the number of hits accumulated in each position during one second. The central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

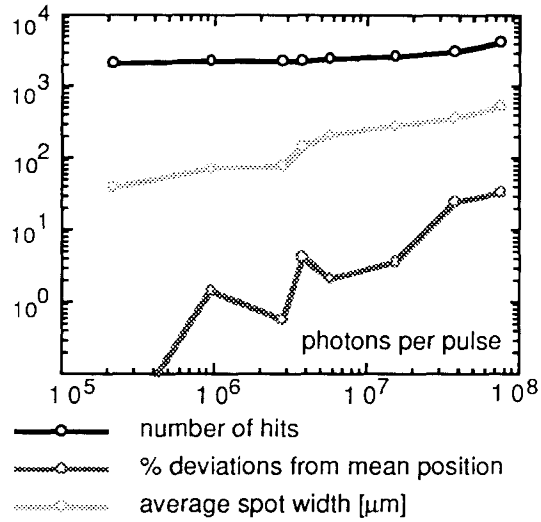

Fig.4 statistical properties of the detection of a large number of pulses, as a function of pulse intensity. X-axis: total number of photons in a pulse. Combined Y-axis: The number of hits • the average spot width = the difference between left and right edge positions • "% deviations" = the percentage of spot positions that deviates (by 1/2 pixels) from the median position.

5. REFERENCES

1 B. Dierickx, Nucl. Instr. and Meth. A275 (1989) 542.
2 B. Dierickx, Nucl. Instr. and Meth. A305 (1991) 561.