First results from the Development of a New Generation of Hybrid Photon Detectors: EBCMOS

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The proximity focusing Hybrid Photon Detector (HPD) concept is implemented to develop a single photon sensitive Electron Bombarded CMOS (EBCMOS). The first demonstrator has been produced by the collaboration between the EBCMOS group of IPNL, the CMOS sensor group of IPHC and the R&D department of PHOTONIS. The prototype characteristics (dark current, gain, spatial and energy resolutions) are presented. The futur developments of this type of photo detector are discussed.

Keywords: EBCMOS, MAPS, hybrid photo detector, fluorescence, bioluminescence, single molecule tracking.

1. Introduction

This development is related to the design and the integration of a Monolithic Active Pixel Sensor (MAPS) into a photosensitive proximity focusing vacuum-based tube. This Hybrid Photo Detector is dedicated to the fluorescent and the bioluminescent high speed imaging. The project is de-

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veloped within the framework of the GIS (Grouping of Scientific Interest) PHOTONIS-IN2P3.
The first goal of this project was to produce and characterize a demonstrator based on a large scale back-thinned MAPS, sensitive to a single photon with a micrometric spatial resolution.

2. The EBCMOS demonstrator

2.1. *Demonstrator description*

The Minimum Ionizing MOS Active sensor (MIMOSA[1]) chips are developed by the IPHC team and are dedicated to the tracking of the charged particles in HEP experiments. The first mega-pixel sensor (17 μm pitch, 1024x1024 pixels, 3.5 cm^2) of the MIMOSA chip family, named MIMOSA5[2], have been back-thinned (MIMOSA5B[3]) and post-processed in order to be sensitive to low energy electrons. This process has been done within the framework of the SUCIMA FP5 European Project[4]. The precise characteristics of MIMOSA5B and his capabilities on low energy electron detection are presented in Refs 3,5,6.
The back-thinned MIMOSA5B chip is mounted in the die cavity of a ceramic carrier. The cathode-sensor gap is of the order of one millimeter. A tunable high voltage is put on the cathode ($\leq$ 10 kV). The cathode is a standard multi-alkali S20 type and provides a quantum efficiency equals to $15 \pm 2\%$ for a 520 nm wavelength. A picture of the first EBMIMOSA5 is presented in Fig. 1. The sensor encloses the cathode with a useful diameter of 18 mm.

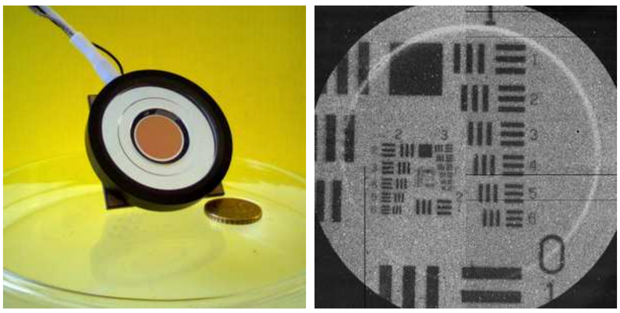

Fig. 1. On the left, the demonstrator EBMIMOSA5 with S20 photocathode. On the right, example of a *1951 USAF* resolution test chart imaging. The USAF target is mounted on a binocular with a magnification factor equals to 1.3. The illumination is tuned to 200 μLux and the high voltage to 4 kV.

2.2. *Photo-electron response and gain linearity*

The first characterization of the demonstrator is dedicated to single photo-electron energy measurement. The readout method and signal processing of MIMOSA5 are presented in Ref. 7. The readout clock is fixed at 10 MHz which corresponds to 27 ms exposure time for one frame. The signal selection is performed on a seed pixel and the charge deposited by the photo-electron is measured by the charge sum over the 5x5 pixels. The figure 2 shows the *signal-over-noise* ratio of the 25 pixels for a single photo-electron event. In the same figure, the linearity of the response with respect to the high voltage (3-8 kV) is presented.

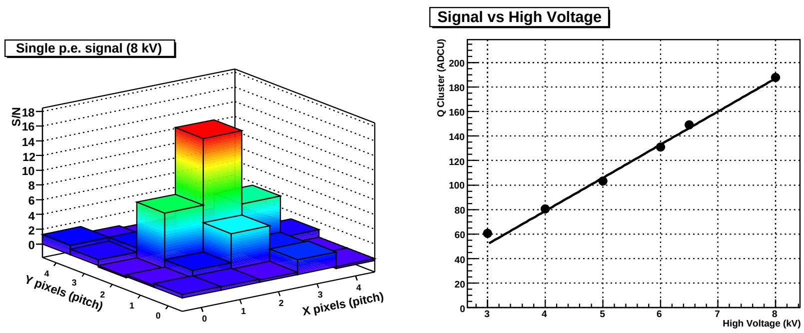

Fig. 2. On the left, signal over noise ratio of 25 pixels for a single photo-electron event at HV=8 kV: the charge sharing around the central pixel (called *seed*) is clearly visible. On the right, linearity of the sensor response *w.r.t* the high voltage.

2.3. *Dark Current measurement.*

The drawback of proximity HPDs is the dark current from the cathode due to thermionic or field effects. The dark current obtained at 6 kV and 10°C is equal to 650 $\pm$ 25 photo-electrons per 27 ms per 2.5 cm^2. This corresponds to a dark current rate close to 100 Hz/mm^2. Cooling the EBCMOS window from 20°C to 10°C reduces the dark current by a factor of 2. No real improvement is observed when cooling below 10°C.

2.4. *Spatial resolution*

The point-spread function (PSF) of the tube is characterized with an optical test bench which provides a 2 μm diameter spot[a] on the photocathode plane. The spot can be precisely positionned with a 3D micro-controlled displacement. The pulse duration of the LED source is calibrated and fixed to 500 ns in order to obtain an average of one photo-electron into a selected sub-window (5x5 pixels). The PSF is obtained by computing, for single photo-electron events, the distribution of the position of the seed pixel. A Full Width at Half Maximum equals to 27.1 $\pm$ 0.1 μm has been measured at HV=8 kV.

2.5. *Photon counting capability*

One of the strong advantage of EBCMOS against EMCCD is its capability to count the number of photo-electrons in the same cluster. Figure 3 presents the charge sum over the 5x5 sub-window without any seed selection. The histogram exhibits a well defined Poisson distribution of the photo-electrons peaks. The peaks corresponding to 0, 1, 2 and 3 photo-electron events are resolved.

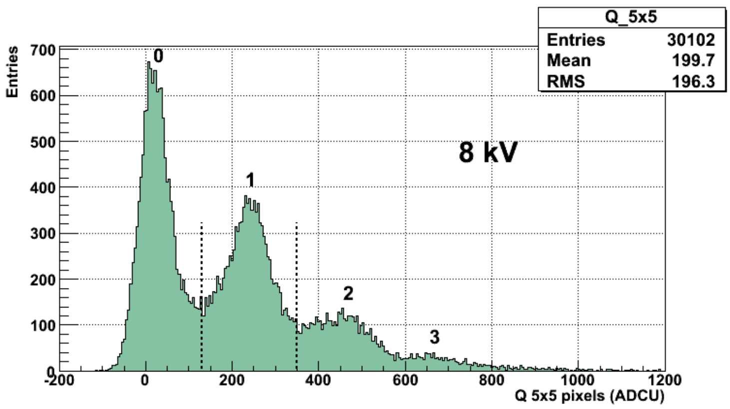

Fig. 3. Multi-photo-electron spectrum in ADC unit for the 5x5 pixel cluster.

[a]The spot is obtained by imaging a 100 μm diameter pinhole through an inverted MITUTOYO long working distance 50X objective.

3. Conclusion and Future plane

3.1. *Tracking concept for bioluminescence and fluorescence imaging.*

The first results obtained on the EBMIMOSA5 demonstrate the concept of proximity focusing vacuum-tube on a back-thinned CMOS sensor. Single photon and multi-photon sensitivity with 27 μm resolution (FWHM) has been obtained with a back-thinned chip which is not optimized for this application. The characterization of the demonstrators is now focused on the main goal of this project: the tracking of fluorescent molecules. Cross comparisons between existing devices on fluorescence imaging of cell division (in zebrafish eggs) and on bioluminescence of calcium flow in drosophila brain are scheduled for the end of 2007.

3.2. *Future plans*

To overcome the limitation of the MIMOSA5 for the considered applications, we will produce in 2008 a Large-scale Ultra-fast SIngle PHoton trackER (LUSIPHER) with a dedicated back-thinned CMOS chip (medium-scale 400x800 pixels, 10 μm pitch, 8 analogue outputs and 40 MHz clock frequency, ST 0.25 μm process). A new acquisition ethernet board is currently developed to achieve 1000 frames per second (the equivalent data flow is equal to 3.6 Gb/s). LUSIPHER will be our first prototype dedicated to ultra-fast single photon tracking in fluorescence and bioluminescence experiments of single molecule tracking.

4. Acknowledgments

We would like to thank the acquisition team of CMOS sensor IPHC group for providing support on their USB2 DAQ board and technicians and engineers involved in this project at IPNL, IPHC and PHOTONIS.

References

1. R. Turchetta, et al., *Nucl. Instr. and Meth. A* **458** 677 (2001).
2. Yu. Gornushkin, et al., *Nucl. Instr. and Meth. A* **513** 291 (2003).
3. G. Deptuch, *Nucl. Instr. and Meth. A* **543** 537 (2005).
4. M. Caccia, et al., *Nucl. Phys. B (Poc. Suppl.)* **125** 133 (2003).
5. G. Deptuch, *Nucl. Instr. and Meth. A* **570** 165 (2007).
6. W. Dulinski, *Nucl. Instr. and Meth. A* **546** 274 (2005).
7. G. Claus, et al., *Nuclear Science Symposium Conference Record, 2004 IEEE 16-22 Oct.,* **Vol. 3** 1512 (2004).