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HYBRID MICROPIXEL DETECTOR AT THE FOCAL PLANE OF THE MASS-SPECTROMETER

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Results on testing TimePix micropixel chip as a detector of low energy ions in a focal plane of the laser mass-spectrometer are presented. Two options were tested: hybrid micro-pixel detector as well as metal micro-pixel detector (naked read-out chip with a metal mesh to improve a charge collection). For both cases a response uniformity of pixels over ion mass, energy and detection position has been thoroughly studied. The results obtained illustrate capability of both detector modes to be used for creating “electronic focal plane” of a mass-spectrometer with obvious advantages of real time devices.

Keywords: TimePix micropixel chip, hybrid micro-pixel detector, metal micro-pixel detector, mass-spectrometer, secondary electron emission.

Introduction

The MEDIPIX Collaboration has developed few versions of a pixel readout chip [1] used for a variety of applications. The TIMEPIX chip [2] (a successor of MEDIPIX-2) consists out of (256 × 256) identical elements, designed in a commercial 0.25 μm 6-metal CMOS technology. It has a low electronic noise (~100 e- rms) and a gain of ~16.5 mV/ke resulting in the minimum detectable charge of either ~650 e- with a naked chip or ~750 e- when bump-bonded to a detector. It provides independently in each pixel information on arrival time, time-over-threshold or event counting. Each readout pixel includes preamplifier, discriminator and counter.

We report on the results of the first test of a TimePix as a detector of low energy (3 - 20 keV) ions in a focal plane of the laser mass-spectrometer. Two detector configurations were tested: a hybrid silicon micro-pixel detector as well as a metal micro-pixel detector - a bare read-out chip with a minor additional structure to improve a charge collection. Data were taken with a Time Over Threshold (TOT) configuration of the read-out chip. For both cases pixels response uniformity over ion mass, charge and energy has been thoroughly studied. The results obtained illustrate capability of both detectors to be used for creating “electronic focal plane” of a mass-spectrometer allowing for a simultaneous measurement of the spatial distribution of ions impinging on the focal plane. It is an essential advantage of a real time device in comparison with a scanning mass-spectrometry, in which ion distribution over mass is measured at successive times.

In a conventional mass-spectrometry few steps are usually made to convert the intensity of the ions with a definite mass at the focal plane into a digital data for presentation. In most of cases Micro Channel Plates (MCP) are used to transform the ions into electron streams (gained up to 10^8 times) collected then by different detector arrays [3]. Studies with monolithic active pixel sensors for mass-spectrometry were described elsewhere [4]. Single ion detection sensitivity to few keV energy $^{27}Al^+$-ions has been achieved for a system combining micro-channel plate and stacked CMOS active pixel sensors (SCAPS) [5]. SCAPS as two-dimensional imaging devices were applied for stigmatic secondary ion mass-spectrometry [6]. Detection of sub keV ions by a charge-coupled device at the focal plane of a miniature mass spectrometer has been reported [7].

Experimental setup

The TimePix chip was mounted in a vacuum chamber (Fig. 1) on a moveable platform at the focal plane of a laser double-focussing mass spectrometer MC3103 [8] of the Institute of Applied Physics NASU (Sumy, Ukraine).

Fig. 2 shows schematics of the ion path in a mass-spectrometer. The ion beam has been generated at the sample-target (*2*) by infrared laser (*1*) (1.064 μm wavelength, 15 ns pulse duration and repetition rate 50 Hz). Ions passed the field-free region in anode chamber (*3*) were accelerated by the electric field (*3 - 4*) and focused to the object slit (*5*). An ion beam was shaped by object (*5*) and aperture (*6*) slits defining aperture angle of the ion source. It passed then through an energy analyzer (*7*), energy slit (*8*) and mass analyzer (*9*) in magnetic field

Fig. 1. Photo of TimePix mounted in a vacuum chamber on a moveable platform at the focal plane of the laser mass spectrometer.

having arrived finally to a position sensitive detector (*10*), moveable in a focal plane (*11*) of a mass analyzer. Geometry factors affecting mass-spectrometer performance with double focusing are described in details elsewhere [8]. The results of calculations were used for alignment of the mass-spectrometer and position sensitive detector (TimePix) in a focal plane.

The width of the beam tuned by slits *5, 6, 8* (see Fig. 2) was in the range of (20 - 200), (200 - 2000), (200 - 2000) μm, respectively. Passing through the magnetic sector ions were focused accordingly to their mass over charge ratio in a focal plane (210 mm long) of the mass-spectrometer. TimePix chip (*10*) was readout by the PIXELMAN hardware/software [9] via USB-connection to PC. In the TimePix readout chip each pixel was programmed to record TOT data getting in this way analog information. The charge created by bunches (time of flight of the slowest ions up to ~10 μs, 20 ms period) of impinging ions at each pixel of the TimePix is amplified and stored in a capacitor consecutively discharged by adjustable constant current. For each bunch of ions detected by a pixel a triangular pulse (0.5 – 100 μs width adjusted by discharging current) is formed with a height proportional to a number of ions in a bunch. The pulse is compared with constant threshold level and when it is higher the analog data is converted into a digital one by counting number of clock pulses for the time over threshold interval. Whenever the new bunch of ions arrives at the pixel its counter content is increased accordingly to the number of ions in the bunch. Digital integration providing large dynamic range and good linearity in response to number of ions, real-time digital information, high speed digital communication and data transfer are essential features of TimePix chips for a mass-spectrometry. As far as detector length is much smaller than the length of a focal plane some mass-spectra were obtained by scanning over magnetic field or position of a pixel detector by means of a step-motor alongside the length of the focal plane.

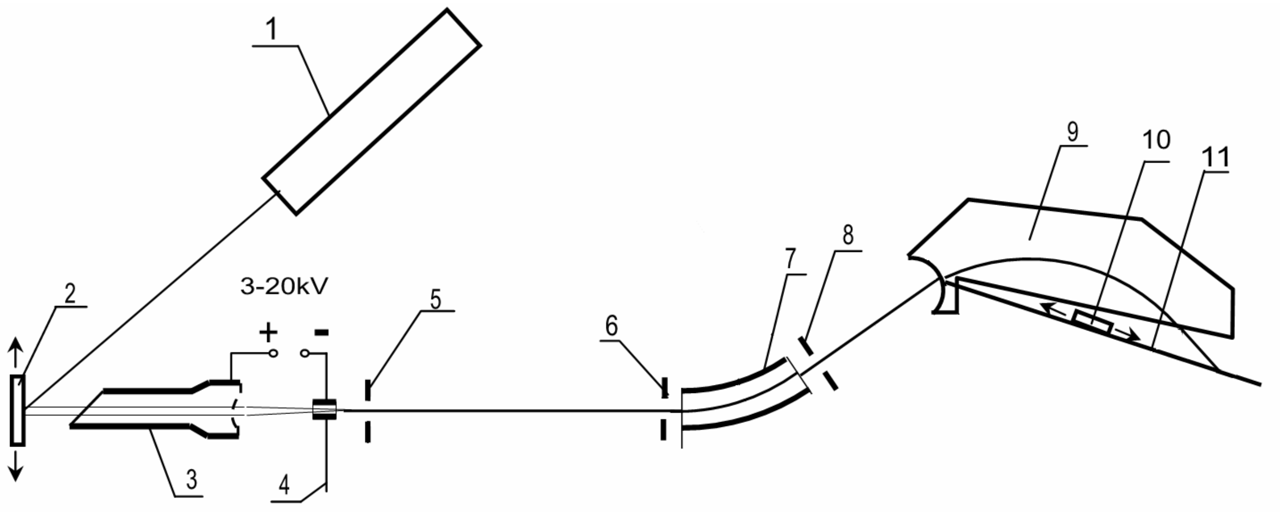

Fig. 2. Schematics of ion path in a laser mass-spectrometer.

Experimental results

Two TimePix detector configurations were tested: a hybrid silicon micro-pixel detector as well as a metal micro-pixel detector - a bare read-out pixel chip with a minor additional structure to improve a charge collection.

TimePix hybrid detector

The TimePix hybrid pixel device consists of a silicon (300 μm thick) semiconductor chip with a common n-side electrode and a (256 × 256) matrix of p-side (55 × 55) μm^2 pixels bump-bonded to a readout chip with the same pixel structure. TimePix charge sensitive preamplifiers can operate input signals of both polarities providing leakage current compensation per pixel. There are two discriminators with globally adjustable threshold and a possibility of 3 bit threshold adjustment per pixel. 13 bit pseudo-random counter is activated via external shutter signal. For testing and masking purposes there are 1 test-bit and 1-mask bit per pixel.

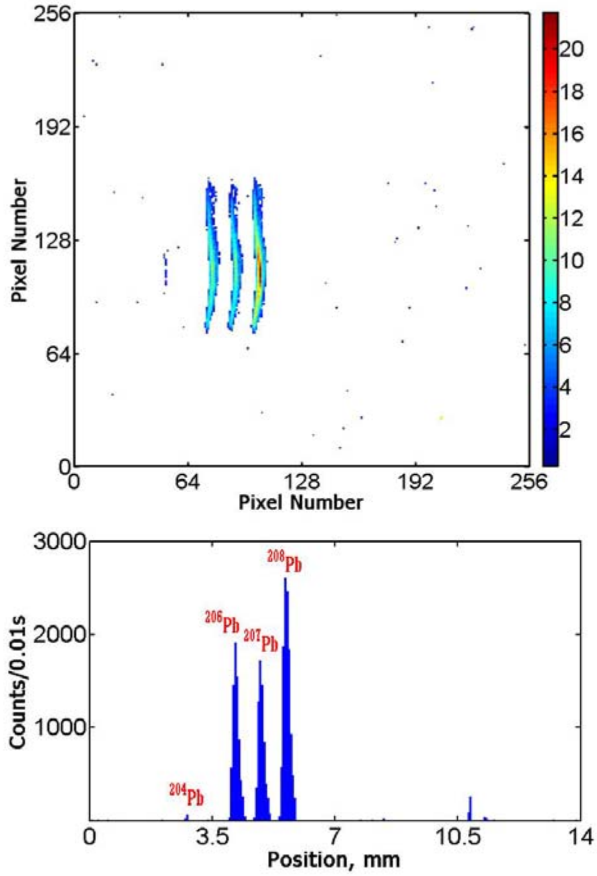

Fig. 3. TimePix (a hybrid-detector) – an “electronic plate” at the focal plane of a mass-spectrometer. Top picture – 2D- image of lead isotopes “lines”. Bottom – projection of data onto horizontal axis (mass – spectrum). Energy of ions is 12.1 keV.

Fig. 3 (upper part) shows two dimensional plot of data measured by a hybrid silicon pixel detector (bias voltage – 100 V) at the focal plane of a laser mass-spectrometer (see Figs. 1 and 2). Position of the detector, accelerating voltage and magnetic field were adjusted to observe 12 keV double charged ions of the lead isotopes detected approximately at the middle part of the sensor. A horizontal pixel number (see Fig. 3, top) corresponds to a mass of detected ions while vertical one shows an ion beam shape defined by aperture slits. Z-axis (see Fig. 3, top) reflects a number of measured counts, proportional to a number of ions detected by pixels. It is a dynamically varying picture measured in real time (fixed in former times by photographic plate positioned in a focal plane of mass spectrometer).

Thus, the TimePix detector providing two-dimensional picture surveys as an “electronic plate” imaging ion beams and their charge/mass distribution. Such images could be used for tuning mass spectrometer “on-line” (focusing, alignment, testing stability of electric and magnetic field, quality of the magnetic field uniformity etc.,) or for “off-line” data analysis taking into account the shape of the chosen ion line (“locus”) to improve mass resolution by projecting mass-data from that locus rather than simply onto the horizontal axis (see Fig. 3, bottom).

Fig. 4 shows more complicated mass spectrum measured by TimePix hybrid detector for copper (1^+), zink (1^+) and tin (1^+ and 2^+) ions emitted by the standard sample 662 with known isotopes abundances. The 15 mm wide range of the focal plane has been measured moving detector as well as varying magnetic field of a mass analyzer. The isotope abundance measured by TimePix is in agreement (within ±10 %) with the table data. An estimate shows that approximately 10^4 single-charged ions arriving at detector pixel create a charge quantum corresponding to a single TimePix count.

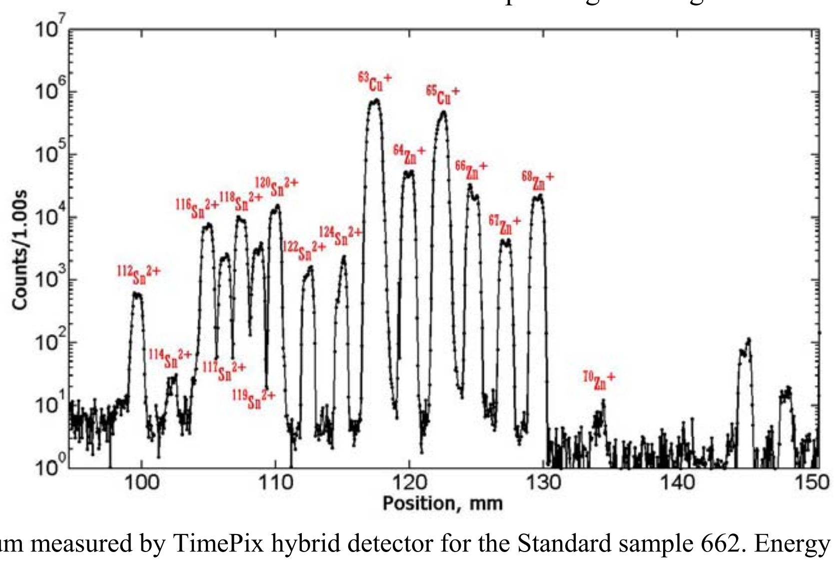

Fig. 4. Mass spectrum measured by TimePix hybrid detector for the Standard sample 662. Energy of ions is 12.1 keV.

For performing routine mass-spectra measurements one has to know uniformity of all pixels response over ion mass, charge and energy. These studies are currently in progress and detailed results will be reported soon. Preliminary results indicate that the level of the observed non-uniformity allows for taking it into account by careful calibration.

TimePix - metal detector

The goal of this study was to test a possibility of detecting low energy ions directly at the metal electrode of the individual pixel of the TimePix. That would allow eliminating a semiconductor micro pixel detector from a detection chain with obvious advantages for a performance of a mass-spectrometer. A metal TimePix detector has higher radiation tolerance as well as a lower risk of charge accumulation with forthcoming breakdown, dangerous for input stages of the chip. TimePix naked readout chip has been successfully tested as a detector of electrons in combinations with micro-patterned gas detector systems MICROMEGAS and GEM [10]. A metal octagonal electrode for bump bonding of pixel sensors served there as a collecting anode. Calibration performed gave a value of ~ 62 electrons at the system input per TimePix count. Keeping in mind that gas amplification was about 1000 it means ~ 60 000 electrons at the pixel metal electrode.

A metal electrode covers an area of ~ 100 μm^2 which has to be compared with 3025 μm^2 for a single silicon pixel detector. Thus, in comparison with the hybrid silicon pixel detector the TimePix in a metal detector mode at the focal plane of a mass-spectrometer has an efficiency of ion detection by factor of 30 less in accordance with the ratio of areas where charged ions are detected. To explore to a full extent a metal detector physics principle of operation we have applied a positive voltage to a thin metal mesh fixed over the detector area to amplify a positive charge appearing on the metal electrode due to the secondary electron emission [11].

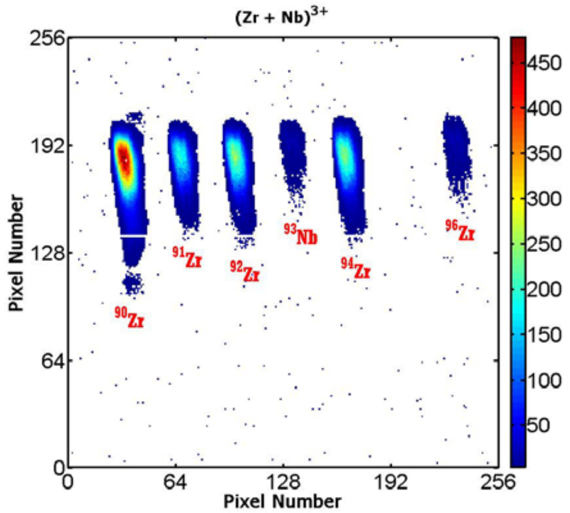

Fig. 5. Two-dimensional distributions of Zr and Nb ions with different charges and masses measured by TimePix in a metal mode of operation.

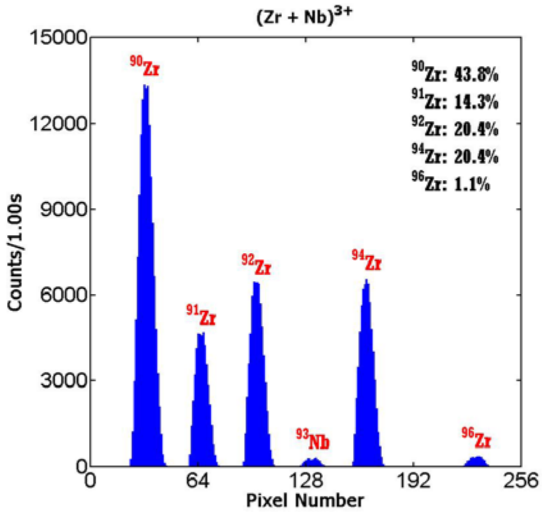

Fig. 6. Mass-spectra of Zr and Nb ions with different charges obtained by projecting two dimensional distributions shown at Fig. 5.

Figs. 5 and 6 show two-dimensional and projected onto the mass-axis data measured by TimePix (metal) for Zr and Nb triple-charged ions with different masses. Energy of ions is 21 keV. Inserted in Fig. 6 are the values for isotope abundance extracted for the sample studied. These have to be compared with the table data: ^{90}Zr – 51.46 %, ^{91}Zr – 11.23 %, ^{92}Zr – 17.11 %, ^{94}Zr – 17.40 %, ^{96}Zr – 2.8 %.

Conclusions

Studies performed with TimePix (hybrid silicon detector and metal detector) have shown its applicability for low (3 - 20 keV) energy ion detection, in particular at the focal plane of a mass-spectrometer. Results obtained indicate perfect perspective of creating electronic focal plane for mass-spectrometers with advantages of real time devices. Two-dimensional images obtained with TimePix could be used for “on-line” tuning mass spectrometer or similar devices. Mapping isotope population over the sample area by scanning it with laser or charged particle micro-beam might be useful for applications in microbiology, evaluation of material technology production etc. Detailed experimental studies with TimePix in a focal plane of the double-focusing mass-spectrometer are under way to characterize pixels response as a function of ion charge, mass, energy and intensity. Results will be published soon.

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ГІБРИДНИЙ МІКРОПІКСЕЛЬНИЙ ДЕТЕКТОР У ФОКАЛЬНІЙ ПЛОЩИНІ МАС-СПЕКТРОМЕТРА

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Представлено результати тестування мікропіксельного детектора TimePix як детектора іонів низької енергії у фокальній площині лазерного мас-спектрометра. Було досліджено два випадки: гібридний мікропіксельний детектор та металевий мікропіксельний детектор (голий зчитуючий чіп з металевою сіткою, що покращує накопичення заряду). В обох випадках було повністю вивчено однорідність відгуку пікселів щодо маси іонів, енергії та реєстрації положення. Отримані результати ілюструють можливість використання обох моделей детекторів для створення "електронної фокальної площини" мас-спектрометра з перевагами отримання даних вимірювань у режимі реального часу.

Ключові слова: мікропіксельний чіп TimePix, гібридний мікропіксельний детектор, металевий мікропіксельний детектор, мас-спектрометр, вторинна електронна емісія.

ГИБРИДНЫЙ МИКРОПИКСЕЛЬНЫЙ ДЕТЕКТОР В ФОКАЛЬНОЙ ПЛОСКОСТИ МАСС-СПЕКТРОМЕТРА

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Представлены результаты тестирования микропиксельного детектора TimePix как детектора ионов низких энергий в фокальной плоскости лазерного масс-спектрометра. Было исследовано два варианта: гибридный микропиксельный детектор и металлический микропиксельный детектор (голый считывающий чип с металлической сеткой, что улучшает накопление заряда). В обоих случаях было полностью изучено однородность отклика пикселов относительно массы ионов, энергии и регистрации положения. Полученные результаты демонстрируют возможность использования обеих моделей детекторов для создания "электронной фокальной плоскости" масс-спектрометра с преимуществами получения данных измерений в режиме реального времени.

Ключевые слова: микропиксельный чип TimePix, гибридный микропиксельный детектор, металлический микропиксельный детектор, масс-спектрометр, вторичная электронная эмиссия.

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