Micro-strip Metal Detector for the Beam Profile Monitoring

Valery Pugatch [a], Marina Borysova [a], Alexey Mykhailenko [a],
Oleg Fedorovitch [a], Yuriy Pylypchenko [a],
Vladimir Perevertaylo [b], Hermann Franz [c], Kay Wittenburg [c],
Michael Schmelling [d], Christian Bauer [d]

[a] *Kyiv Institure for Nuclear Research, Kyiv, Ukraine*
[b] *Institute of Micro Devices, Kyiv, Ukraine*
[c] *Deutsches Elektronen-Synchrotron, Hamburg, Germany*
[d] *Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany*

Abstract

The Micro-strip Metal Detector (MMD) design and production technology, readout electronics as well as areas of applications are described. The MMD was designed for beam profile monitoring of charged particles and synchrotron radiation beams. Using photolithography and plasma-chemistry etching technologies we succeeded in creating detectors with metal strips thickness less than 2 micrometers and without any other materials in the working area. The principle of operation is based on the Secondary Electron Emission (SEE). The results obtained with the MMD at the monochromatic synchrotron radiation beam at HASYLAB (DESY) are also presented. The current version of the MMD allows measuring a beam profile and position with a 20 micrometers accuracy.

---

1 Introduction

At manifold applications of synchrotron radiation and charged particles beams there is a necessity to provide on-line beam profile monitoring. Among the general requirements to the Beam Profile Monitor (BPM) are high resolution, high radiation tolerance and ability of non-destructive monitoring. For low intensity beams a silicon micro-strip detector could provide a position resolution even at sub-micron level. However, radiation hardness aspect makes this approach rather limited. The Micro-strip Metal Detector (MMD) has an advantage here because of using metal as detecting material instead of semiconductor. The position resolution of few micrometers is in the reach for the

Preprint submitted to the XIth VCI 2007 *22 February 2007*

current manufacture technology of MMD and applying latest achievements in lithography position resolution at sub-micron level could also be attained. In this paper we present results of measuring synchrotron radiation beam profile at the HASYLAB (DESY) by means of the MMD.

2 MMD principle of operation

Passing through the metal strips beam of charged particles or synchrotron radiation initiates SEE (Fig. 1). A positive charge appearing at the electrically isolated strip is integrated by a sensitive Charge Integrator (CI) [1]. To improve extraction of secondary electrons (SE) an accelerating electric field $\vec{E}$ is created around the strip. A majority of secondary electrons have energy in the range of few eV allowing for an operating bias voltage of 20 V, only. Secondary electrons are emitted mainly from thin (10-50 nm) surface layers [2], [3]. Thus, one may consider a possibility to create submicron thick detectors without a significant loss of their sensitivity.

3 MMD production technology and technical details

Design, technology and structure of the MMD are determined by the principle of operation and application requirements. The main MMD feature determining complexity of their manufacturing is micrometer sizes of the strips stretched over the working area. The strips manufacturing by applying plasma-chemistry technologies for etching of multilayer structures is described in details in [4]. The MMD production technology includes micro-photolithography, plasma-chemistry etching and assembling. These steps are briefly described below.

The sensor layer of the MMD prototype has 32 nickel strips (1-2 μm thick, 70 μm pitch) placed on 500 μm thick silicon wafer. Every strip is connected by one end to the individual charge integrator input channel and by other end to the stable current source of 25 or 250 pA (*baseline*). This allows for checking integrity of the strips as well as making corrections for possible baseline variation.

3.1 Photolithography

On the silicon wafer (500 μm thick) two dielectric layers are created to isolate future metal strips from semiconductor. At first, the silicon oxide (SiO_2, 0.1-0.3 μm thick) is grown up covered later by 0.2 μm thick silicon nitride (Si_3N_4). To improve adhesion the dielectric layer is overlaid with thin titanium film (about 50 nm). Finally, 1-2 μm nickelfilm is deposited. Such "sandwich" structure is created on both sides of the silicon wafer: 32 strips (40 μm width, 70 μm pitch) with connection pads are formed by photolithography methods on front side, while at the back side of the Si-wafer a nickel mask is kept for the forthcoming plasma-chemistry etching.

3.2 Plasma-chemistry etching

To remove the silicon wafer from the working area of the MMD (making metal strips hanging there free) a plasma-chemical reactor at KINR with variable ion energy has been used. At first, through the additional metal foil mask a thin surface layer (20-80 μm) of silicon on the front side of the wafer is removed. Then through the rectangular shaped window on the back side the plasma-chemical etching is performed. The initial etching speed is in the range of 2.5 μm/min at an ion energy of 80 eV and at a discharge current of 10 A. When the silicon wafer thickness approaches 50-100 μm the etching speed is slowed down to 0.3 μm/min by decreasing the current to 4 A and the ion energy to 20 eV. In this way it is possible to produce MMD with completely removed Si-wafer in the working area (10x15 or 6x15 mm^2) and all 32 strips survived. Similarly the accelerating layers are produced. The differences are just in the amount of the strips - the accelerating layers have two strips placed at a distance a bit wider than that between outermost strips of the sensor layer.

3.3 MMD assembling

The sensor and accelerating layers are glued one to the specially designed ceramic pitch adapters. These adapters are glued together. Every strip pad of layers is connected by supersonic welding to the ceramic metallisation and further through a flexible polyamide cable to the 50-pin D-Sub connector. All this construction is anchored in protective metal case (see photo at Fig. 2). The connection to the charge integrators is provided by 5 m long coaxial cables. The frequency outputs of the charge integrators are proportional to the measured beam intensity and readout by VME-based scalers, while corresponding software makes data presented on line at computer display.

4 Applications

Nowadays microbeams of charged particles as well as synchrotron radiation are widely used for science and technology. In many of these applications there is a necessity to know the distribution of the intensity in the beam. In comparison with other detectors MMD has such advantages as:

- Low thickness of detecting material (less than 1-2 μm)
- High sensitivity relative to the minor impact to the beam
- Low operating voltage (20 V)
- Simple DAQ (charge integrators, scalers, computer)
- High radiation tolerance (*gigarad* level)
- High position resolution (20 μm now and up to 1 μm in the near future)

In view of just listed advantages of MMD one may consider it as perspective device for microbeams profiling. We consider that MMD could be also used for intensive beams of high energy charged particles as a feedback element for stabilizing and/or focusing collider beams. Indeed, even if the central part of detector is burnt out the remained strips operating in the beam halo would provide necessary feedback signals.

5 Experimental results

During MMD production technology development we carried out several experiments with different prototypes of detector. The first MMD was used for the on-line control, positioning and focusing of 32-MeV alpha-particles beam at Tandem generator for single events upset studies of the BEETLE chip (MPIfK, Heidelberg) [5]. The other measurements were performed with monochrome synchrotron radiation beam at Low Energy Beamline PETRA 1 HASYLAB (DESY). The beam has a mean energy of about 20 keV and intensities up to 10^{12} ph/$(s \times mm^2)$. These previous results obtained at HASYLAB are described in [6].

In the following, we have been exploiting two styles of measurements: *dynamic* mode (whereby the change of beam position or size was simulated) and *static* mode respectively.

5.1 Measurements of X-ray beam profile in the atmosphere

The monochrome synchrotron beam went through the special beryllium window out of the vacuum pipe to the atmosphere. On a distance of 20 cm from the beryllium window the beam passed through the vertical and horizontal slits. After the slits the MMD and an Ionization Chamber (IC) were located sequentially. We were enabled to move the slits simulating changes of beam size. By means of the IC we could measure the intensity of the passing beam.

The MMD was able to measure the beam profile, but the air ionization caused signal distortions: By opening of the slit step-by-step we observed an increasing of the signals at all strips simultaneously in spite of the fact that the beam was hitting just a few strips due to its geometrical collimation. Also due to air ionization the measured conversion coefficient (i.e. a ratio of incident photons to secondary electrons) was equal to few photons per one electron whereas the order of this coefficient in a vacuum is about 5 000 ph/e^- [6]. Summarizing we can conclude that we did not obtain accurate information about beam profile in the atmosphere but it was still possible to work with low intensities beams determining their intensity and core position.

5.2 Measurements of X-ray beam profile in vacuum

At this experiment the MMD was placed inside the vacuum chamber standing on a special table which could be moved horizontally and vertically with micro-level precision. The beam dimensions were 5 mm wide (along the strips) and 0.5 mm high (transversely to the strips). During dynamic mode the detector scans the beam by transverse moving in it.

On Fig. 3 two beam profiles measurements made in a dynamic mode are depicted. The distance between positions of the detector in these measurements is 400 μm. As one can see the X-ray beam profiles are not symmetric and are slightly different. That is explained by the beam intensity reduction (which has been proven by indications of ionization chamber).

6 Conclusions and outlooks

In summary, it was shown that the technology of the micro-strip metal detector allows realizing non-destructive measurements of X-ray intensity distribution as well as beam profile with accuracy of up to 20 μm in vacuum. The developed MMD also proved to be a reliable new tool for the charged particle radiation monitoring in a wide range of aplications. We have performed studies demonstrating a good performance of the MMD in the focal plane of a mass-spectrometer. Further developments of the MMD technology includes:

- Improving position resolution (up to sub-micron level) by applying electron

lithography for the strip pattern production
- Applying microchips charge integrators and scalers

7 Acknowledgments

We appreciate an essential help provided by A. Ehnes and T. Kracht during the MMD tests at HASYLAB. These studies have been performed within the Agreement between DESY and KINR and financial support from the DESY site.

8 Figure captions

Fig. 1: MMD principle of operation

Fig. 2: MMD view. There are enlarged sensor strips in the circle (32 strips: 40 μm width, 70 μm pitch)

Fig. 3: Two beam profiles measured at different positions of MMD in dynamic mode. The distance between detector positions is 400 μm

References

[1] N. M. Tkatch, V. A. Kiva, Scientific Papers of the Institute for Nuclear Research, No. 2(4) (2001) 72.

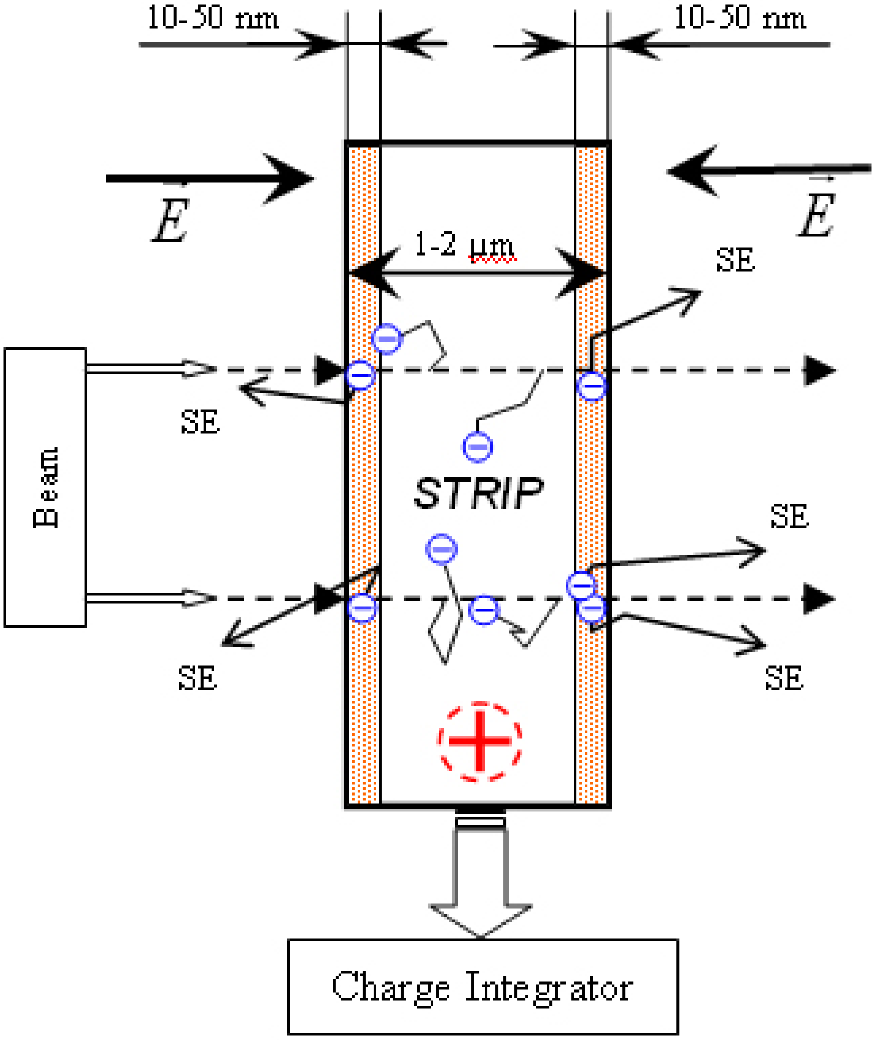
[2] E. J. Sternglass, Theory of Secondary Electron Emission by High-Speed Ions // Phys. Rev. 1957. - 108. p.1 - 12.

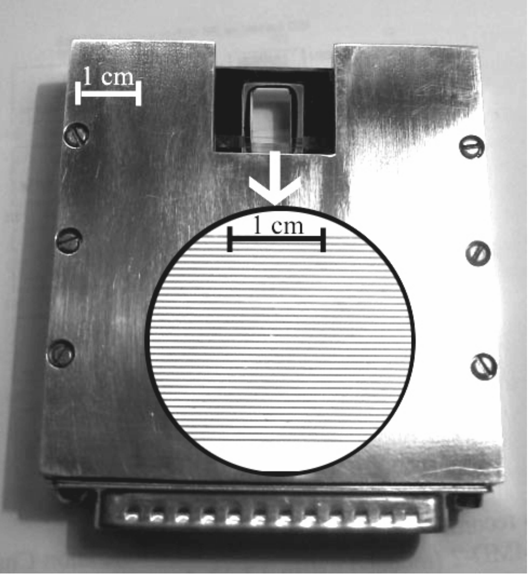
[3] H. Rothard et al., in: Springer Tracts in Modern Physics, Springer, Berlin, (1992) 97.

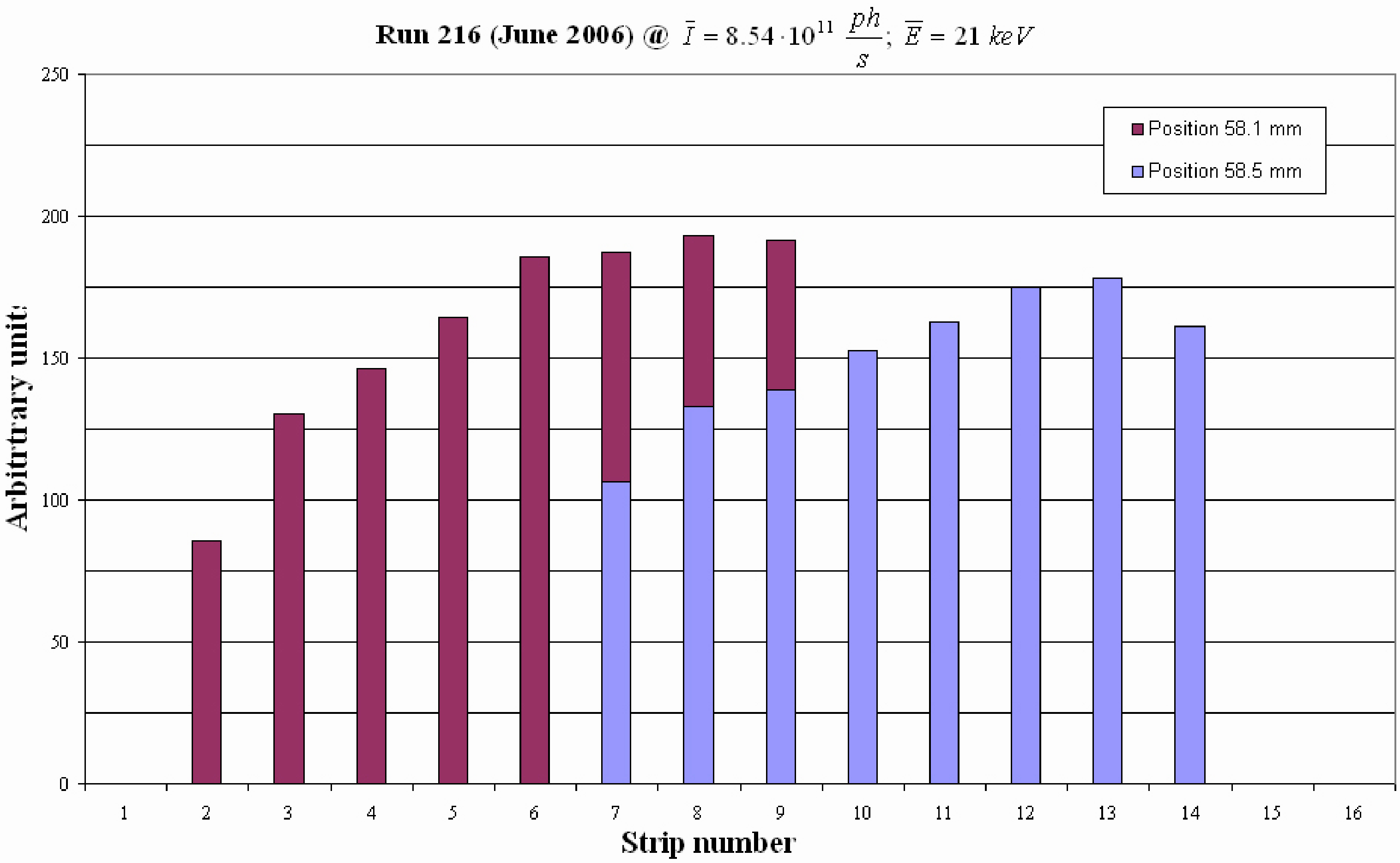
[4] O. Fedorovich et al., Plasma technologies for manufacturing of metal microstrip detectors of ionizing radiation. 11th International Conference on Plasma Physics and Controlled Nuclear Fusion, 11-16 Sept. 2006, Abstracts, p. 172, Alushta 2006.

[5] N. van Bakel et al., The Beetle reference manual, Version 1.0, LHCb Note 2001-046 (2001).

[6] V. Pugatch et al., Micro-strip metal foil detectors for the beam profile monitoring, Proc. DIPAC 2005. Lyon (France). 2005. p. 18 - 20.


10-50 nm
10-50 nm
$\vec{E}$
$\vec{E}$
1-2 µm
SE
SE
SE
SE
SE
Beam
STRIP
Charge Integrator


1 cm
1 cm


Run 216 (June 2006) @ $\bar{I} = 8.54 \cdot 10^{11} \frac{ph}{s}$; $\overline{E} = 21\ keV$
Position 58.1 mm
Position 58.5 mm
Arbitrtrary unit
Strip number
0
50
100
150
200
250
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16