METAL MICRO-DETECTORS: DEVELOPMENT OF "TRANSPARENT" POSITION SENSITIVE DETECTOR FOR BEAM DIAGNOSTICS

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Metal Micro-strip Detector (MMD) represents a novel position sensitive detector for wide range of applications. The main advantages of MMD are low thickness, high radiation resistance and high spatial resolution. MMD production technology includes some stages: micro-strip layout made by photo-lithography on silicon wafer, plasma-chemistry etching of the silicon wafer in the operating window, micro-cabling connection to the readout electronics and DAQ. Commercially available read-out systems (VA_SCM3 microchip preamplifier, Time Pix readout chip, Gotthard, X-DAS) have been studied for use with MMD. Characterization studies of the MMD are presented in details.

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INTRODUCITION

MMD is a 0.5…1.0 micrometer thick semi-transparent radiation hard micro-strip detector designed for non-destructive online measurements of radiation beam parameters. It has been developed at the Institute for Nuclear Research NASU for the beam profile monitoring of the synchrotron radiation as well as for the charged particles beam profile monitoring. The current technology allows for production of the thin (~1 µm) Ni-strips with a pitch of about few micrometers, providing high position resolution.

MMD advantages are:

• extremely low thickness of sensor (about 1 µm) - unreachable in other types of micro-detectors;

• high radiation resistance (>100 MGy);

• transparency for charged particle beams (transmittance up to 90%) allows for including MMD into a feedback system for focusing and stabilization of a beam;

• low operational voltage (20 V);

• high spatial resolution (5…25 µm);

• unique, well-developed production technology;

• commercially available read-out hardware and software;

• reliable performance.

MMD applications are rather wide:

• diagnostics at accelerators and synchrotron radiation sources;

• imaging hidden objects exploring micro-beams (micro-electronics, medicine, microbiology, etc.);

• electronic focal plane in mass spectrometers, electron microscopes, X-ray diffractometers et al.;

• visualization and detection of hot plasma emission.

PRINCIPLE OF OPERATION

The principle of MMD operation is based on the phenomenon of Secondary Electron Emission (SEE) [1]. Beam of charged particles or photons (Fig. 1) passing through the thin strip initiates SEE resulting in thereby a positive charge. The charge is measured by high-sensitivity charge integrator (ChI) connected to the strip. To improve extraction of secondary electrons (SE) accelerating electric field is created around the strip.

As far as a primary role in SEE belongs to a thin near-surface layer of a metal (10…50 nm thick) this provides an opportunity to create ultra-thin detectors with minimum mass of detecting material without any losses in the sensor sensitivity.

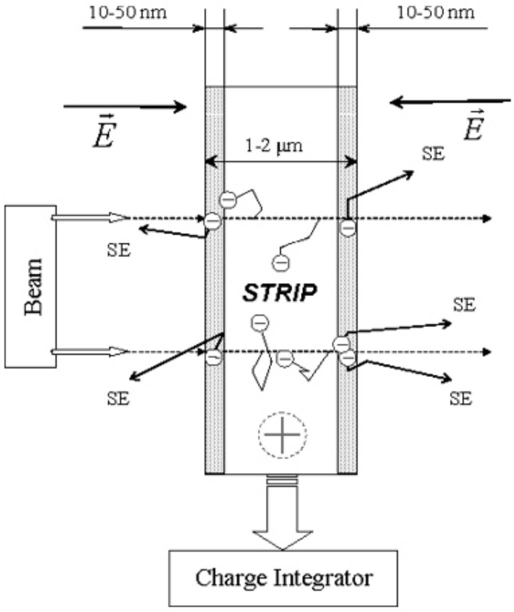

Fig. 1. Principle of operation of MMD

Currently available microchip based readout systems (VA_SCM3, Gamma Medica – Ideas, Norway, Time Pix (Medipix Collaboration, CERN), X-DAS (Sens-Tech, UK) provide high sensitivity and performance.

TECHNOLOGY OF PRODUCTION

Production technology of MMD [2] has been significantly improved during last few years (Fig. 2). Main stages of it are described below.

For MMD production silicon substrates are mainly used as far as microelectronic technologies of silicon processing are well developed.

The silicon wafer (400…480 μm thick, 100 mm in diameter) is used as a substrate. For creation of isolation layer silicon substrate is oxidized. The layer of silicon nitride (Si_3N_4) 0.1…0.2 μm thick is disposed on SiO_2.

A silicon substrate prepared in this way is covered by photo-resistive layers from both sides. By means of a photolithography the required geometry for Ni-strips is provided. Chemical etching of nickel is processed to obtain the figure set by a lithography (providing exact overlapping of layouts from both side).

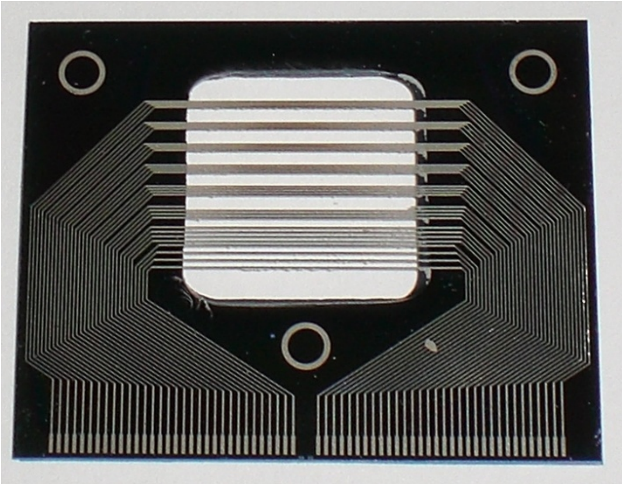

Fig. 2. Photo of the MMD with variable pitch (8 groups of strips with pitch varying from 3 to 300 μm)

Next step is removing out of a silicon substrate together with SiO_2- and Si_3N_4-layers in an operating area of the detector. This is realized by using plasma-chemistry or chemical etching or their combination.

The plasma-chemistry reactor with adjustable energy of ions [3] has been developed. The energy of chemically active ions in this reactor is adjusted by means of controlled magnetic fields in the range of 20…700 eV. The optimal etching speed is about 2.5 μm/min at the ion energy of 80 eV and discharge current of 7 A.

In this way MMD-sensor is produced with completely removed Si-wafer in the operating window without damaging nickel strips.

This technology has been successfully explored for the MMDs production with up to 1024 strips (10 …200 μm width, up to 8 mm long) surviving during long term of conservation and operation.

CHARACTERIZATION STUDIES

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) [3].

The MMD was applied successfully for the X-rays beam profile monitoring at HASYLAB (DESY, Hamburg) [4]. MMD (32 Ni strips, 70 μm pitch, 2 μm thickness) has been introduced into the 15 keV X-ray beam ($4.5 \cdot 10^{14}$ photons/second/mm^2). The conversion factor has been evaluated as $1.5 \cdot 10^4$ photons/e.

Mass-distribution of low energy ion beams was measured at the focal plane of the laser mass-spectrometer [5]. Metal Micro-detectors measuring and imaging in real time high level dose distribution of the synchrotron radiation at the Mini-beam Radiation Therapy setup (beam-line ID17, ESRF, Grenoble) have demonstrated reliable performance [6].

MMD has been also applied for the proton beam monitoring at electrostatic accelerator EGP-10K (INR NASU, Kiev) (E_p = 3 MeV, I =1…10 nA). To keep the proton beam axis and the center of the targets we have used specially designed MMD with two sensors rotated by 90° to each other. 24 strips (12x12) have been connected to the X-DAS read-out system. Preliminary tests have shown high sensitivity of this DAQ with linearity up to 20 nC (Fig. 3).

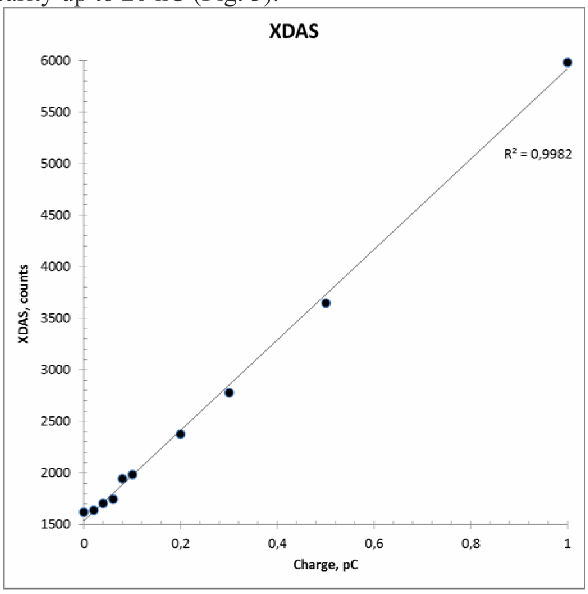

Fig. 3. X-DAS linearity test

Original software provides online monitoring and saving the data. Beam positions as well as beam profile (Fig. 4) have been measured with high spatial resolution (70 μm).

Measured data have been successfully used for optimization of the beam tuning.

CONCLUSIONS

New technology for production of “transparent”, high sensitive, radiation hard metal micro-strip detectors has been successfully developed. Studies at different radiation facilities have demonstrated reliable performance as well as advantages of MMDs.

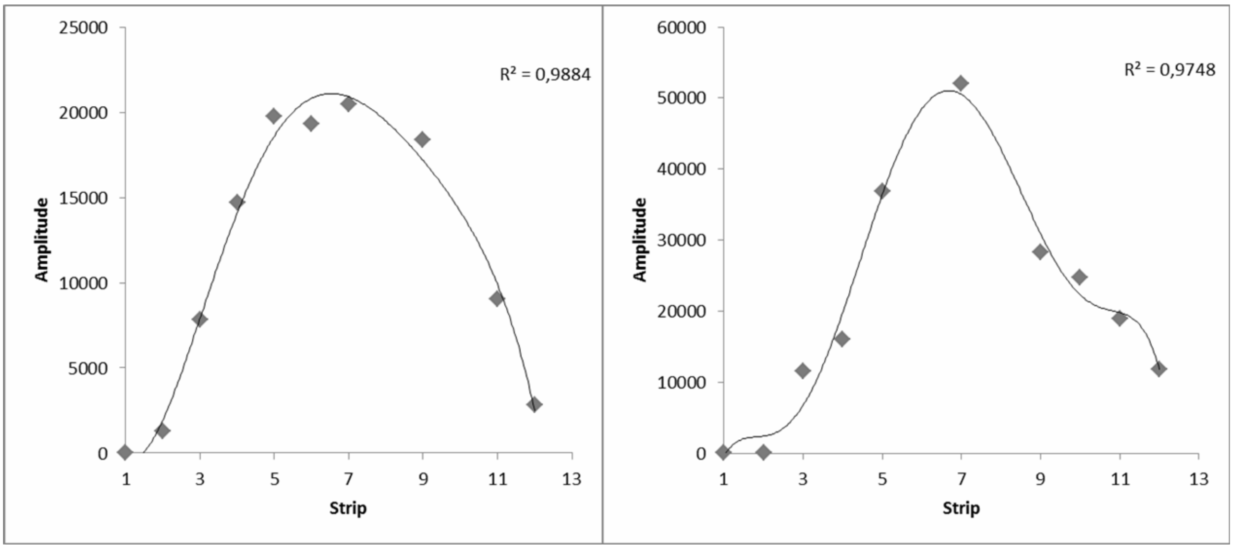

Fig 4. Proton beam profile measured by MMD (X axis – left, Y axis – right)

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МЕТАЛИЧЕСКИЕ МИКРО-ДЕТЕКТОРЫ: РАЗРАБОТКА «ПРОЗРАЧНЫХ» ПОЗИЦИОННО-ЧУВСТВИТЕЛЬНЫХ ДЕТЕКТОРОВ ДЛЯ ДИАГНОСТИКИ МИКРОПУЧКОВ

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Металлический микростриповый детектор (ММД) представляет собой новый позиционно-чувствительный детектор для широкого спектра применений. Основные преимущества ММД: малая толщина, высокая радиационная стойкость, высокое пространственное разрешение. Технология производства ММД включает в себя несколько этапов: микростриповая структура создается при помощи фотолитографии на кремниевой пластине, плазмо-химическое травление кремниевой пластины в рабочем окне, подключение микро-кабелем к считывающей электронике. Коммерчески доступные системы считывания и обработки данных (VA_SCM3, TimePix, Gotthard, X-DAS) были изучены для использования с ММД. Представлены результаты исследований MMD на пучках разных частиц.

МЕТАЛЕВІ МІКРО-ДЕТЕКТОРИ: РОЗРОБКА «ПРОЗОРИХ» ПОЗИЦІЙНО-ЧУТЛИВИХ ДЕТЕКТОРІВ ДЛЯ ДІАГНОСТИКИ МІКРОПУЧКІВ

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Металевий мікрострiповий детектор (ММД) являє собою новий позиційно-чутливий детектор для широкого спектру застосувань. Основні переваги ММД: мала товщина, висока радіаційна стійкість, висока просторова роздільна здатність. Технологія виробництва ММД включає в себе кілька етапів: мікрострiпова структура створюється за допомогою фотолітографії на кремнієвій пластині, плазмо-хімічне травлення кремнієвої пластини в робочому вікні, підключення мікро-кабелем до зчитуючої електроніки. Комерційно доступні системи зчитування й обробки даних (VA_SCM3, TimePix, Gotthard, X-DAS) були вивчені для використання з ММД. Представлено результати дослідження MMD на пучках різних частинок.