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FEATURES OF THE METAL MICROSTRIP DETECTORS FOR BEAM PROFILE MONITORING

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Abstract

Features of Metal Microstrip Detectors (MMD) are presented for application in beam profile monitoring of charged particles and synchrotron radiation beams. Through an innovative plasmachemistry etching production process, thin metal micro-strips only 1–2 µm thick are aligned. Because of the very thin nature of the strips, the MMD is nearly transparent, and can be used in situ for measuring, tuning and imaging the beam online. Metal structure of sensors guaranties high radiation tolerance (about 100 MGy) providing their stable response to the beam particles (by the secondary electron emission) independent upon the accumulated fluence. The spatial resolution of the MMD is determined by the strips pitch constituting from 5 to 100 µm in currently manufactured samples. The data obtains with MMDs read out by the low noise X-DAS system providing integration time from 1 to 500 ms, and the ability to process signals in real time. The scope of MMD & X-DAS is scientific and applied research using beams: in control systems of accelerators and synchrotron radiation sources. New possibilities are discussed for equipment requiring high spatial resolution and radiation hardness.

INTRODUCTION

Beam diagnostics is an important component of any accelerator. In modern experiments in high-energy physics, particle fluxes reach extremely large values. The increase in intensities and energy leads to an increase in radiation loads on the detector systems. It is known that silicon, scintillation and other detector systems used in most experiments have limited radiation resistance, and at too high radiation fluxes lose their performance. In addition, the main requirement for conducting physical experiments is that the measuring device must not distort the measured value. To date, most detector systems do not meet this statement. In this case, the requirements for detector systems for precision measurements are only increasing. Medical accelerators play a special role in this task, because the life and health of patients depend on the precision of the accuracy and intensity of the beam. A detector system that would independently control the position, size and intensity of the ionizing radiation beam would significantly increase the reliability and safety of irradiation.

This paper describes a detector system that can be used to monitor a beam for various types of radiation therapy, and for accelerators used in high-energy physics experiments. The direction of research is the development of detectors based on the phenomenon of secondary electron emission. Features of secondary electron emission allow to create structurally simple reliable detector systems for monitoring the flow of charged particles and X-rays. This type of detectors includes metal microstrip detectors presented in this article [1–4].

METAL MICROSTRIP DETECTOR

A distinctive feature of MMD from micro-detectors based on semiconductor or insulating materials, which either completely absorb the investigated beam or significantly deform it, metal sensor is almost ideal operation as a measuring and monitoring device without distorting the characteristics of the investigated particle beam or synchrotron radiation. The MMD sensor is made entirely of metal, making this detector one of the most radiation-resistant.

Principle of Operation

Figure 1 shows the operation principle of an MMD second emission monitor grid with ultra-thin wires/strips. One end of each strip is connected to a charge integrator or other measuring system and the other to a stable current source. Incident x-rays on the strips initiate secondary electron emission as they pass through the nearly transparent medium. When this happens, a positive charge appears at the integrator end and is measured.

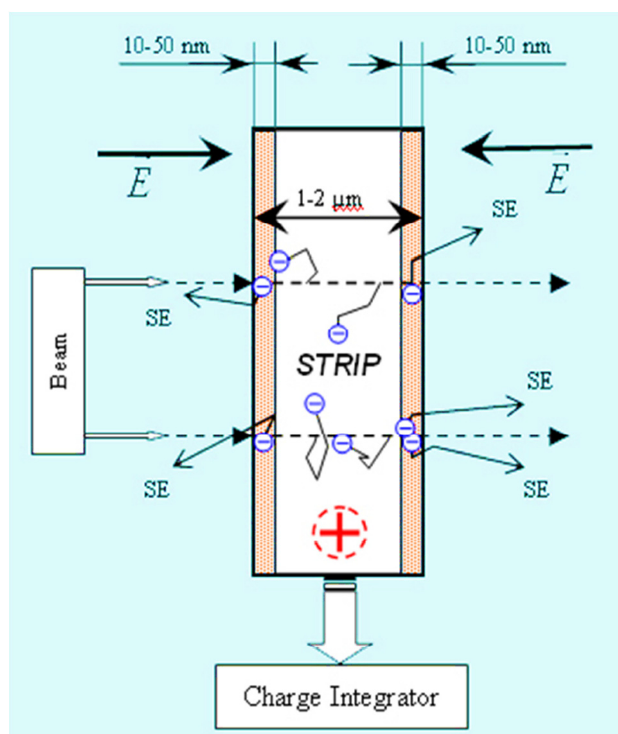

Figure 1: Operation principle of MMD.

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To improve the extraction of secondary electrons, an accelerating electric field is applied around the strip. This technology works with x-rays, proton and ion beams. Additionally, the strips are 99.9% transmitting to x-rays, significantly reducing radiation degradation that is experienced by absorbing detectors.

MMD PRODUCTION TECHNOLOGY

The design, technology and structure of MMD are determined by the principle of operation and application requirements. The main feature of MMD, which determines the complexity of the production process, is the micrometric size of the bands that serve as sensors. Figures 2 to 4 show MMDs for different purposes.

Figure 2: MMD 1024, 1024 strips with a pitch of 60 µm for heavy ions registration in mass spectrometry.

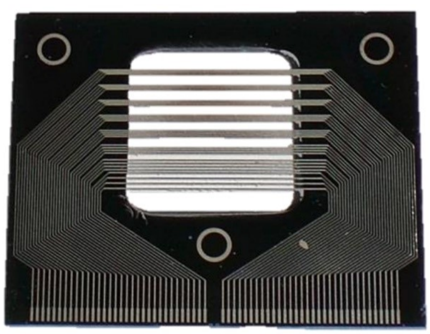

Figure 3: MMD32v, 32 strips with variable pitch (2 to 300 µm) for micro-beams focusing.

Figure 4: MMD64, 64 strips with a step of 100 µm – for XY-positioning and profiling of mini- and micro-beams of charged particles and X-ray radiation.

MMD production technology includes micro photolithography, plasma chemical etching and assembly. These steps are briefly described below. The sensor layer of the prototype MMD may include from 1 to 1000 strips with a maximum length of 15 mm (at greater length, they begin to tear) with a width of 5 to 100 µm. The strips are placed on a silicon wafer with a thickness of 500 µm or 300 µm. Each band is connected to an individual input channel of the reading electronics.

Photolithography

Two dielectric layers are created on the silicon wafer to insulate future nickel bands from the semiconductor. Initially, silicon oxide (SiO_2, 0.1-0.3 µm thick) is grown and subsequently coated with silicon nitride 0.2 µm thick (Si_3N_4). To improve adhesion, the dielectric layer is covered with a thin titanium film (about 50 nm). Finally, a nickel film 1–2 µm thick is applied. This multilayer structure is created on both sides of the silicon wafer. Strips with connecting plates are formed on the front side by photolithography methods, while on the back side of the Si-plate a nickel mask for future plasma chemical etching is stored.

Plasma Chemical Etching

To remove silicon from the working zone of MMD (due to which the metal strips hang freely there), a plasma chemical reactor is used in KINR with variable ion energy. First, with the help of an additional mask made of metal foil on the front side of the plate, a thin surface layer (20–80 µm) of silicon is removed. Then, through a rectangular window on the back, plasma chemical etching is performed. The initial etching rate is in the range of 2–5 µm per minute at an ion energy of 80 eV and a current of 10 A. When the thickness of the silicon wafer approaches 50–100 µm in the working area of the sensor, the etching rate slows to 0–3 µm per minute, the current decreases up to 4 A, and the energy of ions up to 20 eV. Thus, it is possible to make MMD with completely remove silicon from the working area and leave only nickel strips. In the same way the accelerating layers are made. The only difference is the number of bands: the accelerating layers have two bands located at a distance that is slightly wider than between the outer bands of the sensor layer. In the same way the accelerating layers are made. The only difference is the number of lanes, the accelerating layers have much fewer sprays.

Assembling

The sensor and high voltage are glued to special ceramic plates. Ceramics connected to the PCB base also with glue. Each strip is connected by supersonic welding with metallization on an adapter, which can be in the form of a flexible polyamide multichannel cable or in the form of prepared PCB. The entire structure is locked in a protective metal frame to avoid mechanical damage and electromagnetic interference. The X-DAS connection to detector is provided by Samtec LSHM connectors. The reading system is connected directly to the computer, and the corresponding software presents the data online on the computer display.

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DATA ACQUISITION SYSTEM

The MMD requires special reading equipment. The sensor reading system have to be highly sensitive, radiation resistible and has other characteristics to satisfy capabilities of the MMD.

Sens Tech X-DAS System

The XDAS reading system, which is a modular system for a wide range of applications, best meets the requirements of MMD. XDAS is a very flexible system. It allows you to create large detector arrays that are read simultaneously in an accessible digital format. The XDAS system has a modular architecture, which allows you to operate freely by placing detector modules in space. The system consists of Detector Head Boards (XDAS-DH) with analogue output and Signal Processing Boards (XDAS-SP) with 16-bit digital output. Each detector module has 128 channels. With a USB2 adapter, the output is transferred to a PC. The number of read strips in the system reaches 21.504 (128x24DHx7SP). The system has low electronic noise, dynamic range on the maximum charge at the input from 3 pC to 60 pC. The minimum signal integration time is 60 µs with simultaneous data accumulation and reading. The dynamic range of the output signals is 16 bits.

The inputs of the reading system are connected to the microstrip sensors by means of specially designed and manufactured adapters. Connect to a control computer via a USB 2.0 or Ethernet port. The number of samples in each of the 128 registration channels (maximum 65536 samples) corresponds to the intensity of the quanta registered in a particular channel. Gamma quant energy – from 10 keV.

CHARACTERISATION OF THE MMD+X-DAS SYSTEM

To characterize the bundle of microstrip metal detector and X-DAS reading system, studies were carried out on a Pu-239 alpha particle source and on a tandem generator with protons. The measurements were carried out with different detector models, in vacuum and atmosphere.

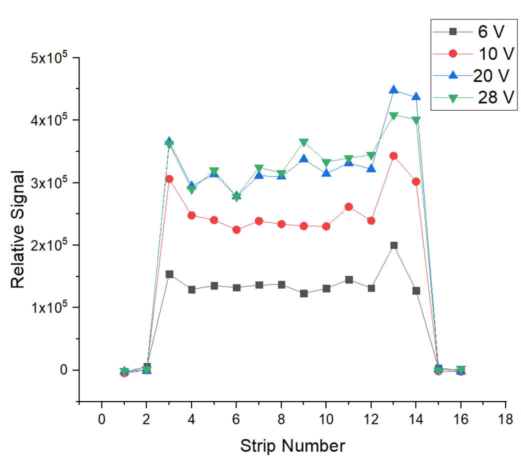

Figure 5: Dependency of the detector response on the voltage at the accelerating electrodes.

MMD Studies on Alpha Source Pu-239

Measurements of a 16-channel microstrip detector with a X-DAS reading system on alpha particles with an energy of 5.24 MeV from the Pu-239 isotope were performed. Figure 5 shows the dependence of the detector response on the voltage at the accelerating electrodes.

Research on the Tandem Generator KINR NASU (Kiev)

Characteristic studies of MMD operation on a proton beam were performed on a tandem generator of the Kyiv Institute for Nuclear Research of the NAS Ukraine in a vacuum chamber on the central ion pipe of the proton hall. For these studies, a detector with two microstrip metal sensors MMD64, specially designed for two-dimensional measurement of the beam profile of charged particles (see Fig. 6), was prepared [5].

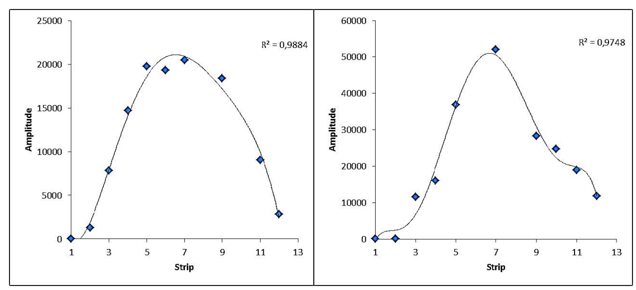

Figure 6: Spatial (horizontal and vertical) Proton beam profiles.

The detectors were mounted in an aluminium frame with a 25-pin D-Sub connector. 12 strips were connected from each sensor. This number of strips was chosen due to the limited number of electrical connectors on the vacuum chamber (see Fig. 7).

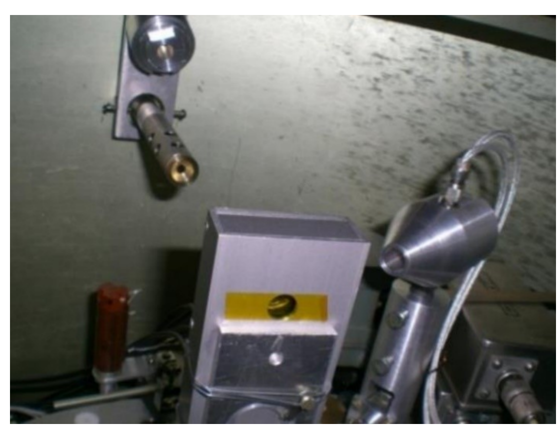

Figure 7: Photo of MMD installed in an accelerator vacuum chamber.

Figure 8 shows a photo of the studied sensor (nickel strips thickness: 2 µm, step: 100 µm, width: 40 µm). Two sensors are mounted on top of each other forming an angle of 90 degrees between the strips, to obtain a two-dimensional intensity distribution of the studied beam.

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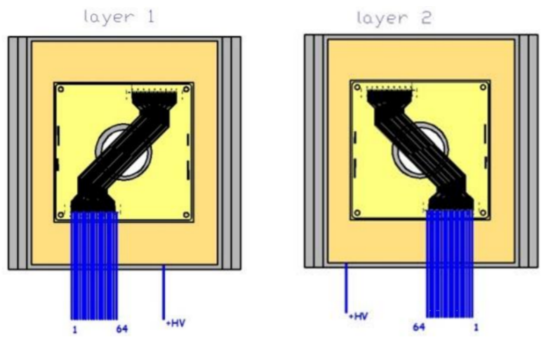

Figure 8: Layout of sensors in the MMD-64 detector.

CONCLUSION

Micro-strip metal detectors of various shapes and types for measuring the profile and position of charged particle beams in the atmosphere and in vacuum have been developed and manufactured.

MMDs of various configurations, made in the Institute of Nuclear Research of the National Academy of Sciences of Ukraine according to the original technology of plasma-chemical etching. The thickness of the sensors is 1–2 µm, the step is from 2 µm, the number of strips is up to 1024. The possibility of using mmd with a commercially available multi-channel X-DAS reading system has been tested.

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