MICRO-STRIP METAL FOIL DETECTORS FOR THE BEAM PROFILE MONITORING.*

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Abstract

The Micro-strip Metal Foil Detectors (MMFD) designed and used for the Beam Profile Monitoring (BPM) are discussed. The results obtained for the MMFDs produced by different technologies are presented. The MMFD deposited onto the 20 μm thick Si-wafer has been used for the BPM of the 32 MeV alpha-particle beam at the MPIfK (Heidelberg) Tandem generator. Another MMFD with totally removed Si-wafer at the working area has been applied for the on-line X-ray BPM at the HASYLAB (DESY).

INTRODUCTION

Current developments in fundamental and applied research require non-destructive 'on-line' profile monitoring of micro-beams. For low intensity beams a proper approach could be realized by using silicon micro-strip detectors successfully progressing last two decades. Manufacturing technology allows for a position resolution at sub-micron level. Yet, radiation hardness aspect makes this approach rather limited. The experience was reported [1] for the high intensity micro-beam profiling by means of fine strips supported by thin membranes. In this paper we present the first results of the beam profiling by the MMFD manufactured by different lithography and etching technologies. The MMFD deposited onto the 20 μm thick Si-wafer has been used for the BPM of the 32 MeV alpha-particle beam at the MPIfK (Heidelberg) Tandem generator. Another MMFD with totally removed Si-wafer at the working area of (8 x 10) mm^2 has been applied for the on-line X-ray beam profile monitoring at the HASYLAB (DESY).

MMFD PHYSICS AND TECHNICAL DETAILS

The general physics and registration principles of the Metal Foil Detector (MFD) are discussed in details somewhere [2]. Charged particles (or photons) hitting a metal sensor-foil initiate Secondary Electron Emission (SEE) at 10-50 nm surface layers, mainly [3, 4]. The electron yield is measured by a sensitive Charge Integrator connected to a sensor. To stabilize the electron yield two accelerating and two grounding foils are surrounding the sensor from both sides, creating complete MFD setup as a 5-layer structure. The first SEE monitor has been built in 1955 [5] and in its later modifications a typical position resolution was in the range of a millimeter. We have applied the technology developed for the silicon micro-strip detector manufacturing to produce metal micro-strip detectors for the purposes of the precise beam profile monitoring. 16 or 32 narrow metal strips(10-50 μm width, 20 - 100 μm pitch) are individually connected through the UHV feedthroughs to Charge Integrators (ChI). ChI designed and built for that purpose by the joint effort of the KINR (Kiev) [6] and Max- Planck Institut für Kernphysik (Heidelberg) have reached a fA level of a sensitivity, also due to the direct conversion of the measured current into the output frequency. Some of the advantages of the Micro-strip MFD BPM are as follows:

- Extremely low mass of the detecting material.
- Simple structure (thin, up to few tens nano-meter, metal strips self-supported in the operating area at Si-wafer).
- Low operating voltage ($\approx$ 20 V), which provides nearly total charge collection.
- Simple read-out electronics (charge integrators and scalers).
- Very high radiation tolerance (at Gigarads level).
- Position resolution of 1 μm is in the reach for the current manufacturing technology.
- Profile monitoring of a bunch train (below thermal electron emission threshold).
- Bunch by bunch profile monitoring possible.

The last two items are prospective for the MMFD connected to the readout microchip [7]. We have built and tested few prototypes of the Micro-strip MFD for the Beam Profile Monitoring (BPM).

MMFD SETUP FOR THE MONITORING OF THE 32 MEV HE-3 BEAM.

The first MMFD monitor has been used for the on-line control, positioning and focusing charged particles beam (32 MeV alpha-particles at the MPIfK (Heidelberg) Tandem generator for SEU (Single Events Upset)studies of the BEETLE chip [7].

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Sensors Preparation and MMFD Layout

The sensors have been manufactured by photo-lithography technology used for the silicon micro-strip detectors production and wet chemical etching. The 32 strips (pitch 30-35 μm) are 1 μm thick, 10 μm wide Al ribbons deposited via masks onto a Si-wafer (460 μm thick) over 0.1 μm thick Si_3N_4. A narrow rectangular window of (6 x 10) mm^2 was made by chemical etching of a Si-wafer in the part to be introduced into the beam. The thickness of the beam window (20 μm thick) has been optimized with respect to the mechanical stability and heat dissipation.The rigid surface of the Si-wafer provides reliable mechanical stability of the thin metal layers (which could be in the range of 0.1 μm resulting in the same physical signal of the SEE), and being still massive carrier of the heat load. Using adapter cable one side of strips is connected to the calibrating current source and the opposite one to the read-out Charge Integrator. This defines well the way of the charge transportation from the beam-strip interaction area. The sensor layer is surrounded from both sides by metal layers (grids) biased by a low positive voltage. The voltage accelerates secondary electrons and provides their efficient removal from sensors resulting in a 5 times larger signal at the Charge Integrator input. This 3-layer structure is finally surrounded from both sides by metal layers which should be well grounded to make an efficient shielding of the device. The above mentioned auxiliary metal layers are 1 μm thick, supported by the Si-wafers etched in a way similar to the sensor's case. Thus, the complete MFD is a 5-layer structure made out of thin metal foils. The sensitivity of the MMFD to the radiation flux is determined by the sensitivity of the charge integrators as well as by fluctuations of the charge at their input due to the leakage currents, temperature/humidity impact, r/f pick-up etc.

There is a big concern with respect to the MFD strip breakage [1]. The 5-layer structure of the MMFD has to prevent microwave heating which was considered as amajor cause of the wire breakage. The complete MFD prototype introduced into the beam 3 μm thick Al and 30 μm thick Si, in total. Connection of both ends of the micro-strip to the Charge Integrator has three-fold task: monitoring of the integrity of the micro-strip; limiting of the current through the strip by introducing serially a 1 GOhm resistor and finally providing a possibility of a correction of systematic error related to a variation of the charge integrator baseline and/or sensitivity. The level of an output frequency fluctuations measured from the stable calibrating current is in the range of +/- 2 Hz. The dynamical range is 1500 with a possibility to adjust the input current to be measured from 10 fA to 10 μA. The charge integrator read-out is provided by the vme-based 32 channel scaler with a software allowing for on-line beam profile monitoring also measured during specified time windows.

This setup has allowed to perform the study of the readout micro-chip BEETLE-128 with respect to the Single Event Upset probability. The He-3 beam intensity distribution over different parts of the chip has been measured by the MMFD and used for the SEU cross-section evaluation [7].

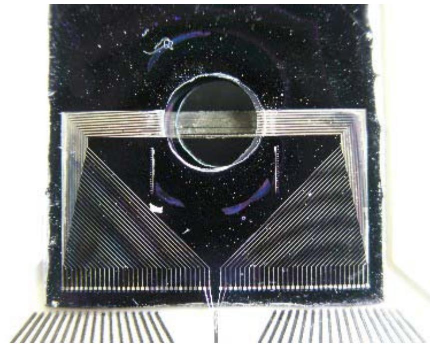

Figure 1: Metal Foil Micro-strip Detector (the HV-layer and sensor layer are visible). The operating window with totally removed Si-wafer (diameter 8 mm) is in the center. The calibrating current feeds through the left/right hand pads and strips.

EXPERIMENTAL SETUP AT HASYLAB

There are considerations to apply the micro-stip MFD for the undulator radiation monitoring at the PETRA facility (similar to the device described in [8]). We expect an improved performance of the MFD detector in comparison with [8] due to its 5-layer structure as well as much better spatial resolution should be obtained.

Sensors Preparation and MMFD Layout

The sensors were prepared by means of micro-electronics technology and plasma-chemistry etching. To isolate a metal film from the wafer the dielectric layers were grown up on both sides of a wafer. At first, the silicon oxide (0.1 - 0.3 μm thick) was grown up covered later by 0.2 μm thick silicon nitride. A thin (0.1 μm) titanium layer was deposited onto dielectric layers. Afterward, nickel (0.5 μm) layers covered finally by silver layers (0.6 μm) served as films for the photo-lithography shaping of the strip pattern as well as contacting lines and pads.

A window from the back side has been created for the plasma-chemistry etching. The KINR plasma-chemical reactor with variable ion energy has been used. The initial etching speed was in the range of 2.5 μm/min at the ion energy of 80 eV and discharge current of 10 A. When the silicon wafer thickness approached 50-100 μm the etching speed was slowed down to 0.3 μm/min by decreasing the current to 4 A and the ion energy to 20 eV. In this way the MMFD (Fig.1) has been manufactured with 30 (out of 32) self-supporting strips (20 μm width, 70 μm pitch) which survived in the operating window with a diameter of 8 mm.

The strips were bonded to the ceramics based pitch adapter and connected by a flexible Kapton isolated cable to the 50 pin-connector and through the additional cable via the UHV feedthroughs to Charge Integrators housed inside

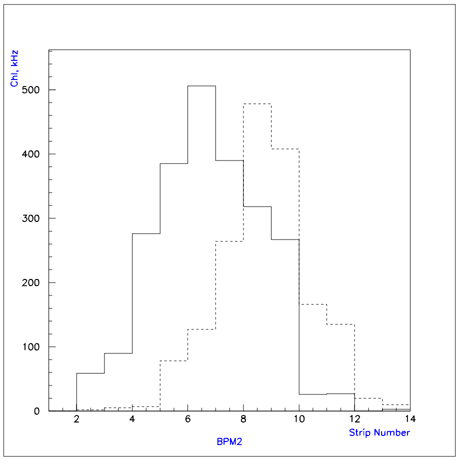

Figure 2: X-ray Beam Profile measured at two MMFD setup positions. The difference between positions is 150 μm.

the NIM crate (3 mm coaxial cables fed the signals from the flange with UHV feedthroughs).

The experiment has been performed at the HASYLAB (DESY) on beam-line BH6. The electron ring PETRA was filled with an injection current ranging from few mA to 40 mA. The beam was monochromated to allow X-ray energies 15 or 18 keV. The beam size was determined by the copper slits and varied from 0.1 to 1 mm in vertical direction while horizontally it was in the range from 1 to 4 mm. The MMFD setup was mounted on a copper cooling table equipped by horizontal and vertical translation stages, allowing positioning and scanning in the plane perpendicular to the beam axis. Fig.2 illustrates a beam profile measured at three fixed MMFD positions (solid and dashed lines) differing by 150 μm. The vertical beam size defined by the slits in that case was 500 μm, which fits well with the width of the intensity distributions shown in Fig.2.

For the X-ray ($\approx$ 15 keV) beam intensity of 4.5 $\times$ 10^{14} photons/second/mm^2) the conversion coefficient (number of photons per single SEE) has been evaluated as (1.5 +/- 0.5)$\times$ 10^4 ph/e. Accordingly to [8] the synchrotron flux of 2 $\times 10^8$ photons/s/100mA/mm^2 with the energy of 8 keV resulted in the SEE-current in their sensors around 0.5 - 1.0 pA. The current we observed in a single strip was in the range of 1 nA. This means that with this setup 3-4 orders of magnitude lower intensity X-ray beams could be well monitored. On the other hand as far as this is very close to the upper limit of the most sensitive charge integrators (1 Hz - 1 fA) to be able to make test at the nominal PETRA current of 50 mA we switched to other charge integrators with a sensitivity of 1 Hz per 1 pA. The preliminary measurements have shown that those charge integrators will provide a reliable beam profile monitoring. Yet, even if the X-ray flux loss inside the MMFD did not exceed 3 $\%$ the problem with overheating of the strips has to be solved, as far as some strips were broken during the test at high intensity X-ray beam (average energy 15 keV, total flux 1.7 $\times 10^{16}$ photons/s over the slit of (1 x 0.5) mm^2.

In summary, one may conclude that the developed technology of the micro-strip metal detector manufacturing allows to provide non-destructive measurement of X-ray intensity distribution over area of up to 50 mm ^{2} with an accuracy of 10-20 μm with a possibility of its improvement by factor of 5. A sub-micron position resolution is expectedly in the reach by applying electron lithography for the strip pattern production.

OUTLOOK

The program of the forthcoming tests of the MMFD at PETRA includes:

- Study of the thermal threshold;
- Profile measurements with very high resolution;
- Noise and Higher Order Mode studies;
- Dynamic range;
- Long term stability of the conversion factor;
- Radiation hardness;
- Damage threshold, etc.

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