Micro-strip Metal Foil Detectors for the Beam Profile Monitoring. Status Report. April 22nd, '04.

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Abstract

Micro-strip Metal Foil Detectors for the micro-beam monitoring are described.

Key words: micro-strip detector, synchrotron radiation, secondary electron emission, charge integration, beam profile monitoring

1 Introduction

To monitor particles beam profile numerous methods have been developed. We report here on the approach based on the so called Metal-Foil-Detectors [1]. We define a Metal Foil Detector (MFD) as a device which measures a flux of particles by means of the charge integration originated in the thin metal foil due to the Secondary Electron Emission (SEE) initiated by the incident particles.

It has been shown that SEE yield under the charged particle bombardment saturates already at the thickness of the foil in the range of few tens nanometers [2,3]. Thus, few μm thick Al foils should provide a low fraction of the radiation length and reliable mechanical stability.

The first SEE monitor has been built in 1955 [4]. Since then various types of the SEE beam profile monitors were built. It was established that the yield of

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the SEE exceeds by factor of 10 directly produced δ-electrons [5].

Concerning radiation hardness and thermal features of the SEE monitors stable operation was established under the impact of the average beam density of 150 μA/cm^2 and fluence of 10^{20} protons/cm^2 [6] as well as low temperature dependence has been observed.

The above mentioned features of SEE served us as a basis for the designing Metal Foil Detectors (MFD) for the charged particle fluxes monitoring. We present briefly some of the MFD which were built and tested during last years. Finally, the Micro-strip MFD designed and built for the micro-beam profile measurements (both for charged particles and synchrotron radiation) is described. Progress and further steps in the work related to the test of built devices at real beams is presented in the Appendix.

2 Experience with Metal Foil Detectors for the Radiation Monitoring.

Physics and registration principles of the MFD are illustrated at Fig. 1. Fast particles hitting a metal foil initiate SEE. SEE occurs at 10-50 nm layers from both foil surfaces. Registration of the positive charge appearing in the foil due to electrons emission is provided by a charge integrator connected to the isolated metal foil.

The first MFD we have used was a single-layer structure explored for the multi-target steering at the HERA-B experiment. The charge integration method proved to be the most reliable tool for the multi-target steering with on-line luminosity equally shared [7].

The HERA-B targets are thin conductive ribbons connected through the UHV feedthroughs to Charge Integrators (ChI) [8] being used at HERA-B since 1996. Few modifications improved their sensitivity by more than 3 orders of magnitude. To suppress the external r/f sources impact the analog signal is converted inside the charge integrator into the output frequency.

The scheme for the Charge Integrator connections is shown at Fig.2. The calibrating current from the stable source permanently flows through the target to the Charge Integrator allowing for checking of its stability as well as monitoring of the target integrity.

The reliability of the luminosity sharing by charge integrators has been verified by reconstructing the distribution of primary interaction vertices on the targets by means of the HERA-B vertex detector [9]. The relative number of

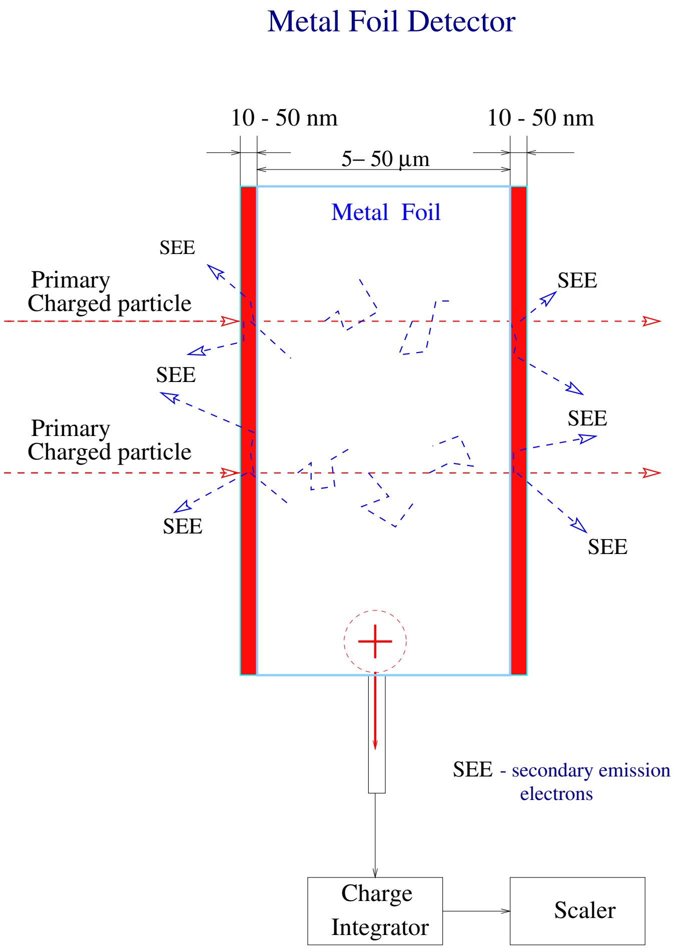

Fig. 1. Schematic view of the MFD

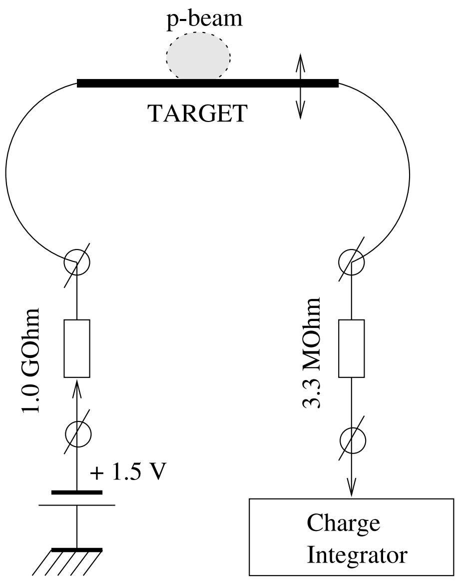

Fig. 2. Charge Integrator connections to the Target.

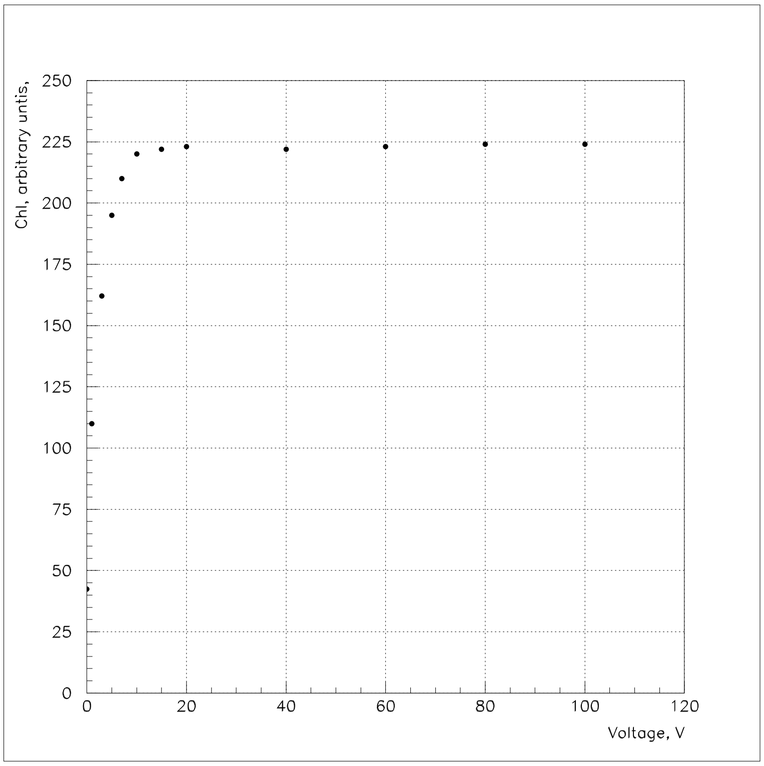

Fig. 3. The MFD response dependence upon the accelerating voltage. 21 MeV protons incident at the 12.5 μm thick Ni-foil surrounded from both sides by similar Ni-foils.

vertices on each target is in a perfect agreement with the partial IR deduced from the ChI rate [10].

The sensitivity of the MFD 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. The charge collection efficiency was significantly improved by placing from both sides of the sensor accelerating foils biased by positive voltage.

Fig.3 illustrates the dependence of the MFD response to the constant proton beam intensity upon the voltage applied to the accelerating foils. The rate saturates already at 20 V in a perfect agreement with the expected prevailing yield of low-energetic secondary electrons. The sensitivity of the MFD has grown up in this way by factor of 5.

To prevent the impact of the external electro-magnetic sources two shielding foils connected to the ground are placed from both sides of the three-layer structure. Thus, the complete MFD is a 5-layer structure made out of thin metal foils (Fig.4).

With the charge integrator sensitivity of 1000 Hz per 1 pA calibrating current, it is possible to measure charged particle flux distribution with an intensity

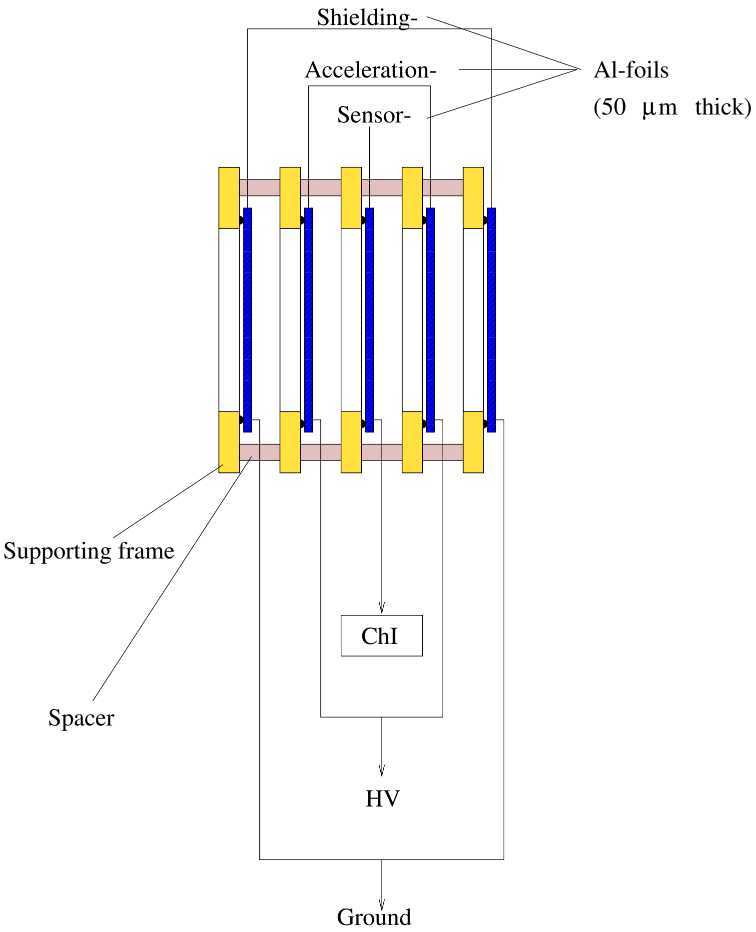

Fig. 4. 5-layer structure of the MFD.

exceeding 10 fA per sensor.

The MFD technology of the MIP fluxes monitoring has been also applied to build a beam profile monitor for characterization studies of the Si-micro-strip detectors for the the LHCb Inner Tracker ([11]) at CERN.

16 X- and 16 Y-sensors (Al, 50 μm thick, 5 mm wide, 6 mm pitch) covering the area of 96 x 96 mm^2 were connected by 3 m long cables to Charge Integrators with a 1000 Hz output frequency per 1 pA input current. The X- and Y-sensors were separated (3 mm distance) by accelerating and shielding Al foils (50 μm thick).

VME based DAQ allowed for the readout of 32 channel VME Scaler, while a corresponding software provided a beam profile image presentation in the control room. The MFD BPM data (Fig.5) have shown perfect correspondence with a similar data measured by a regular BPM devices at CERN (multi-wire proportional chambers).

The reliable performance illustrated by the two-sensor layers of the MFD

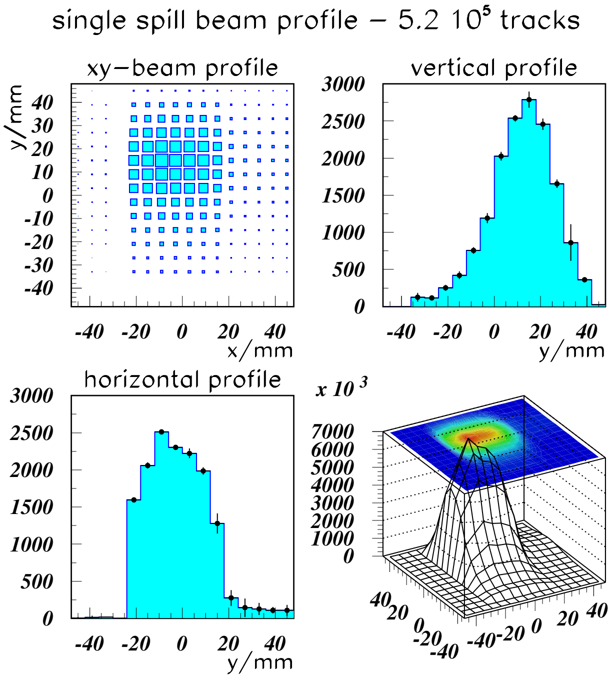

Fig. 5. MFD BPM performance at X7 test beam facility at CERN: 190 GeV muons beam with 5.2 * 10 5 particle per 2.4 s spill.

means also a possibility of building a multi-layer MFD to increase its sensitivity by a factor close to the number of layers.

The MFD monitor of much less size (32 Al strips, 10 μm wide with a 32 μm pitch were deposited onto the 20 μm thick Si-wafer and connected to the ChIs) has been designed and tested for the online 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 [12].

3 Micro-strip Metal Foil Detector for the Beam Profile Monitor.

Few prototypes of the Micro-strip MFD were designed for the Beam Profile Monitoring (BPM) of micro-beams with sigma 10-200 μm. Some sensors were manufactured and proposed for the tests (PETRA, TTF2, ATF, SLC).

Some of the advantages of the Micro-strip MFD BPM are as follows:
1) Extremely low mass of the detecting material.
2) Simple structure (thin, up to few tens nano-meter, metal strips supported by the Si-wafer).
3) Low operating voltage (20 V), which provides nearly total charge collection.

4) Simple read-out electronics (charge integrators and scalers.
5) Very high radiation tolerance (at Gigarads level).
6) Position resolution of 1 μm is in the reach.
7) Profile monitoring of a bunch train (below thermal electron emission threshold).
8) Bunch by bunch profile monitoring possible.

There is a big concern wrt MFD strip breakage [13]. The experience with Wire Scanners [14,15] as well as with the Optical Transition Radiation Beam Profile Monitor [16] suggests to cue the problem by making wires with low Z, thin, well grounded material to provide better charge/heat load dissipation.

Our micro-strip MFD was manufactured by Si micro-strip detectors technology modified to have met the above mentioned constraints. In particular, its 5-layer structure has to prevent microwave heating which was considered as a major cause of the wire breakage. Connection of both ends of the micro-strip wire to the input of the Charge Integrator for pushing through it a calibrating current of 25 pA will make three-fold service: permanent monitoring of the integrity of the micro-wire; make limit of the current through the wire by introducing serially a 1 GOhm resistor and finally provide a tool for correction of systematic error related to possible variation of the charge integrator sensitivity.

The 32 strips (pitch 30-35 μm) are 1 μm thick Al (Ti, Cr) 10 μm wide ribbons deposited onto a Si-wafer (460 μm thick) over 0.1 μm thick Si3N4 Fig.6).

A narrow window (1 - 30 μm thick) is made by etching a Si-wafer in the part to be introduced into the beam.

The thickness of the beam window has to be optimized for the mechanical stability and heat dissipation. One sample has been produced with the Al-strips just being free stretched over the beam-window while for others the thickness varies from 5 to 30 mum. The rigid surface of the Si-wafer provides reliable mechanical stability of the thin metal layers (which could be in the range of 0.1μm resulting in the same physical signal of the SEE), and being still massive carrier out the heat load.

Using adapter cable (Fig.7) 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. On the other hand, the on-line monitoring of the strip integrity and the MFD performance is provided in this way, as well as it could serve as an additional filter for high frequency r/f pick-up.

To get rid of any impact from the external sources of the background the complete MFD is a 5-layer structure (see Fig.4).

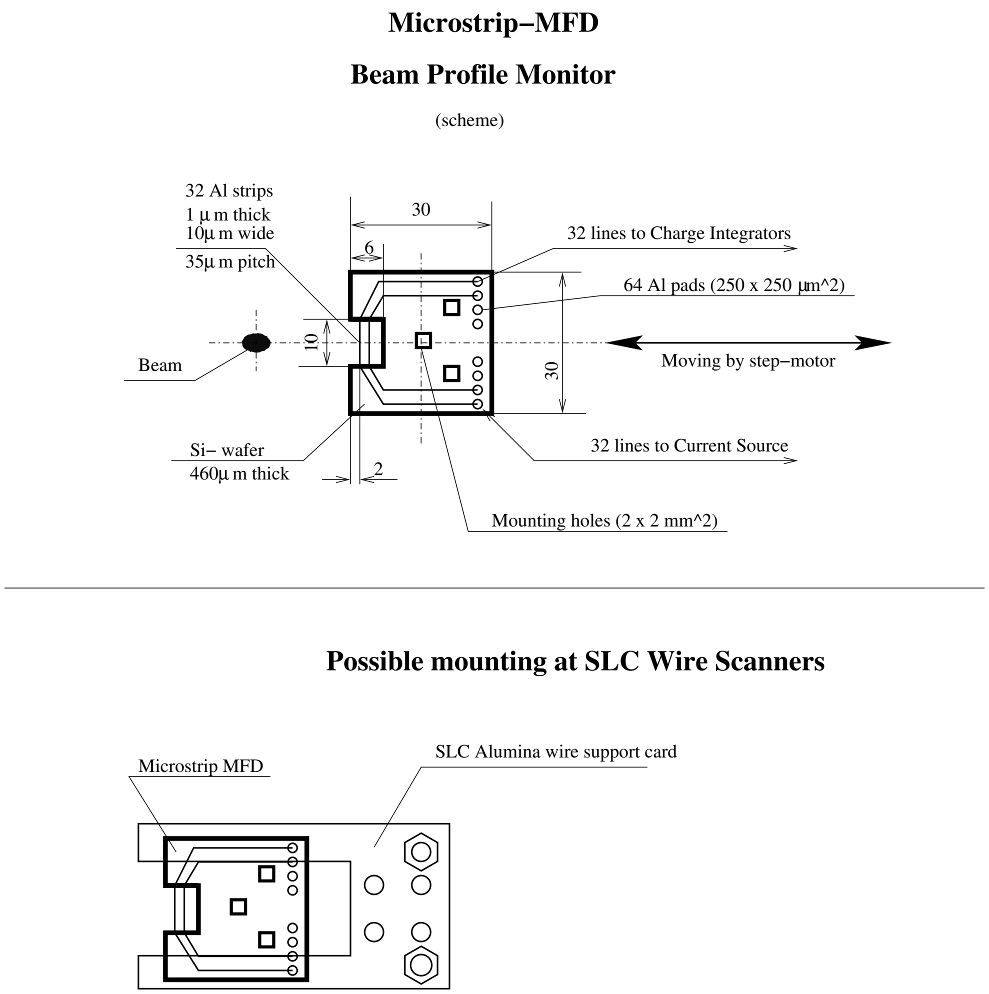

Fig. 6. Scheme of the micro-strip MFD.

The sensor layer (described above) is surrounded from both sides by metal layers (grids) (Fig.8) biased by a low positive voltage, accelerating secondary electrons and providing by their efficient removal from sensors also 5 times larger signal at the Charge Integrator input.

This 3-layer structure is finally surrounded again 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. As far as the beam size is in the range of 1 mm the grid (Fig.8) could be replaced by a single pixel/circle made out of 1 μm thick Al wire. It will be deposited onto the auxiliary Si-wafer from one side while from another one (after the etching) the grounding layer is deposited.

Thus, the complete MFD prototype would introduce into the beam 3 μm thick Al and 5-10 μm thick Si, in total. This could be reduced to fewμm altogether, later.

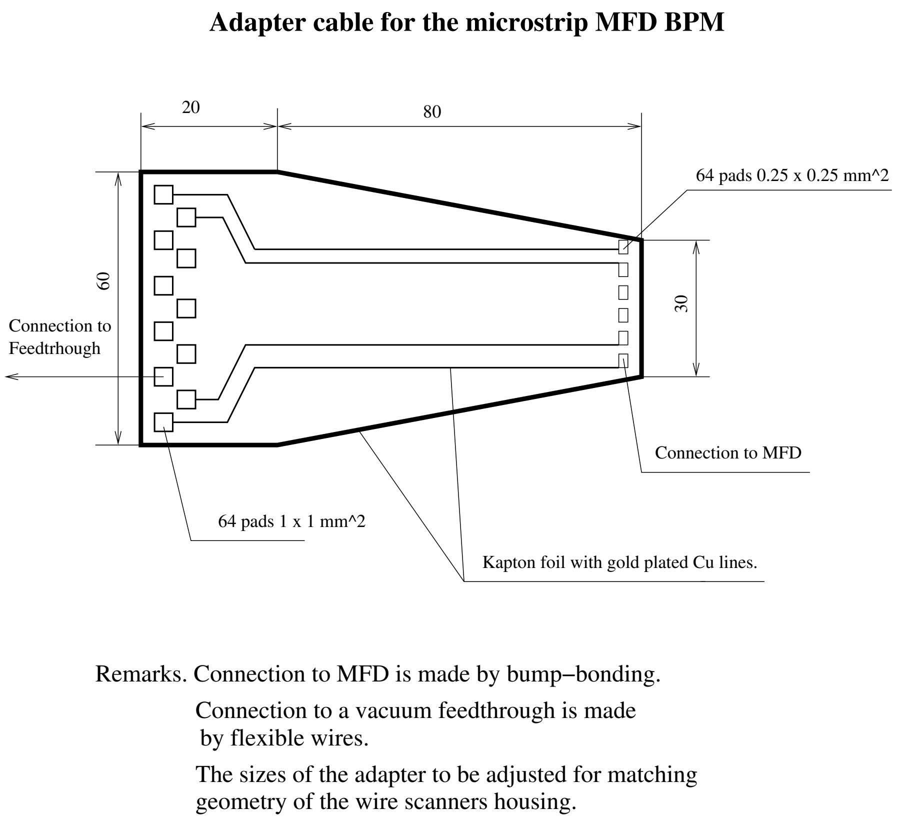

Fig. 7. Scheme of adapter for the micro-strip MFD.

The strip width and pitch could be easily modified to the level of few micrometers as well, providing 1-2 μm position resolution.

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 (see Fig.5.

Current sensitivity of the charge integrator is 1 kHz per 1 pA input current. The level of fluctuations measured from the stable calibrating current (25 pA) is in the range of +/- 2 Hz. The dynamical range is 1500 with a possibility to

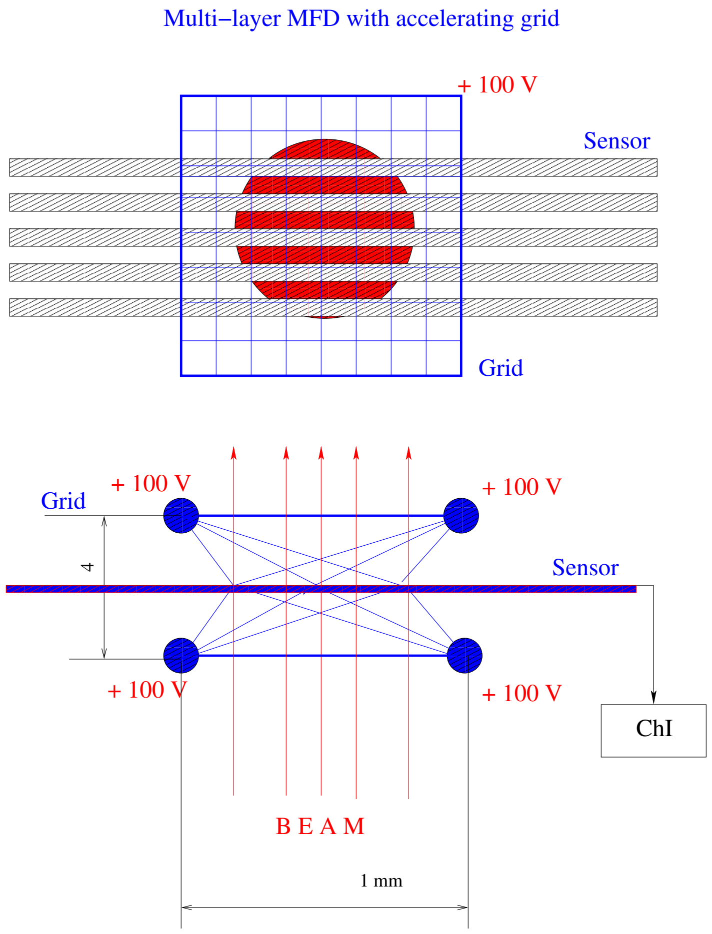

Fig. 8. Accelerating grid for the micro-strip MFD.

adjust the input current to be measured ranging from 10 fA to 10 μA.

There are considerations to apply the micro-stip MFD for the undulator radiation monitoring at the PETRA facility (similar to the device described in [17]). We expect an improved performance of the MFD detector in comparison with [17] due to its 5-layer structure as well as much better spatial resolution should be obtained. Accordingly to [17] 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 arround 0.5 - 1.0 pA. This level of signal should be easily detected by our device, with hopefully much better performance.

4 Outlook

1. The programme of the forthcoming tests of the MMFD at PETRA includes: Study of the thermal threshold;

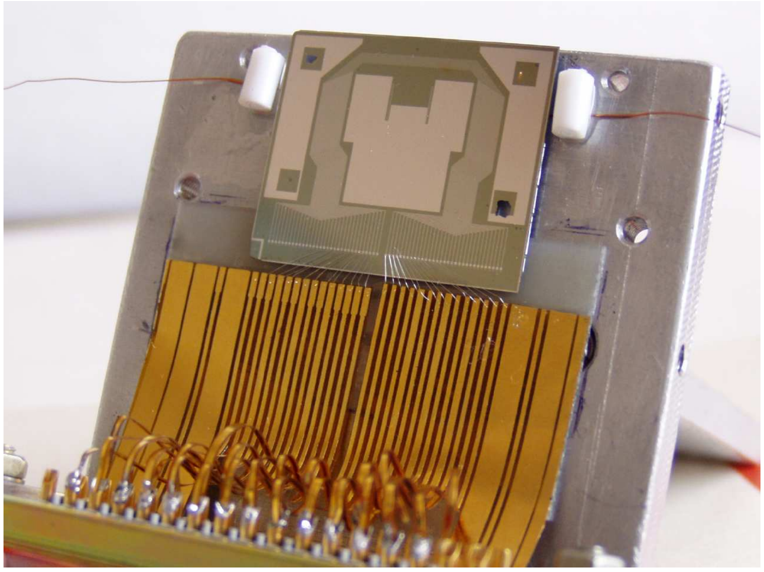

Fig. 9. Photo of the micro-strip MFD (Si-wafer based) connected via pitch adapter to 50-pin connector.

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.
2. Progress and Further steps (see Appendix).

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6 Appendix

6.1 Progress since December '03.

1. Two prototypes of the Micro-strip MFD designed for the micro-beam profile monitoring are available for a test (one of them has 1 μm thick Al strips free hanging over the completely etched region of the Si-wafer).

2. Test setup (CAMAC based DAQ) at the Kiev LINAC (5 MeV electrons) is completed and available for test (including heavy irradiation) measurements.

3. Setup for the test experiment at PETRA (HASYLAB) is under construction: 3.1. Synchrotron Beamline place is defined. 3.2. UHV-feedthrough ordered (will be available soon). 3.3 The first MMFD (Si-wafer thickness 10 μm) mounted on the Al supporting plate and connected via pitch adapter to the 50-pin connector Fig.9 is ready for mounting at the Cu-cooling plate inside the beamline vaccuum tube.

4. Negotiations to use the HERA-B Target DAQ during test measurements at PETRA are under way.

5. Software (ADONIS project) is under modification for using ROOT package for the data analysis.

6. Two students from Kiev University and Polythechnical Institute are working fro the project.

7. UHV compatibility of the poly-imide based detector has been succesfully verified at DESY.

6.2 Further steps.

1. Complete a test setup at the PETRA site (V. Aushev, Yu. Vasiliev, S. Prystupa in close collaboration with H. Franz and K. Wittenburg). (Contact persons at DESY: 1. Vladimir Aushev - aushev@mail.desy.de , tel. 2843, Build. 66, room 2,
Yurij Vassiliev - yuri@mail.desy.de , tel. 2842, Build. 66, room 9).

2. Make test at PETRA (before the end of May '04).

3. Analyze data and prepare a report (before the end of June '04).

4. Submit an Abstract to the Conference 'Cyclotrons 2004' .

5. Make test at the KINR LINAC. Study temperature dependence of the MMFD performance. Analyse data and publish a report at the KINR Scientific Paper.

6. Make an attempt to get a financial support for further activity including tests at high energy charged particle facilities.

7. Design and produce next MMFD prototypes (May-July '04).

8. Study temperature impact onto the MMFD performance (May '04)

9. Continue tests at PETRA side (July-September '04).