PROTOTYPE OF THE PARTICLE FLUENCE MEASUREMENT DEVICE

by

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A method of measuring particle fluence and ion beam current in experiments of ion implantation is presented. The design and technical details of a realized prototype device are discussed. Special care is devoted to the effect of secondary electrons and its elimination. An electrostatic solution with two electrodes for the suppression of secondary electrons has been realized. Our approach provides redundancy and allows lower bias voltages to be used for the suppression of electrons. The presented results illustrate the efficiency of the proposed solution.

Key words: fluence, ion beam, measurement device, secondary electron

INTRODUCTION

Ion implantation experiments constitute one of the main activities within the facility for the modification and analysis of materials with ion beams (FAMA) project [1], being realized at the Laboratory of Physics at the Vinča Institute of Nuclear Sciences in Belgrade, Serbia. In order to provide reliable ion beam current and fluence measurements for these experiments, we designed and constructed a prototype of an appropriate measuring device. It has been installed in a beamline connected to a volume ion source producing beams of both positive and negative ions: 1.2 mA of H^-, 500 μA of H_2^+, and 900 μA of H_3^+ ions. The source can also produce D^-, D_2^+, D_3^+, and $_4He^+$ ion beams [2].

One of the crucial parameters in the modification of materials with ion beams is the particle fluence that irradiates the target. In principle, one can measure the particle current impinging the target continuously and obtain the fluence by integrating the current over the time of irradiation. The devices for measuring the electrical current of ion beams are known as Faraday Cups (FC). These devices are beam-interceptive, *i. e.* they interrupt the process of irradiation during the measurement. A common, but not very precise way of measuring the fluence, is by inserting a FC into the beam at regular time intervals and, using an appropriate acquisition system, recording the measured ion beam current. Assuming that the beam current fluctuations are rather low, one can interpolate the current over the time interval of interest and perform time integration to estimate the fluence at the target. This approach works for stable continuous ion beams and requires that the target and measuring positions be close enough so that the beam transverse dimensions are almost equal at both positions.

Substantial improvement can be achieved by unifying the function of the FC and the fluence-measuring device in a way that the collecting electrode of the FC – the one that collects the ions from the beam - can serve as a target holder. This modification allows a continuous measurement of the ion beam current, meaning that time-dependent ion beam intensities do not present a problem. An additional advantage is the fact that the beam current and fluence are both measured at the target position. We chose this approach in designing our measuring device and made the corresponding prototype for the measuring fluence device (PMF-3). Besides its basic purpose, that of measuring fluence, it can alternatively be used as an ordinary FC, simply by removing the target sample.

Starting from the particle fluence definition for the unidirectional flow of particles, one can find the relation

$$F(\tau) = \frac{\int_0^{\tau} i(t)\,\mathrm{d}t}{SZe} \qquad (1)$$

where F is the particle fluence, τ – the duration of the measurement, $i(t)$ – the ion beam current, S – the surface of the irradiated target, Z – the degree of ionization of the ions within the beam (*e. g.* ion X^{+Z}), and e – the elementary charge unit.

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Since $i(t)$ is continuously measured and recorded via an appropriate acquisition system and a personal computer, the integral in the above equation can be calculated either online or as a post-processing task, using appropriate software for numerical integration.

In case of a continuous beam with a constant current $i(t) = I$, one can find the necessary irradiation time τ for a predetermined value of the fluence F at the target as

$$\tau \quad \frac{FSZe}{I} \qquad (2)$$

Figure 1 gives a schematic view of the device illustrating the working principle. The ion beam hits the target sample, being electrically connected to the collecting electrode (1). The charge of the ions within the beam sinks to the ground potential via ampere-meter (A) which gives online information on the ion beam electrical current over time. This information is being acquired and recorded for further fluence calculation.

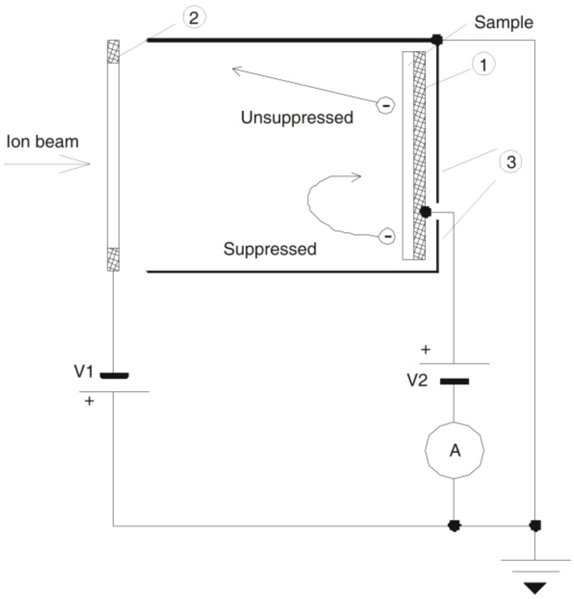


Figure 1. Schematic view of PMF-3: 1 – collecting electrode, 2 – suppression electrode, 3 – grounded housing, A – ampere-meter, V1 and V2 – DC power supplies for secondary electron suppression; suppressed and unsuppressed electrons are illustrated

SUPPRESSION OF THE SECONDARY ELECTRONS

It is well known [2] that, due to the interaction of the ion beam with the irradiated target material, a considerable number of electrons are being emitted from the incident surface of the target sample. Their yield and energy distribution weakly depend on the target material, as well as the projectile type and its energy. For the proton energies of a few tens of keV, the yield does not exceed around three secondary electrons per incident proton. Secondary electrons have energies below 50 eV, while most of them lie below 5 eV [3, 4].

Secondary electrons can also cause false readings of the measured ion beam current if they are not collected by the collecting electrode, *i. e.* if they have, in some way, left the measuring circuit. Namely, the emitted electrons can terminate their paths from the sample to the ground via the grounded housing (see fig. 1), forming an additional circuit: ion beam – sample – vacuum space – ground. The measured current value can be higher or lower than the exact one, depending on whether the ions are of positive or negative polarity, respectively. In order to prevent this effect, secondary electrons should be suppressed, *i. e.* be forced to go back to the target sample, as illustrated in fig. 1.

This suppression is usually achieved by applying a static electric or/and magnetic field [5]. By choosing the appropriate configuration and intensity of these fields, it is possible to force the electrons to move in the desired direction. Suppression by a static magnetic field excited by permanent magnets is a very convenient choice due to the absence of power supplies and is often used with ordinary FC where the housing is a part of the collecting electrode, so that the suppressed electrons do not need to have very precisely guided trajectories. The disadvantages of this approach are the phenomenon of ageing and radiation damage of the magnetic material.

Secondary electron suppression by electrostatic fields needs a constant use of DC power supplies providing voltages not higher than 100 V. Despite of this relatively small inconvenience, the proposed method is more flexible since it allows the generation of a changeable field configuration and strength by using several biased electrodes and variations of the biasing voltage. In the design of the PMF-3 device, we have used the electrostatic suppression method with two biased electrodes: a collecting electrode and a suppression electrode, as shown in fig. 1. The suppression electrode, shaped in the form of a circular ring, is biased at a negative potential V_1. It creates an electric field which pushes the electrons back to the collecting electrode. In addition to this function, the collecting electrode (being at the same time a measuring electrode risen to a positive potential V_2), attracts the electrons, enhancing the overall suppression effect. The presence of the two biased electrodes permits the decrease in the values of potentials V_1 and V_2, contrary to the system with just one electrode.

The effect of the secondary electron suppression is shown in fig. 2. The diagram gives the dependence of the measured beam current on the biasing potential at the collecting electrode. The beam consists of 10 keV deuterium (D^+) ions. As can be seen, the positive potential of 18 V is high enough to suppress all secondary electrons.

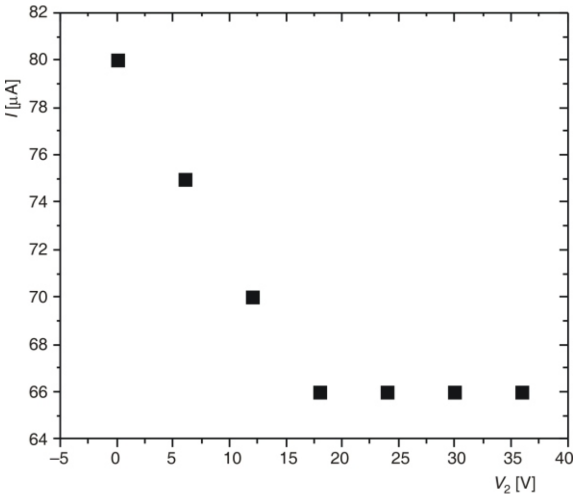


Figure 2. The effect of the biasing potential applied to the collecting electrode on the measured ion beam current

TECHNICAL DESCRIPTION OF THE DEVICE

The PMF-3 device consists of an electrical and a mechanical part. The role of the electrical part is to provide necessary bias voltages for the suppression of secondary electrons, as well as to measure the ion beam current and, consequently, particle fluence at the target. The mechanical part holds the target sample, supports the electrodes and provides the appropriate configuration for ion beam current measurement and secondary electron suppression [6].

The main idea in designing the PMF-3 was to make it simple, inexpensive and adaptable to experimental needs.

The circuit diagram of the electrical part is shown in fig. 3, while the external and internal view is given in figs. 4(a) and 4(b). The collecting electrode is used to raise the potential of the conductive sample for the suppression of secondary electrons. This voltage is provided by standard AA batteries of 1.5 V, housed in a standard four-battery case and equipped with adequate connectors. A rotary six position switch (SW1) is used allowing the V2 bias voltage at the collecting electrode to be selected in six steps, 6 V, 12V, 18 V, 24V, 30 V, or 36 V, nominally. Similarly, the voltage for the suppression of the electrode is selected by a rotary switch (SW2) with five positions, 6 V, 12 V, 18 V, 20 V, and 24 V, nominally.

The ion beam current is measured by the instrument with a moving coil whose maximal measuring

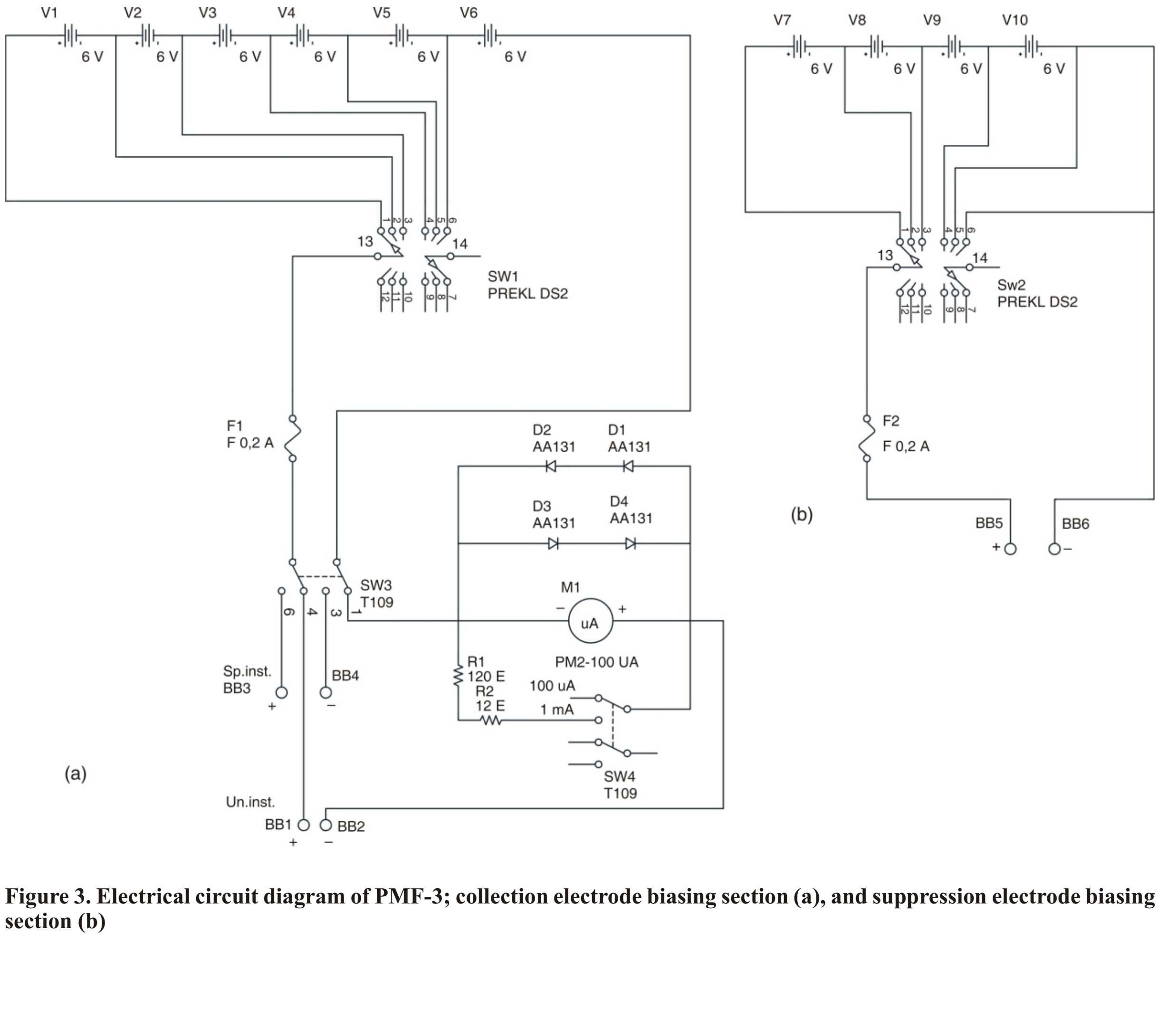
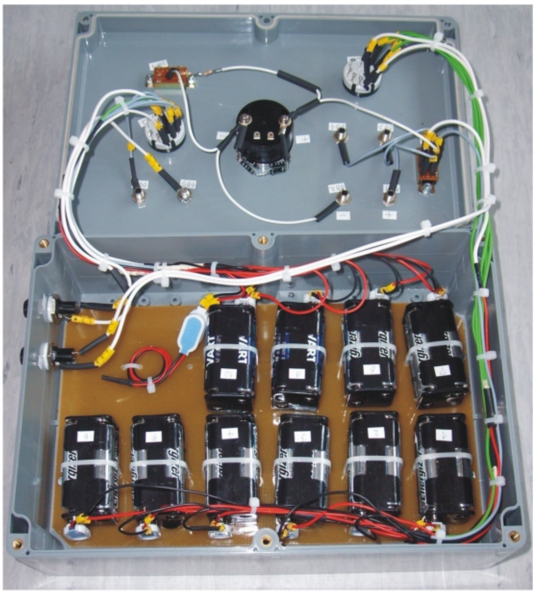


Figure 3. Electrical circuit diagram of PMF-3; collection electrode biasing section (a), and suppression electrode biasing section (b)

(a)



(b)

Figure 4. (a) – Front panel, and (b) internal view of the electrical part of PMF-3

value of 100 A can be increased to 1 mA by using two resistors, R1 and R2, as a shunt of 133.33 . Four diodes and a fast fuse protect the instrument from overloading. Optionally, the current can be measured with an external ampere-meter (of a higher precision or range), which could be connected to BB3 and BB4 sockets via a SW3 switch, as shown in fig. 3 [7].

The mechanical part of PMF-3 is actually a target sample equipped with electrodes for current measurement and electron suppression, basically, a modified and adapted version of a FC. It consists of: a housing made of Al, polyethylene (PE) cup to isolate the housing from electrodes, collecting electrode both for collecting the beam ions and a suppressor of secondary electrons, and a PE fastener to hold the target sample and suppressor to the electrode. Its axial cross-section is given in fig. 5. The role of the PE fastener is dual: to isolate the suppression electrode from the target sample and that of maintaining the target sample at the collecting electrode. It should be noted that the suppressing electrode has to be replaced and fabricated for each specific target, as well as the PE fastener itself. When the voltage is not applied to the suppressing electrode, it should be connected to the ground.

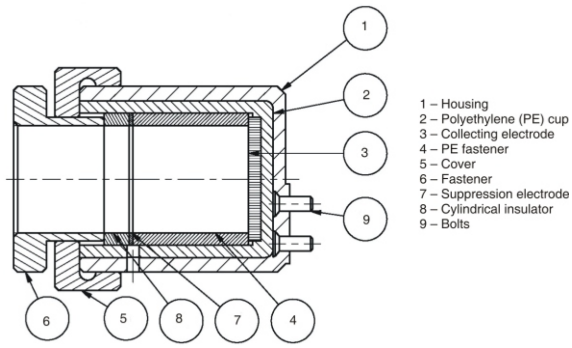


Figure 5. Axial cross-section of the mechanical part of PMF-3

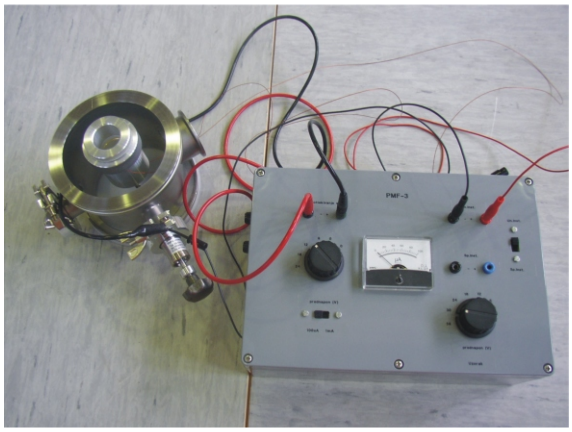


Figure 6. Assembled PMF-3 mounted on commercially available vacuum components

A photograph of the assembled PMF-3, with its mechanical part mounted on commercially available vacuum components, is shown in fig. 6.

CONCLUSION

In order to provide reliable and precise measurements of the particle fluence and ion beam current in the irradiation experiments conducted within the frame of the FAMA project, a design and subsequent realization of a prototype of the appropriate device have been carried out. In essence, the design used the working principle of a FC diagnostic device, adapting it to the needs of fluence measurements. Special care was paid to the realization of the secondary electron suppression technique which resulted in the elimination of current and fluence measurement errors. For this purpose, our device has used electrostatic fields created by two electrodes biased to both a positive and negative potential. This approach provides the reliability of suppression and allows operation with low voltages, within the range of 0 to 50 V. Besides, due to the flexibility of the design, the device uses both internal and external (more precise) current measuring instruments and is also flexible in accommodating the target samples of different dimensions by adapting its mechanical part. Having in mind the relatively low expenses of the realization of such a device, it should prove to be a highly acceptable experimental component for small projects with a limited budget.

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AUTHOR CONTRIBUTIONS

Theoretical analysis was carried out by Petar D. Beličev, Ivan M. Trajić, Srdjan M. Petrović, and Boško P. Bojović, experiments were carried out by Ivan M. Trajić and Petar D. Beličev, mechanical and electrical design as well as figure preparation was carried out by Milan N. Rajčević and Dragan M. Munitlak. All authors analysed and discussed the results.

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ПРОТОТИП УРЕЂАЈА ЗА МЕРЕЊЕ ЧЕСТИЧНОГ ФЛУЕНСА

Приказан је метод мерења честичног флуенса, као и струје јонског снопа, у експериментима јонске имплантације. Дискутовано је техничко решење са детаљима реализованог прототипа где је посебна пажња посвећена појави секундарних електрона и њиховом потискивању. Усвојен је приступ потискивања електростатичким пољем у конфигурацији са две електроде, што обезбеђује редундансу и дозвољава коришћење нижих преднапона за потискивање. Добијени резултати мерења показују ефикасност примењеног решења.

Кључне речи: флуенс, јонски сноп, мерни уређај, секундарни електрон