ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB300

DESCRIPTION OF THE BEAM DIAGNOSTICS SYSTEMS FOR THE SOCIT, SODIT AND SODIB APPLIED RESEARCH STATIONS BASED ON THE NICA ACCELERATOR COMPLEX*

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Abstract

Within the framework of the NICA project an Innovation Block is being constructed. It includes an applied research station for microchips with a package for Single Event Effects (SEE) testing (energy range of 150-500 MeV/n, the SODIT station), an applied research station for testing of decapsulated microchips (ion energy up to 3,2 MeV/n, the SOCIT station), and an applied research station for space radiobiological research and modelling of influence of heavy charged particles on cognitive functions of the brain of small laboratory animals and primates (energy range 500-1000 MeV/n, the SODIB station). The systems for diagnostics and control of the beam characteristics during the certification and adjustment as well as the systems for online diagnostics and control of the beam characteristics of the SOCIT, SODIT and SODIB applied research stations are described.

INTRODUCTION

NICA (Nuclotron-based Ion Collider fAcility) is a new accelerator complex being constructed at the Laboratory of High Energy Physics of the Joint Institute for Nuclear Research to study properties of dense baryonic matter [1]. Within the framework of the NICA project, it is planned to create three experimental stations for conducting applied researches with accelerated long-range ion beams extracted from the Nuclotron, and accelerated short-range ion beams extracted from the heavy ion linear accelerator (HILAc) [2]. Effective studies at the applied research stations are impossible without reliable ion beam diagnostics and control systems. The ion beam diagnostics and control systems should be duplicated by the type of detector. All detectors should be placed on stepper motors that transversely move and withdraw detectors from the beam area. The diagnostics equipment is designed to measure and control such beam characteristics as the ion flux density, ion fluence, ion beam linear energy transfer (LET), mean energy, beam profiles, and absorbed dose [3].

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SOCIT APPLIED RESEARCH STATION

The SOCIT station (Fig. 1) is designed to research and test promising semiconductor micro- and nanoelectronics products for determination of SEE sensitivity to low energy heavy charged particles at the exit from the HILAc.

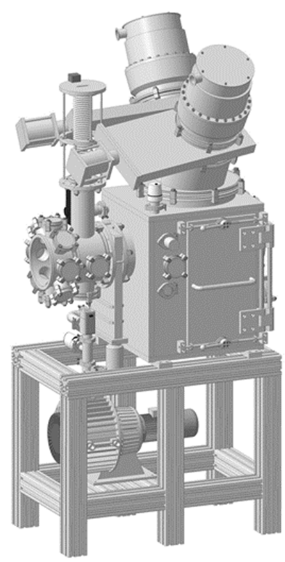

Figure 1: General 3D view of the SOCIT station.

Table 1 shows the sufficient ion beam parameters for the planned work.

Table 1: Technical Requirements for the Ion Beams at the SOCIT Station

Ion types	$^{12}C^{4+}$, $^{40}Ar^{8+}$, $^{131}Xe^{22+}$, $^{84}Kr^{14+}$, $^{169}Tm^{21+}$, $^{197}Au^{31+}$, $^{209}Bi^{34+}$
Ion energy at the exit from the HILac, MeV/n	3,2
Ion flux density, particles/(cm^2·s)	10^2..3·10^5
Maximum irradiation area, mm	Ø29
Beam diameter, mm	Ø73

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The equipment for the SOCIT station is being developed as part of the JINR-ITEP-SPELS/MEPHI-GIRO-PROM-VST collaboration.

The ionization detector based on microchannel plates (MCP) is used for nondestructive control of the intensity and spatial distribution of the ion beam in the horizontal plane during irradiation at the SOCIT station. The MCP detector capability of detecting Au^{31+} ions is $1.6 \cdot 10^4$ to $1.7 \cdot 10^6$ particles per pulse, the ion beam current range is 2.6-278 nA, and the spatial resolution is 3 mm.

The system for online diagnostics and control of peripheral ion flux density and fluence is comprised of four scintillation-fiber detectors based on multichannel photomultipliers installed in the beam halo at the distance of 70-90 mm from the beam axis. The working field of the scintillator is 10×10 mm, and its thickness is 3 mm. The sensitive area of the scintillators is covered by aluminum with the thickness of 0.05-0.1 µm.

The fast total-absorption phosphor detector with optical readout is used to measure beam profiles. The size of the phosphor detector is Ø90 mm, the phosphor-fall time is not more than 500 ns, the movement area is 120 mm, and the beam nonuniformity measurement accuracy is 10%.

The fast total-absorption scintillation detector with optical readout is used to control the ion flux density and flux stability in time. The intensity range varies from 1 to 10^7 particle/s, the registration efficiency is 99.5%, and the flux density measurement accuracy is no worse than ±10%. The working field of the scintillator is 80x80 mm, its thickness is 4 mm, and the light signal is recorded with 1-mm-thick fibers. The light signal is detected by a photomultiplier tube (PMT) or a multichannel PMT.

A Faraday cup is used to control the ion flux density during beam adjustment before the experiment. The accuracy of ion flux measurement is no worse than 10%, the working field is 100 mm, and the detector movement area is 200 mm.

The signals from the detectors are integrated into the general data acquisition system.

SODIT APPLIED RESEARCH STATION

The SODIT station (Fig. 2) is designed to research and test promising semiconductor micro- and nanoelectronics products for determination of SEE sensitivity to high-energy heavy charged particles.

The equipment for the SODIT station is being developed as part of the JINR-ITEP-SPELS/MEPHI-GIRO-PROM collaboration.

Within the NICA project, a specialized DPS-NICA detector for mass testing of integrated circuits is being developed. The tasks of the detector include precision localization of the particle track in a chip and energy release in it, precise localization of the chip crystal for positioning in the installation. The DPS-NICA is being developed as part of the JINR-SINP MSU collaboration [4].

Figure 2: The positioning system of the SODIT station.

Table 2 shows the sufficient parameters of the ion beam for the planned work.

Table 2: Technical Requirements for the Ion Beams at the SODIT Station

Ion types, energy MeV/n	$^{197}Au^{79}$	150-350
	$^{131}Xe^{54+}$	150-367
	$^{12}C^{6+}$	150-392
Ion flux density, particles/(cm2·s)	$10^2..3 \cdot 10^5$	
Irradiation area in the scanning mode/nonscanning mode, mm	200x200/Ø29	
Flux uniformity for the maximum irradiation area in the scanning mode/nonscanning mode, %	15/10	

Ionization chamber 1 based on a scintillation-fiber detector is used to measure the ion flux density during ion beam adjustment before the experiment, to measure the time profile of the ion beam and control the stability of the ion beam current, and to measure the beam profile in the plane perpendicular to the beam axis. The working field is 80x80 mm, the spatial resolution is 2-3 mm, the ion detection probability is 99.85% in the 10-500 MeV/n energy range, and the ion flux measurement accuracy is 10%.

Proportional wire ionization chamber 2 (128-channel) is used to measure the ion flux density in the target area before the experiment during the adjustment in the scanning mode. The working field area is 250x250 mm, the accuracy of ion flux density measurement is 10%, the ion detection probability is 99.8% in the 10-500 MeV/n energy range, the spatial resolution is 2 mm, and the accuracy of ion beam center of gravity measurement is 2 mm.

Miniature gas-filled ionization chamber 3 is used to measure the LET in the target area before experiment. The working field area is 10x10 mm, the ion energy range is 3-30 MeV/n, the LET measurement range is

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5-80 MeV·cm^2/mg, the LET measurement accuracy is no worse than 5%, the LET measurement linearity in the nuclear charge range is 18-79, the movement area is 200x200 mm, the movement step is 1 mm, and the positioning accuracy is 1 mm.

A silicon detector is used as a duplicate detector to control and measure the LET of ions in the target area before experiment. The working field area is 10x10 mm, the ion energy range is 3-30 MeV/n, the registration efficiency is 99.8%.

A particle flux density meter based on four scintillators (or four silicon detectors) is used to control the ion flux density in the peripheral area of the ion beam in real-time. The working area of the detectors is 10x10 mm. The motion range of the detectors is 20-100 mm from the beam center, and the position of each detector is set independently from each other.

The absolute measurements of the ion flux density can be performed using 0.1-mm-thick plastic foils as offline detectors at specified points.

SODIB APPLIED RESEARCH STATION

The SODIB station (Fig. 3) is designed for radiobiological research to simulate the effects of heavy charged particles of galactic and solar cosmic rays on the cognitive functions of lower primates and small laboratory animals.

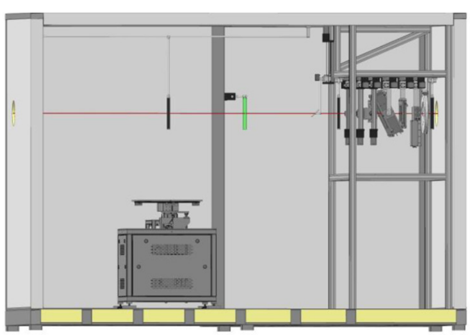

Figure 3: General 3D view of the SODIB station.

The equipment for the SODIB station is being developed as part of the JINR-VST collaboration.

Table 3 shows the sufficient parameters of the ion beam for the planned work.

Table 3: Technical Requirements for the Ion Beams at the SODIB Station

Ion types	$^{12}C^{6+}$, $^{40}Ar^{18+}$, $^{56}Fe^{26+}$, $^{84}Kr^{36+}$
Ion energy at the exit from the Nuclotron, MeV/n	500-1000
Ion flux density, particles/(cm^2·s)	$10^3..10^6$
Radiation dose, Gy	1-3
Irradiation area in the scanning mode/nonscanning mode, mm	100x100/Ø10

Diagnostic chamber 1 based on scintillation-fiber detectors is used to measure ion flux density, beam profiles without scanning before the experiment during beam adjustment. The working field area is 50x50 mm, the ion energy range is 500-1000 MeV/n, the ion flux measurement accuracy is ±10%, the spatial resolution is 1-1.5 mm, and the beam nonuniformity measuring accuracy is ±10%.

Diagnostic chamber 2 based on the IC64-16 strip ionization chamber is a duplicating chamber for ionization chamber 1 and solves similar problems.

The thin scintillation counter is used to determine impurities in the beam of non-target ions. The working area of the counter is 80x80 mm, and the non-target ion impurity concentration measurement accuracy is 3%.

Ionization chamber 3 based on a slanted multi-section dosimetric ionization chamber with column recombination suppression is used to determine the absorbed dose. The working field is 200x200 mm, the LET measurement range is 5-400 keV/μm, the linearity of the LET measurement in the nuclear charge range 6-36 is 5%, the movement area is 100x100 mm, and the angle between the normal to the electrode plane and the beam axis is 30º.

Ionization chamber 4 based on a model QIC-2S four-channel ionization chamber is used as a local dose detector.

A diamond semiconductor detector is used as a detector of the local dose and average ion energy. The working field is 10x10 mm, the detector movement area is 100x100 mm, the movement step is 1 mm, the positioning accuracy is 1 mm, and the detector radiation hardness is 10^5 Gy.

The system based on four scintillation detectors arranged in a circle of the given radius in 90 degrees is used for online diagnostics and control of the peripheral ion flux density. The distance from the detectors to the beam axis varies in the 50-100 mm range. The working field of the scintillator is 10x10 mm, and its thickness is 3 mm.

Experiments with ion beams at the applied research stations are to start in 2022.

ACKNOWLEDGEMENTS

Work supported by grant for young scientists. Unique ID 21-102-09.

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