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COMMISSIONING OF THE SOCHI APPLIED STATION BEAM AND BEAM TRANSFER LINE AT THE NICA ACCELERATOR COMPLEX

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Abstract

The SOCHI (Station of CHip Irradiation) station was constructed at the NICA accelerator complex for single event effect testing of decapsulated microchips with low-energy ion beams (3.2 MeV/n). The peculiarity of microchip radiation tests in SOCHI is connected with the pulse beam operation of the heavy ion linear accelerator (HILAc) and a restriction on the pulse dose on the target. The SOCHI station construction, the equipment and the results of the first beam runs are discussed.

INTRODUCTION

During the development of the space industry the electronics used in spacecraft is becoming more complex and small-sized. In order to ensure the long-term operation of spacecraft, there is an urgent need to test electronics for radiation hardness. One of the methods for predicting, evaluating and controlling the radiation hardness of microelectronic products to the effects of charged particles is based on conducting tests on ion accelerators. The SOCHI applied station (Fig. 1) was created as part of the NICA accelerator complex [1].

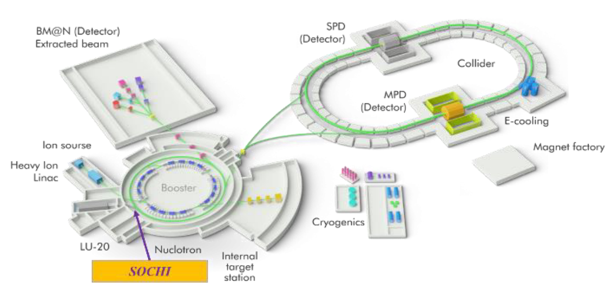

Figure 1: Area 1 infrastructure layout.

SOCHI BEAM TRANSFER LINE

The SOCHI beam transfer line is integrated into the existing HILAc-Booster beam line. The description of the SOCHI beam transfer line as well as its beam optics is given in [2].

The technical specification for the magnets is presented in Table 1.

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Table 1: Technical Specification for the Magnets

Dipole magnet	
Type of power source	Pulse
Effective length, m	0.65
Max. magnetic field, T	1
Gap, mm	45
Quadrupole lenses	
Type of power sources	Pulse
Effective length, m	0.29
Max. gradient, T/m	10
Gap (diameter), mm	95

The integration of the SOCHI station at a pressure of 10^{-3} Pa into the HILAc-Booster channel at a pressure of 10^{-6} Pa requires the following vacuum equipment: cryogenic trap, pulsed diaphragm, and turbomolecular pumps. This equipment should prevent the ingress of heavy gases into the existing HILAc-Booster transfer line and in the Booster, where the pressure is 10^{-9} Pa. According to the results of the vacuum tests in November-December 2021, it was confirmed that the developed and manufactured vacuum system of the SOCHI station and beam transfer line meet these requirements. Figure 2 shows the signal of the Microvision 2 mass-spectrometric gas analyzer at measurements of the composition of the residual gas in the transfer line after its connection to the SOCHI station.

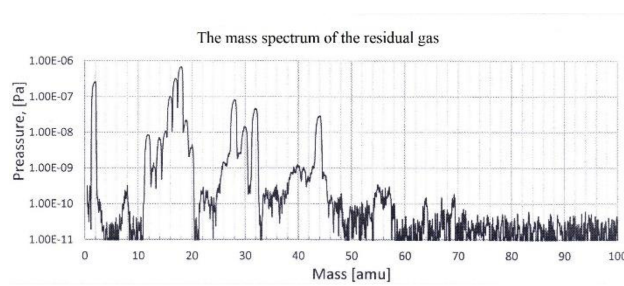

Figure 2: Total mass spectrum of residual gases at the end of the vacuum tests.

As shown in Fig. 2, the residual gas pressure (less than 10^{-6} Pa) behind the dipole magnet is lower than the pressure in the HILAc-Booster channel (10^{-6} Pa, before dipole magnet).

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The particle collimation system (CS) is designed to reduce the beam current from a mA level in the HILAc to the hundred nA level required for chip irradiation. The CS is already installed in the existing HILAc-Booster channel in front of a triplet of quadrupole lenses. It includes: 50 µm stainless foil target unit with several slits: 260 µm×35 mm, 30 µm×35 mm, and 234 holes 30×15 µm with a step of 150 µm; movement system VAb Vacuum-Anlagenbau GmbH, model MSI 40-100 S2, the positioning accuracy is ±100 µm and controlled by a linear potentiometer, way of movement is 100 mm; vacuum fittings.

SOCHI APPLIED RESEARCH STATION

The equipment for the SOCHI station (Fig. 3) is being developed as part of the JINR-NRC Kurchatov Institute collaboration with the participation of SPELS/MEPHI, GIRO-PROM, and VST.

Table 2 shows the required ion beam parameters.

Table 2: Technical Requirements for the Ion Beams at the SOCHI 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/(cm²·s)	10^3...10^5
Maximum irradiation area, mm	Ø29
Beam diameter, mm	Ø73

The SOCHI station (Fig. 4) includes a vacuum chamber, pumping, a gas composition analyzer and pressure control; a positioning and movement system for the test board with device under test (DUT), including a laser guidance system; universal test board for DUT; a temperature setting system; a beam diagnostics and control system, including a positioning and movement system for detectors of the beam diagnostics and control system; a control panel; workplaces in the control room and experimental hall.

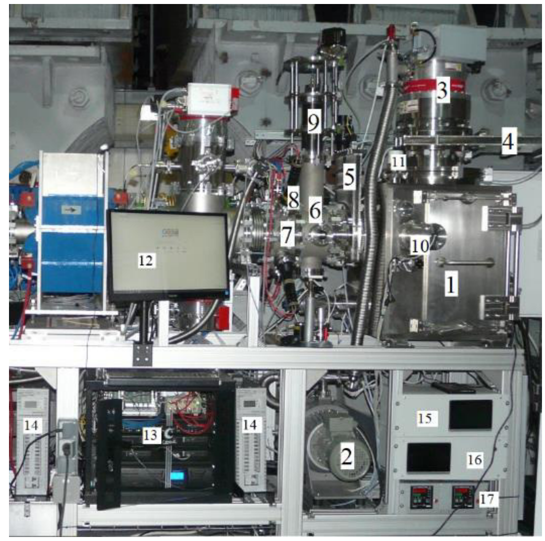

Figure 4: External view of the SOCHI station with the main components: 1 – main vacuum chamber; 2 – forevacuum pump; 3 – turbo molecular pump; 4 –gate valve; 5 – gate valve; 6 – vacuum chamber 2; 7 – vacuum chamber 1; 8 – real-time beam parameter monitoring system; 9 – detector positioning system; 10 – video monitoring system for positioning DUT; 11 – vacuum gauge; 12 – monitor of the control panel; 13 – rack with control equipment; 14 – voltage stabilizer; 15 – vacuum system control unit; 16 – control unit of the DUT positioning system; 17 – temperature setting system control units.

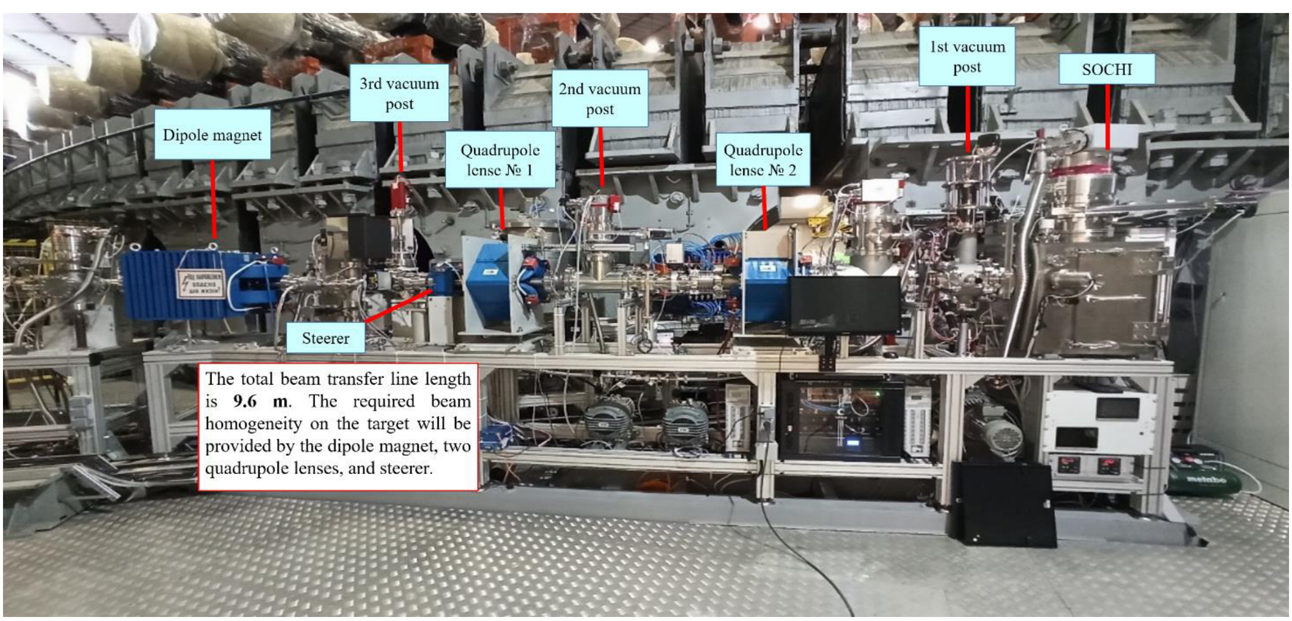

Figure 3: SOCHI beam transfer line and the applied station.

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Inside the SOCHI vacuum chamber (Fig. 5) there are a positioning system for DUT, universal test board for connecting test equipment with DUT, DUT, cables, a heating module, a phosphor detector of full absorption, and a gas analyzer.

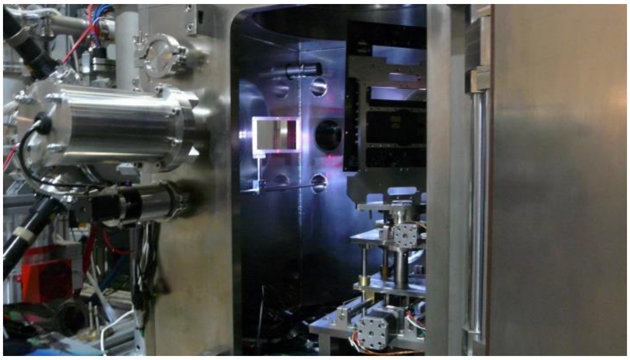

Figure 5: Internal view of the SOCHI vacuum chamber.

The diagnostics system is represented by the following detectors: the MCP-based detector and the system for online diagnostics and control of peripheral ion flux density and fluence (four fiber-scintillation detectors based on multi-channel photomultiplier) (Fig. 6); the fast total-absorption scintillation detector with optical readout, the Faraday cup (Fig. 6), and the fast total absorption phosphor detector. The signals from the detectors are integrated into the general data acquisition system.

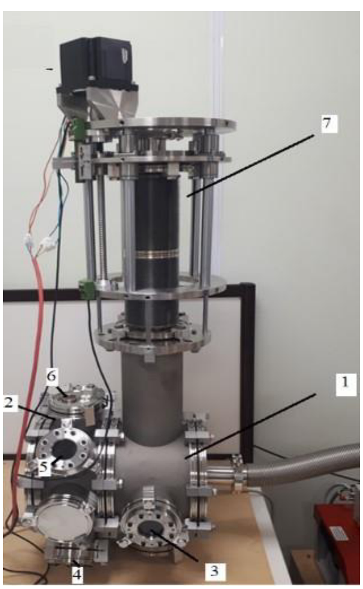

Figure 6: External view of vacuum chamber 1 and 2 with the positioning system and the stepper motor.

PHYSICAL START-UP

The mounting of the SOCHI station was completed in December 2021. Physical start-up of the station with $^{12}C^{4+}$ carbon ion beams with energy of 3.2 MeV/n was carried out. The ion beam current at the exit of the HILAc in front of the CS was 3.5 mA, pulse duration 3 µs, repetition frequency 4 s. The photo in Fig. 7 shows the beam spot on a phosphor detector. Shadows from the system for online diagnostics and control of peripheral ion flux density and fluence (four scintillators) are visible in the corners.

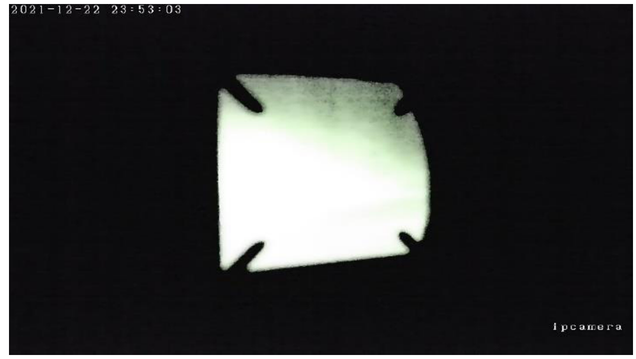

Figure 7: Internal view of the SOCHI vacuum chamber.

The maximum rate of the pulse radiation dose on the silicon semiconductor should be less than 1 rad/µs. To provide this radiation dose rate, a collimator with 20 holes 30 µm in diameter with a step of 700 µm between them to reduce beam current on target to level of few hundreds of nA was used. However, in this case the beam spot has a nonuniform structure of the striped character (Fig. 8). To provide good dose uniformity on the target when using a small ion beam and the collimator with holes, the CS was modified as described above.

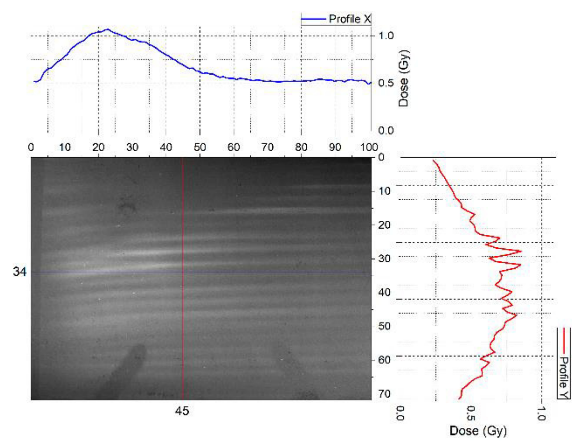

Figure 8: $^{12}C^{4+}$ ion beam spot on the monochrome film.

CONCLUSION

The first SOCHI beam runs were performed at the end of 2021. Further commissioning works at the SOCHI station will be continued in 2022; the next beam run is planned with argon ion beams.

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