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TRANSMISSION STUDIES WITH ION BEAMS WITHIN FAMA*

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Abstract

FAMA is a user facility for materials science with low-energy ion beams in the Vinča Institute of Nuclear Sciences, Belgrade, Serbia. It includes a heavy ion source, a light ion source, two channels for modification of materials, and two channels for analysis of materials. Recently, the designing of a channel for transmission studies within FAMA has begun. The initial studies to be undertaken in this channel are related to the rainbow effects with very thin electrostatic lenses and two-dimensional materials.

INTRODUCTION

FAMA is a facility for materials science with low energy ion beams. It is the low energy part of the TESLA Accelerator Installation, a large user infrastructure for production, acceleration and use of ion beams in science, technology, medicine and education. Currently, FAMA includes a heavy ion source, a light ion source, and a small proton cyclotron complex. The heavy ion source delivers multiply-charged heavy ions of energies of 10–20 keV per charge unit, while the light ion source produces positive or negative light ions of energies of 10–30 keV. These beams are used in two channels for modification of materials. The cyclotron complex delivers protons of energies between 1 and 3 MeV, and they are employed in two channels for analysis of materials. Recently, the designing of the channel for transmission studies (C3) of FAMA has begun, in which the ion beams from the heavy and light ion sources will be used.

INITIAL TRANSMISSION STUDIES

The first planned series of experiments in the C3 channel is related to ion transmission through very thin electrostatic multipolar and rainbow lenses (VTELs) [1–3]. The focusing properties of these lenses are fully determined by the rainbow effect. In the first measurements, the projectiles will be H^+ ions of energy of 15 keV from the light ion source and $^{40}Ar^{12+}$ ions of energy of 180 keV from the heavy ion source while the targets will be the quadrupole and square rainbow lenses [2, 3]. The beams should come on the targets closely parallel with the diameters of about 15 mm. The experiments will be performed in the high vacuum conditions.

The second planned series of measurements in the C3 channel is based on using the rainbow effect for specific characterization of 2D materials – by ion transmission [4–6]. In the first experiments, the projectiles will be 10 keV H^+ ions from the light ion source and 20 keV $^4He^{2+}$ ions from the heavy ion source. The ion beams should come on the targets closely parallel with the diameters of about 10 μm. The targets will be the flakes of graphene. The measurements require the ultra-high vacuum conditions.

CHANNEL FOR TRANSMISSION STUDIES

A scheme of the C3 channel is depicted in Fig. 1. It is connected to the mass analyser of one of the channels for modification of materials (C2). The transport elements of the channel are: two steering magnets, to be used to correct the ion beam direction toward the target if needed, and three magnetic quadrupole lenses, making a quadrupole triplet, to finally shape the beam impinging on the target. The characteristics of the magnetic quadrupole triplet have been determined on the basis of the transport calculations for the above specified ion beams, to be used in the first experiments. The transport line of the C3 channel, extending down to its interaction chamber, contains two diagnostic boxes, both being high vacuum cylindrical chambers made of stainless steel, each including a variable circular ion beam collimator, to be used to generate a closely parallel beam. The standard diameters of the collimators are 5 mm in experiments with VTELs and 2 mm in the experiments with 2D materials. In the measurements with 2D materials, the differential pumping apertures with the standard diameters of 2 mm are placed at the entrance and exit of the interaction chamber.

The transport calculations have been conducted using the first-order matrix formalism and the Ion Beam Simulator computer code. As a result, we have adopted 2.0 T/m as the maximal magnetic field gradients on the axes of the magnetic quadrupole lenses. Besides, we have adopted 14 mT as the maximal horizontal and vertical components of the magnetic induction on the axes of the steering magnets.

The interaction chamber of the C3 channel is an ultra-high vacuum cylindrical chamber made of stainless steel. There are two target holder assemblies in the interaction chamber – for VTELs and 2D materials. The former assembly includes a three-axis manipulator while the letter assembly comprises a five-axis goniometer and a sample acceptor stage, enabling one to remove the irradiated target from the interaction chamber for analysis. An electrostatic deflector is placed immediately after the target holder assembly for 2D materials, to be able to move away from the axis of the channel the ions that remained charged upon the interaction with the crystal, and thus record the angular distribution of neutralized ions. The deflector will also enable one to measure the charge state distribution of transmitted ions. The crystal structure of the chosen 2D material will be determined using a reflection high energy electron diffraction (RHEED) system, attached to the interaction chamber.

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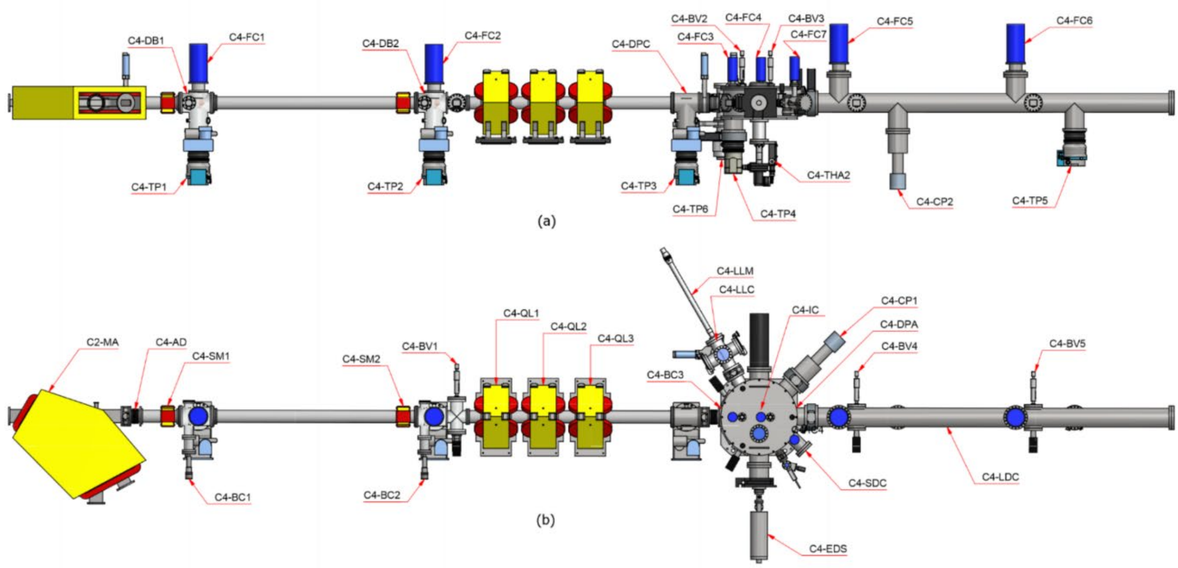

Figure 1: Vertical and horizontal projections of a scheme of the C3 channel – (a) and (b), respectively: C2-MA – the mass analyser of the C2 channel; C3-AD – the alignment device; C3-SM1 and C3-SM2 – the steering magnets; C3-DB1 – the first diagnostic box; C3-BC1 and C3-FC1 – the first beam collimator and the first Faraday cup; C3-TP1 – the first turbomolecular pump; C3-DB2 – the second diagnostic box; C3-BC2, C3-FC2 and C3-BV1 – the second beam collimator, the second Faraday cup and the first beam viewer; C3-TP2 – the second turbomolecular pump; C3-QL1, C3-QL2 and C3-QL3 – the magnetic quadrupole lenses making the quadrupole triplet; C3-DPC – the differential pumping chamber; C3-TP3 – the third turbomolecular pump; C3-IC3 – the interaction chamber; C3-DPA1, C3-FC3, C3-BC3, C3-FC4, C3-BV2, C3-FC5 and C3-DPA2 – the entrance differential pumping aperture, the third Faraday cup, the third variable circular beam collimator, the fourth Faraday cup, the second beam viewer, the fifth Faraday cup and the exit differential pumping aperture; C3-THA2 – the target holder assembly for 2D materials; C3-LLC – the load-lock chamber; C3-LLM – the load-lock manipulator; C3-EDS – the electron diffraction system; C3-CP1, C3-TP4 and C3-TP6 – the first cryogenic pump, the fourth turbomolecular pump and the sixth turbomolecular pump; C3-DC – the detector chamber; C3-FC6 and C3-BV3 – the sixth Faraday cup and the third beam viewer; C3-CP2 – the second cryogenic pump; C3-FC7 and C3-BV4 – the seventh Faraday cup and the fourth beam viewer; and C3-TP5 – the fifth turbomolecular pump, respectively.

The C3 channel also contains a load lock chamber and a detector chamber, both being high vacuum cylindrical chambers made of stainless steel. The former chamber enables one to introduce a 2D material in the interaction chamber. In the latter chamber, there will be two 2D position-sensitive detectors. The larger detector, with the diameter of 40 mm, will be used for measuring the spatial distributions of ions transmitted through the chosen VTEL at different distances from it while the smaller detector, with the diameter is 25 mm, will be employed for recording different parts of the angular distribution of ions transmitted through the chosen 2D material. The larger detector, placed in the interaction chamber, will be also used to measure the charge state distribution of transmitted ions.

The vacuum system of the C3 channel will include five turbomolecular pumps of the pumping speed of about 700 l/s, one turbomolecular pump of the speed of about 300 l/s, and two cryogenic pumps of the speed of about 1200 l/s. The aim is to ensure the pressure of 5×10^{-8} and 5×10^{-10} mbar in the interaction chamber in the experiments with VTELs and 2D materials, respectively.

The control and safety system of the C3 channel will be composed of the Group 3 Control hardware and the WonderWare InTouch software.

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