SIMULATIONS OF RADIOFREQUENCY ION FUNNEL OF MULTIPLE-REFLECTION TIME-OF-FLIGHT MASS SPECTROMETER

P. Kohout[a,b], A. Opíchal[a,b], Ľ. Krupa[a,c], A.M. Rodin[a], E.V. Chernysheva[a], A.V. Gulyaev[a], A.V. Gulyaeva[a], J. Kliman[d], A. Kohoutová[a,b], A.B. Komarov[a], A.S. Novoselov[a], J. Pechoušek[b], V.S. Salamatin[a], S.V. Stepantsov[a], A.V. Podshibyakin[a], V.Yu. Vedeneev[a], S.A. Yukhimchuk[a]

[a]Joint Institute for Nuclear Research, Flerov Laboratory of Nuclear Reactions, Joliot Curie 6, Dubna, Moscow region, 141980 Russia;
[b]Faculty of Science of Palacký University Olomouc, 17. listopadu 1192/12, 779 00 Olomouc, Czech Republic;
[c]Institute of Experimental and Applied Physics, Czech Technical University in Prague, Husova 240/5, Prague 1, Czech Republic;
[d]Institute of Physics, Slovak Academy of Sciences, Dubravská cesta, 9, Bratislava, 84228 Slovakia;

ABSTRACT

Multiple-reflection time-of-flight mass spectrometer (MR-TOF MS) is being built in Flerov Laboratory of Nuclear Reactions in Joint Institute of Nuclear Research in Dubna. MR-TOF MS will help to determine mass of superheavy elements produced there. To measure mass of produced superheavy nuclei, those nuclei have to be slowed down first. This is done by using cryogenic gas stopping cell (CGSC). After stopping the ions are then guided from the CGSC to the MR-TOF MS using a radiofrequency (RF) funnel. RF funnel is an ion guide that consists of 76 individual ring electrodes with a decreasing inner diameter from 266 mm to 5mm towards the extraction nozzle. Between neighboring electrodes, a 180° phase-shifted radio frequency is applied creating a repulsive electric field force to prevent the ions from hitting the electrodes, where is located extraction radio-frequency quadrupole (RFQ). This paper deals with development of radiofrequency (RF) funnel. Optimal RF field in RF funnel was simulated using COMSOL Multiphysics and NI Multisim. Circuit layout was designed and optimized using data from simulations.

INTRODUCTION

The CGSC consists of two chambers, smaller one is located inside of other one and they are separated by uhltrahigh vacuum, so they can work as dewar vessel. The inner one is filled with helium gas at temperature about 40 K to ensure the high purity of helium. Recoils with helium atoms stops the ions entering the CGSC in it. Inside of the helium filled inner chamber there is also RF funnel, which ectracts ions after stopping in it. The RF funnel of CGSC uses RF fiels to guide ions. Radiofrequency of alternating polarity between neighboring electrodes creates a repulsive field force F_{RF} perpendicular to the cone surface of the funnel (dashed line). The resulting effective force F_{eff} guides the ions through the RF funnel [1], see Fig. 1(A).

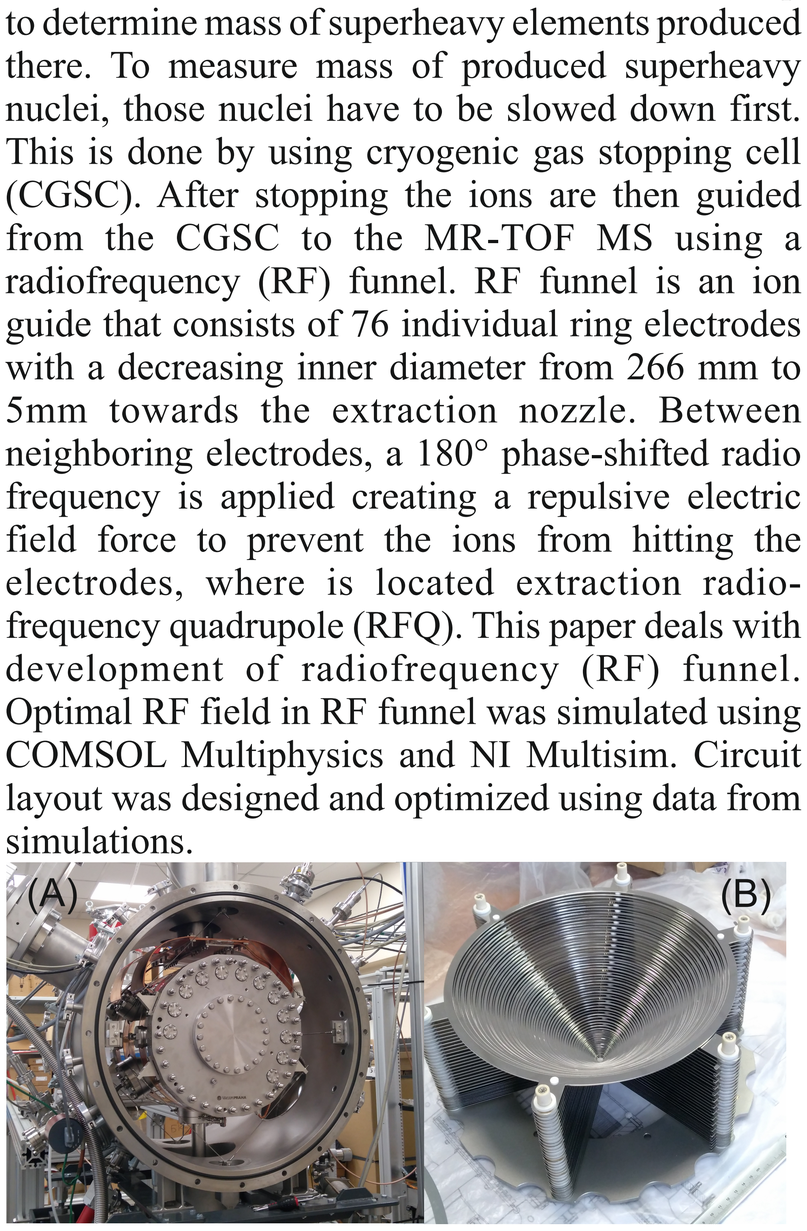

Figure 1: Cryogenic gas catcher chamber of MR-TOF-MS (A) and its RF funnel (B)

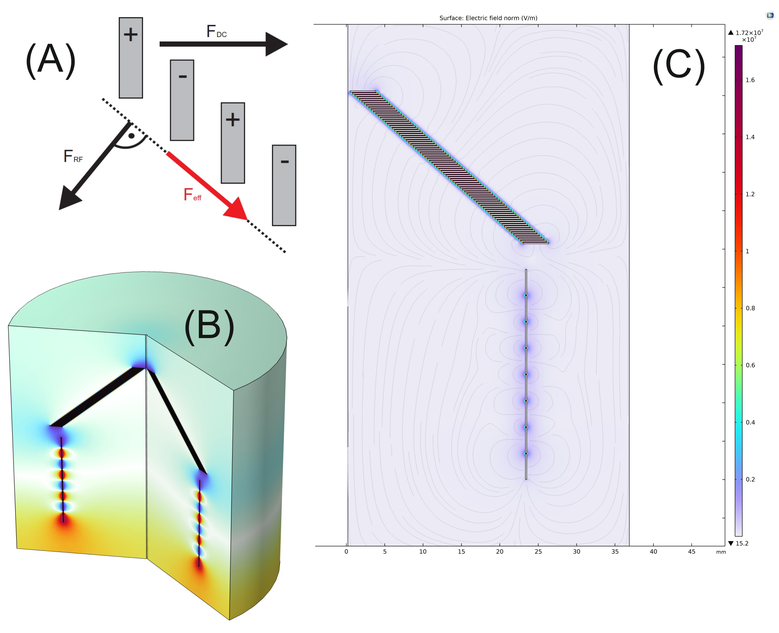

Figure 2: Repulsive force of RF funnel (A) [1], 3D View of Electric potential (B) and radial section of Electric field (C)

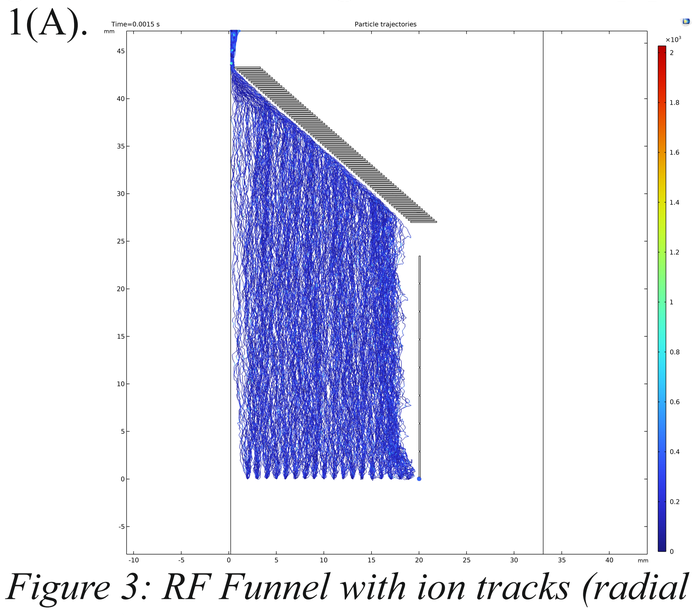

Figure 3: RF Funnel with ion tracks (radial section).

METHODS

The RF funnel was simulated using COMSOL Multiphysics and Particle Tracing Module and AC/DC Module. Optimal parameters were determined by extraction efficiency parameter, which was determined as ratio of ions entering the chambers to ions exiting the chamber. The Extraction efficiency as a function of the voltage difference between the nozzle and the closest RF funnel ring segment is displayed on Fig. 4.

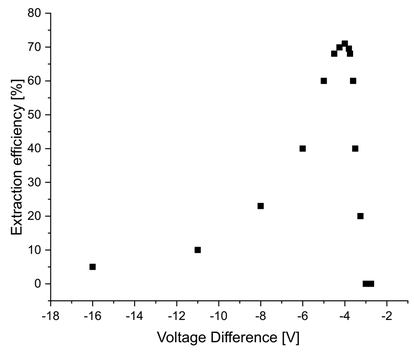

Figure 4: Extraction efficiency as a function of the voltage difference between the nozzle and the closest RF funnel ring segment

RESULTS AND DISCUSSION

Optimal RF field parameters of RF Funnel were found and RC (resistor-capacitor) circuit was designed and simulated in NI Multisim. The RF Funnel consists of cascade of electrodes. The electrodes potential is determined by RC circuit, which consists of cascade of resistors and capacitors. The cascade of resistors and capacitors is divided from RF source by air core transformer. Simulation provided the optimal capacitances and resistances of capacitors and resistors in RC circuit. Then printed circuit board (PCB) was designed and manufactured using materials suitable for ultra high vacuum and cryogenic temperatures.

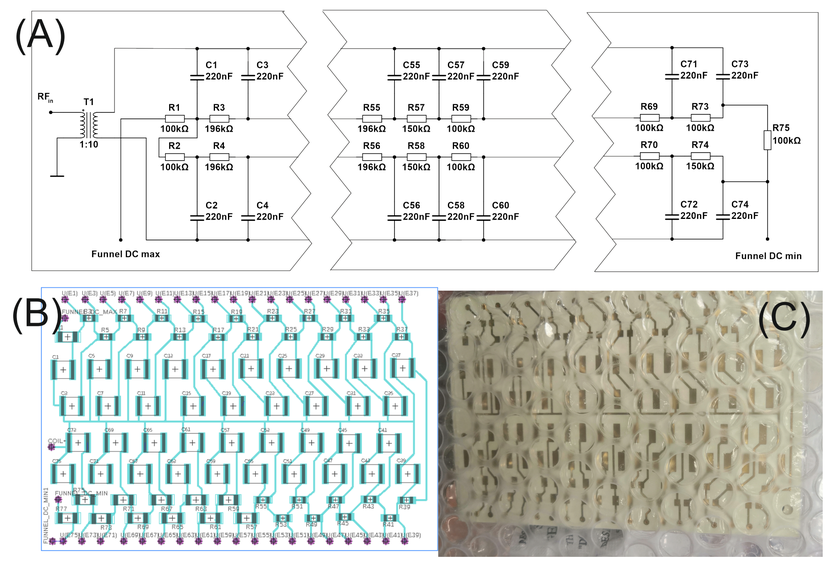

Figure 5: RC circuit modelled in NI Multisim (A), PCB layout of one one branch of RF-/DC-mixing board (B) and actual PCB (C).

FURTHER DEVELOPMENT

In future, testing measurements using ^{223}Ra alpha ray source will be done and efficiency of CGSC will be determined experimentally. After that, CGSC will become part of MR-TOF-MS and will be mounted on the beamline of DC-280 cyclotron and will be used in experiments leading to determination of masses of superheavy nuclei.

REFERENCES

[1] DROESE, C., S. ELISEEV, K. BLAUM, et al. The cryogenic gas stopping cell of SHIPTRAP. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms. 2014, 338, 126-138. ISSN 0168583X. doi:10.1016/j.nimb.2014.08.004

The authors gratefully acknowledge the support by internal IGA grant of Palacký University Olomouc (IGA_PrF_2022_003).

Joint Institute for Nuclear Research

JINR 114 Flerovium FLNR Dubna

Flerov Laboratory of Nuclear Reactions

Palacký University Olomouc

Department of Experimental Physics