DEVELOPMENTS OF ION SOURCE COMPLEX FOR HIGHLY INTENSE BEAM AT RCNP

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Abstract

Several developments of Ion Source Complex at RCNP have been carried for the purpose of beam quality improvement. For 18 GHz superconducting (SC)-ECR which produces highly charged heavy ions, the new extraction system to increase the beam current has been developed and the heavy ion current has been improved. Studied for relation between this extraction and beam emittance and transmission also has been done, and it is found that there are some aperture limitations and the beam transport line should be modified to obtain more ions. Highly intense proton (HIP)-ECR the 2.45GHz permanent magnet ECR which provides highly intense proton beam has also been developed for further beam brightness improvement. Some modifications have been done and the proton beam quality also has been improved.

INTRODUCTION

Ion source complex at RCNP consists with four ion sources as shown in Figure 1. The 18 GHz SC-ECR is installed in order to increase beam currents and to extend the variety of ions, especially for highly charged heavy ions which can be accelerated by cyclotrons at RCNP. The mirror magnetic field is produced with four liquid-helium-free superconducting coils and the permanent magnet hexapole is of Halbach type with 24 pieces of NEOMAX-44H material. The production development of several ion like B, C, O, N, Ne, Ar, Ni, Kr and Xe has been performed and these beams are already provided to experimental users[1,2,3]. For further improvement of beam quality and intensity, it is needed more improvement not only for the SC-ECR itself like extraction system but also for the beam transport line. For that purpose, the extraction electrode has been modified to increase extracted beam from plasma chamber of SC-ECR. The detail studies for transmission and emittance also have been carried. Another ion source, 2.45 GHz HIP-ECR is installed to extend the proton beam power[4]. Intense 400 MeV proton beam accelerated by Ring Cyclotron at RCNP is required for ultra cold neutron experiment, neutron irradiation test of semiconductors, muon source, RI production for medical application, and so on. The beam current requirement is over 10 uA although the maximum present current is about 1.1 uA. So the high brightness proton ion source with low emittance and high current of over 1 mA is needed. This 2.45 GHz ECR using a set of ring-shaped permanent magnets was originally developed at CEA-Saclay to produce a 100 keV CW proton beam with the intensity more than 100 mA [5]. The design of our HIP-ECR is similar to this CEA-Saclay source, but the extraction system was optimized for 15 keV protons to match with the injection system of the RCNP AVF cyclotron which is the injector of Ring cyclotron. The development of proton beam production with this source has been carried successfully[4]. For further improvement of beam quality, some modification has been done.

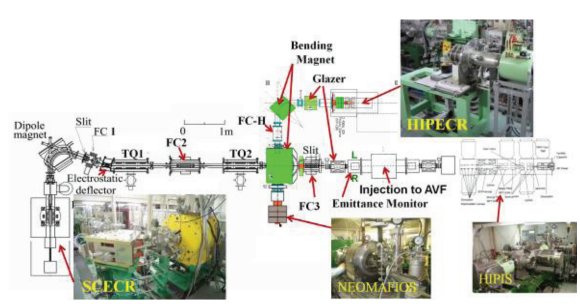

Figure 1: Ion Source Complex at RCNP: The room for ion sources is upstairs of AVF cyclotron; the transport line is 5980mm behind of median plane of cyclotron. There are 4 ion sources; HIPIS for polarized p, d, 2.45 GHz HIP-ECR for intense p, 10 GHZ NEOMAFIOS for p~Mg and 18GHz SC-ECR for highly charged heavy ions.

EXTRACTION ELECTRODE MODIFICATION FOR 18GHZ SC-ECR

Plasma electrode, extraction electrode and einzel lens are modified in order to increase the ion beam current. Figure 1a) shows the original electrodes and 1b) shows the electrodes after modification. The new extraction electrode can be applied to -20 kV against the plasma electrode which applied to +15kV. The baffle slit downstream of einzel lens is ground level. The position of

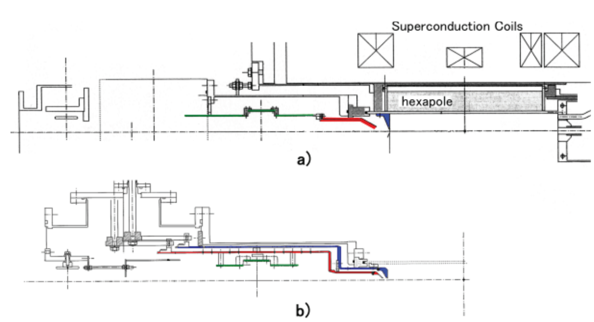

Figure 2: The schematic views of extraction system before modified in a) and after in b).In case of b) both positions of plasma and extraction electrode can be controlled from outside of vacuum chamber. New extraction electrode also can be applied to -20 kV. The baffle slit downstream of einzel lens is ground level.

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ISBN 978-3-95450-128-1

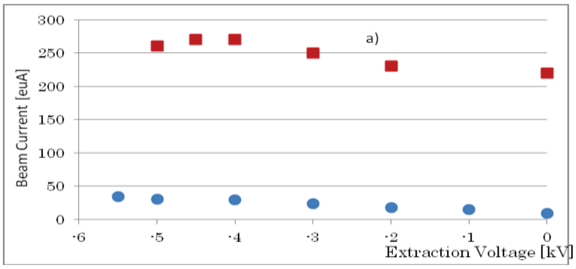

Figure 3: Beam currents versus extraction voltage. Circles show the current of 12C5+ made by CO2 gas and squares show the 12C5+ by CH4.

both of these new plasma and extraction electrode can be controlled from outside of vacuum chamber and those positions are monitored by potentiometer. This movable plasma electrode would control the eigen mode of RF resonance inside the plasma chamber which take important role in combination with bias disk[2]. Movable extraction electrode would optimize the beam extraction. The einzel lens which focuses the extracted beam is fixed inside the extraction electrode.

The beam test of the 18 GHz SC-ECR with this new extraction electrode has been carried with applied voltage bellow -6kV. The geometry of the SC-ECR and its beam transport line is shown in Figure 1. The test has been done by 12C5+ beam. The beam current is measured by Faraday cup FC1 in Fig.ure 1. Low current 12C5+ beam bellow 50euA is produced by CO2 gas and middle current beam around 250 euA is by CH4 gas. The results of the extraction voltage dependence of beam current are shown in Fig. 3a). Another parameters like mirror coil current, etc. are fixed during this studies. The case of low current 12C5+ beam shown by circles in Figure 3a), the current is increasing as the extraction voltage increasing. The case of middle current beam shown by squares in 3a), there is optimum value of extraction voltage around -4 kV. In both case, applied extraction electrode works well to increase the beam current. The difference of these two cases about the extraction voltage dependence might come from the effect of space charge. The dependence of einzel lens voltage also measured for every extraction voltage in the case of middle current by CH4 and the related voltage is optimum around 1.2kV against the extraction voltage as

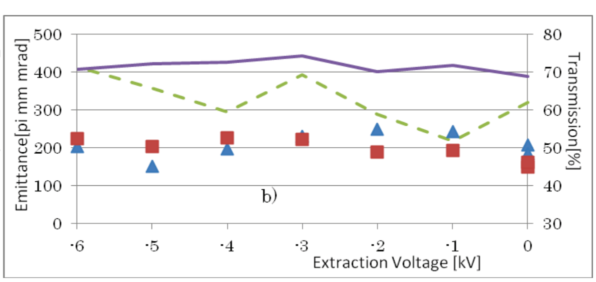

Figure 4: Squares are for x emittance measured by emittance monitor installed just after the FC3 and triangles are for y emittances. The dashed line shows the calculated emittance at the baffle slit the end of extraction system by IGUN code. The beam transmission between FC1 and FC3 is shown by solid line

shown in Figure 3b) for any values of extraction voltage bellow -6 kV at least.

TRANSMISSION AND EMITTANCE OF BEAM FROM SC-ECR

The extraction voltage dependence for the beam transmission and emittance also has been studied. Beam transmission of intense 16O6+ beam is measured by Faraday cup FC1 and FC3 shown in Figure 1. AVF main coil has been turned off for this measurement to avoid the effect of field leakage from AVF main coil[3] whose median plane is about 6 m behind of ion source transport lines. The result of measurement is shown in Figure 4a). Both of FC1 and FC3 increase as extraction voltage increases and so applied extraction electrode also effective for intense 16O6+ but the dependence is small. The transmission fC3/FC1 takes constant value of about 70% as shown by solid line in Figure 4b). The emittance measurement also has been done at the same time. The emittance monitor[6] is installed just downstream of FC3. The measured emittances are shown in Figure 4b). The emittances take constant values of about 200 pi mm mrad. The emittance calculated for the beam at the end of extraction of SC-ECR by IGUN code[7] is laso shown in Figure 4b) by dashed line and there is large extraction voltage dependence in comparison with the measured ones. It seems to be that there is some kind of aperture limitation on transport line. The further studies about this limitation would be continued to extend the beam current of highly charged heavy ion beam.

SOME MODIFICATIONS FOR 2.45GHZ HIP-ECR

Though the intense 400 MeV proton beam from Ring Cyclotron is required for several experiments, high brightness proton ion source with low emittance and high current of over 1 mA is needed. For that purpose the 2.45 GHz HIP-ECR has been installed and some beam developments has been already done with current of about 600uA with the RF of 150W successfully[4]. For further improvement of beam intensity, several modifications

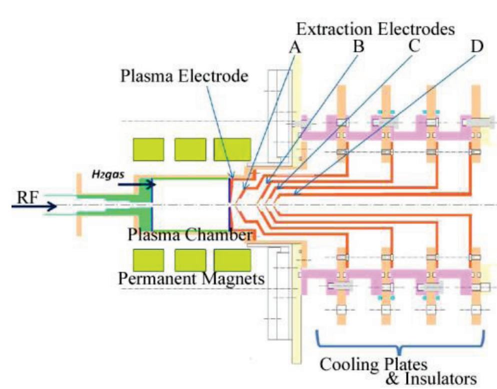

Figure 5: Schematic view of 2.45 GHz HIP-ECR. Extraction electrodes are connected to cooling plates separated by insulators.

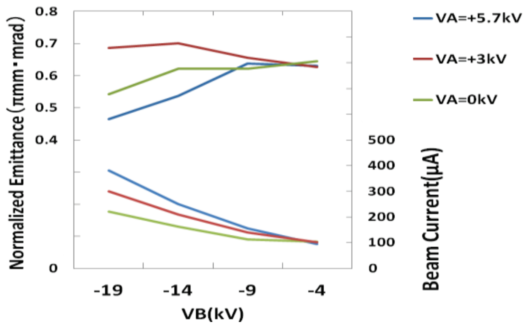

Figure 6: The proton beam production test with several conditions of applied extraction voltages. VA is the voltage of A-electrode shown in Figure 5. VB is for B-electrode. VC the C-electrode voltage is fixed to +4kV and VD is on ground. Upper lines show measured normalized emittances for each VA and VB. Lower lines show measured beam currents.

have been done as follows.

The extraction electrodes have been connected to cooling plates separated by insulators as shown in Figure 5. Then the beam stability has been improved with avoiding discharge problem. The plasma electrode position has been moved closer to resonance point. The optimization of positions and applied voltages of extraction electrodes has been well considered by IGUN[7] calculation and the beam test with near optimum condition also has been done. The beam test result for relation between beam current and A-electrode voltage and B-electrode voltage is shown in Figure 6. Near the calculated optimum values of VA=+11.5kV and VB=-20kV against the plasma chamber of +15kV, the measured beam has been maximum and emittance has been minimum. These plasma and extraction electrodes optimization works well. Impedance matching between

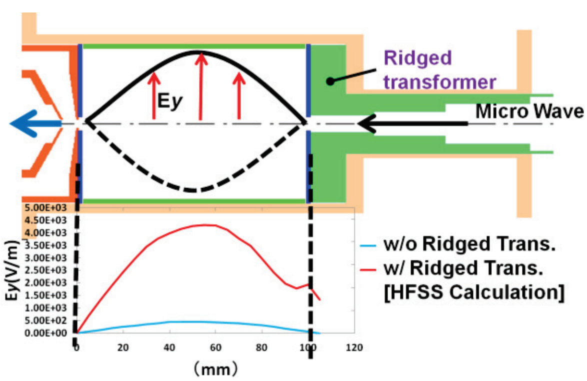

Figure 7: The result of micro wave inside plasma chamber calculated with ANSYS HFSS.

Wave Guide WR-284 (~660 Ω) and Plasma Chamber (~100 Ω, L=101.2mm, R=45.3mm) has been considered with additional Ridged transformer by calculation with ANSYS HFSS code[8] and much more electric field inside plasma electrode is expected with the transformer. Beam test with this new Ridged transformer will be carried and more beam current can be expected. Developments for highly bright low emittance beam should be continued further more.

SUMMARY

To improve the beam quality provided by RCNP Cyclotron Facility, some developments for ion source complex have been done.

The modifications of extraction electrode system have been done for increasing beam current from the SC-ECR ion source. Installation has been done and the beam test has been carried with up to -6 kV extraction voltage against the 15 kV plasma voltage and ion beam of low current 12C5+ of less than 50 euA is increasing as the extraction voltage rising even though the middle current 12C5+ about ~250euA has optimum extraction voltage assound -4 kV. This difference might come from space charge effect.

The extraction voltage dependences for transmission and emittance are also measured for 16O6+ and those values take almost constance against the extraction voltage. It seems to be that there is some kind of aperture limitation on transport line. More transmission and beam current can be expected with detail studies about transport line aperture and so on.

Some modifications for HIP-ECR also have been done to improve the beam intensity and emittance. The cooling system for extraction electrode improved beam stability. The optimization of plasma and extraction electrodes works well. According to the ANSYS HFSS calculation, much more beam current is expected with Ridged transformer.

Further developments would be continued for RCNP ion source complex to obtain much better beam quality.

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ISBN 978-3-95450-128-1