7. New injector linac to the RRC

The recent success of the discovery of the new super heavy element (SHE), $^{278}113$ using the RILAC, the CSM and the GARIS strongly encourages us to further pursue the heavier SHE search and to more extensively study nuclear physical and chemical properties of the SHEs. This compels us to provide a longer machine time for these experiments.

However, this SHE research and the RIBF research are incompatible with each other, because both of these two researches use the RILAC.

Thus, we propose to construct a new additional injector linac to the RRC, which will make it possible to concurrently conduct the SHE and the RIBF researches. The new injector will be used exclusively to produce the 350 MeV/nucleon primary beams (It is operated at the fixed frequency like the fRC.)

We made a design of the new injector linac as shown in Fig. 1, which is planned to place in the RRC vault as shown in the bird's-eye view of the RARF/RIBF layout (see Fig. 1 in Chapter 1 ("Overview of the RIBF Project")).

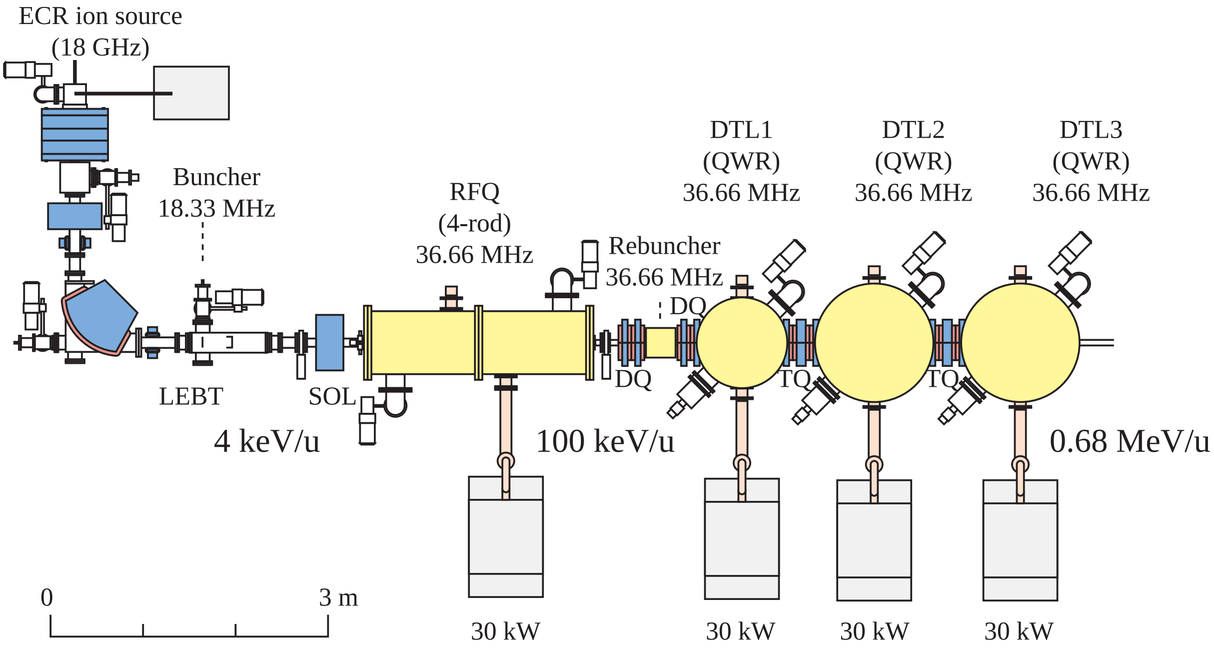

Fig. 1. Initial design of the new injector linac to the RRC.

The injector consists of an ECR ion source of 18 GHz, low-energy beam transport (LEBT) section including a buncher, an RFQ linac based on the four-rod structure, and three drift-tube linacs (DTL) based on the quarter-wavelength resonator (QWR). Strong quadrupole magnets will be put into the beam line between the rf-resonators. This linac accelerates ions of mass-to-charge ratio of 7 up to the energy of 680 keV/u in the cw mode. The output beam is injected to the RRC without charge-stripping.

Figure 2 shows the schematic drawing of the new 18 GHz ECR ion source. The new source has an additional solenoid coils between two solenoid coils as shown in Fig. 2. We found that the magnetic field gradient at the resonance zone plays essential role to increase the plasma density and the electron temperature. The field gradient strongly depends on the minimum magnetic field strength (B_{min}) of mirror field. Using this coil arrangement, we can change the B_{min} without changing maximum magnetic field (B_{ext} and B_{inj}) independently to optimize the magnetic field gradient at the resonance zone. The maximum magnetic field strength of mirror field will be 1.4 T.

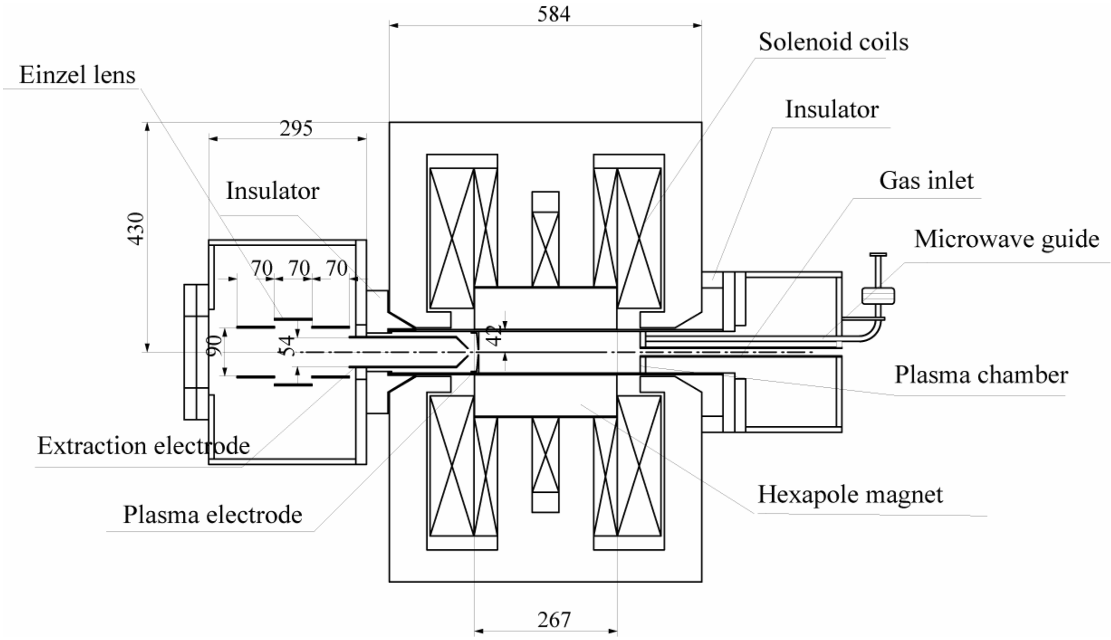

Fig. 2. Schematic drawing of the new RIKEN 18 GHz ECR ion source.

To confine the plasma radially, we use the hexapole magnet which consists of 36 segments of permanent magnets. The field strength at the magnet surface will be 1.4 T.

The inner diameter and length of plasma chamber is 78 and 300 mm, respectively. The magnetic field strength at the surface of the inner wall of the plasma chamber is 1.25 T. To evacuate the plasma chamber to order of 10^{-8} Torr, 150 and 300l/s turbo molecular pumps is used.

The input energy to the RFQ is chosen to be 4 keV/u; the maximum extraction voltage of the ion source is 28 kV. In order to increase the acceleration gradient of the injector, the resonant frequency of the resonators is set to be 36.66 MHz, which is twice the rf frequency of the RRC. The input beam is bunched in the fundamental frequency (18.33 MHz) before entering the RFQ, which helps to reduce the beam loss caused by the higher rf-mode operation of the injector linac.

The output energy of the RFQ is set to be 100 keV/u. The main parameters of the RFQ, determined by the PARMTEQ code, are listed in Table 1.

Table 1. Design parameters of the RFQ

Frequency (MHz)	36.66
Duty	100 %
Mass-to-charge ratio (m/q)	7
Input energy (keV/u)	4
Output energy (keV/u)	100
Input emittance (mm mrad)	200 π
Vane length (cm)	214
Intervane voltage (kV)	42.2
Mean aperture (r0: mm)	7.98
Min. aperture (a: mm)	4.55
Max. modulation (m)	2.41
Beam margin	1.35
Focusing strength (B)	6.8
Max. defocusing strength (Δrf)	-0.225
Final synchronous phase (deg.)	-30

The DTL parameters are optimized by calculating the beam dynamics and the rf-characteristics iteratively. A computer program, developed for the CSM design, is used for the beam-dynamics calculation, whereas the computer code MAFIA is used for the estimation of the rf-power consumption. Table 2 shows the parameters of the DTLs.

Table 2. Design parameters of the DTLs.

Resonator	DTL1	DTL2	DTL3
Frequency (MHz)	36.66	36.66	36.66
Duty	100 %	100 %	100 %
Mass-to-charge ratio (m/q)	7	7	7
Input energy (keV/u)	100	220	450
Output energy (keV/u)	220	450	680
Length (= Inner diameter: m)	0.8	1.1	1.1
Gap number	10	10	8
Gap voltage (kV)	110	210	260
Gap length (mm)	20	50	65
Drift tube aperture (a: mm)	17.5	17.5	17.5
Peak surface field (MV/m)	8.2	9.4	9.7
Synchronous phase (deg.)	-25	-25	-25

The optical calculations in the DTLs mentioned above require two types of quadrupole magnets with different effective lengths (six and ten centimeters) and very high field gradients (0.4 T/cm). The maximum beam size estimated in the calculations is 45 millimeters. We made magnetic field calculations using TOSCA to investigate whether conventional normal-conducting quadrupoles fulfill the present requirements or not.

In the magnetic field calculations, we use the BH curve built in the TOSCA, which gives slightly lower magnetic fields compared with magnets made in the RIBF project. The boa diameter was chosen to be 50 millimeters for both shorter and longer quadrupoles. Based on the quadrupole magnet used in the IH linac of Sumitomo Heavy Industries, Ltd., we made some modifications and obtained the following results illustrated in the Figures 3 and 4. For the longer quadrupole, the field gradient of 0.41 T/cm is excited by 11,900 ampere turns per pole, which corresponds to the overall current density of 6 A/cm^2. On the other hand, the field gradient of the shorter quadrupole remains 92 % of the required value with the excitation current of 14,900 ampere turns per pole (=7.5 A/cm^2). One prescription to increase the field gradient is that we reduce the boa diameter from 50 millimeters to 48 millimeters and adopt a lozenge-shaped beam duct. Magnetic field calculations performed here imply that normal-conducting quadrupoles with conventional design will work well as focusing elements of the new injector system, though we need further investigations on the shorter quadrupole magnets, especially on the coil-cooling problem.

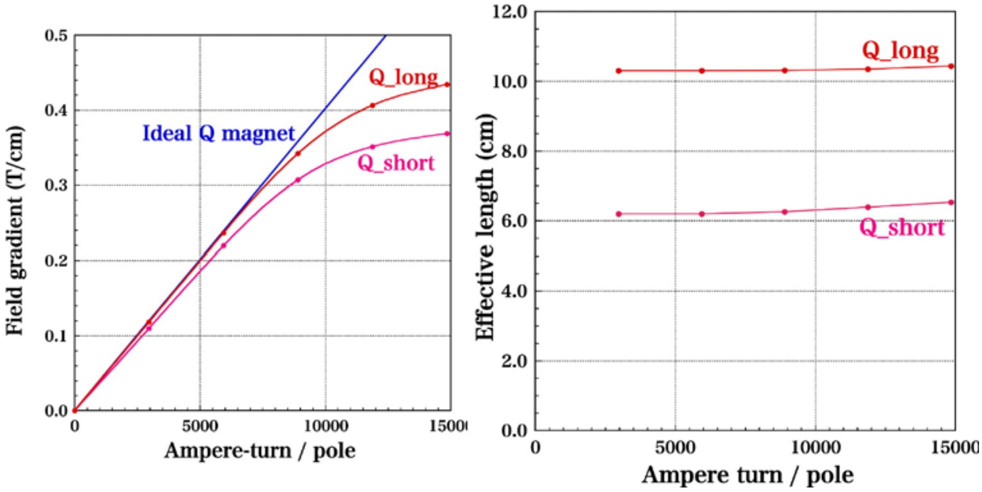

Fig. 3. Field gradient and effective length of quadupole magnets.

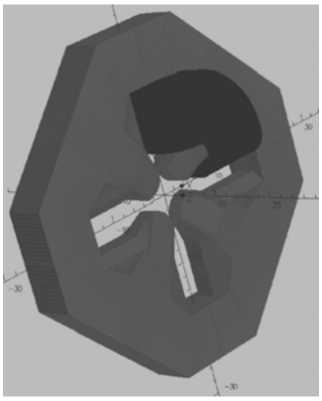

Fig. 4. Perspective view of the shorter quadupole magnet.

Estimation

Cost:	700 Myen
Manpower:	7 persons
Period:	2007 - 2008