Charge State Selective Ion Beam Acceleration Using the RFQ Linac

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In the field of Heavy ion beam Inertial Fusion (HIF) [1], one of the promising ion species as the driver beam is Bi^{2+}. Considering a scenario based on the RF accelerator, a laser ion source with the Direct Plasma Injection Scheme (DPIS)[2] has the advantage to provide high-intensity heavy ion beams[3]. Ion charge states produced by laser ion sources has distribution[4]. With DPIS, all charge states of ions can be injected into an RFQ linac. However, in the case of Bi^{2+} production, Bi^{1+} and Bi^{3+} would also be injected. These unnecessary ions would waste RF power and/or cause unexpected radioactivation. Thus, charge-state-selective acceleration using the RFQ linac is desired. In this study, a scheme to achieve charge-state-selective ion beam acceleration is discussed.

In the case of accelerating ions with a charge state q and a mass number A different from the desired particle with q_0 and A_0, the condition for stable acceleration is described as below[5]:

$$\frac{q}{A}\cos(\phi_s) = \frac{q_0}{A_0}\cos(\phi_{s0}), \tag{1}$$

where ϕ_s is the synchronous phase of a particle with charge-to-mass ratio q/A, and ϕ_{s0} is that of the desired particle. Then, the condition of capture for the case of $A = A_0$ is

$$0 < \frac{q_0}{q}\cos(\phi_{s0}) < 1. \tag{2}$$

Usually, the synchronous phase of the the desired particle in the accelerating section of the RFQ linac is approximately $-30°$. Therefore, by choosing Bi^{2+} as the desired particle ($q_0 = 2$), Bi^{1+} ($q = 1$) has no stable phase and would not be accelerated, while unwanted Bi^{3+} will be accelerated. The results of a particle tracking simulation show that more than 30% of Bi^{3+} are captured and accelerated by a conventionally designed RFQ for Bi^{2+}.

One of the solutions to accelerate only Bi^{2+} is the following scheme: 1) The ions are injected into the RFQ with different momentums depending on charge state q. Using this initial momentum difference between Bi^{2+} and Bi^{3+}, these ions can be pre-bunched separately in the longitudinal phase space. 2) The modulation or acceleration voltage is raised when Bi^{2+} ions are in the acceleration phase and Bi^{3+} ions are in the deceleration phase, and Bi^{2+} ions would gain energy while Bi^{3+} ions would be decelerated. 3) Due to the energy difference between Bi^{2+} and Bi^{3+}, only Bi^{2+} ions would be captured in the RF bucket and be stably accelerated. To realize this scheme, we varied cell lengths in the bunching section. An example of the sequence of the designed cell parameters is shown in Fig. 1. Fig. 2 shows the particle tracking simulation results with the cell parameters shown in Fig. 1. The capture rate of Bi^{3+} could be suppressed by up to 3 %.

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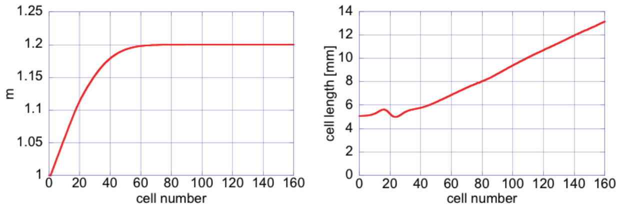

Fig. 1. Applied cell parameters versus cell number.

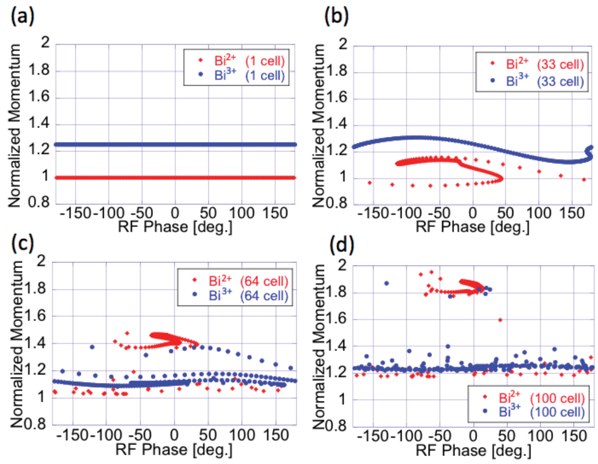

Fig. 2. Result of longitudinal phase space distribution. Red: Bi^{2+}, Blue: Bi^{3+}. The ordinate axis shows momentum normalized to Bi^{2+} initial momentum. The abscissa shows RF phase. (a) Initial distribution, (b) after pre-bunching, (c) after capturing Bi^{2+}, (d) after acceleration.

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