Development of a compact ECR ion source for various ion production


Abstract

There is a desire that a carbon-ion radiotherapy facility will produce various ion species for fundamental research. Although the present Kei-type ion sources are dedicated for the carbon-ion production, a future ion source is expected: 1) carbon-ion production for medical use, 2) various ions with a charge-to-mass ratio of 1/3 for the existed linac injector, and 3) low cost for modification. A prototype compact electron cyclotron resonance (ECR) ion source, named Kei3, based on Kei series has been developed to correspond to produce these various ions at National Institute of Radiological Sciences (NIRS). The Kei3 has an outer diameter of 280 mm and a length of 1120 mm. The magnetic field is formed by the same permanent magnet as Kei2. The movable extraction electrode has been installed in order to optimize the beam extraction with various current densities. The gas-injection side of vacuum chamber has enough space for an oven system or two-frequency microwave feeding.

Requirement to new source (Kei3)

- Various ion production
  - H\textsuperscript{+} to Fe\textsuperscript{11+}, H\textsuperscript{+} to Ne ion beam for biological experiment like an irradiation of mouse, Ar and Fe beam for irradiation of cell and physical experiment.
- Improvement of beam intensity
  - Change to mass ratio of ion is up to 1/3, because, we don’t want to change the injector line. 
  - Ion production from solid material.
  - Kei series were designed for production of C\textsuperscript{6+} ions. Therefore, it is difficult to produce enough intensity of heavier ions and molecular ions.
- Low cost
  - A change of expensive parts (magnets and microwave system) is not made so that it can upgrade from the existing compact source easily.

Design concept of Kei3

- Low cost
  - Same microwave system as the KeiGM (9.75 - 10.25 GHz, 750 W)
  - Same magnet as the KeiGM
- Improvement from existing Kei series for various ion productions
  - Improvement of insulation (increase the extraction voltage)
  - Improvement of vacuum in extraction region (high voltage extraction)
  - Movable extraction system (various current densities)
  - 2 bottle of gas for gas mixing
  - 2 waveguide for double frequency heating
- Ion production from solid material
  - MOVIC method
  - evaporator (resistance heating oven, induction heating oven)

Specifications

- Ion source
  - Diameter: 280 mm
  - Length: 1120 mm
- Wiper magnets
  - Material: NeFeB
  - Max. field strength (extraction side): 0.579 T
  - Max. field strength (gas injection side): 0.876 T
  - Minimum B strength: 0.240 T
- Hexapole magnet
  - Material: NeFeB
  - Maximum field strength on the chamber surface: 0.795 T
  - Length: 105 mm
  - Inner diameter: 58 mm
- Microwave
  - Amplifier: TWTamp
  - Frequency: 30 - 18 GHz
  - Maximum power: 250 W
  - Operation mode: pulse/CW

Beam tests

The ion source is being operated at a test stand. It consists of an analyzing magnet, four monitor boxes for Faraday cups, horizontal slits, an emittance monitor, and two vacuum pumps (500 l/s turbo molecular pump). In order to study the basis performance of the source, a beam test is being conducted using CH\textsubscript{4} and Ne gas.

In order to know the basis performance of Kei3, dependence of the operation parameters were checked. The tuning parameters of the source are the gas flow, microwave power, microwave frequency, biased disk voltage, and its position. In this time, following operation parameters were checked, microwave frequency, extraction voltage, distance between the plasma electrode and puller, gas mixing effect.

Conclusion and next step

We developed new compact ECR ion source, named Kei3, for various ion production. Preliminary beam test was already finished at test stand. The maximum beam intensity of C\textsuperscript{6+} and Ne\textsuperscript{+} were 206 eA and 7.8 eA under an extraction voltage of 15 kV.

We will test some improvement technique for increase the beam intensity. 1) increase the extraction voltage up to 30 kV, 2) optimization of extraction system, 3) increase the microwave power, 4) gas mixing method, and 5) two-frequency microwave feeding.

Requirement values of various ion

<table>
<thead>
<tr>
<th>Ion</th>
<th>Required intensity (eA)</th>
<th>Kei3 intensity (eA)</th>
<th>Material</th>
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<tbody>
<tr>
<td>H\textsuperscript{+}</td>
<td>500</td>
<td>270</td>
<td>H\textsubscript{2} gas</td>
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<tr>
<td>He\textsuperscript{+}</td>
<td>100</td>
<td></td>
<td>Ne gas, 50% He</td>
</tr>
<tr>
<td>Li\textsuperscript{+}</td>
<td>100</td>
<td></td>
<td>P</td>
</tr>
<tr>
<td>Li\textsuperscript{6+}</td>
<td>100</td>
<td>120</td>
<td>C\textsubscript{2}H\textsubscript{2}B\textsubscript{12}</td>
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<tr>
<td>Li\textsuperscript{7+}</td>
<td>200</td>
<td>680</td>
<td>CH\textsubscript{4} gas</td>
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<tr>
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<td>H\textsubscript{2} gas</td>
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<td>SF\textsubscript{6} gas</td>
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<tr>
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<td>Ne gas</td>
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