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医療サイクロトロン用大電流負イオン源の開発

Development of a High Current Negative Ion Source for Medical Cyclotrons

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Negative hydrogen ion (H^-) beam is widely used for medical cyclotrons whose applications are cancer therapy and diagnostics. A high-current DC H^- source has been developed to improve these cyclotrons' beam intensity. The multi-cusp DC arc-discharge type source has a beam extraction system which consists of a plasma electrode, an extraction electrode and a grounded electrode. H^- ions are produced by the volume production process [1] and the surface production process with addition of caesium (Cs) [2]. In our previous studies, stable 10 mA of H^- beam current has been obtained without Cs addition [3], and it has reached 22 mA in Cs-seeded operation [4].

In order to enhance H^- current in both the Cs-free and the Cs-seeded operations, some additional studies have been done. First, the extracted H^- current dependences on the extraction voltage (V_{ex}) and on the acceleration voltage (V_{acc}) is investigated. Experimental results show that higher V_{ex} and V_{acc} have to be applied to extract higher H^- currents (Fig. 1). These experimental results are compared with the beam optics calculation by using BEAMORBT [5]. The optimum V_{ex} which gives the highest H^- current at each V_{acc}, shows good agreements with the simulation results. In the beam optics calculation, the optimum V_{ex} is determined so as to minimize the beam divergence. Extrapolating the V_{ex} dependence on H^- current density, V_{ex} of more than 5.5 kV will be necessary to extract more than 30 mA of H^-. The simulation also shows that the distance between the extraction electrode and the grounded electrode has to be shortened in order to minimize the beam divergence and the beam losses at the extraction electrode.

Second, the relationship between the H^- production and the design/operating parameters (such as arc-discharge voltage and current, magnetic filter field strength, and so on) is being studied experimentally and numerically. A systematic numerical study of electron energy distribution function (EEDF) in the source plasma has been conducted by KEIO-MARC simulation code [6], and the resultant H^- density through the volume production process in the source has been analyzed by the zero-dimensional (0D) rate equation for different arc-discharge conditions as shown in Fig. 2. The results of the analysis explain the H^- current dependences on the arc voltage and on the arc current obtained experimentally.

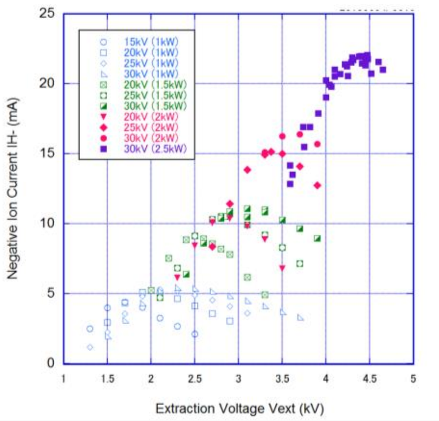

Fig. 1. H^- current dependence on V_{ex} and V_{acc}

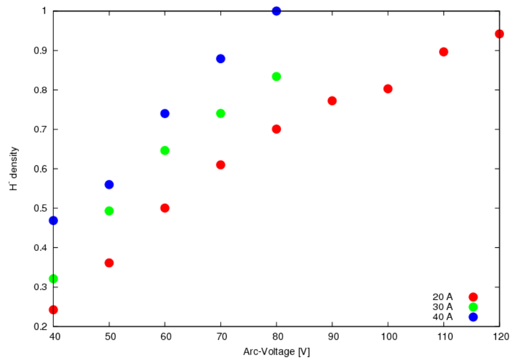

Fig. 2. H^- density vs. arc voltage

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