THE EBIS OPTION FOR HADRON THERAPY

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Abstract

An electron beam ion source (EBIS) can deliver sufficiently short and intense pulses of fully stripped light ions for single turn injection into a dedicated synchrotron for hadron therapy. In order to reach the injection energy of 2 to 3 MeV/u only one stage of rf acceleration without stripper will be needed, consisting of a RFQ of about 2 to 4 m length with a few Watts of average power consumption. While EBIS sources have shown in the past their ability to deliver the required intensities as well as the short pulse shape for single turn injection, attention must be paid to the question of beam purity. Different options will be discussed, especially the removal of impurity ions by ion-cyclotron-resonance excitation at intermedium charge states during stepwise ionisation.

1 INTRODUCTION

The use of heavy ion beams in the treatment of tumors was first employed in Chiba, Japan[1], and has now started in Germany at the GSI[2] applying beams delivered by the heavy ion synchrotron SIS. While this first approach using large accelerator centers is giving proof-of-principle the realisation of the next generation of smaller machines being dedicated especially to this purpose is underway. The concepts are governed by the need for compactness and simple operation. This is the point where the electron ion beam source (EBIS) may come into consideration. This source delivering rather moderate average currents in comparison to other sources like the electron cyclotron resonance source (ECR) has its benefits in providing very intense ion pulses of bare nuclei in a sufficiently short time interval well suited to a single turn injection into a synchrotron. We had therefore suggested the combination of an EBIS with a RFQ as an injector for a medically dedicated synchrotron[3]. Advantageously, the lifetime of an EBIS resembling travelling wave tubes in satellites can easily reach ten years since it has no consumable parts.

2 THE MEDEBIS PRINCIPLE

Since a few years we have started a research on a prototype of an EBIS as an injector ion source into a tumor therapy synchrotron[4]. To reduce complexity we are using a normal conducting solenoid of 0.8 T to focus the electron beam. The electron gun and the collector are magnetically shielded by iron cylinders of high permeability. The beam parameters for the first prototype were 170 mA at 3 keV at a current density of 70 A/cm^2 being sufficient for the production of bare light ions in less than a second. For the first time the fast ion extraction in about 2 μsec to fulfil the requirement of single turn injection was reached by the use a rather short trap length of 0.25 m being just sufficient for the production of the required amount of ions and a new technique for the axial expulsion of the ions. For the time of extraction an external potential gradient of about 5000 V/m had to be applied to the ions to push them out of the source. For this purpose tapered slits were machined into the trap electrode (see fig.1). If the potential of this electrode is raised, the potential of the vacuum tube surrounding the trap electrode will influence the potential distribution inside the structure through the slits. By appropriate shape of the slits the axial gradient can become linear, which optimises the bunching.

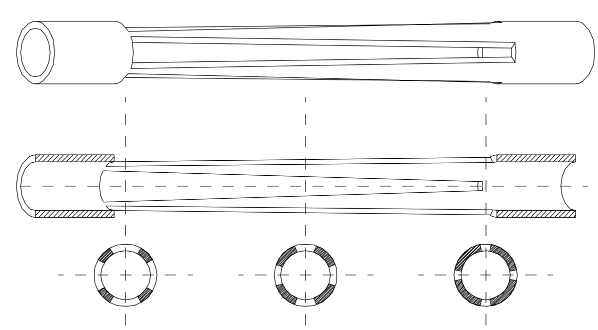

Figure 1. Schematic drawing of the electrode structure

3 MEASUREMENTS AND RESULTS

The results so far were very promising , using oxygen as feed gas, with a confinement time of 200 msec bare nuclei could be made dominant in the spectrum , but there was also still a large amount of O^{7+} and O^{6+} ions. The observed pulse length of 2 μsec FWHM shows that we can expell the ions fast enough. To test the reliability of the source we operated it for two months continuously delivering bare oxygen. Its performance was absolutely stable, the spectrum stayed completely unchanged for 10 days, i.e., until we changed parameters for further studies[5].

4 FURTHER IMPROVEMENTS

The lower charge states in the extracted spectrum result from the relatively high residual gas pressure in the trap region. This can be improved by better pumping conditions, shifting the onset of space charge compensation to ionization times sufficiently long to saturate the spectrum with bare nuclei. The low conductance given by the relatively small diameter of the vacuum tube surrounding the trap electrode results from the small 20 mm inner diameter of the solenoid. In the mean time we have drilled out the two innermost windings and installed a tube almost twice in diameter. The loss in magnetic field strength is compensated for by

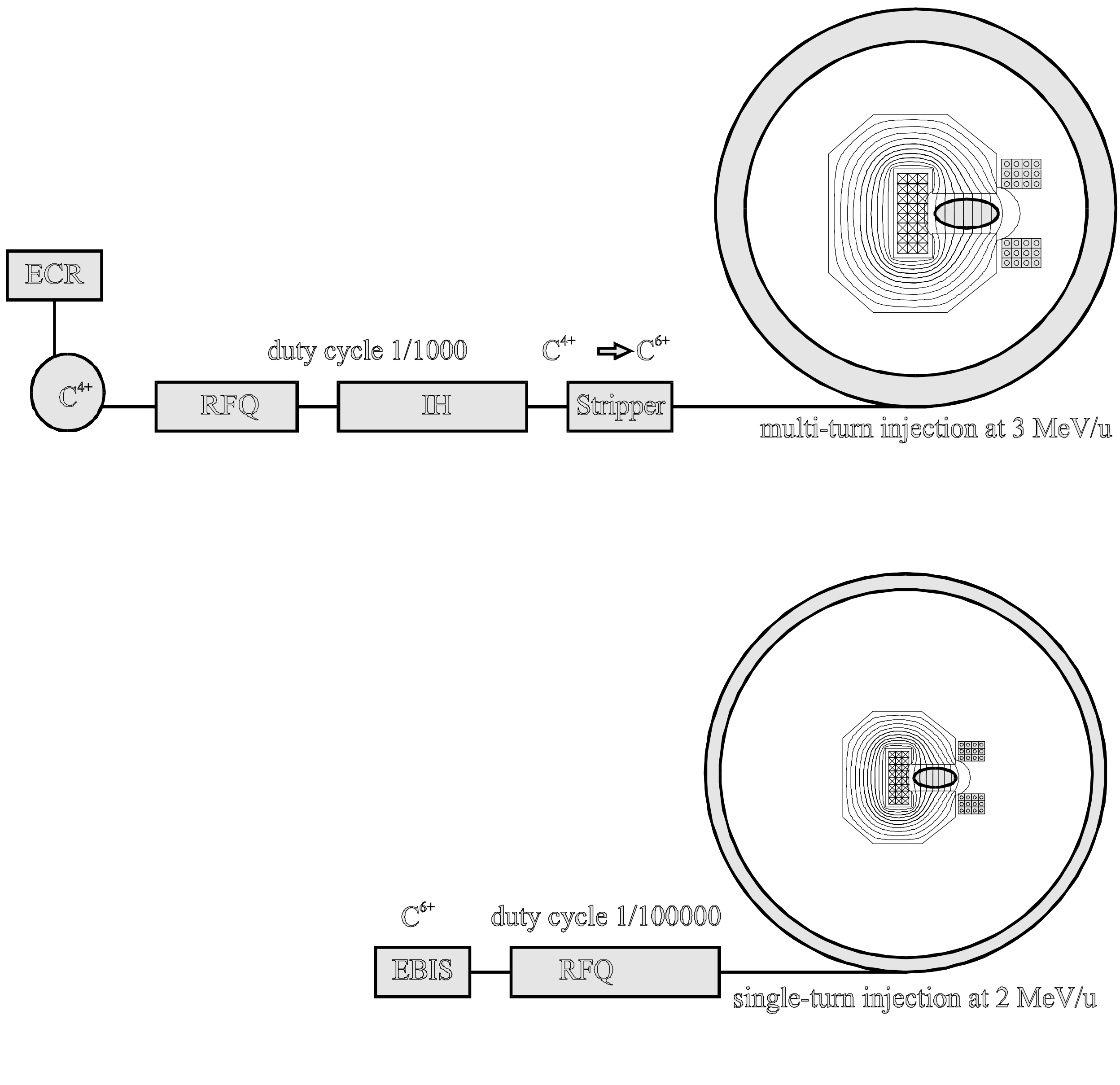

Figure 2. Comparison of the accelerator systems for light ion therapy
upper panel: based on a ECR ion source, producing C^{4+} ions
lower panel: based on an EBIS ion source, producing C^{6+} ions

employing soft iron shielding discs of high permeability on both ends of the solenoid. Magnetic field measurements have shown even an improvement in the homogeneity. The larger vacuum tube diameter allows also the installation of NEC getter material to improve the vacuum in situ. The matching of the electron gun has also been redesigned now offering operating parameters of 1A / 6.5 keV. The reassembly is underway, new results will be expected soon.

5 BEAM PURITY

The medical application of the ion beam makes beam impurity an important question. Different species of bare nuclei will have different biological effect , which puts up the question which amount is tolerable (none, 1%, 10%?). All ion sources usually deliver an ion spectrum of different charge states and species. This is especially a problem with ions of the same charge to mass ratio. In the GSI proposal therefore magnetically selected C4+ ions will be accelerated up to the injection energy of the synchrotron where they then will pass a stripper to remove the final two electrons to offer bare nuclei to the synchrotron. By this procedure bare nuclei of nitrogen or oxygen are not accepted simultaneously by the synchrotron, offering a very low impurity admixture. Of course an EBIS could also be operated at lower confinement time or current density delivering now a spectrum of ions peaking at C^{4+}. The lower relative abundance necessitates a higher loading of the source capacity which could be counteracted by a higher electron current, which is easy at lower current density .

6 REMEDIES FOR THE SIMPLE EBIS CONCEPT

On the other hand it is much more advantageous to use the ability of the EBIS to shift the spectrum into saturation of abundance at bare nuclei. The higher charge state allows a much simpler accelerating principle: no charge state analysis, RFQ with low duty cycle, no IH-structure, no stripper, no multiturn injection (see fig. 2). The RFQ will reach the injection energy of 2 to 3 MeV in a single stage consisting of a 2 to 4 m long structure with only a few Watts power consumption due to the low duty cycle of 10^{-5}. But how to handle the problem with impurities? The best situation would be to keep them as low as possible. If the device is leak tight there is no N^{7+}. Bare nuclei of oxygen have to be considered since there will always be some CO_2 in the residual gas. Again the question has to be raised which amount of this impurity can be tolerated.

For the EBIS a special operation can be taken into consideration, where the impurity ions are removed by the use of ion-cyclotron-resonance excitation, well known from Fourier Transform Ion Cyclotron Resonance (FT-ICR) methods applied in Penning traps to remove unwanted ion species. We have a combination of an EBIS with such a Penning trap under operation to study the influence of the heating on the charge state spectrum in an EBIS[6]. This principle could be applied to remove all residal gas ions at intermediate charge states during successive ionization where they are distinguishable by their charge-to-mass ratio, thus not influencing the charge state evolution of the wanted carbon ions.

Last not least the use of commercially available isotopes can eliminate the possible confusion with ions of charge-to-mass ratio of 1/2. In order to proof the beam purity of produced ions we will operate our source with $^{13}CH_4$ to test the situation.

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