STATUS OF ION SOURCES AT HIMAC

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Abstract

The Heavy Ion Medical Accelerator in Chiba (HIMAC) at the National Institute of Radiological Sciences (NIRS) was designed as a clinical dedicated facility. The carbon ions are utilized for the heavy-ion radiotherapy, so its production is the most important aim for ion sources at HIMAC. However HIMAC has a second essential task to operate as a facility for basic experiments. In that scope it accelerates many ions. In order to serve all HIMAC users at best, three ion sources have been installed. This report summarizes the status of the ion sources to produce carbon ions and to extend the range of ion species.

INTRODUCTION

The National Institute of Radiological Sciences (NIRS) was funded in 1957 and has been researching on the effects of radiation on the human body, protection from radiation, diagnosis and treatment of radiation injuries, and medical uses of radiation. The HIMAC (Heavy Ion Medical Accelerator in Chiba) project is one of the most important research subjects in NIRS [1], and it has successfully realized the heavy-ion radiotherapy with 140-400 MeV/u carbon beams since 1994 [2]. HIMAC was designed as a clinical dedicated facility, but it has as a second essential task to operate as a facility for basic experiments in e.g. biomedical and material science, physics and chemistry. In order to accelerate various ion species, two ECR ion sources and one PIG ion source are installed. The carbon ions for the daily treatment are mainly provided with a 10GHz ECR ion source called 'NIRS-ECR'[3]. The NIRS-ECR is sometimes utilized for lighter gaseous ions too. A PIG ion source, ('NIRS-PIG'), supplies relatively lighter ions, especially metallic ions by the sputtering method [4]. An 18GHz ECR ion source called 'NIRS-HEC', produces relatively heavier gaseous ions[5,6]. Since the three ion sources are almost occupied with daily operations, it's difficult to spend a time for the development to extend the range of ion species. The installation of a new local injector linac is scheduled to be completed in the spring of 2011. Another ECR ion source, called 'Kei2' had been developed as a prototype of a hospital specified facility[7], is now under commissioning for the new injector. It is expected that the other three ion sources will be free from the carbon production for the daily clinical operation. Several developments for these four ion sources are now in progress. The present status of carbon-ion production and the trial for the extension of the range of ion species with ECR ion sources are presented in this paper.

CARBON-ION PRODUCTION

Difficulty of carbon- ion production

The production of highly charged carbon ions with good stability and reproducibility is harder effort than other ions. NIRS-PIG realizes a very low-duty pulsed operation and a feedback of the arc power. In addition, its carbon vapour is supplied by sputtering from graphite resulting decreasing amount of carbon atoms in the chamber. So that, the lifetime can extend about one week [4]. However the change of conditions of consumptive parts like a cathode finally requires the tuning by manual operation. It's not satisfied for the medical requirement. Unfortunately, this difficulty is also true for the ECRIS, the source well known for its long lifetime and good performance for highly-charged ion production. Based on the experiences at NIRS-ECR and NIRS-Kei2, the performance of the ECR ion source is degraded due to carbon deposition on the parts, especially the chamber wall. In order to increase the intensity of highly charged carbon ions like C^{4+}, it's effective to feed hydro-carbonic C_xH_y gases[8]. However, the deposition is unavoidable under the use of such gases, and causes serious unfavourable effects.

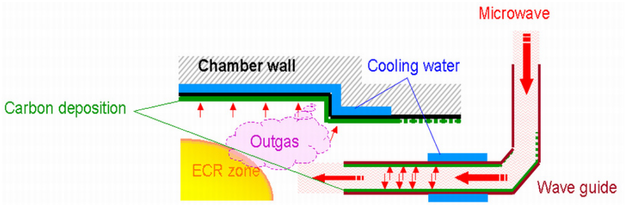
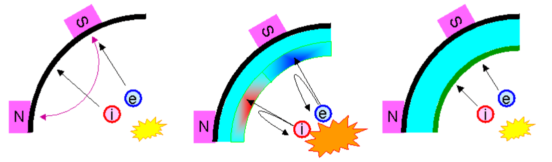


Figure 1: Microwave absorption on the dirty carbon deposited wall.

The microwave power absorbed on the walls of the waveguide and the plasma chamber increases with increasing the deposition on the walls. The less microwave power can reach into the ECR zone shown in Figure 1, thus the plasma density and the electron energy distribution must be low. When the microwave power is increased in order to compensate for this deficit, more loss of the microwave power causes heat-up of the walls and the heat-up induced the change of the vacuum pressure. As a result, reproducibility is much worse. In order to solve the problem, we improved the water cooling system for plasma chamber and the waveguide, however the transmission efficiency is consequently worse. Therefore, the maximum power of the microwave amplifier must be sufficiently high.

The deposition on the wall of the plasma chamber also causes another unfavourable effect, i.e. a decreasing of the beam, especially for the higher charge-state ions due to the surface material of the plasma-chamber wall. Considering the particle loss fluxes in a 'normal ' ECRIS, the electron flux dominates the axial losses and the ion flux dominates the radial diffusion; both fluxes compensate in the conducting surface material forming the so-called 'Simon short circuit'. In the case some depositing material on the wall forming a dielectric surface, ions diffusing to the wall will charge up the surface of the wall and forms a repelling potential. Thus the loss fluxes are reduced, the short circuit is broken; this leads to better performance and the beam intensity increases [9]. This beneficial effect usually is called the 'wall-coating' effect shown in Figure 2B. However, when operating the source with carbon, the wall will be completely covered by carbon material, forming a well conducting surface layer shown in Figure 2C; it appears that the beam intensity gradually decreases. This is likely due to the 'adverse (or anti-) wall-coating' effect [3].



A) Normal metallic wall B) Dielectric wall (wall coating effect) C) Carbon deposition (Adverse wall coating effect)

Figure 2: Adverse wall-coating effect in the carbon production.

Status of carbon-beam operation

The condition of the deposition on the wall depends on the operation parameters and it sometimes shows hysteresis. For example, oxygen gas removes the deposited carbon atoms from the wall shown in Figure 3. The varying of the condition immediately gives instability or bad reproducibility. The exchange of ionising gasses is especially undesirable.

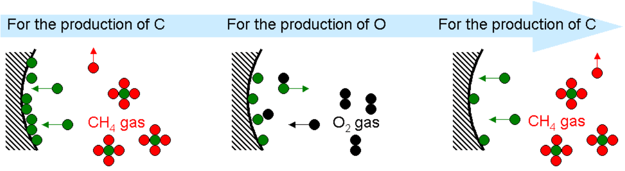


Figure 3: Cycle of carbon deposition on the wall.

In order to maintain enough reproducibility and stability under the dirty condition, the suppression of any change of the vacuum pressure due to the heat-up process is necessary. The cooling for the plasma chamber, the waveguide, and the extraction electrode are effective. Good thermal conductivity is a major consideration for the material of the chamber, because it does not affect the intensity due to carbon deposition. In this meaning, copper is also a good candidate. The extraction slit and the puller are also important heat-up parts. These are therefore made of molybdenum, and the puller is cooled by water. Pulsed operation is also effective to reach to a stable condition as soon as possible. Finally, we obtained typically 70 % decreasing of the beam after a few months of operation, but it's still available to produce a sufficiently intense and stable beam [3]. Although the beam intensity varies during the first few tens of minutes, it becomes fairly stable within 1 hour.

TRIAL FOR THE EXTENSION OF THE RANGE OF ION SPECIES

In order to extend the range of ion species with our ECR ion sources, the optimization of the extraction configuration, the gas mixing technique, and the MIVOC method gave successful results. We have reported the scope and history of our developments in Ref. [10]. The points to be considered for development are as follows.

- No ion source specialist is required for tuning.
- Since the ion sources are almost occupied for the daily operation, the short development time is only available.
- With the present ion sources' structure the required reproducibility and stability is fulfilled. New developments are in a way disturbing the situation.
- For developments one has to cope with 'dirty' plasmas and many contaminations in the available sources.

The high priority is assigned to the two-frequency heating technique and the MIVOC method at present. They are discussed in the next points.

Two frequency heating

Many reports pointed at the improvement of highly charged ion production by feeding multiple microwaves with different frequencies [11]. In an early stage of the development of two-frequency heating with the HYPER-ECR at the Institute for Nuclear Study, the University of Tokyo, we could confirm that the two different frequency microwaves using two klystron amplifiers (KLY) were absorbed at different ECR zones by observing the shapes of visible radiations [12].

In order to investigate the frequency dependence precisely, we added an additional travelling wave tube amplifier (TWTA) with a wide frequency range between 10 and 18 GHz to NIRS-HEC. We also concluded that it is also important to adjust one frequency to the other frequency[13]. Since our TWT had only a maximum power of 250 W at the former experiments, it was not enough to improve the performance.

The recent experiments were performed with NIRS-HEC which has an 18.0 GHz KLY with a maximum power of 1500W. An additional TWT system was added to NIRS-HEC. The frequency range and maximum power of TWTAs are 17.75 to 18.25GHz and 600W, respectively.

The detailed experimental setup had been described in Ref. [10].

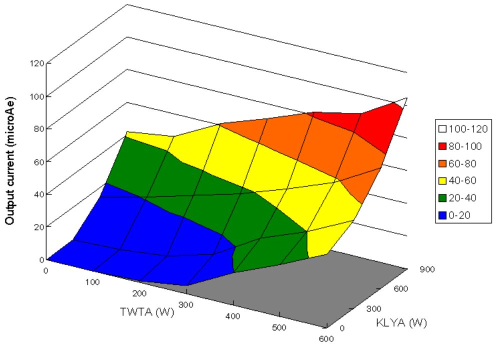


Figure 4: Calibration of microwave power from each amplifier.

The present experimental data were obtained with ^{132}Xe gas (isotopic enrichment 90%). Initially, the parameters of KLY, i.e., microwave power, amount of gas, magnetic field, extraction voltage, and so on, were optimised. Then, the frequency of TWT was optimised. Figure 4 shows a dependence of the output current of ^{132}Xe^{21+} on microwave power of KLY and TWT. The frequencies of microwave are 18.0 and 17.88 GHz, respectively. The relation of input microwave power and output beam current showed that 900 W by KLYA has the same effect as 600 W by TWTA. Both powers were measured by crystal detectors midway the chamber from the amplifiers. The two waveguides had the different loss of microwave. It seams that the transmission efficiency from KLY is likely about 2/3 of TWT. The microwave power of TWT was normalized by KLY power in Figure 5. The red line shows the output currents of ^{132}Xe^{21+} by TWT only. The blue line shows the output currents by KLY only. The broken blue line indicates the region of instable plasma. The green line shows the output currents by mixture of TWT and KLY. The green line was slightly lower than red and blue lines. Although we suppose interference with each other slightly occurred, the output current mainly depended on the total power of two frequencies.

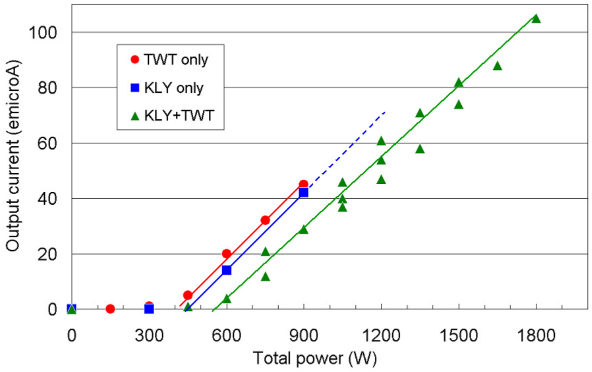


Figure 5: Dependence on total microwave power.

In the case of the total 1200W with 300W TWT and 900W KLY, when TWT was stopped and only KLY supplied, the beam intensity was decreased from 60eμA to 40eμA. When the microwave power from KLY was increasing, the output current was also increasing. However, the beam instability was appeared over 900 W as shown in Figure 6. The plasma collapsed every several milliseconds and recovered in about 1 ms. When TWT turned on in this situation, the beam stability was improved and the large output current was obtained.

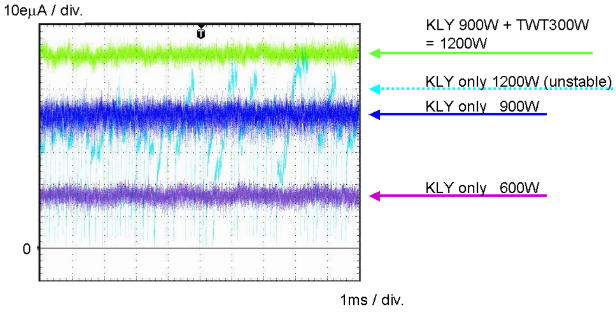


Figure 6: Limitation of microwave power for instability.

As a conclusion, the two frequency heating improved the beam intensity under the conditions of enough power and precise frequency tuning for the additional microwave. It seems it is mainly due to prevent the plasma instability. The effect appears to be most important on the higher charge states, therefore further study needed. The optimised microwave power is not saturated in our cases. Applying a more powerful TWT would be promising. For higher charge state ions, it is more effective.

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