Nitrogen Acceleration with a Cold Cathode Type PIG Ion Source

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1. Designing of the Heavy Ion Source and Its System

     Since a few years, the CYRIC cyclotron have routinely accelerated light ions
of mass number $A \leqslant 4$. Furthermore, the acceleration of heavier ions have been
successful with the floating cathode type PIG ion source which was originally
designed in aim of high current helium beam.[1] The ion source of this type,
however, is not applicable to multicharged ion production. A small cold cathode
type PIG heavy ion source was designed and $^{14}N^{4+, \ 5+}$ ions were accelerated with
this one. Because of the very limited space and the sophisticated geometrical
conditions in the centre region of the cyclotron, design of a small size heavy
ion source is indispensable. This limitation give us some additional difficulties
to produce highly charged ions, that is, high power consumption to the ion source
is restricted by the limited anode and cathodes cooling capability and the sputter-
ing at certain places besides the arc chamber.

     The construction of the ion source is shown in fig. 1. The anode block and
corn block are made of copper and are cooled with water through the water pipes.
The cathode support water pipe is made of stainless steel and is covered with Ta
pipes to protect itself from the sputtering by discharges between the electrodes.
In order to avoid the short circuit caused by the sputtered material from the Ta
cathodes, an insulating wall made of boron nitrides was placed between the bottom
cathode and the anode inside. The bore diameter of the ion source is 8 mm and
can be reduced by inserting a cylindrical Ta sleeve. The ion source was designed
to be fitted into the 36-mm diameter ion source shaft which could be inserted
into the operating position through the lower pole of the cyclotron.

     The capacity of the arc power supply is 30 kW, and it can be operated in
both DC and pulsing mode. Since the beam current from the ion source for higher
charge state ions is fairly sensitive to the gas flow rate, the gas control sys-
tem is provided with an electric piezo valve for fine adjustment at a minimum
flow rate of 0.02 cc/min. The description of gas system is reported in detail
on another title[2] in this annual report.

2. Acceleration and Ion Source Operation

     For an optimum pulse operation, ^{14}N ions were accelerated with appropriate
harmonics H = 3th (for N^{5+}) and H = 4th (for N^{4+}), then masimum beam intensities

obtained were 3.5 μA and 5.0 μA for $^{14}N^{5+}$ and $^{14}N^{4+}$ ions, respectively, at R = 650 mm. The $^{14}N^{5+}$ ions of $E_{^{14}N}$ = 84 MeV were extracted from the cyclotron and its beam intensity was 1.5 μA. Then the 6.4 mm inner diameter of arc bore was realized by inserting a Ta sleeve into the arc chamber. The beam intensity increases with the decrease of the bore diameter, and also depends on the duty factor of the operating pulses.

The life time of the Ta cathodes in the pulse operation is at least 6 hours for a supplied electrical power of 2 kW.

3. Data and Analysis

The N^{5+} ion current extracted from the PIG ion source is measured as a function of the arc pulse width in a region of 0.75-4.0 msec. The variation of N^{5+} ion current with the pulse width are plotted for the duty factors of 20, 25, 30 and 35 % in fig. 2. The length of vertical bars denotes an error by fluctuation of N^{5+} ions beam intensity that was measured in a fixed duty factor. In this case, electric power applied to the ion source is 400 W in average, that is, the arc current I = 1A and the arc voltage V = 400 V. These data have maximum peak values for around 1.5 msec pulse width.

The time dependence of the number of nitrogen ions in the plasma colum of pulsed discharge is calculated to explain the results of the present data. The calculations[3] are performed applying the solar corona model, in which the electron temperature and density in the plasma discharge are taken as parameters. The results of the calculations are compared with the experimental data in fig. 2. The theoretical curves are generally in agreement with the experimental data. These curves exhibit a tendency toward a flat curve with increasing duty factor, and this tendency is also shown on the experimental data. In fig. 3, the maximum values of the variations of N^{5+} ion current with the pulse width are plotted versus the pulse duty factor. The result of calculation is denoted by the solid curve, which increases smoothly with the duty factor. If the applied power to the ion source is consumed only by the arc plasma discharge for any duty factor, the production of multicharged ions should increase with the duty factor. But some disturbance in the arc plasma may be induced by applying the arc power exceeding the ability of the ion source. Then, the applied arc power may be not only consumed by the arc plasma discharge but by other discharges like hash. Therefore, multicharged ions will not increase with the arc power above a certain critical duty factor.

4. Summary

It is difficult to operate such a small cold cathode PIG ion source with high electroc power because of insufficient cooling capability and construction. Therefore, in producing multicharged ions, the supplying electric power should be reasonably lowered. In compliance with this request, the pulsed operation of the arc power supply is extremely useful. Furthermore, the gas flow is one of the most critical parameters for an efficient production of multicharged ions

and for a long life of the cathodes. In order to obtain meaningful results, a steady condition is indispensable for the plasma discharge in the arc bore. In other words, the applied power to the ion source must be consumed only by the arc plasma discharge. Therefore, it is very important to search the optimum parameters for multicharged ion production for using the lower arc power as possible, and the life of cathodes may be longer.

The parameters used in the calculation are in correlations with gas pressure, arc voltage, and magnetic field. The electron temperature which is also one of the parameters depends on gas pressure, arc voltage and arc current. The effect of the magnetic field on the electron temperature may be primarily to reduce the effective mean free path of the electrons, and the importance of inelastic collision will increase with the strength of magnetic field. The electron temperature in the plasma plays an important role for ionization and recombination coefficients. We cannot, however, obtain exact values of the electron temperature as a function of arc voltage, gas pressure, and magnetic field. Thus, the electron temperature of 20 eV was taken as a parameter to fit the experimental data.

The discharge parameters of the arc plasma may also depend on the diameter of arc bore and the shape and material of the cathodes. Furthermore, these parameters are in correlations with each other. In the present work, the parameters used in the calculation are assumed to be independent of each other in reproducing the experimental data. Although the values of the parameters used in the present calculation may not have a certain physical evaluation, the results of the present analysis will help us to understand what is predominantly going on in the plasma discharge of a cold cathode PIG ion source.

References

1) Shinozuka T., Yamaya T., Sakurada U., Kotajima K. and Fujioka M., Int. Conf. on Cyclo. & Their Appli. Caen, France (1981).
CYRIC Annual Report (1980) p. 253.
2) Onodera T., Kotajima K., Omori S., Oshima M., Yamaya T., Shinozuka T. and Fujioka M., in this annual report.
3) Yamaya T., Kotajima K., Shinozuka T., Fujioka M., Sakurada U., Onodera T., Ishimatsu T. and Morita S., submitted to N. I. & M.

CATHODE SUPPORT COVER
(TANTALUM)

TOP CATHODE

ARC BORE SLEEVE
(TANTALUM)

SLIT (TANTALUM)

GAS

CATHODE WATER
PIPE

10°

BOTTOM CATHODE

ANODE WATER PIPE

INSULATOR

ALUMINA

BORON NITRIDE

TEFLON

CATHODE WATER PIPE
JUNCTION (BRASS)
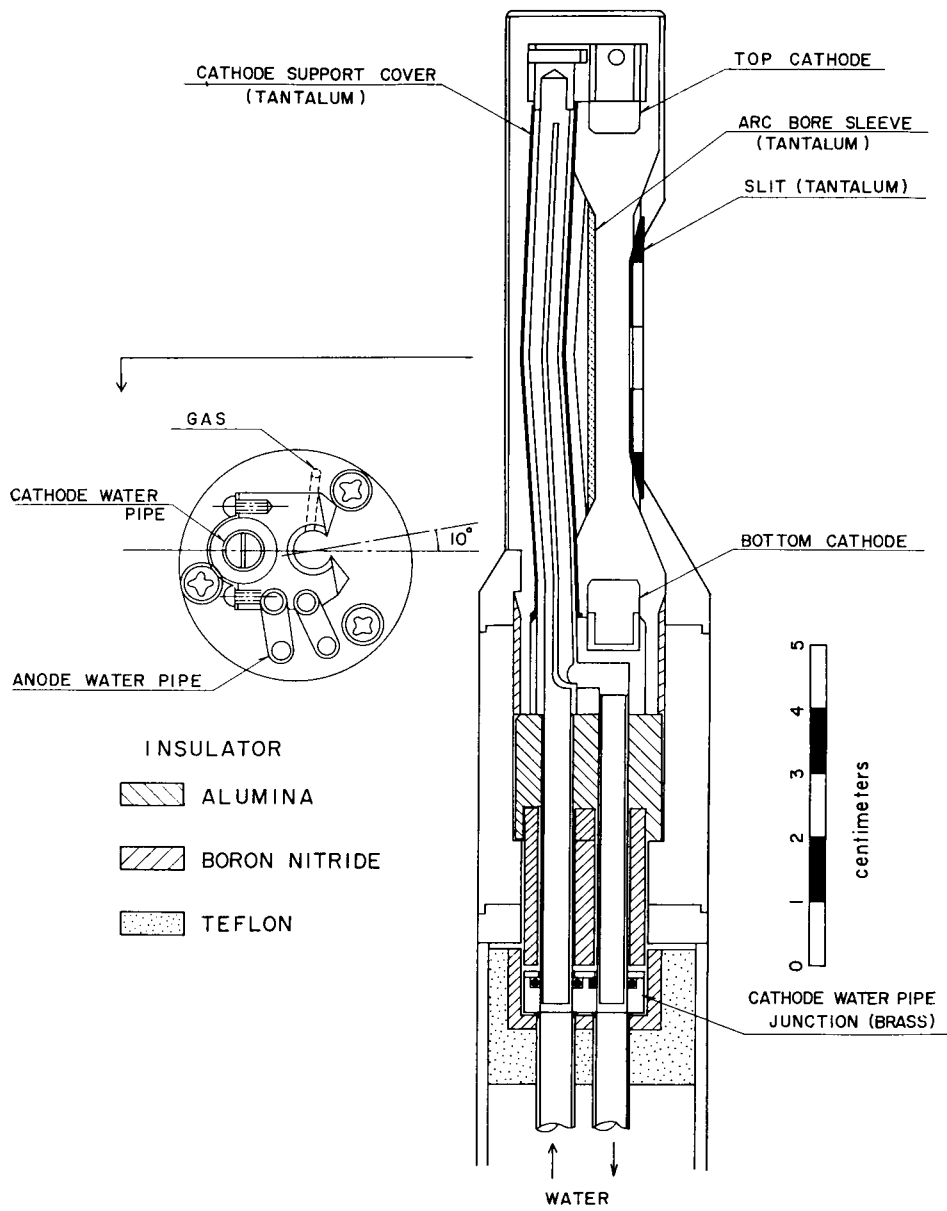
centimeters

WATER

Fig. 1.   Sectioned view of the small PIG ion source for heavy ions.
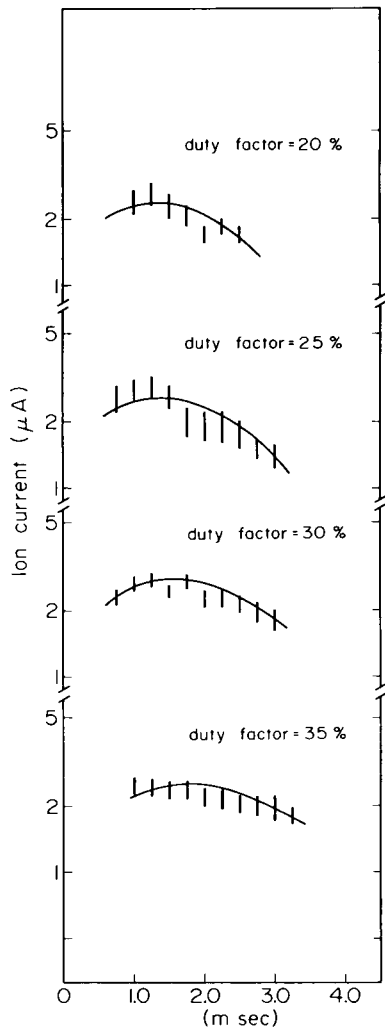
Fig. 2. Comparison between
the calculation
curves and the
experimental data.
The calculated
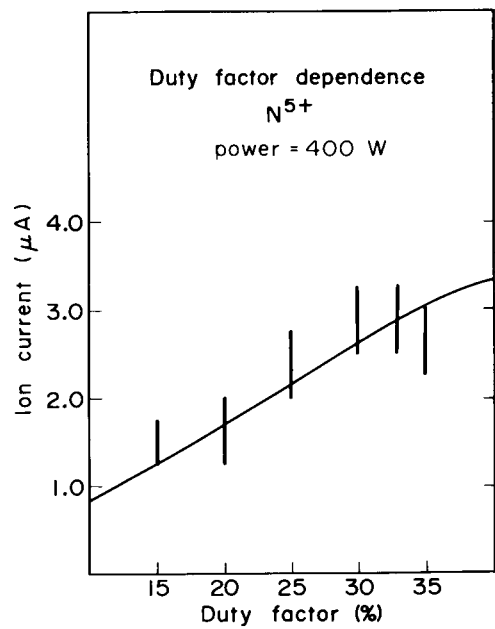curves are in agree-
ment with the data
qualitatively.

Fig. 3. Maximum values of N^{5+} ion
current for different duty
factors compared with the
result of the calculation.
The calculated curve
reproduces the most data.