Experiment of two frequency heating for production of multiply charged ion at compact ECR ion source

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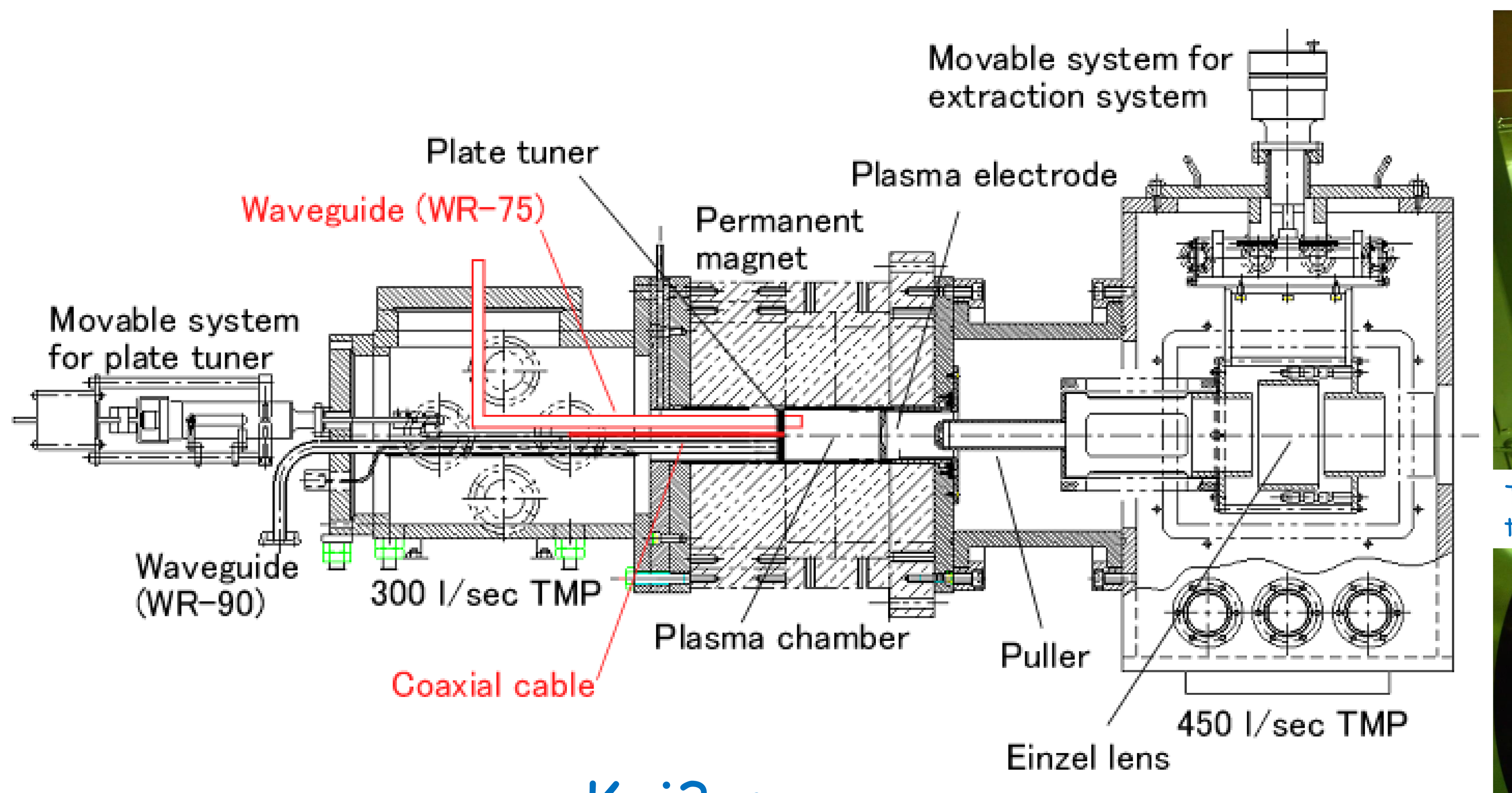
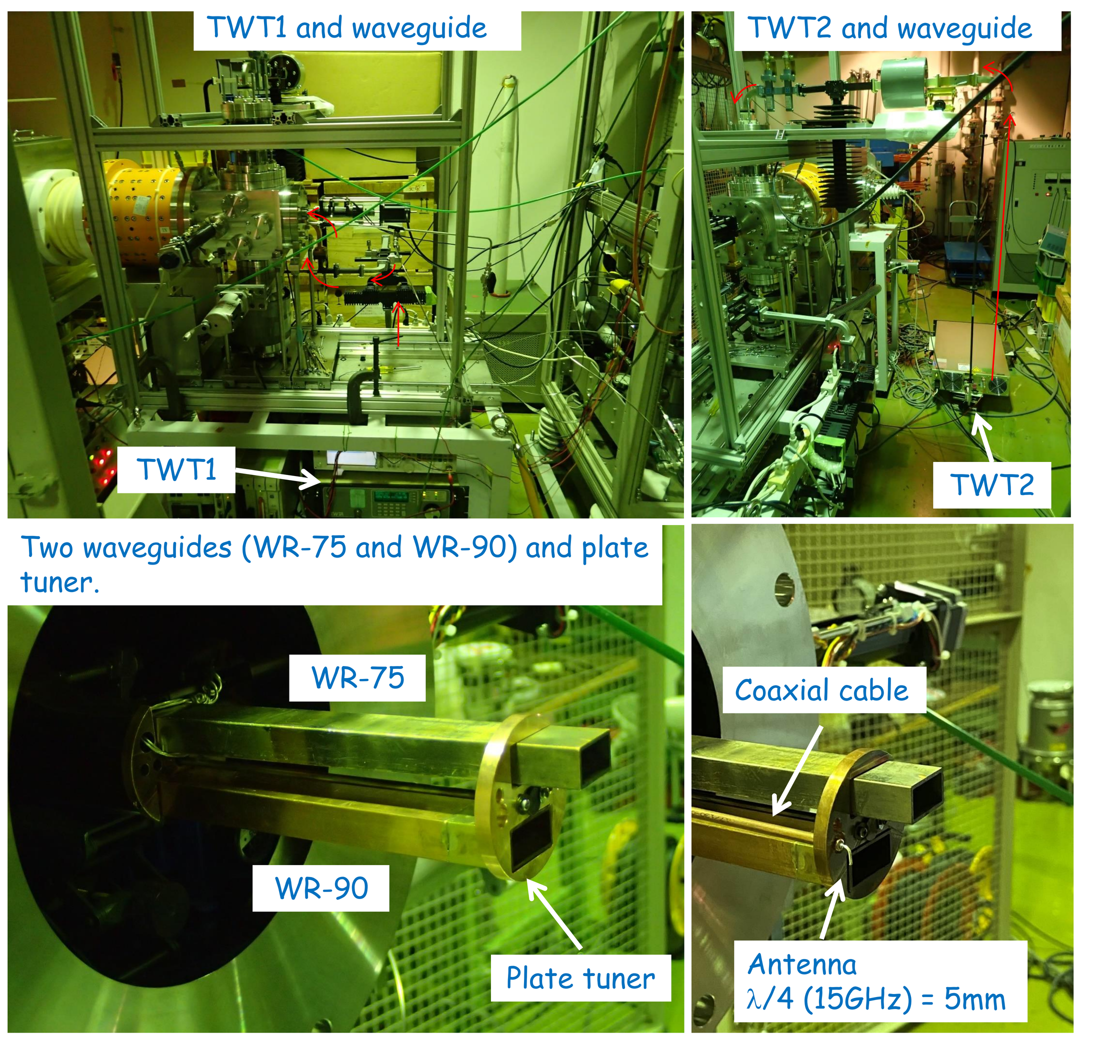
Introduction

The multi-ion radiotherapy with dose distribution and Liner Energy Transfer optimization is being studied at QST-NIRS. Helium, carbon, oxygen and neon ions are considered as ion species for multi-ion therapy. However, in the case of compact accelerator for high-energy heavy-ion radiotherapy facility, it is desirable to use with one ECR ion source with all permanent magnets from the viewpoint of cost, operation and maintenance. Currently we are developing an compact ECRIS for multi-ion irradiation. A prototype compact electron cyclotron resonance ion source, named Kei3, based on Kei series has been developed for production of various ions at the National Institute of Radiological Sciences (NIRS). In order to increase a beam current of multiply charged ion such as Oxygen, Neon and Argon, we tested two-frequency heating method.



Kei3 source

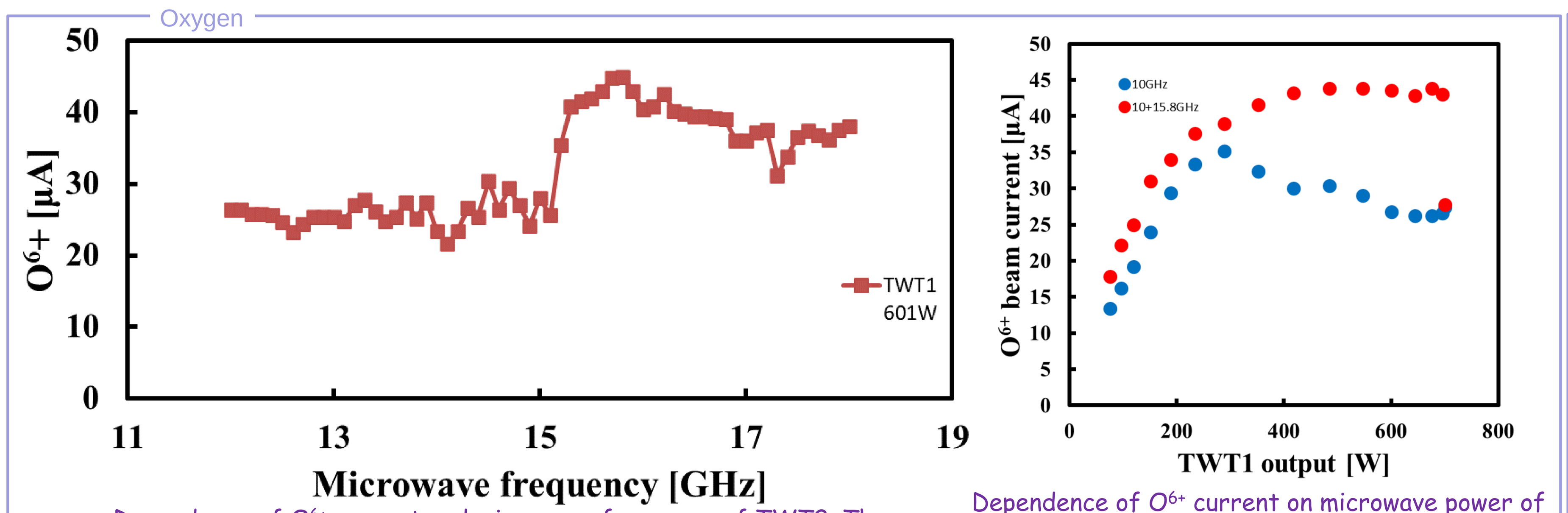


Specifications of Kei3

·Ion source	
Diameter	280 mm
Length	1120 mm
·Mirror magnets	
Material	NdFeB
Max. field strength (extraction side)	0.579 T
Max. field strength (gas injection side)	0.876 T
Minimum B strength	0.260 T
·Hexapole magnet	
Material	NdFeB
Maximum field strength on the chamber surface	0.757 T
Length	105 mm
Inner diameter	58 mm
·Microwave	
TWT1	
Frequency	9.75 - 10.25 GHz
Maximum power	750 W
Operation mode	pulse/CW
TWT2	
Frequency	10 - 18 GHz
Maximum power	250 W
Operation mode	pulse/CW

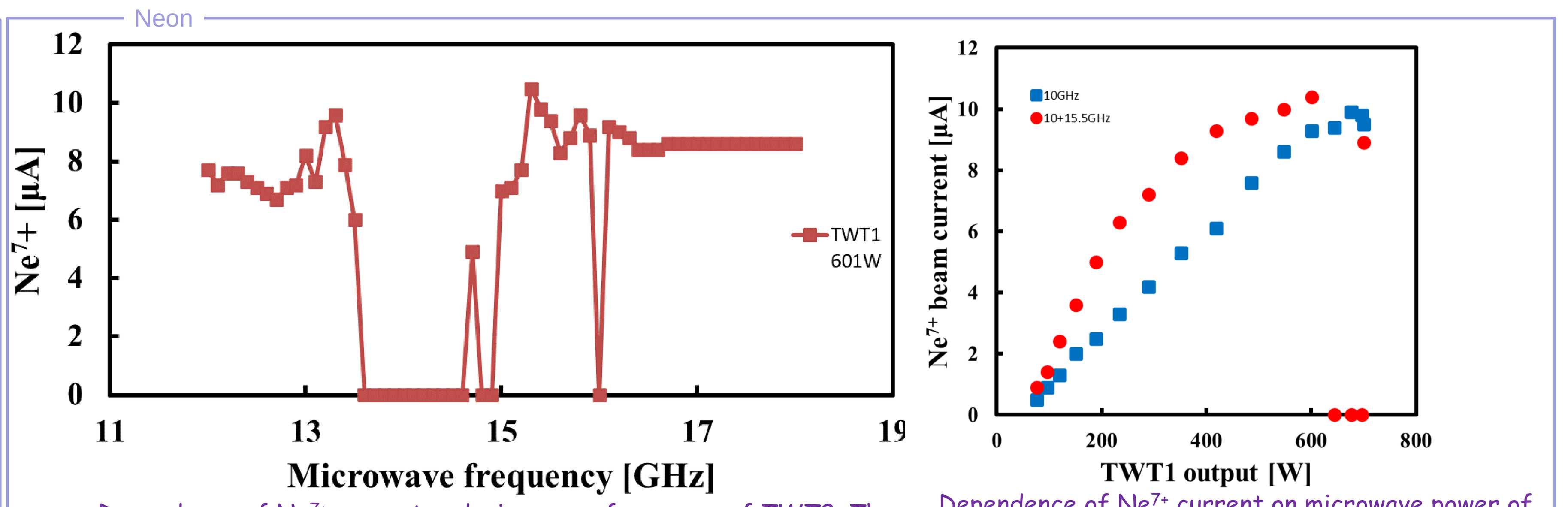
Two-frequency heating experiment

Microwaves are introduced from the vacuum box on the upstream side of the permanent magnet through the rectangular waveguide of the WR-90 at Kei3. A traveling wave tube (TWT) amplifier made by NEC (LD79X75A1: TWT1) is used as the microwave source. The frequency band is 9.75-10.25 GHz and the maximum output power is 750 W. The WR-75 waveguide is introduced from the upper part of the upstream vacuum box and installed on top of the existing WR-90 waveguide. A TWT amplifier manufactured by Xicom (XTRD-300IJ: TWT2) was used as a microwave source for two frequency heating. The frequency band is 10-18 GHz and the maximum output power is 300 W. A plate tuner is installed at the end of the WR-90 waveguide (upstream mirror magnetic field peak) and can be moved 30 mm upstream from that position. A voltage of 10 kV is applied to the permanent magnet, plasma chamber, upstream vacuum chamber, and TWT1 for the beam extraction. CH_4 gas was used for mixing gas in production of neon ion.



Dependence of O^{6+} current and microwave frequency of TWT2. The frequency of TWT1 is 10 GHz and the power is 601W. The TWT2 has a frequency range of 12-18 GHz and a power of 99.6 W.

Dependence of O^{6+} current on microwave power of TWT1. The TWT1 has a frequency of 10 GHz and a power range of 76-700 W, and the TWT2 has a frequency of 15.8 GHz and a power of 99.6 W. The position of the plate tuner is the end of the waveguide (peak of the upstream mirror magnetic field).

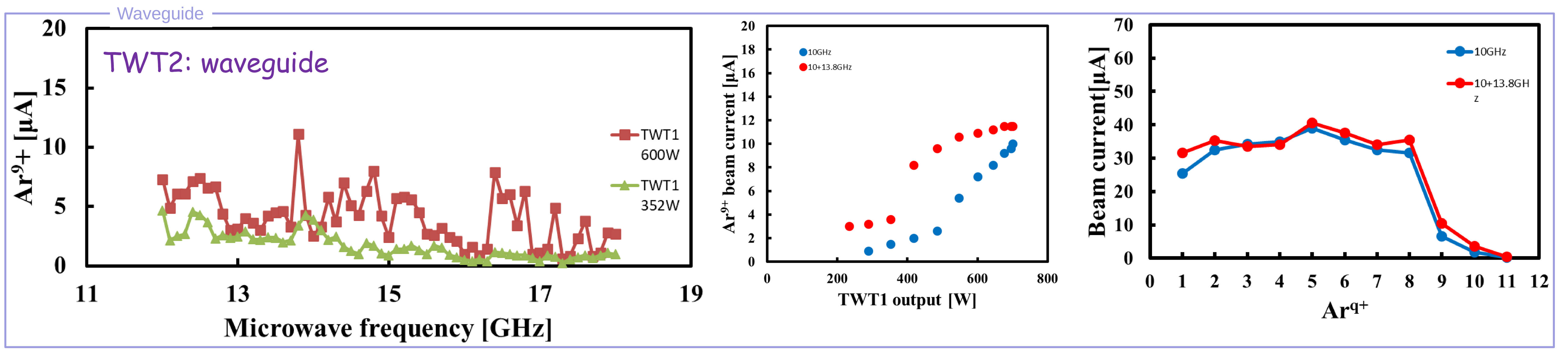


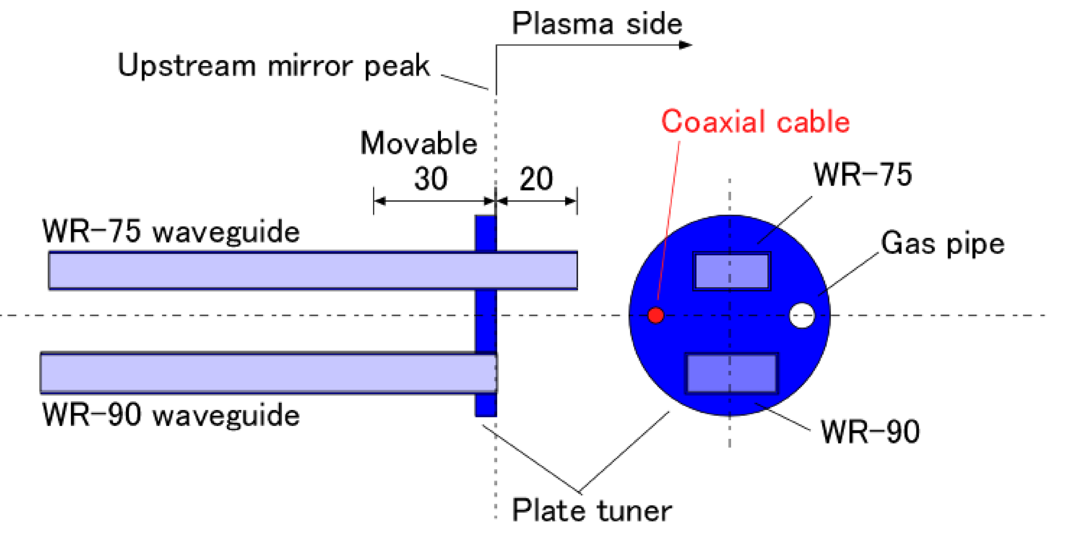
Dependence of Ne^{7+} current and microwave frequency of TWT2. The frequency of TWT1 is 10 GHz and the power is 601 W. The TWT2 has a frequency range of 12-18 GHz and a power of 57 W.

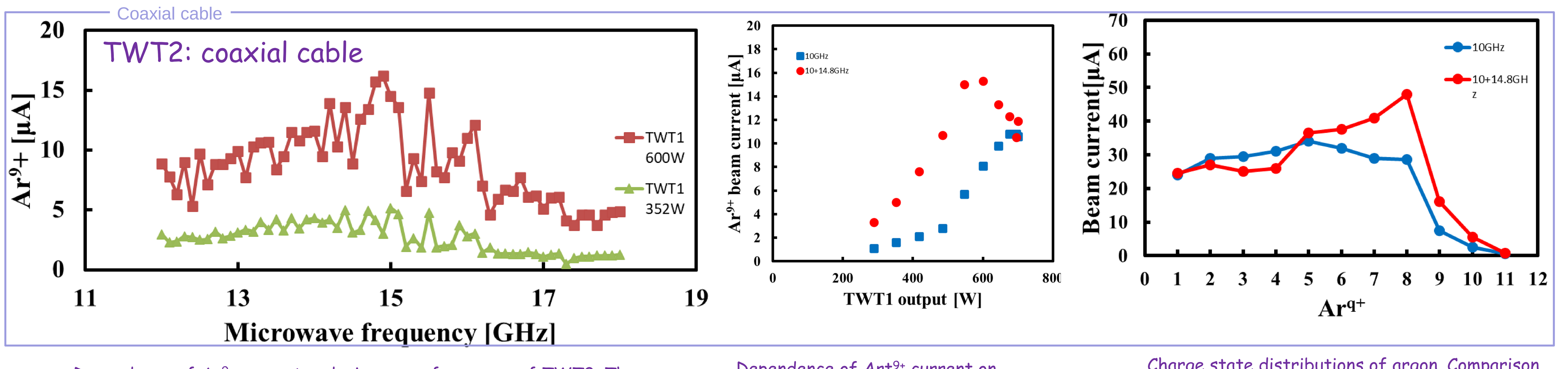
Dependence of Ne^{7+} current on microwave power of TWT1. The TWT1 has a frequency of 10 GHz and a power range of 76-700 W, and the TWT2 has a frequency of 15.5 GHz and a power of 57 W. The position of the plate tuner is the end of the waveguide (peak of the upstream mirror magnetic field).

Microwave injection by coaxial cable

An ECR ion source that forms a confinement magnetic field with an all permanent magnet tends to have a smaller inner diameter of the magnet in order to generate a strong magnetic field. Two rectangular waveguides installed in the compact ECRIS for two-frequency heating adversely affects the vacuum. From the results of the beam tests, it is possible to introduce microwaves using a coaxial cable without using a waveguide because the output of TWT2 is 100 W or less and a sufficient beam current is obtained. The length of the antenna was 5 mm ($\lambda/4$ at 15 GHz).







Dependence of Ar^{9+} current and microwave frequency of TWT2. The frequency of TWT1 is 10 GHz and the power are 352 and 601W. The TWT2 has a frequency range of 12-18.

Dependence of Art^{9+} current on microwave power of TWT1. The TWT1 has a frequency of 10 GHz and a power range of 76-700 W, and the TWT2 has a frequency of 13.8 GHz for waveguide and 14.8 GHz for coaxial cable.

Charge state distributions of argon. Comparison between single heating (10.0 GHz) and two-frequency heating (13.8 GHz for waveguide, 14.8 GHz for coaxial cable).

Conclusion and next step

Microwave two-frequency heating was tested in a Kei3 ion source and found to be effective in production of multiply charged ions. The beam current was increased compared to the case of the waveguide by introducing the TWT2 microwave using the coaxial line.

We plan to optimize the length and position of the antenna.