DESIGN OF TRANSMISSION LINE AT 28 GHz, 10 kW FOR ECR ION SOURCE IN KBSI

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Abstract

The 28 GHz gyrotron system was designed to deliver the microwave power from gyrotron oscillator to an electron cyclotron resonance ion source (ECRIS) for simultaneously producing high current and highly charged ions. The microwave power from 28 GHz gyrotron were measured from the range between 0.5 kW and 10 kW with frequency variation from 27.9740 to 27.9893 GHz. The gyrotron oscillator of transmission system operates in continuous wave regime with the smoothly regulated output microwave power. A transmission line was designed for the transport of microwaves to an ion source. For the electrical insulation between gyrotron system and ion source chamber applied to high voltage, we installed a DC break. In order to evaluate gyrotron operation, a dummy load was developed to consume such high microwave power.

INTRODUCTION

Development of an ion source is quite important issue for the beam production of highly charged heavy ions. Not a few efforts has been made to improve the performance of ion sources but it is well known that electron cyclotron resonance ion source (ECRIS) is most effective one of them [1]. Both mean ion charge state and intensity of ion beam from ECRIS are generally enhanced as increasing the operating resonance frequency. In recent years, third generation ECRIS has been constructed and operated at the frequency up to 28 GHz as well as 10 kW of microwave power (VENUS at LBNL and SECRAL at Lanzhou, SC-ECR ion source at RIKEN) [2]. It is explicitly clear that next generation ECRIS can be realized by employing an substantially increased resonance frequency and microwave power [3]. The gyrotron-based microwave power source is suitable for ECRIS. Today, state of the art of gyrotrons is enable to produce the microwave power above 10 kW and the frequency over 30 GHz. A manufacturing of 28 GHz ECR ion source for highly charged heavy ion beam production is in progress by Korea Basic Science Institute (KBSI). This paper presents the design of transmission line at 28 GHz, 10 kW gyrotron system, which has been installed at the microwave system of KBSI ECRIS.

MICROWAVE TRANSMISSION LINE

A transmission line for 28 GHz, 10 kW microwave from gyrotron to ECRIS plasma chamber consists of following components as shown in Fig. 1. Gyrotron is used as microwave power source and high power microwave is delivered the high transmission ratio and through the waveguide from the gyrotron to the ECRIS. Some parts in the waveguide component are used for the particular purpose, which will be described next section in detail. The entire transmission line is operated in remote mode with PC-based controller, as depicted in Fig. 1.

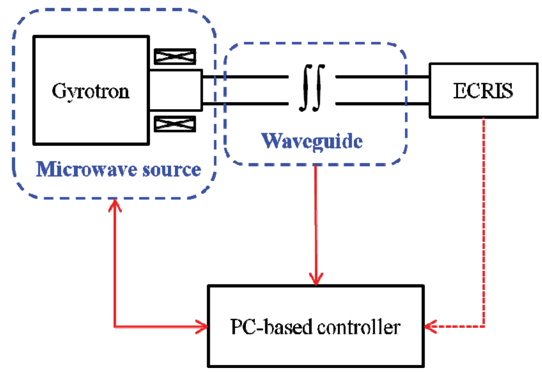


Figure 1: Diagram of microwave transmission line.

Microwave Power Source

The 28 GHz, 10 kW gyrotron was provided by the CPI which are combined an oscillation tube, high voltage power, electromagnet, and controller for automatic/ manual processing. Fig. 2 shows the operating conditions including the electron gun voltage, magnet current, and frequency of 28 GHz gyrotron as a function of the microwave output power. Microwave power was operated by increasing from 0.5 kW to 10 kW. We monitored the microwave power by measuring absolved energy in dummy load. Then, the output frequency variation at 28 GHz was from 27.9740 to 27.9893 GHz and the accuracy was found to be below 0.1 %.

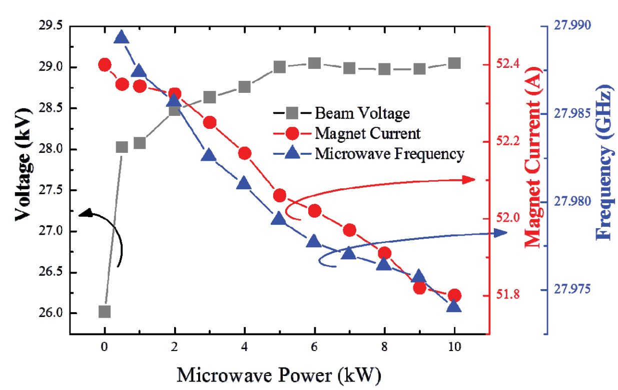
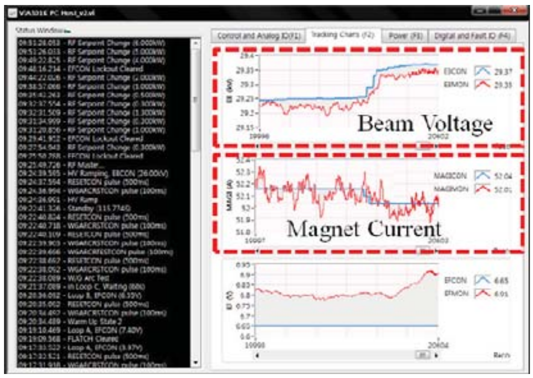
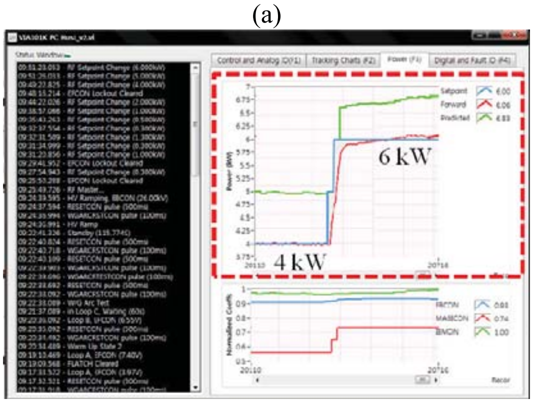


Figure 2: Beam voltage, magnet current and output frequency characteristics in gyrotron as a function of output power.

The forward and reflected microwave powers of gyrotron were also measured by bi-directional coupler installed in waveguide line. Fig. 3 shows monitored results from gyrotron controller, which is beam voltage, magnet current and microwave output power from gyrotron.



(a)



(b)

Figure 3: (a) The beam voltage and magnet current monitor of the microwave output, and (b) on screen of gyrotron controller.

Design of Microwave Waveguide

The waveguide in microwave transmission line consists of the following components as in Fig. 4: gyrotron oscillator, arc detector, bi-directional coupler, mode filter, mode converter from TE_{02} to TE_{01}, and vacuum window. The microwaves are initially emitted from a gyrotron with 28 GHz, 10 kW at a TE_{02} mode through a circular waveguide. To avoid the damage arisen from any reflected power, some components are inserted in the waveguide for the safety reason to protect the devices and personnel. Two 90-degree corrugated bends and three linear waveguides are used to connect the gyrotron to the plasma chamber. All the parts except DC break and linear waveguide were supplied from CPI. All the components of waveguide in the transmission line is described in following:

- Arc detector: used to detect sparks on the RF window of gyrotron for the safety.
- Bi-directional coupler: measure forward and reflected microwave power from the gyrotron. The calculated value of TE_{02} transmission loss is 0.5%.
- Mode converter (TE_{02} to TE_{01}): the smooth circular waveguide having a small axisymmetric, periodic radius perturbation converts the gyrotron output mode TE_{02} into a TE_{01} mode because this method can offer lowest transmission loss. The period and amplitude of the perturbation and the length of the mode converter were optimized. Mode conversion efficiency is higher than 95% and ohmic loss is lower than 1%.
- Mode filter: Only single mode (TE_{01} or TE_{02}) can pass through a mode filter. The water cooled mode filter can absorb any other mode reflected from either DC break or vacuum window or ECR plasma chamber for the protection of gyrotron. The attenuation was 0.1dB (2%) for the TE_{01} mode and 0.15dB (3%) for the TE_{02} mode.
- 90-degree corrugated bend: the bend was designed for both a compact size and a low mode conversion by optimization of the corrugation depth and curvature distribution. The overall transmission efficiency was 98.7%.
- DC break: for the electrical isolation of the waveguide potential from the ECRIS charged on high DC voltage, a DC break was designed as a part

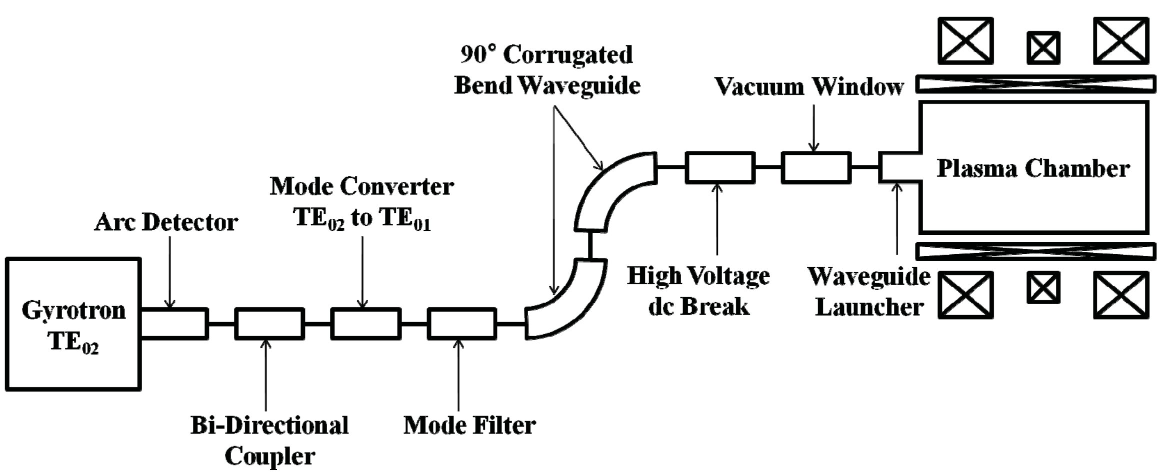


Figure 4: Schematic drawing of the 28 GHz microwave transmission line from gyrotron to ECR ion source.

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of the transmission line in Fig. 5 through cooperating with Korea Atomic Energy Research Institute (KAERI). The DC break consists of alternatively stacked copper and insulator rings. Teflon was used as the insulating material because of easy manufacturing and a low dielectric constant. Moreover, a resistor (200 MΩ) was connected between copper rings in each stack for generating a equilibrium state of electric field intensity. This structure also offers the low transmission loss of TE_{01} mode and a blocking of any modes from the axial wall currents.

- Vacuum window: For maintaining a high vacuum state in the plasma chamber and delivering a microwave power into the chamber with less loss, vacuum window is placed between the end of transmission line and plasma chamber. Vacuum window made of sapphire is adopted a water cooling system. The 28 GHz microwaves are coupled successfully to the ECRIS with an efficiency of about 95%.

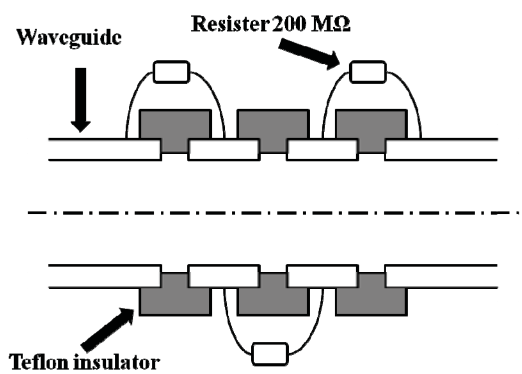

Figure 5: The design of DC break.

SUMMARY AND FUTURE WORK

28 GHz, 10 kW microwave transmission line was successfully installed in KBSI and all the components of transmission line works well. As soon as completing the plasma chamber and superconducting magnet for electron cyclotron resonance ion source, the microwave power will be transmitted from the gyrotron to the plasma chamber through transmission line. As a result of microwave transmission, the beam production of highly charged heavy ions from ECRIS will be expected.

ACKNOWLEDGMENT

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