VERSATILE HIGH POWER MICROWAVE SYSTEM FOR FREQUENCY TUNING OF THE CAPRICE ECRIS

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Abstract

In the last years it was demonstrated that the variation of the microwave frequency generating the plasma inside ECR Ion Sources (ECRISs) allows to enhance the extracted current of highly charged ions both for gaseous and for metallic elements. In order to use this technique for the performance improvement of the CAPRICE-type ECRIS installed at the High Charge State Injector (HLI) of GSI, the microwave system has been modified. The new arrangement includes - besides the existing Klystron high power amplifier (HPA; max. 2 kW at 14.5 GHz) - two combined Traveling Wave Tube Amplifiers (TWTA) covering a bandwidth of 12.75-14.5 GHz, providing 750 W output power each, which are driven by one or two synthesizer tuners. The new system has been used during the routine operation of the ECRIS for production of different ion beams to be injected into the RFQ of the HLI. A detailed description of the main components of the new microwave system is presented, and the achieved characteristics of ion beam production using different microwave frequencies are described.

INTRODUCTION

In the last years several experiments using the technique of frequency tuning were carried out at the ECR injector test setup (EIS) of GSI in order to investigate the influence on the performance of the CAPRICE-type ECR Ion Source (ECRIS) in terms of enhanced ion currents of high charge states [1, 2]. It was demonstrated that this technique allows increasing the ion current extracted from an ECRIS both for gaseous and for metallic elements [3]. In order to use this technique for the routine operation of the ECRIS installed at the high charge state injector (HLI) of GSI, the microwave injection system has been modified.

At the HLI a CAPRICE-type ECRIS is installed for the production of high charge state ion beams at mass/charge ratios of up to 8.5 for the UNILAC at GSI. The ECRIS is designed to operate at 14.5 GHz and so far Klystron amplifiers were used to send the high power microwaves to the ECRIS to generate the plasma. In order to use the frequency tuning technique at the HLI an upgraded system using wideband high power Traveling Wave Tube Amplifiers (TWTA) has been conceived and assembled. The new arrangement includes two combined TWTAs covering a bandwidth of 12.75-14.5 GHz, providing up to 1500 W CW power, which are driven by one or two synthesizer tuners. In the following the upgraded system and the achieved results of ion beam production using different microwave frequencies are described.

HLI UPGRADED MICROWAVE SYSTEM DESCRIPTION

The schematic view of the upgraded microwave system installed at HLI is shown in Fig. 1. A sweeping signal generator provides the microwave signal to be amplified by two TWTAs. Each of them provides up to 750 W in the frequency range 12.75-14.5 GHz. When the required power is higher than 750 W, the power of the two amplifiers is summed up through a WR62 waveguide power combiner. Otherwise the power combiner is replaced by a high power wideband isolator. Both, the isolator and the power combiner have an insertion loss lower than 0.5 dB and an isolation higher than 20 dB. This last feature allows running the frequency sweeping without interruption of forward power due to the high reflected power amplifier protection in case of power mismatch. For the maximum summed power at the high power combiner, a phase shifter is used and the phase shift is adjusted whenever the frequency is tuned to an optimized condition. The system is integrated into the existing waveguide system with a WR62 mechanical switch. With this versatile setup the microwave input can be switched from the waveguide line connected to the klystron HPA to the one where the upgraded system including the TWTAs is installed. A high power load able to handle up to a CW power of 3000 W is connected to the switch and is used to test and perform measurements of the amplifiers.

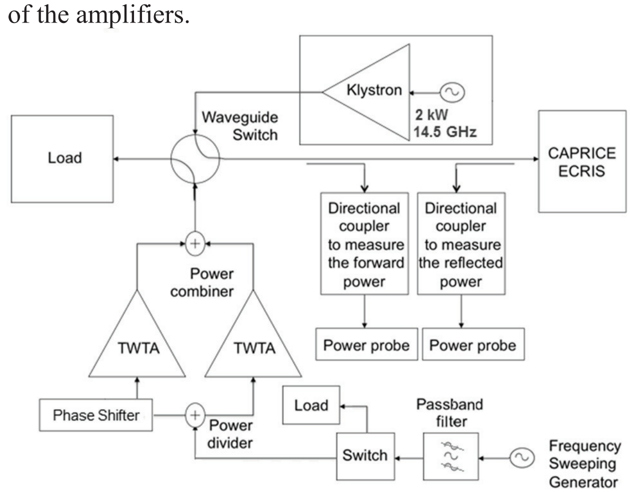

Figure 1: Block diagram describing the main components of the microwave injection system at HLI.

Two directional couplers are inserted between the switch and the ion source. Microwave power probes are connected to each directional coupler to measure the forward power to and the reflected power from the

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ECRIS. The knowledge of the reflection coefficient is beneficial to optimize the microwave coupling to the plasma, which is a fundamental condition for a good performance and stable operation of the ECRIS [1].

In order to maintain the lifetime of the vacuum tubes of the amplifiers, together with the use of a low insertion loss band-pass filter (the bandwidth is corresponding to the amplifiers) a protection system has been developed. The main components of this system are a coaxial SMA switch controlled by a logic board connected to the amplifiers. Figure 2 shows the electric scheme resuming the elements and the interconnections of the protection system of the TWTAs. Since there are two TWTAs which can operate simultaneously, the interlock signal is doubled from the interlock circuit.

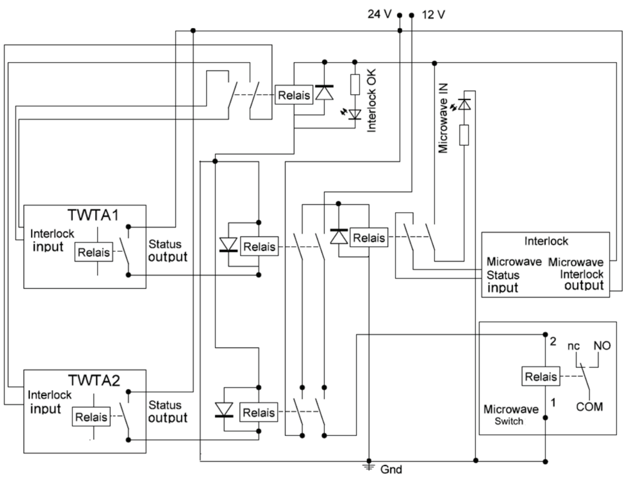

Figure 2: Circuit diagram describing protection system of the TWTAs.

The interlocking system communicates with the amplifiers and as long as they are in stand-by mode or a fault (i.e. high reflected power or for arcing events) or another interlock event (i.e. high pressure or low magnetic field) occurs, the system will toggle the microwave switch to send the input power to a load. As long as the TWTAs status is on high voltage mode, the communication system acts on the switch to provide the input power to the amplifiers.

By avoiding sending power to the tubes when they are not under high voltage status, this arrangement will prevent damages of the tubes and will save their lifetime.

EXPERIMENTAL RESULTS

Since the upgraded microwave system was installed at HLI, it was used several times for the beam production whenever the Klystron amplifier was in maintenance or repair status. In Fig. 3 the ion beams so far produced with the TWTA system are reported.

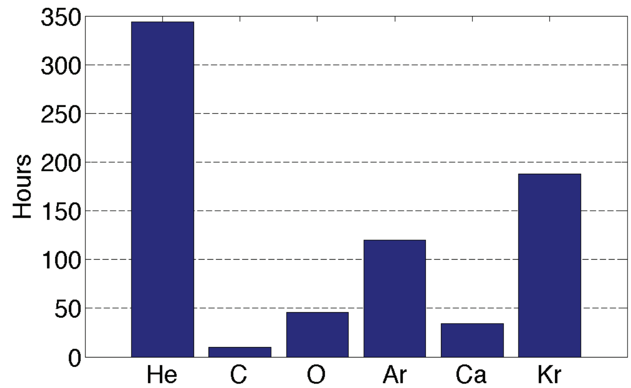

Figure 3: Ion beams produced with the upgraded system at HLI.

For the production of $^{4}He^{1+}$ and $^{16}O^{3+}$ no frequency optimization was required and the requested beam intensities of 300 μA and 180 μA were achieved with 50 W, and 300 W, respectively.

A $^{40}Ar^{9+}$ beam was requested with moderate intensity, and 80 μA were obtained with 300 W microwave power at 14.5 GHz. The spectrum of Argon is shown in Fig. 4.

If higher charge states of Argon, i.e. $^{40}Ar^{11+}$ or $^{40}Ar^{12+}$, will be required, the frequency can be optimized to get higher intensities as reported in [2].

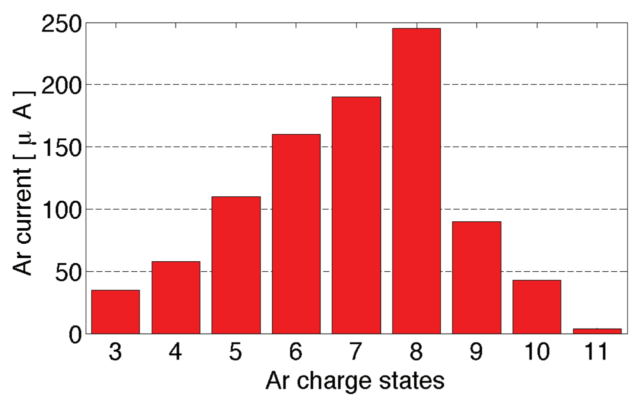

Figure 4: Charge state distribution of Argon.

During several days of ion beam production of $^{48}Ca^{10+}$, a beam intensity of around 50 μA was achieved with 600 W power by setting the synthesizer at the optimized frequency of 14.366 GHz. This setting guaranteed a stable beam with sufficient intensity in a very short setup time. However, for Calcium operation, a further extensive test campaign is required to identify the optimized frequencies for the long term beam production.

The new TWTA-based microwave system was also utilized during a $^{84}Kr^{13+}$ beam time. This operation opened the opportunity to perform further investigations on microwave frequency tuning at the CAPRICE ECRIS under operating conditions using the ^{84}Kr ion beam with its broad charge state distribution. By tuning the microwave frequency to 14.464 GHz up to 40% more current of $^{84}Kr^{13+}$ was provided with respect to the standard operating frequency of 14.500 GHz. The charge state distributions shown in Table 1 confirm that the

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frequency tuning can be used to increase the intensity of higher charge states (i.e. $^{84}Kr^{n+}$ with n>11) for operating.

At the operating frequency of 14.444 GHz the highest intensity of the highest detected charge state, $^{84}Kr^{19+}$, was measured and a current gain of 16 times was obtained with respect to the normal operating frequency. This result is reported in Fig. 5 which shows the Krypton current gain for the optimized frequencies with respect to the normal operation frequency [4].

Table 1: Intensities of Krypton Charge States at Different Frequencies

KRYPTON CHARGE STATE	ION CURRENT AT 14.444 GHz [µA]	ION CURRENT AT 14.464 GHz [µA]	ION CURRENT AT 14.500 GHz [µA]
6+	7.9	8.7	9.7
7+	9	10.6	12.2
8+	13.9	17.5	21.5
9+	19.4	24.2	28.6
10+	23.5	28.1	31
11+	26.1	30.9	30.3
12+	30.6	33.3	28.7
13+	29.5	29.8	21.2
14+	27.8	25.7	15.6
15+	21.3	17.8	7.7
16+	13.7	10	3.4
17+	7.8	5	1.2
18+	4.4	3.2	0.8
19+	1.6	0.8	0.1

The upgraded microwave system was also used for an investigation concerning the production of $^{12}C^{5+}$ beams. For the generation of hydrogen like C ions all L-shell electrons plus one further K-shell electron have to be removed in the plasma by successive electron impact ionization. This requires high power operation of the ECRIS. Besides the standard configuration for $^{12}C^{2+}$ ion beam with CO_2 as working gas and O_2 as auxiliary gas, respectively, CH_4 was investigated as alternative working gas, while He was used as auxiliary gas.

With respect to the fixed frequency operation with the klystron amplifier slightly higher intensities could be obtained by careful frequency tuning of the TWTA. Using the klystron amplifier at 14.5 GHz the highest intensity of $^{12}C^{5+}$ current was around 40 µA, and by switching the microwave system to the TWTA, a $^{12}C^{5+}$ beam current around 60 µA could be achieved with the same setting of the ion source and at 13.470 GHz [5].

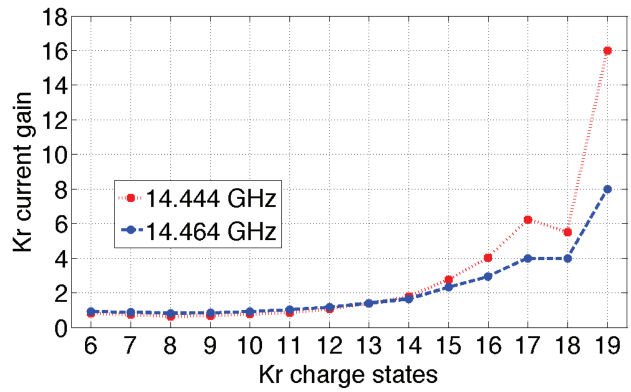

Figure 5: Kripton current gain for optimized frequencies over the normal operating frequency.

CONCLUSIONS

An upgraded microwave injection system has been commissioned for the high charge state injector HLI of the UNILAC accelerator. The new versatile system has been integrated in the existing microwave system. During the operation of the new system an enhancement of the CAPRICE performance has been observed. The capabilities of the frequency tuning for routine operation have been verified.

The arrangement allows making also use of the double frequency heating technique by connecting two separate signal generators to the amplifiers. As long as the TWTAs and the synthesizer will be integrated in the remote control system of GSI, the new system will be fully operational for standard ion beam production.

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