MEASUREMENTS OF BREMSSTRAHLUNG RADIATION AND X-RAY HEAT LOAD TO CRYOSTAT ON SECRAL *

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Abstract

Measurement of Bremsstrahlung radiation from ECR (Electron Cyclotron Resonance) plasma can yield certain information about the ECR heating process and the plasma confinement, and more important a plausible estimate of the X-ray heat load to the cryostat of a superconducting ECR source which needs seriously addressed. To better understand the additional heat load to the cryostat due to Bremsstrahlung radiation, the axial Bremsstrahlung measurements have been conducted on SECRAL (Superconducting Electron Cyclotron Resonance ion source with Advanced design in Lanzhou) with different source parameters. In addition, the heat load induced by intense X-ray or even ϒ-ray was estimated in terms of liquid helium consumption. The relationship between these two parameters is presented here. Thick-target Bremsstrahlung, induced by the collision of the hot electrons with the wall or electrode of the source, is much more intensive compared with the radiation produced in the plasma and, consequently, much more difficult to shield off. In this paper the presence of the thick-target Bremsstrahlung is correlated with the magnetic confinement configuration, specifically, the ratio of B_{last} to B_{ext}. And possible solutions to reduce the X-ray heat load induced by Bremsstrahlung radiation are proposed and discussed.

INTRODUCTION

Driven by the increasing demand of heavy ion accelerators devoted to nuclear physics and high energy physics for more intense and higher charge state heavy ion beam, the technology of highly charged ECR (Electron Cyclotron Resonance) ion sources have been developed dramatically in the past decades. The production of more intense and higher charged state heavy ions can be realized by the increase of the plasma density and confinement time and, according to the scaling laws [1], finally realized by the enhancement of the frequency and power of the microwave and the magnetic confinement field. In the past twenty years, beam intensities of highly charged heavy ions produced by ECR ion sources have increase by a factor of 10-100 for different ions. However, nowadays the trend of ECR ion sources towards to higher microwave frequency and power and higher magnetic field is limited not only by the technological limits of microwave and superconducting magnets but also by the presence of intense high-energy X-ray flux produced by electron-ion collisions in the plasma or electron-wall collisions, which is severe especially for superconducting ECR ion sources because the X-ray can lead to substantial heat load to the cryostat. The presence of high energy electrons, with energy up to 1 MeV, in third generation ECR ion sources has been proved experimentally [2], [3]. The collisions of these high energy electrons with plasma ions lead to Bremsstrahlung radiation. In addition, some lost electrons strike on the chamber wall or the electrode and, consequently, thick-target Bremsstrahlung is produced. The produced X-ray deposits energy in the structure of ion sources, and turns out to be substantial heat load to the cryostat in the case of superconducting ECR ion sources.

To better understand the heat load of SECRAL, the axial Bremsstrahlung spectra have been measured at 24 GHz with different source parameters, and the heat load to the cryostat was estimated in terms of LHe (Liquid Helium) consumption simultaneously.

In some cases, the plasma electrons lose confinement and strike on the structure of the source, which leads to thick-target Bremsstrahlung that is much more intense and with much higher energy compared with the radiation produced in plasma. Obviously, this kind of radiation should be avoided in the point view of the reliable operation of the source. The axial Bremsstrahlung measurements have been carried out in different magnetic confinement configuration to provide insights about the thick-target Bremsstrahlung in ECR ion sources.

EXPERIMENTAL SETUP

The bremsstrahlung spectra were measured with an HPGe (High Purity Germanium) detector. To measure the axial radiation, the HPGe detector was located behind the straight-through port of the 110° analyzing magnet. The signals produced by the detector were amplified and shaped by a main amplifier, then sent to a MCA (Multi-Channel Analyzer) and finally displayed and stored on a PC (personal computer).

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The main challenge in the measurements of Bremsstrahlung is to build an effective collimation system. The original system used in the previous measurements [4] turned out to be not effective to keep the counting rate reasonably low in the case of high frequency and high power. So a new collimation system has been designed and constructed. The collimation comprises two copper blocks and one lead block. The first copper collimator is positioned just behind the straight-through port of the analyzing magnet, about 2.5 m away from the plasma electrode of the source. It is 100 mm long and has a 1 mm circle aperture. The function of this collimator is to reduce the number of the photons that enter the rest of the collimation system. The second copper collimator, 100 mm long and with a 3 mm circle aperture, is placed 850 mm away from the first one. The last collimator, a lead block with an aperture of 10 mm, is located directly before the detector. The last two collimators are used to prevent the X-ray photons scattered by the surrounding material from entering the detector. With this system, the dead time of the acquiring system decrease from tens of percent to less than one percent.

AXIAL BREMSSTRAHLUNG RADIATION AND HEAT LOAD TO CRYOSTAT AT 24GHz

As presented in [3], the X-ray flux increases with the 24 GHz RF power and the axial minimum magnetic field Bmin. Here we focus on the correlation of the axial Bremsstrahlung radiation and the heat load to the cryostat at 24 GHz. The heat load to the cryostat is estimated in terms of LHe consumption. The LHe consumption of the source at different 24 RF power or different Bmin is presented as a function of the axial Bremsstrahlung radiation energy, which is estimated by integration of the spectra in the whole energy range. The LHe consumption increases with the X-ray radiant energy as expected. However the dependence is not linear.

The non-linear relation between the axial radiant energy and the LHe consumption can be explained as follows. Firstly, the radiant energy in our study is in the axial direction while the LHe consumption is mainly correlated with the radial X-ray radiation. According to ECRIS physics, the high energy electrons in ECR plasma are energized primarily in the radial direction. Thus the X-ray radiation of ECR plasma is highly anisotropic. With the increase of the RF power and B_{min}, the electron energy increases and the power radiated by electrons during collisions tends to be more forward, and then the anisotropism becomes more pronounced. In other words, the radial radiation may increase quicker with the RF power and B_{min} than the axial one. Secondly, this may be attributed to the shielding effect of the chamber. The chamber used in this study is enclosed with a 1.5 mm thick tantalum tube to reduce X-ray absorbed by the cryostat. The attenuation effect of tantalum has been measured with axial radiation. The experimental result shows that the tantalum almost has no effect for the radiation above 500 keV. But as shown in previous research, the electron energy increases with the increasing power and Bmin. So the shielding effect of the tantalum weakens as the high energy component increases.

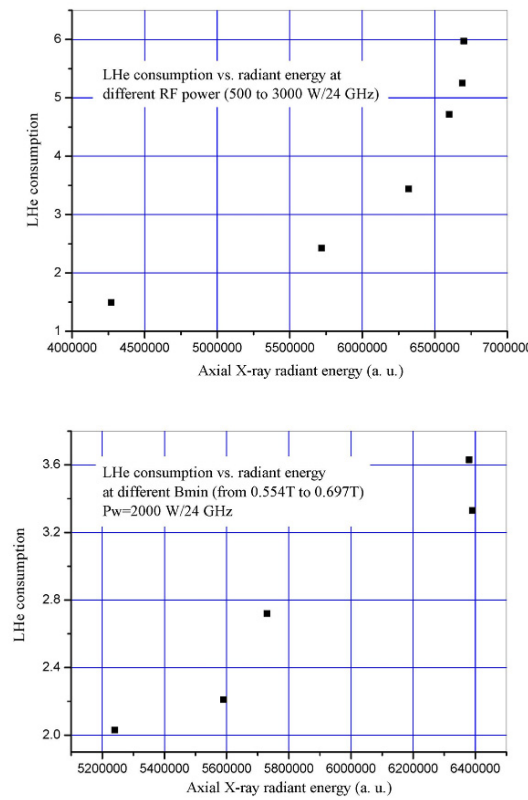

Figure 1: The LHe consumption as a function of the axial radiant energy.

Anyway, the non-linear increase of the LHe consumption with axial radiant energy demonstrates that the problem of X-ray heating turn to be much more severe for higher frequency and power ECR ion sources with higher magnetic confinement field.

THICK-TARGET BREMSSTRAHLUNG AND MAGNETIC CONFIGURATION OF ECRIS

As found in a previous experimental research [5], there is a sudden increase both in X-ray flux and energy of the axial Bremsstrahlung spectra with the increase of B_{rad} or the decrease of B_{ext}. In [5] the sudden change of the spectra is attributed to thick-target Bremsstrahlung. To confirm this, systematical experiments have been carried out on SECRAL at 18 and 14.5 GHz RF power. The experimental results are presented in Fig. 2.

The spectra were measured at different B_{rad} or B_{ext}. In one group of data, only one field was varied and the other one kept constant. As shown in Fig. 2, no matter which field is varied, the jump of the spectra is only correlated with the ratio of the B_{last} to B_{ext}; the value of B_{last} is estimated by

$$B_{last} = \sqrt{B_{ext}^2 + B_{min}^2} \quad (1)$$

These results turn to be the further confirmation of the statement in [5]. When $B_{last}>B_{ext}$, the thick-target Bremsstrahlung will be produced in the axial direction; on the contrary, the thick-target Bremsstrahlung will be produced mainly in the radial direction when $B_{last}<B_{ext}$. Therefore from the point view of X-ray heating, both situations of $B_{last}>>B_{ext}$ or $B_{last}<<B_{ext}$ should be avoided in the operation of ECRISs.

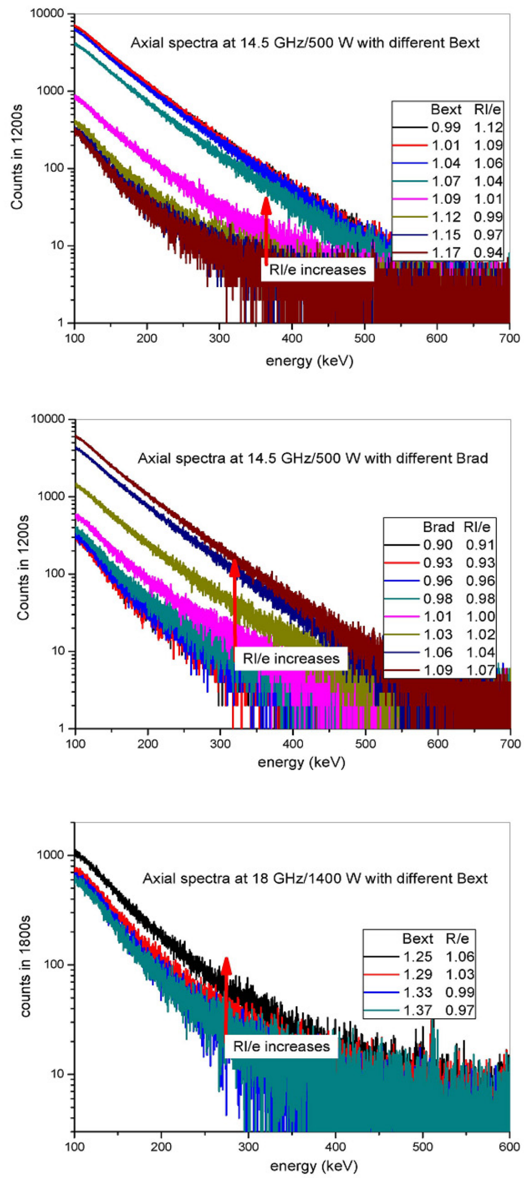

Figure 2: Axial Bremsstrahlung spectra with different magnetic configuration (Rl/e is ratio of B_{last} to B_{ext})

CONCLUSIONS

As one of key issues in the development of ECRIS, the heat load to cryostat induced by Bremsstrahlung radiation is addressed in this paper. The possible solutions to this problem can be summarized as follows,

Firstly, the heavy-metal shielding is the simplest method to reduce the influence of Bremsstrhlung radiation on the cryostat. However the shielding is just effective against radiation with energy below 500 keV. So this method turns out to be incapable in high frequency and high power ECRIS.

Secondly, by choose appropriate ratio of B_{last} to B_{ext} the thick-target Bremsstrahlung radiation can be avoided effectively. And this can decrease both the intensity and the energy of produced Bremsstrahlung radiation to a large extent.

In addition, it was found in our experiments the Bremsstrahlung radiation in an aluminum chamber was lower than that in a stainless steel one at the same source condition. This may be due to the effect of an aluminum chamber to maintain the ambipolarity in the plasma [6], [7], but further experiments and analysis are necessary to confirm this.

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