第 31 卷 增刊 I　　高 能 物 理 与 核 物 理　　Vol. 31, Supp. I
2007 年 7 月　　HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS　　Jul., 2007

Observation of Burst Frequency in Extracted ECR Ion Current

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Abstract Earlier we reported an ion current jump which was observed at a fixed negative biased disc potential in the 6.4GHz ECR ion source at VECC, Kolkata. In a recent experiment with neon ions, we measured the time spectra of the ion current and observed the presence of a burst frequency in the kilohertz range. This frequency shows a correlated jump with the ion current jump described above. Another interesting feature is that the observed burst frequency shows a good linear correlation with the extracted ion current. The higher the ion current, the higher is the burst frequency. This means that current per burst is a constant factor; when there are more number of bursts, the current also increases.

Key words biased disc, ion current, burst frequency

1 Introduction

There are various techniques available for enhancing the beam current from an ECR ion source. Adding a lighter gas to the sample gas reduces the ion temperature thereby increasing the retaining time and thus the ion current[1]. Another approach is to supply low temperature electrons to the main stage plasma. In this process the plasma becomes more stable, as a result of which the ion confinement time increases. Wall coating[2], use of an electron gun[3], and the insertion of a biased disc[4—6] are the methods of the electron supplying technique.

In recent years, biased disc technique has become the most popular method of increasing the extracted ion current from an ECR ion source. In the early 1990's Melin et al.[4] first demonstrated the usefulness of the biased disc in their ECR source.

Gammino et al.[7] systematically studied the effect of biased probes on the ion current. They inferred that when a negative potential is applied to the disc, the electron density increases and thus increases the ion current. Another explanation was put forward by D. Meyer[8] who suggested that with the application of a negative potential on the disc, the plasma potential decreases and the plasma becomes more stable. With a stable plasma, production of high charge state ions increases. Measurements by Tarvainen et al.[9] and Mironov et al.[10] on the plasma potential showed that the plasma potential decreased when the negative potential at the biased disk was increased. Electron supply by other methods[11] also is supposed to increase the ion current by lowering the plasma potential. At Variable Energy Cyclotron Centre, Kolkata, we have been using a biased disc since 1992[12, 13].

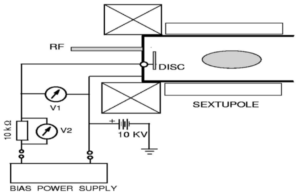

Fig. 1. Scheme of experiment with biased disc.

Received 20 April 2007

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Recently we studied the performance of the biased disc systematically by varying the bias potential[14]. The vacuum system of the source underwent a modification. This allowed the source to sustain a base pressure of 6×10^{-8} Torr on the injection side. As the negative bias potential was increased, the extracted ion current for any species showed a small decline and then at a small negative potential it jumped to a large value. As the potential was further increased, the ion current also increased and saturated at a large bias potential. Fig. 1 shows the measurement scheme.

Figure 2 shows typical results of the measurement on ions of various charge states. It is to be noted that the potential at which the current abruptly jumps is the same for all species. Another interesting feature is that for H^+ the ion current jumps to a lower value.

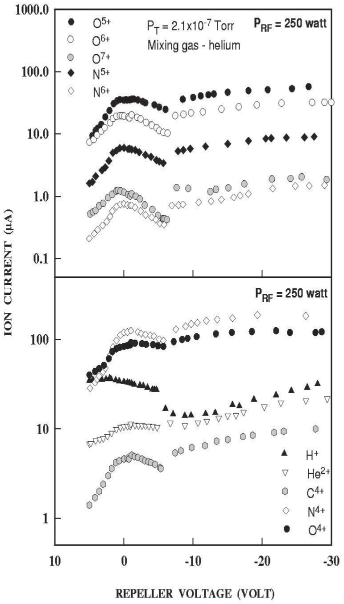

Fig. 2.　Variation of ion current with bias voltage.

2　Experiment

In order to understand the mechanism of jump we investigated the time spectra of the extracted ion current. The ion current was measured in a Faraday cup located beyond the 90° analyzing magnet. This allowed us to measure the spectra for individual analyzed ion species. The output of the Faraday cup was fed to a 200MHz Tektronix storage oscilloscope. We stored data at intervals of 0.01ms. Duration of each measurement was 100ms allowing us to collect 10000 data points in each spectra.

The spectra were Fourier analyzed by using the fast Fourier transform available in MATLAB software. Fig. 3 shows a typical time spectrum of Ne^{6+}. Figs. 4(a), and 4(b), 4(c) show the Fourier spectra before and after the jump in ion current.

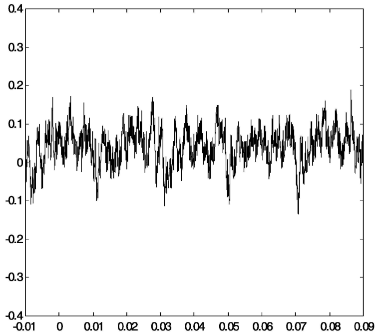

Fig. 3.　Typical time spectrum for Ne^{6+} with no bias.

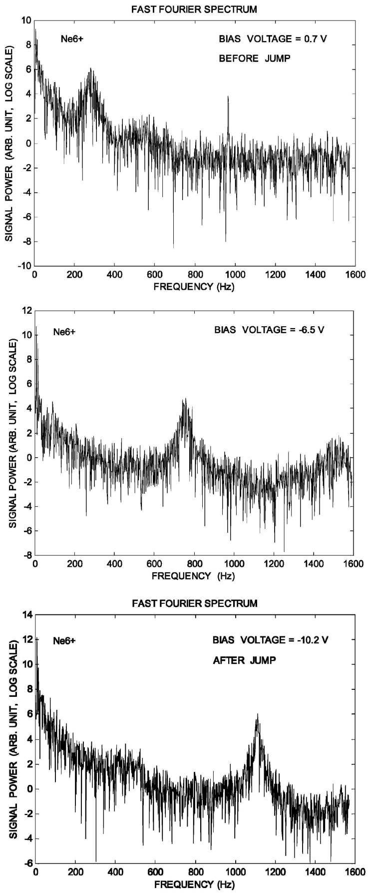

Fig. 4.　Fourier spectra of the ion current. The burst frequency changes with the applied bias voltage.

3 Discussions

The time spectra were Fourier analyzed for a number of applied bias voltages. All the spectra revealed the clear presence of a frequency peak different from the usual 50Hz noise. When no bias voltage was applied the frequency was around 300Hz. As the negative bias was increased the current showed a marginal decrease and at a small negative voltage (-2V) the current shows an abrupt jump. Simultaneously the frequency also showed an abrupt change (Fig. 5). It increased to a value of about 1170Hz. Thereafter both the current and the frequency remained essentially constant.

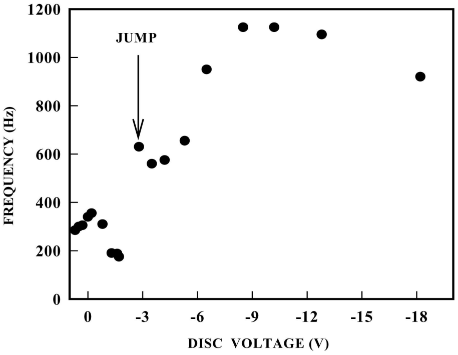

Fig. 5. Jump in the burst frequency (Ne^{7+}).

Figure 6 shows a plot of the frequency with the extracted ion current. The general trend is that the frequency increases as the current increases. In fact the plot shows a good linear correlation between the frequency and the current. The statistical correlation coefficient comes out to be 0.85.

The presence of a frequency peak in the Fourier spectra means that the ions come out of the source periodically, i.e., in bursts. If we subtract the minimum ion current (just before the jump) then the frequency-current plot becomes a straight line passing through the origin. Thus we can see two parts of the current, one is the constant part (i.e., the minimum part) and the other is the frequency dependant part.

At saturation, the frequency dependant part gives the major contribution to the ion current. The fact that the ion current (I-$I_{\min}$) is proportional to the burst frequency, then simply means that the more the number of bursts per unit time, the more is the current. It also says that the current per burst is a constant factor. Thus increasing the burst frequency by some means appears to be the key factor in increasing the extracted ion current. We have measured the time spectra and done the analysis for Ne^{7+} also. In this case also we have obtained similar results.

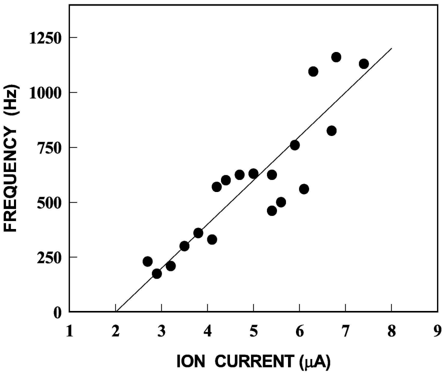

Fig. 6. Correlation between the burst frequency and the ion current.

R.C. Garner et al., in association with a plasma generated by microwaves, showed that the ions and electrons in a plasma show a burst in the kilo-Hertz frequency range.

Garner et al. observed[15—17] that a mirror confined plasma, which is inherently anisotropic when the electrons are heated to energies greater than the plasma potential, may be whistler unstable. The whistler instability means an electron micro-instability which is driven by the temperature anisotropy of the electron velocity space distribution. This whistler instability is driven by the warm electron component (~2keV), but hot electrons (~450keV) are micro stable. Unstable rf emission in a regime near the electron cyclotron resonance frequency ($0.7f_{\rm ce}$ to $f_{\rm ce}$) has been obtained in the mirror-confined ECR heated plasma. This rf emission associated with the micro-instability occurs in fairly regular burst with a fixed burst time. The energy per burst was found to maintain a constant value. It was also experimentally observed that the rf emission burst correlates with the electron end-loss burst as well as burst of ion end-loss.

The regularity of the burst depends upon the mid-plane magnetic field and the operating pressure. Whistler B occurs at lower operating pressure ($<5\times10^{-7}$ Torr) and whistler B and C both exist at marginally high operating pressure (7×10^{-7} to 2×10^{-6} Torr). In case of whistler B the end losses are along the axis.

Garner quoted a value of 5×10^{-6} J per burst in their 10GHz ECR device. In our 6.4GHz source, the total ion current is about 400μA. Taking a value of 30eV for the energy per ion and a measured burst frequency of 1.2kHz, the overall energy per burst comes out to be about 3×10^{-5} J. This is of the same order of magnitude as that obtained by Garner. So it can be surmised that the periodic bursts observed in our experiment is of similar origin to that discussed by Garner.

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