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CHARACTERISTICS OF S-X HYBRID ECR TYPE ION SOURCE WITH SUPER CONDUCTING MAGNET

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ABSTRACT

Further heating has been achieved by superposing short pulsed X-band (9.3 GHz) microwave to the S-band (2.45 GHz) ECR plasma. Asymmetric magnetic mirror configuration has been formed by adding the super conducting magnet to the normal one and the resonance condition is satisfied for both band of microwaves. Electron heating is confirmed by X-ray measurement and the effect on the charge state distribution is investigated.

INTRODUCTION

The characteristics of the electron cyclotron resonance (ECR) plasma has long been studied since the onset of the nuclear fusion research.[1] It, however, becomes obvious that the microwave power only contributes to raise the electron temperature and that it is no use to heat ions, which results a temporal slow-down of the progress of the study. Afterwards, it has been shown that the ECR plasma is effective as a target plasma for the neutral particle injection, and also shown possibility of application to the multiply-charged heavy ion source. As a result, the study of the ECR plasma becomes prevailing again all over the world. Furthermore, it is also utilized as a plasma processing device to form a semi-conductor thin film in place of the usual plasma CVD system.[2]

The characteristic feature of the ECR plasma is its high temperature electrons and full ionization, that is, the temperature easily rises to several tens keV or sometimes to more than a hundred keV. Such a hot-electron plasma can emit both Bremsstrahlung and characteristic X-rays of high intensity, which could be utilized as the means of medical diagnosis and therapy.[3,4]

If the plasma is confined stably in a magnetic field, ionization of gases occurs successively and the orbital electrons are stripped off in turn, which causes the production of the multiply-charged ions. At the same time the K-shell ionization due to hot electrons is accompanied with both emission of characteristic X-rays and the Auger effect, the latter also contributing the production of the multiply-charged ions.

In the present experiment the plasma is produced with the S-band microwave power and then the X-band microwave power is superposed to the ECR plasma for the purpose of further heating. The super conducting magnet will be arranged to satisfy the ECR condition for the X-band microwave, which would result a compact plasma, that is, increase in the energy density of plasmas.

EXPERIMENTAL APPARATUS

The hybrid system of both S-band and X-band microwave is adopted in this experiment and the effect of the further heating is investigated. In the present report, although, as the experimental data with the super conducting magnet have not been in time, only those data obtained under a situation where the ECR condition is satisfied only for the S-band microwave. In Fig. 1 is shown the schematic diagram of the experimental apparatus. The microwave power generated with the S-band magnetron (600 W, 2.45 GHz) is introduced into a vacuum chamber with a little rare gas admitted in it perpendicularly to the external magnetic field and the ECR plasma is produced. When the plasma density increases to reach the value over which the plasma frequency would exceed the microwave frequency, it becomes impossible for the microwave power to penetrate into into the plasma and only the surface thin layer would be heated. This is the reason why the microwave power of higher frequency generated with the X-band magnetron (100 kW, 9.3 GHz) is adopted and introduced into the plasma parallelly to the magnetic field. Since

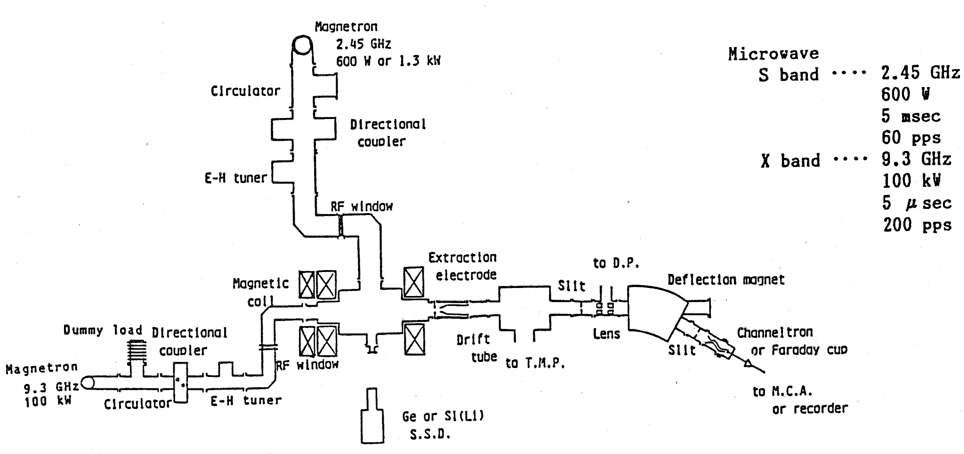


Fig. 1 Schematic diagram of the experimental apparatus.

this frequency is much higher than the original plasma frequency, it is expected that more microwave power would be absorbed in the plasma and both temperature and density of the plasma would be further raised. In the figure in addition to the microwave circuit the semi-conductor radiation detector for the energy spectrometry and also the measuring system for the multiply-charged ions such as an extraction electrode and a deflection magnet.

An additional magnetic coil is set to the side where the S-band microwave is introduced in order to make the magnetic flux density a little stronger than that of the opposite side and the magnetic configuration becomes asymmetric as shown in Fig. 2. The magnetic flux density satisfying the ECR condition is 880 Gauss for 2.45 GHz microwave and two equipotential surfaces exist at both sides of the chamber. The plasma electrons are resonantly heated up each time when they pass through the surfaces. If there exists 1.1 kGauss surface inside the chamber, the electron cyclotron frequency of which is 3.1 GHz and is 1/3 of the input microwave frequency, 9.3 GHz, it might be expected that the third harmonic electron cyclotron wave would resonate to the X-band microwave and cause resonant power absorption.

These magnetic coils will be replaced with the super conducting magnet which could easily realize the ECR condition for the fundamental frequency of the electron cyclotron wave, that is, 3.3 kGauss and then much more power absorption would be expected.

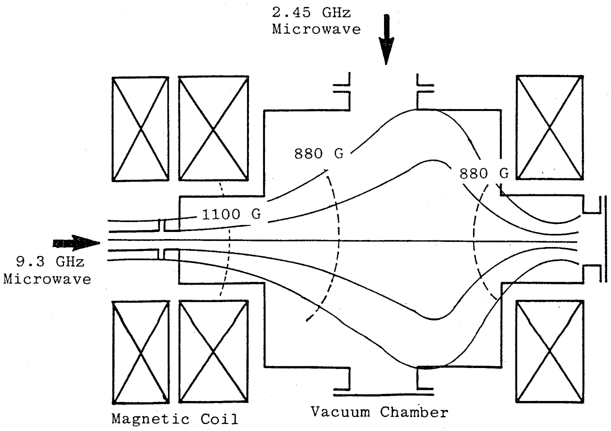
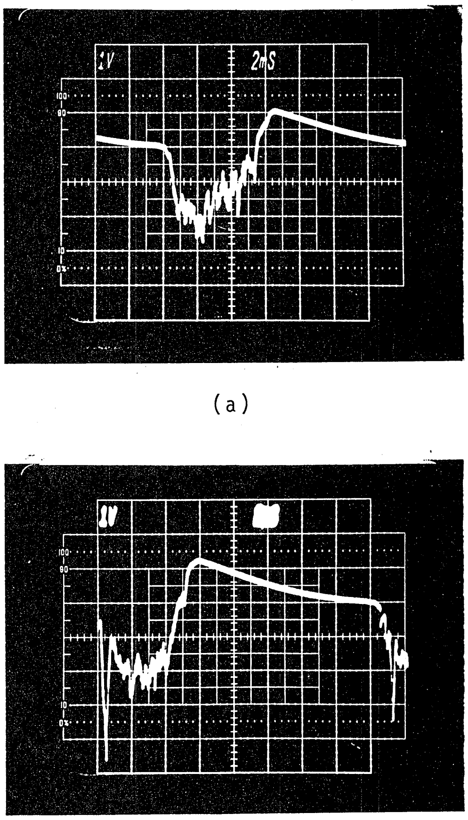


Fig. 2 Asymmetric magnetic mirror configuration.

EXPERIMENTAL PROCEDURE

Further heating of plasmas owing to the power absorption of the X-band microwave as expected could be confirmed by observing the X-ray intensity. The pulse shapes of the emitted X-rays are observed with the NaI scintillator and shown in Fig. 3(a) and (b). The output of the scintillator when the plasma is produced only with the S-band microwave is shown in Fig. 3(a), where the pulse duration of several msec is determined by the operating S-band magnetron. In Fig. 3(b) is shown the output of the scintillator obtained when the X-band microwave is superposed to the S-band one, where sharp pulsed X-rays are observed at the initial stage of the several msec pulse. As the pulse width of the X-band microwave is only 5 μsec, such a sharp peak is considered to represent the effect of further heating.



(a)

(b)

Fig. 3 X-ray pulse from (a) S-band and (b) (S+X)-band ECR plasma.

Since further heating occurs instantaneously, it would be difficult to detect the time averaged data such as increase in the electron temperature and the X-ray intensity. In order to overcome such a difficulty the measuring system as shown in Fig. 4 is adopted. The gate pulse of 10 μsec is applied to the ADC of PHA synchronously only when the X-band microwave is superposed to the S-band one, and the energy spectra of X-rays obtained during the gate pulse are compared with each other for both S-band and (S+X)-band ECR plasma.

EXPERIMENTAL RESULTS AND DISCUSSIONS

As an ionized gas Xenon gas is adopted and the energy spectra of X-rays are detected with the pure Ge semi-conductor detector, which are shown in Fig. 5. The spectrum for only S-band is shown in (a), where the characteristic X-rays, K_α and K_β, are observed in addition to the Bremsstrahlung X-rays. The spectrum in case of (S+X)-band is shown in (b), where it is clear that the intensity of both Bremsstrahlung and characteristic X-rays increases considerably. The X-ray intensity depends largely upon the gas pressure and there exists an optimum gas pressure for the maximum X-ray intensity under a constant power condition. In Fig. 6 is shown the dependence of the characteristic X-ray intensity on the gas pressure, where the hybrid effect is also remarkable. When the gas pressure exceeds 1.0 X 10^{-4} Torr, the X-rays cannot be observed for S-band ECR plasma, but the X-band microwave being superposed, the X-rays come to be detectable. Namely, the effect of further heating is clearly confirmed.

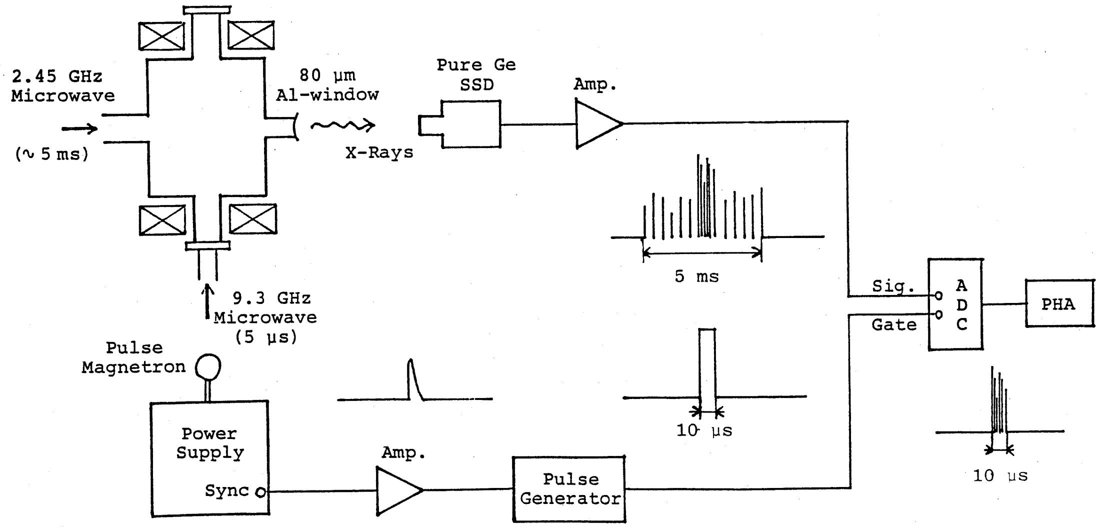


Fig. 4 Measuring system for short-pulsed X-ray energy spectra.

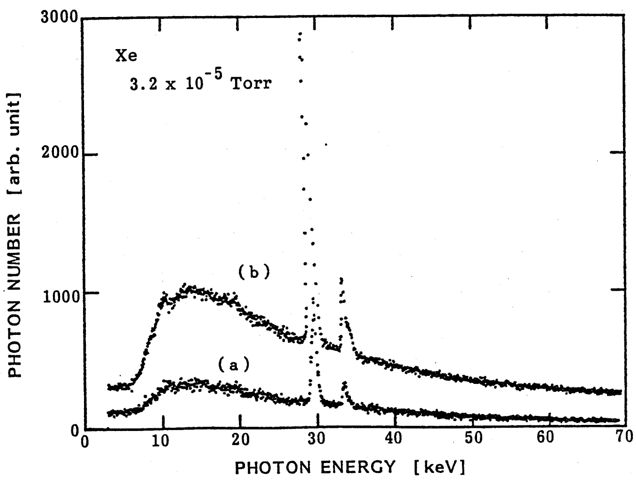


Fig. 5 X-ray energy spectra for (a) S-band and (b) (S+X)-band ECR plasma.

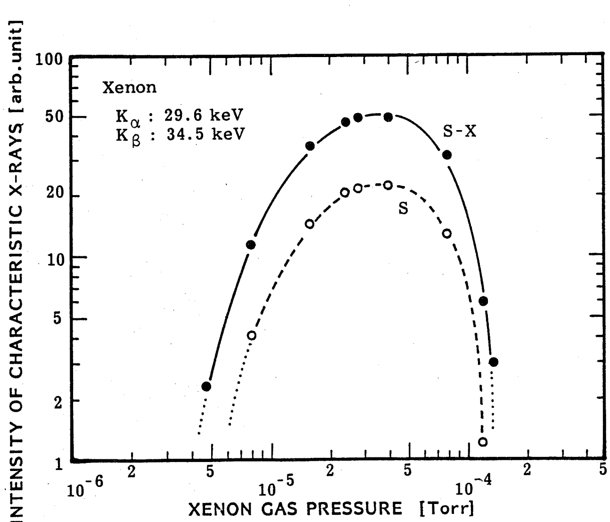


Fig. 6 Dependence of X-ray intensity on gas pressure.

The ordinate of the observed energy spectra being transformed to the energy fluence, the electron temperature could be determined by measuring the gradient of the semi-logarithmic line and also obtained the relative increase of the electron density.[5)]

In Table 1 is shown both increase in electron temperature and increase rate of electron density obtained experimentally for three kinds of gases. In any case such results are observed as seem to be due to the resonant absorption of the third harmonics of the electron cyclotron waves. The effect is especially remarkable in case of Xe plasmas.

Table 1 Hybrid effect on electron temperature and density.

試料ガス	圧力 (10^{-5} Torr)	電子温度 (keV) S	電子温度 (keV) S+X	電子密度 S	電子密度 S+X
Ar	3.0	56.8 →	73.1	1.00 →	1.31
Kr	3.7	38.1 →	47.5	1.00 →	1.33
Xe	3.2	57.4 →	74.5	1.00 →	2.97

Since it has become obvious that the third harmonics of the cyclotron wave is effective for electron heating, it might be expected that almost all X-band microwave power would be absorbed provided that the fundamental wave is made to resonate by introducing the super conducting magnet, and then much more effectiveness would be ascertained. In that case the temperature rise could probably be observed without 10 μsec-gate pulse.

Thus, by adopting the effective hybrid heating system described above, it could be expected that the multiply-charged heavy ion source that could deliver the higher charge-state ions on the average than usual would be realized.

The system would also be effectively utilized as a plasma processing device to produce thin films with special gases whose chemical bonds are rather strong.

The experiments to get charge-state distributions are now in progress.

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