STELLARATORS

ECR-Generated Noble Gas Plasmas in the Stellarator W IIa

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Abstract: Argon and xenon plasmas were produced by electron cyclotron resonance in the W IIa stellarator. Densities ranged from $3\cdot10^{8}$ to $2\cdot10^{11}\mathrm{cm}^{-3}$ and electron temperatures from 4 to 12 eV. The confinement time was estimated to be five to ten times the Bohm time. The general features of the density versus rotational transform curves were similar to those observed with barium plasmas produced by contact ionization except for some cases with xenon.

The confinement of contact ionized barium plasmas in the W II stellarator has been interpreted as approaching the classical collisional limit for axisymmetric fully ionized plasmas and exceeds the Bohm value by about two orders of magnitude [1]. The present paper describes preliminary experiments with noble gas plasmas generated by low power electron cyclotron resonance. The aim of these experiments was to get an estimate of plasma confinement at higher electron temperatures and hence longer electron mean free paths than those in contact ionized barium plasmas and to see whether or not the sudden decreases in density for particular values of the rotational transform observed in barium plasmas were related to the presence of the solid plasma source and its supports. Wendelstein IIa is a circular stellarator with major diameter $2R_o=1$ m and plasma diameter $2r_o=10$ cm. It has continuously wound $\ell = 2$ helical windings which produce a nearly shear-free stabilizing field. Technical details have been given elsewhere [1]. In our experiments the microwave power was radiated from an open X band wave-guide which is flush with the inner surface of the vacuum vessel. Various magnetrons and klystrons with frequencies around 9.8, 13.3, and 15.7 GHz were used with output powers ranging from the minimum value required of 20 to 40 mwatts up to 7 watts. The magnetic field strengths for resonance are 3.28, 4.74, and 5.5 kG. For these values the main magnetic field and the helical windings could be operated in a steady state up to values of $\iota = l/2\pi$ of about 0.6. Operating pressures of argon and xenon ranged from 10^{-6} to 10^{-4} torr. The base pressure was usually a few times 10^{-7} torr. Plasma density and electron temperature were measured using cylindrical Langmuir probes with tips 4mm long and 0.1 mm thick. The probes could be moved in radial direction. The probe data were evaluated using the theory for infinitely long cylindrical probes by Laframboise [2]. The microwave power could also be switched off suddenly in order to observe the subsequent decay in particle density by means of the probes.

Depending on neutral gas pressure and microwave power, the peak particle density n_{eo} attained values between a few times 10^{8} and $2\cdot10^{11}\mathrm{cm}^{-3}$. The electron temperature ranged from 4 to 12 eV. The degree of ionization thus varied between 10^{-4} and 0.6. Rough measurements of the space potential in a few cases indicated that the plasma was charged positively which implies that the electrons have a higher intrinsic loss rate. As indicated from the time decay in the afterglow, the mean plasma life time was of the order of milliseconds. This time is short compared to the time of equipartition between electrons and ions. Moreover, the ions are strongly coupled to the neutral atoms via resonant charge exchange collisions. The ion temperature, therefore, is practically equal to the neutral gas temperature.

The question of plasma confinement was studied by computing the mean particle life time τ, for a number of steady state discharges in argon, where τ is the ratio of the total particle number N, and the production rate $\dot{N}$. The rate coefficients have been taken assuming Maxwellian distribution of electron energies. This assumption is questionable for lower electron densities since the electron-electron collision times are too long. On the other hand, one can estimate the total production rate from the microwave power absorbed and the energy required to produce and to heat an electron to the observed temperatures. Taking the latter energy equal to 50 eV and assuming that all the power entering the discharge tube (i.e. about half the output power, W) is absorbed, the two estimates for the production rate agree reasonably well as seen from the Table below. (The lower numbers $\dot{N}$ refer to the μ-power estimates.) The mean particle life times are given in the same Table. The plasma decay times were usually found to be somewhat higher. A proper interpretation of these decay times which are taken from the ion saturation current traces requires a determination of T_e during the afterglow which has not been done. From the plasma life time an effective diffusion coefficient is deduced, $D_{eff}= (r_o/2.4)^2/\tau$. This value is compared with various theoretical estimates. The Pfirsch-Schlüter value, D_{PS}, is by far too small to account for the observed life times. Next we computed the values, D_K^A, (at max. T_e and n_e) from the theory of Kovrizhnikh [3] for weakly and strongly ionized axisymmetric plasmas which takes the self-consistent radial electric field into account. (The numbers in brackets refer to the respective values for both weakly and strongly ionized plasmas as neither of the criteria given by Kovrizhnikh strictly apply to these discharge conditions). The coefficient D_K^{St} from Kovrizhnikh for an $\ell = 2$ stellarator, which should reflect the influence of particles trapped in the helical mirrors, is given next. Finally, we quote the values of the Bohm diffusion coefficient D_B. Except for the case with high neutral pressure the effective diffusion coefficients range between D_K^A and D_B. As the electron temperature decreases radially outwards and D_K^A depends stronger on electron temperature than D_B, the departure from the Kovrizhnikh value becomes still more pronounced. For discharges with higher microwave frequencies and correspondingly higher magnetic fields the peak densities become somewhat higher at the same power level.

The plasmas in our ECR discharges exhibit relative density fluctuations generally of the order of 10 to 20 %. Measurements with the spectrum analyzer indicate strong activity in the frequency range of the drift waves which is not surprising since the $\ell = 2$ helical windings produce only weak shear.

W P_{ar}	B_o ι	n_{eo} T_e [eV]	$\dot{N}$ $[s^{-1}]$	τ [ms]	D_{eff} $\times10^{-3}$	D_{PS}	D_K^A $\times10^{-3}$	D_K^{St}	D_B $\times10^{-3}$
40mw 6×10^{-6}	3.2 0.125	3.8×10^{8} 8.6	1.3×10^{15} 2.5×10^{15}	1 2	4.3 2.2	0.43	0.7	1.75	16.8
400mw 7×10^{-6}	4.62 0.2	6.3×10^{9} 7.4	4.8×10^{16} 2.5×10^{16}	0.79 1.5	5.5 2.9	1.36	(0.16) (0.008)	1.03	10
7watts 4.6×10^{-6}	3.28 0.328	2.4×10^{11} 12	1.6×10^{18} 0.5×10^{18}	0.3 1	15 4.5	32	(0.51) (0.06)	0.1	23
400mw 2×10^{-4}	4.62 0.2	2×10^{9} 4.4	1×10^{16} 2.5×10^{16}	0.1 0.04	43 133	0.56	0.24	1.8	6

The dependence of the particle density on rotational transform ι in argon was found quite similar to that observed in contact ionized barium plasmas. An analogous pattern is observed with the annular grid-plate particle detector which encloses the plasma and measures part of the radially outstreaming particle flux. This indicates that at the particular values of ι the total plasma production rate is reduced. At higher pressures and microwave power levels the density decreases become less pronounced. With high enough power it is possible to maintain the discharge at all values of ι. In contrast to these results we found a different behaviour in xenon for a wide range of discharge parameters. Superimposed to the general appearance of broad minima there are pronounced density peaks at rational values of ι.

[1] Berkl, E., et.al. Proc. Novosibirsk Conf., 1, 513 (1969) Wien
[2] Laframboise, J.G., UTIAS Report No. 100
[3] Kovrizhnikh, L.M., ZhETF, 56 (1969) p. 877

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