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Measurements of Helicon Wave Propagation and Ar II Emission*

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Abstract

Wave magnetic field, optical and Langmuir probe measurements are carried out to examine fast and thermal electron contributions to plasma ionization in helicon plasma sources. Comparison of double half-turn and a double half-turn helix experiments are carried out. Spatio-temporal measurements of 443 nm peak emission show that the emission is modulated at the source frequency. The peak count phase of the modulation propagates along the plasma at a comparable speed as the local helicon wave phase velocity. Computer modeling is carried out to examine wave field effects on electron acceleration and ionization contributions arising from non-Maxwellian fast electrons.

I. Introduction

The central question in the physics of helicon sources is the cause of their highly efficient ionization and strong wave damping, which is not well explained by either collisional or Landau damping processes. A particular matter at issue is the existence, in some operating regimes, of a population of fast electrons comprising a non-Maxwellian component of the electron distribution, and the significance of its role in helicon ionization processes. In this paper we report on experiments performed on the WOMBAT[1,2] 20 cm diameter helicon experimental facility in which argon plasmas were created by means of a double half-turn antenna with densities in the range 10^{11}-$1x10^{12}/cm^3$. We also report on the 10 cm diameter UW helicon plasma wave facility that is excited by a double half turn helix. The optical measurements are of the Ar II line at 443 nm. The 443 nm emission upper state is 35 eV above the ground state.[1] Thus, electrons of fairly high energy are required to populate these states, and emission at 443 nm is indicative of their presence. The objective of this paper is to show that substantial non-Maxwellian contributions to the source ionization for this regime can exist. Experimental measurements of the wave B_z magnetic field components are compared with those predicted by the AntenaII[3] full wave boundary code for helicon modeling. The code also determines the wave electric fields consistent with the helicon wave hot plasma dielectric tensor. The corresponding wave E_z field produced by the code is incorporated in a non-linear one-dimensional code that illustrates the evolution of a non-

Maxwellian electron distribution and enhanced Argon ionization above what a Maxwellian distribution would produce under these experimental conditions.

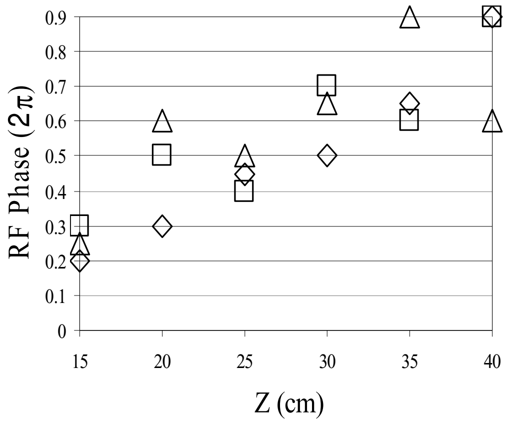

Figure 1: Optical Emission Peak

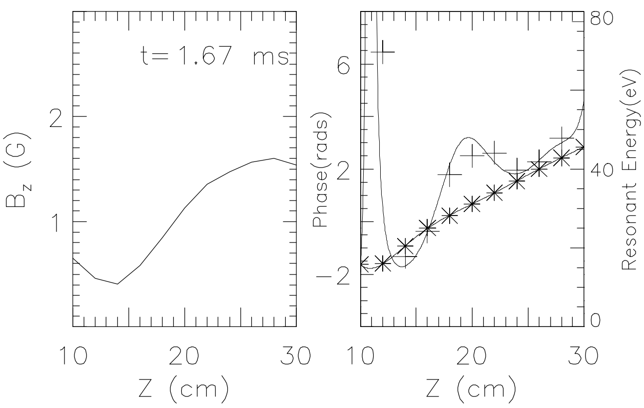

Figure 2: Wave Magnetic Field and Phase Resonant Electron Energy

Figure 1 shows the variation of the peak in the 443 nm emission relative to a reference rf phase vs. optical probe position for three runs of data taken for the above plasma density and wave phase velocity. A single emission peak is observed during a radiofrequency period, which indicates that it is caused by a traveling wave interaction and it is has a 25% modulation. The range of local electron resonant energies corresponding to the peak emission phase velocity corresponds to electron energies of 30-52 eV. This corresponds well to the local wave phase velocity over this range obtained from the B_z probe indicating that traveling wave-particle interactions play a significant role in fast electron creation for ionizing processes in the helicon source for this case.

II. Analysis of the wave field phase velocity and correlation with optical emission

We first analyze the measured wave magnetic field (B_z) local phase velocity and compare it to the observed velocity of the peak Ar II emission. An analysis of the local wave phase velocity and resonant electron energy, $E=mv_\phi^2/2$, was carried out for this case at t=1.67 ms from the start of the pulse where the density is constant as shown in Fig. 2.

The average B_z wave phase velocity for the traveling wave portion of the curve is 3.2 x 10^6 m/s corresponding to an average resonant electron energy of 29 eV over the range from z=12-30 cm. The corresponding local differential resonant electron energies indicated by crosses over the same range are from 18-46 eV. The stars indicate the local wave phase and the smooth curve connecting the crosses serves as a guide to the eye for this data. The electron resonant energies in this range are quite sufficient to excite the upper state for the 443 nm emission either from the ionic ground state or from the neutral state. The wave continues as a traveling wave until about z=35 cm where it changes to a standing wave character. This can be due to the substantial axial density gradient in this region as well as a decrease by 10% in the static magnetic field over this range.

Computer simulations of the wave-plasma interaction for the axial component of the wave electric field corresponding to the measured wave axial magnetic field phase were carried out. They show that enhanced ionization compared to a 3 eV Maxwellian occurs due to the wave field interaction with the electrons with a local maximum ionization rate close to where the measured density peaks at 13 cm downstream from the antenna. An increase in the distribution function for electrons in the energy range (20-45 eV) comparable to the wave phase resonant velocities and energies corresponding to the peak Ar II emission speed is predicted. This implies that a substantial contribution to ionization due to non-Maxwellian electrons under these helicon source conditions exists.

III. Current UW helicon plasma source research.

The University of Wisconsin helicon plasma facility uses a twisted double helix antenna and a 10 cm diameter Pyrex chamber. The length of the chamber is 1.6 meters. A broadband amplifier and a capacitive match box are used to couple up to 1 kW of 13.56 MHz RF power to argon plasma. Diagnostic tools include Langmuir, magnetic field and optical probes. Figure 3 shows an interesting phenomenon that occurs at the transition from the inductive mode to the helicon mode. The density is initially high and then decays as time

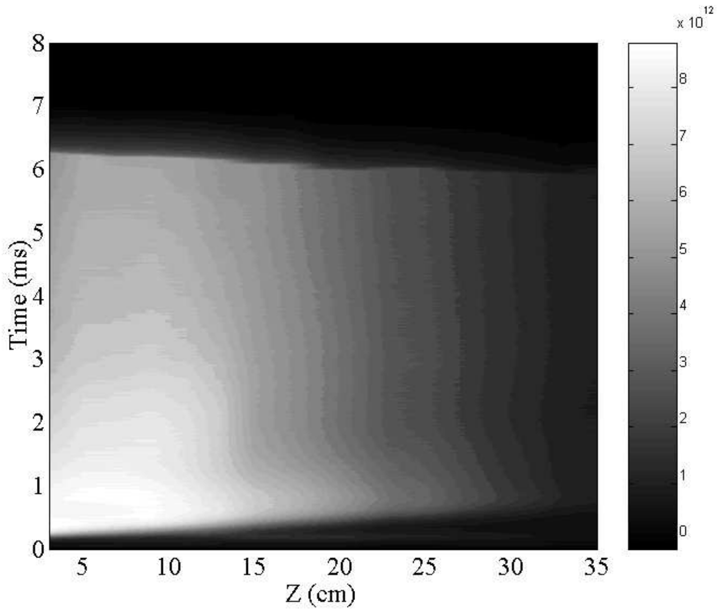

Figure 3: Density (cm^{-3}) assuming an electron temperature of 3 eV verses time during the pulse and axial position for the transition from inductive mode to helicon mode (800 Watts, 200 Gauss).

goes on. This is in contrast to the other cases where the density gradually increases with time. Figures 4 and 5 show magnetic field probe results for the transition mode and the helicon mode. The transition mode has more of a traveling wave character (due to the near linear phase variation) while the helicon mode shows more of a standing wave character.

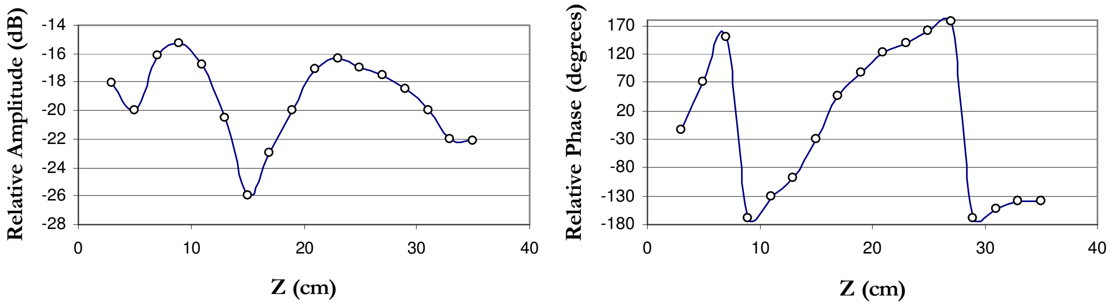

Figure 4: B_z relative amplitude and phase verses axial position for the transition mode (700 Watts, 200 Gauss).

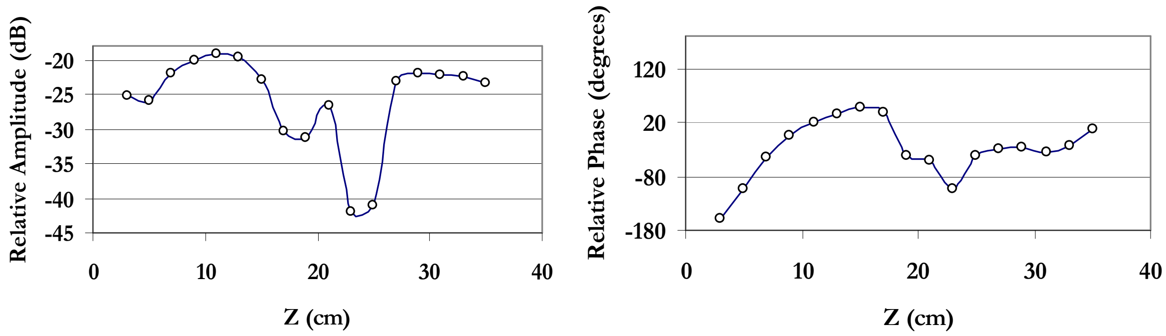

Figure 5: B_z relative amplitude and phase verses axial position for the blue (helicon) mode (800 Watts, 1000 Gauss).

Photon Binning results for the 443 nm emission are being carried out. Care is being taken to use cable with high isolation (>90 dB) so that modulation is not created by noise. Also the Labview software that does the correlating is carefully being checked to reproduce both random and correlated test signals. A new oscilloscope with a fast sampling rate (4 GS/s) has been acquired and is being incorporated into the system.

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