Electron density and electron temperature measurements on an inductively coupled argon plasma

ELECTRON DENSITY AND ELECTRON TEMPERATURE MEASUREMENTS ON AN INDUCTIVELY COUPLED ARGON PLASMA

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Abstract
A new calibration method to obtain the electron density from Thomson scattering on an Inductively Coupled Plasma is discussed. Raman scattering on nitrogen is used for this purpose. Other calibration methods, using Rayleigh scattering on a well known gas, failed due to blooming on the highly sensitive detector by the strong Rayleigh signal. Optically blocking of the Rayleigh peak on the detector prevents blooming. Therefore, the weaker Raman wings are used for a reconstruction of the Rayleigh scattered signal. Furthermore, measured electron densities and electron temperatures are presented with an accuracy in density of about 15% and in temperature of about 500 K.

Introduction
A fundamental study of Inductively Coupled Plasmas (ICP) is necessary to improve their applications in spectrochemical analysis and in the use for light sources. Since the electron temperature and electron density are central plasma parameters, a Thomson scattering set-up is designed for these parameters on a 100 Mhz argon ICP with a typical input power of 1.2 kW. The construction of the diagnostic is very similar to the one realized by Van de Sanden [1] *et al.* One of the features of this diagnostic is a detector, a photo diode-array, with highly spectral resolution in combination with a small apparatus profile.
Since the ICP is an atmospheric plasma of small dimensions, it is necessary to pay more attention to the calibration method. First, a strong laser stray light signal will enter the detector that looks similar to the Rayleigh scattered profile. Therefore, the Rayleigh scattered signal can not accurately be measured seperately and is no longer useful to calibrate the Thomson scattered signal, as is usually done. Second, the presence of atmospheric conditions causes an extremely large intensity of the Rayleigh scattered signal compared to the Thomson scattered signal. This large number of Rayleigh photons, together with stray light, will cause blooming on the detector. This disturbs the spectral broader Thomson signal.

Figure 1: Typical Thomson measured profile with a fitted Gauss.

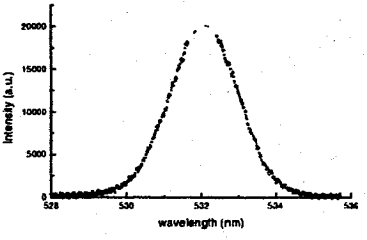
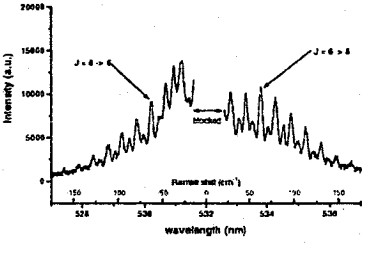


Figure 2: Raman scattered profile measured on nitrogen at room temperature.



Experiment
To eliminate the large number of disturbing photons in our diagnostic, the detector is physically darkened for the channels that would otherwise cause blooming, that is, the channels at the Rayleigh signal. In this way it is possible to measure an undisturbed Thomson scattered profile, from which the central

part is missing, see Figure 1. From the width of this Doppler broadened profile the electron temperature can be calculated [1]. The surface of the profile can be used for calculating the electron density, after calibrating the sensivity of the set-up. Therefore, a procedure is developed to reconstruct the Rayleigh intensity from the Raman spectrum of nitrogen. In Figure 2 a Raman spectrum is depicted. The flanks of the Rayleigh and stray light profile create a background under the Raman spectrum. Fitting the surface under a Raman peak for a value of the rotational quantum number J with a Gaussian profile, a corresponding Rayleigh profile can be reconstructed using conversion factors that can be derived from Raman theory [2]. To increase the accuracy of calibration, more Raman peaks are treated.

Figure 3: The measured T_e as a function of radial position at 7 mm ALC.

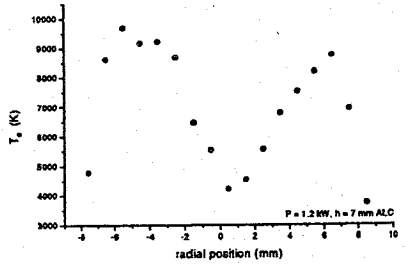
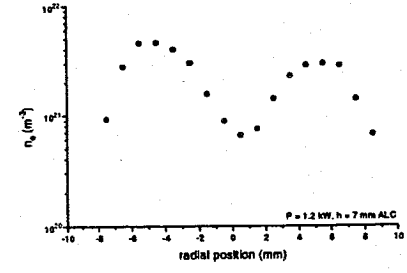


Figure 4: The measured n_e as a function of radial position at 7 mm ALC.



Results

In Figure 3 and Figure 4 sets of measurements for different radial positions at 7 mm above the coil are presented. The asymmetry of the radial dependent electron density and electron temperature profile are due to the asymmetric coil. Furthermore, the lower density and lower temperature in the center of the plasma is a well-known feature of the ICP. Here, the advantage of Thomson scattering is directly shown by the spatially resolved information. Comparing these results with measurements performed by Huang [3] *et al.* we see a much larger difference in density and temperature between the centre and the hottest area of the plasma. In general this difference is due to the skin effect. We conclude that in our 100 MHz plasma a larger skin effect is present in stead of the normally used 27 Mhz.

The highly dispersive grating in combination with the gated light amplifier and the 1024 channel photodiode array are responsible for a very accurately measured Thomson profile (within 1%), see also Figure 2. But still the accuracy of these measurements is about 15% in the electron density and about 500 K in the electron temperature. These inaccuracies include reproducibility, which is an important source of deviations in the electron temperature since the power settings can only be reproduced with about 0.1 kW. The main inaccuracy in the electron density is caused by the calibration of each Thomson measurement. The most important sources are the instabilities in the set-up and the measured Raman spectrum itself. Inaccuracies in Raman measurements will be improved in future by a better defined nitrogen gas sample in order to get a more accurate Raman spectrum.

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[2] D.A. Long, "Raman Spectroscopy", McGraw-Hill, Inc., 1977

[3] M.Huang, D.S. Hanselman, P. Yang and G.M. Hieftje, Spectrochemica Acta **47B** (765), 1992