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ANALYSES OF ELECTRON DENSITIES WITH 160.28 GHZ MICROWAVE INTERFEROMETRY AND MEASUREMENT OF NEGATIVE ION DENSITY BY ADDITIONAL LASER PHOTODETACHMENT TECHNIQUE

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The analyses of electron densities in capacitively coupled plasmas driven by 13.56 MHz is realised by means of a PLL heterodyne microwave interferometer at 160.28 GHz or corresponding wave length $\lambda_{MWI} = 1.87$ mm. The microwave interferometry represents a minimal-invasive diagnostics which can be also applied in reactive as well as in electronegative plasmas without any restrictions. No model assumption is necessary for determining line-integrated electron densities (n_L).

Because of the different phase velocity due to the different refraction index with and without plasma the microwave beam obtains a phase shift $\Delta\Phi$. This phase shift is directly coupled with the integral of the electron density n_e through the line of sight in the plasma. For instance, the lower limit in electron density for CCP is in the order of $1 \cdot 10^{15}\,\mathrm{m}^{-3}$ which results in a phase shift of $0.03\,^\circ$. The detection of this slight phase shift is one of the big challenges applying 160.28 GHz microwave interferometry in low density radio frequency plasmas.

The experimental setup is presented in Figure 1. Beside the used vacuum components, gas and rf power supply, the microwave diagnostic unit is also pictured in this Figure. This unit includes the 160.28 GHz microwave interferometer (MWI) and the special designed horn antennas and elliptical mirrors optimized for the used microwave frequency. Furthermore, it should be highlighted that the whole free space microwave propagation bases on the special Gaussian beam propagation theory [1]. The minimum beam diameter amounts to 10 mm in the centre above the powered electrode. The acquisition and processing of the interferometer data were realised by means of an oscilloscope and computer (PC).

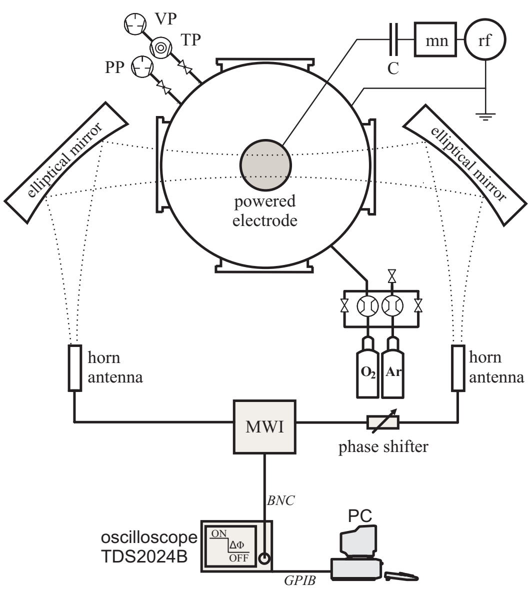

Fig. 1: Picture of schematic experimental setup, where mn is the matching network, rf is the 13.56 MHz power supply, TP is the turbo pump, VP is the pre pump, PP is the process pump and MWI is the 160.28 GHz microwave interferometer.

First systematic analyses of the electron densities were performed in argon and oxygen rf plasma in dependence on the self-bias voltage (rf power) for different total pressure of between 10 Pa and 100 Pa. The measurements in argon and oxygen plasmas lead to different behaviour of the electron density with increasing self-bias voltage. Whereas the electron density in the argon plasma increases continuously, the electron density progress in the oxygen plasma can be divided into two parts. The first part is characterised by a nearly constant low electron density for negative self-bias voltage less than 250 V. The second part is characterised by an approximately linear increase of the electron density with rising self-bias voltage greater than 250 V. Both parts may be explained in connection with formation and detachment of negative oxygen ions (O^-) in oxygen plasmas. The determined electron densities in argon and oxygen plasma averaged over the electrode diameter are in the same order of magnitude compared with measured electron densities from literature [2, 3]. In particular, the comparison of electron densities measured in argon plasma shows overlapping with literature values and their direct continuation in the extended parameter range.

The temporal analyses of electron densities in pulsed rf oxygen plasma reveal an electron peak in the afterglow of the discharge (Figure 2(a)). This electron peak was detected over a wide parameter range of total pressure. First assumptions lead to an extra production channel of electrons by detachment of negative oxygen ions, e.g. by collisions with oxygen atoms O, molecular oxygen O_2 as well as metastable oxygen molecules $O_2\left(a^1\Delta_g\right)$ [4]. Furthermore, the oxygen rf plasma is strongly influenced by attachment induced ionization instabilities (Figure 2(b)) [5, 6, 7]. These instabilities could be detected over a wide parameter range in the applied oxygen rf plasma.

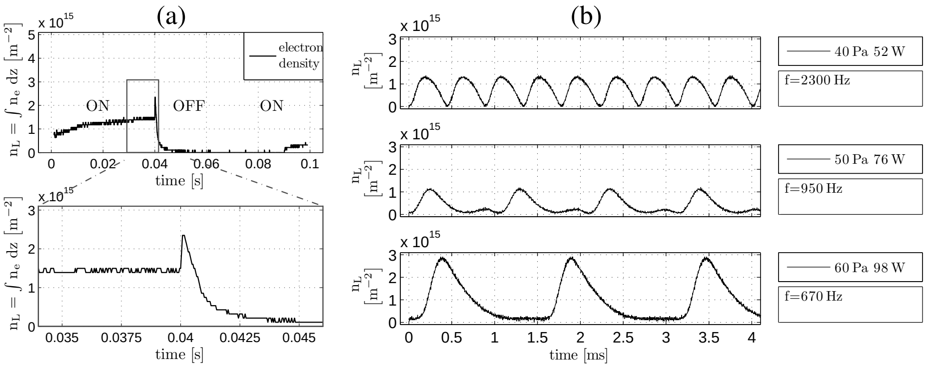

Fig. 2: (a) Electron peak in the afterglow of the oxygen rf plasma. Therefore the discharge was pulsed with 10 Hz and a duty cycle of 50 %. (b) Instabilities of the electron density for an oxygen plasma by different pressures.

Finally first results shall be presented for experimental determination of negative oxygen ion density by using the combination of laser photodetachment technique and 160.28 GHz microwave interferometry. We are not aware of citations using this combination to measure negative oxygen ion in capacitively coupled radio frequency plasmas in oxygen.
The electrons are detached from negative oxygen ions O^- during the interaction with a 10 Hz pulsed Nd:YAG laser and were detected by the microwave interferometer as a corresponding additional phase shift. The direct measured line-integrated negative oxygen ion density is in the range of $n_L^{O^-} = 7 \cdot 10^{13}\,m^{-2}$ at a pressure of 10 Pa and an rf power of 100 W with a corresponding self-bias voltage of 580 V.

Reference

[1] P. F. Goldsmith. Quasioptical Systems. Wiley-IEEE Press, 1998.
[2] L. J. Overzet and M. B. Hopkins. J. Appl. Phys., **74**:4323-4330, 1993.
[3] E. Stoffels et al. Physical Review E, **51**:2425-2435, 1995.
[4] A. Brockhaus et al. Plasma Sources Sci. Technol., **15**:171-177, 2006.
[5] A. Descoeudres et al. Plasma Sources Sci. Technol., **12**:152-157, 2003.
[6] H.-M. Katsch et al. Appl. Phys. Lett., **75**:2023-2025, 1999.
[7] W. L. Nighan and W. J. Wiegand. Physical Review A, **10**:922.945, 1974.