Coupling effects in inductive discharges with RF substrate biasing

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Low pressure inductively coupled plasmas (ICP) operated at 27.12 MHz with capacitive substrate biasing (CCP) at 13.56 MHz are investigated by Phase Resolved Optical Emission Spectroscopy, voltage, and current measurements [1]. Three coupling mechanisms are found potentially limiting the separate control of ion energy and flux: (i) Sheath heating due to the substrate biasing affects the electron dynamics even at high ratios of ICP to CCP power. At fixed CCP power, (ii) the substrate sheath voltage and (iii) the amplitude as well as frequency of Plasma Series Resonance (PSR) oscillations of the RF current are affected by the ICP power.

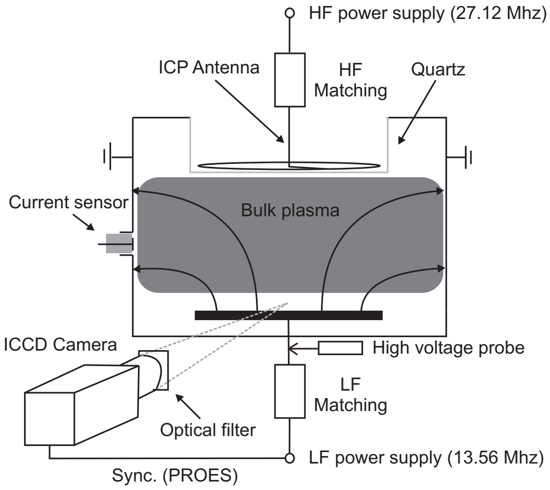

Fig. 1: Experimental setup including all diagnostics (PROES, current and voltage measurements). The arrows indicate the direction of the current flow.

In order to combine the advantages of ICPs (high plasma density) with those of CCPs (control of ion energies and good uniformity) and to realize separate control of the mean ion energy and flux at the substrate, hybrid combinations of ICPs with capacitively biased substrates are used [2]. The idea is, that the ICP power, P_{ICP}, controls the ion flux and plasma density without affecting the energy of ions at the substrate and that the CCP power, P_{CCP}, controls the ion energy at the substrate without affecting the plasma density. Here, these assumptions are tested experimentally by Phase Resolved Optical Emission Spectroscopy (PROES) as well as time resolved current and voltage measurements in an ICP discharge (27.12 MHz) with RF substrate biasing at 13.56 MHz [1]. P_{ICP} is varied from 0 W to 500 W at constant capacitive power of 20 W in a geometrically strongly asymmetric reactor shown in fig. 1. The driving frequencies are not phase locked. Time resolution is realized only within the low frequency period of the capacitive driving voltage waveform. Any modulation of the plasma emission caused by the ICP coupling is not observed, i.e. it is measured as a temporally constant background signal due to averaging.

Based on the experimental results shown in fig. 2 three different coupling mechanisms between the ICP and CCP source are found potentially affecting the separate control of ion properties: Firstly, the power coupled capacitively into the plasma affects the electron dynamics significantly via sheath heating [3] even at high ratios of P_{ICP}/P_{CCP}. This indicates a non-negligible effect of P_{CCP} on the plasma density and ion flux [2]. Secondly, the power coupled inductively into the plasma affects the voltage drop across the sheath at the powered electrode and, thus, the ion energy distribution at the substrate. An increase

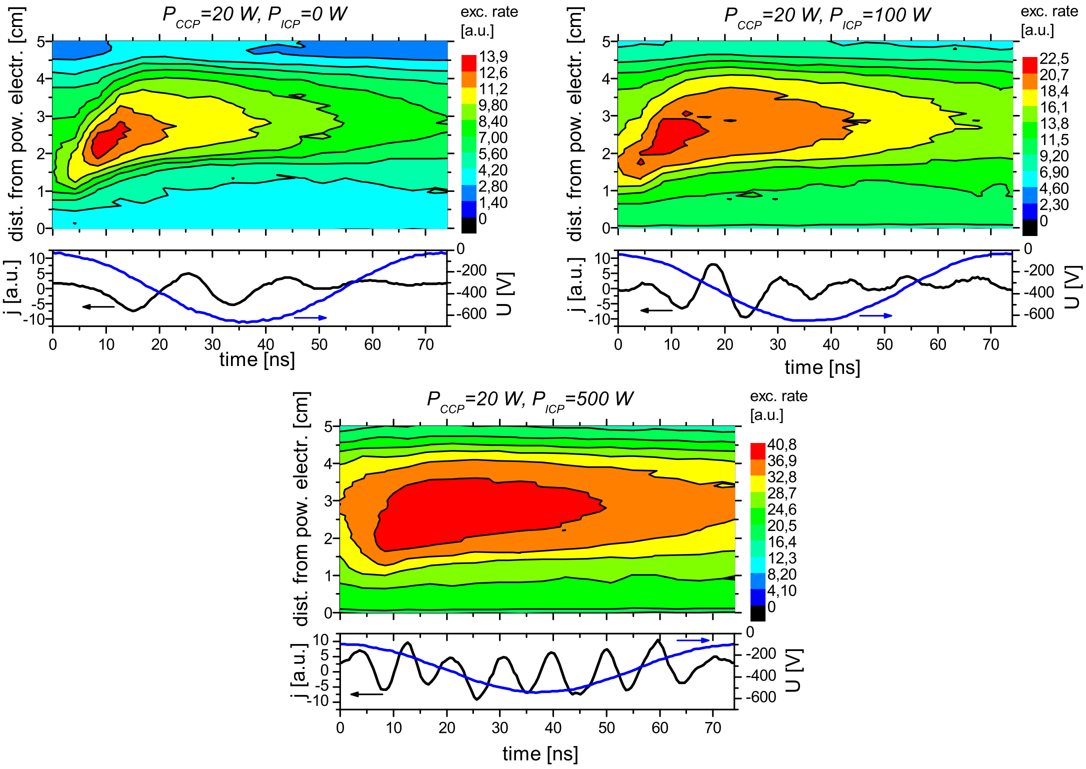

Fig. 2: Measured spatio-temporal electron impact excitation rate from the ground state into the Ne2p$_1$ state, RF current density to the wall, and voltage drop between electrode and ground for different values of P_{ICP} at fixed CCP power of 20 W. The discharge is operated in Neon at 5 Pa. Top: $P_{ICP} = 0$ W, Middle: $P_{ICP} = 100$ W, Bottom: $P_{ICP} = 500$ W.

of P_{ICP} causes the minimum of the measured voltage to increase (-660 V at $P_{ICP} = 0\,\mathrm{W}$ and -540 V at $P_{ICP} = 500\,\mathrm{W}$), since a higher ICP power leads to a higher plasma density and current, which causes the sheath voltage to decrease at fixed CCP power. Moreover, the maximum of the measured voltage decreases as a function of P_{ICP} indicating an increase of the absolute value of the floating potential at the driven electrode (-20 V at $P_{ICP} = 0\,\mathrm{W}$ and -95 V at $P_{ICP} = 500\,\mathrm{W}$). This might be caused by highly energetic electron bombardment of the powered electrode by secondary electrons, which are released at the quartz surface surrounding the ICP antenna due to ion bombardment and accelerated inside the sheath adjacent to this floating surface. Thirdly, the ICP power affects the damping and frequency of PSR oscillations of the RF current [4]. Since the PSR oscillations are damped mainly by electron neutral collisions, an increase of P_{ICP} reduces the damping potentially due to gas heating. The frequency of the PSR oscillations, $\omega_{PSR} \propto \omega_{pe}$ [4] increases as a function of P_{ICP} due to an increase of the electron density. Thus, the sheath expands faster at high ICP powers and capacitive stochastic heating is enhanced as a function of P_{ICP}. Analogous measurements with phase locked frequencies and time resolution within the capacitive and inductive RF period might yield more detailed insights into these coupling mechanisms.

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