DETERMINATION OF ELECTRON DENSITY USING THE MULTIPLE RESONANCE PROBE FOR MONITORING- AND DIAGNOSTIC PURPOSES IN DIFFERENT TYPES OF TECHNOLOGICAL PLASMAS

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0. Abstract

The multipole resonance probe is an industrially compatible diagnostic device, based on the concept of active plasma resonance spectroscopy, which determines important plasma parameters, like electron density, temperature and collision frequency. The MRP is developed from theory to prototype in collaboration of AEPT, EST, HFS and TET in the RMBF project PluTO "Plasma and optical technologies".

1. Industry process compatible plasma diagnostics

- Clear and meaningful process data (v, T, n_e)
- No contamination of the process
- Low budget (investment, handling, maintenance)
- Compliance with fab integration
- Calibration free measurements
- Insensitivity against perturbation by the process
- Small footprint in terms of size and access
- Robustness and stability

2. Model for electron density determination

The system response can be characterized in terms of the complex admittance Y_int = jωC_v - C_v is the vacuum capacitance - Each resonance \( \Omega_{2n+1} \) adds a series circuit to the equivalent lumped element circuit

\[ \Omega_{2n+1} = \frac{1}{2 \pi f_0} \left( \frac{1 - i \alpha}{1 + i \alpha} \right) \]

3. Electromagnetic simulation with CST

The holder consists of three dual layer pch including balun and shielding. The inner pch includes the signal layers and the balun to provide the necessary symmetric signal to the probe head (1) and allows signal feeding with an asymmetric coaxial cable (1). The outer pch are used as a shielding and to minimize outside interference. The pch are combined with prepreg layers and the shielding layers are connected by vias.

4. First realization of a prototype

The two hemispheres are mounted on a holder, which also serves as a balancing unit for an unbalanced signal which is fed by a network analyzer and will be replaced by a self engineered signal generator evaluation unit.

5. Measurement unit

The electronic measurement unit generates extremely short electromagnetic pulses having pulse widths below 100 ps, which result in a useful bandwidth of several GHz.

Pulses reflected by the plasma are digitized and transferred to a PC in real-time.

Appropriate algorithms based on discrete Fourier transformation allow determination of the absolute value of the plasma’s complex reflection coefficient and thus an evaluation of the plasma resonance frequency.

6. Measurements in different types of plasmas

- A clear identification of the resonance frequency \( \Omega_{2n+1} \) is possible independent of discharge type and gas mixture

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Fig. 1: Concept of the MRP / active resonance spectroscopy

Fig. 2: MRP equivalent circuit

Fig. 3: Mesh view of the MRP in CST

Fig. 4: Magnitude of the electrical field

Fig. 5: Schematic of the MRP

Fig. 6: First MRP prototype

Fig. 7: Measurement unit

Fig. 8: Block diagram of the measurement unit

Fig. 9: DICP operating frequency 13.56 MHz

Fig. 10: VHF-CCP operating frequency about 81 MHz

Fig. 11: Syrus-Pro (Leybold Optics) DC-APS-Plasma

Fig. 12: \( \Omega_{2n+1} = 488 \text{ MHz} \) (DICP)

Fig. 13: \( \Omega_{2n+1} = 298 \text{ MHz} \) (VHF-CCP)

Fig. 14: \( \Omega_{2n+1} = 355 \text{ MHz} \) (Syrus-Pro)