Novel Plasma Diagnostics: A Driving Force Behind Plasma based Key Enabling Technologies

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***Abstract*—This report provides a brief summary of the outcome of the project proposed for the 2015 IEEE MTT-S Graduate Fellowship Award. The main goal of the project was to design, investigate, and implement an in-situ sensor array for an effective supervision and control of low-pressure plasma processes. Furthermore, the applied multipole resonance probe and its planar and stacked realization were investigated and optimized. Therefore, detailed 3-D electromagnetic field simulations were performed in order to design and investigate the sensors and a passive parallelization concept. Finally, the parallelization concept was confirmed by in-situ measurements in an argon plasma.**

The research activities have resulted in a journal article and several conference papers.

Keywords*—*3-D electromagnetic simulations, feedback control, multipole resonance probe, plasma diagnostics.

I. INTRODUCTION

PLASMA assisted technologies represent one main driving force for the development of innovative products in numerous industries. Plasma processes are crucial and belong to key enabling technologies for future innovations in research and development, especially in the field of plasma assisted deposition, cleaning, and sterilization. Yet, not only technical evolutions but also economical possibilities play a significant role in the application of plasmas. The resulting product quality is directly affected by the plasma dependent process parameters. Hence, plasma diagnostics are indispensable for an effective feedback control loop of these processes. Due to the various challenges, different sensor concepts are optimized and combined within a sensor array. Multiple sensors can observe the density individually at each sensor in order to characterize and supervise the complete reactor.

Within the presented project, a basic parallelization concept and an applicable signal processing are investigated. For an economic development, extensive investigations are performed by 3-D EM field simulations. Hence, numerous plasma variations yield a precise characterization of the individual behavior and the resulting interaction. Additionally, performed measurements are separated into single combined measurements and complete in-situ measurements inside an argon plasma.

II. CONCEPT

The proposed parallelization method was first presented in [1]. It is based on the multipole resonance probe (MRP), which evaluates the resonance behavior of the system ”probe-plasma” [2], [3]. As shown in [4], the input power of a plasma is proportional to the measured resonance frequency. The return loss depends on the collision frequency ν, which is linked to the gas pressure p, as shown in [5]. Consequently, if measured precisely, both effects can be used for the feedback control of the process via input power and gas pressure. Hence, the determined reflection coefficient Γ_{MRP} and the necessary frequency range only depend on the supervised plasma density. Typically, a frequency range between 200 MHz and 3 GHz is taken into account.

By placing multiple sensors inside the plasma reactor, the density can be observed individually at each sensor in order to characterize and supervise the complete reactor or different chambers. To fulfill the demands of an economical solution, our concept allows for a complete evaluation of all applied sensors by a single measurement device. Furthermore, the evaluation can be regarded to be quasi-simultaneous.

The basic parallelization concept is depicted in Fig. 1. It contains a passive signal divider, e.g., a Wilkinson divider, coaxial end launch connectors, two coaxial cables of different lengths, and two MRPs. Due to the reflection behavior of the MRP and the known time delay, the single reflections Γ_{s1} and Γ_{s2} of the two MRPs can be measured in one combined reflection measurement Γ_{p}. Afterwards, they can be separated in time domain. Therefore, the separation depends on the different cable lengths and the resulting time delay, while the maximum number of probes is only limited by the dynamic range of the applied measurement system.

In a first step, a simulation setup is realized in CST Schematic and the resulting reflection coefficient Γ_{p} is evaluated with Matlab. The single elements are considered through their scattering matrices—$[S_{\mathrm{T}}]$, $[S_{\mathrm{W}}]$, $[S_{\mathrm{C1}}]$, $[S_{\mathrm{C2}}]$—and their reflection coefficients—Γ_{s1} and Γ_{s2}. Both are obtained by 3-D electromagnetic simulations with CST Microwave Studio and numerical models for the coaxial cables.

Depending on the plasma process, limits can be defined, in which the process is stable. Hence, an adequate counteraction can be induced in the feedback control loop based on this information, obtained by only one measurement.

III. MEASUREMENTS

Two types of measurements were performed: Single combined measurements—here, the scattering matrices and the reflection coefficients are replaced by measurements—and an in-situ measurement. Both have confirmed the concept, as presented in [6]. Fig. 2 shows the resulting evaluated reflection coefficients $\Gamma_{\mathrm{p1,m}}$ and $\Gamma_{\mathrm{p2,m}}$ for two different combined measurements: (a) The excitation power for both probes is 170 W and (b) the excitation power is 170 W and 190 W.

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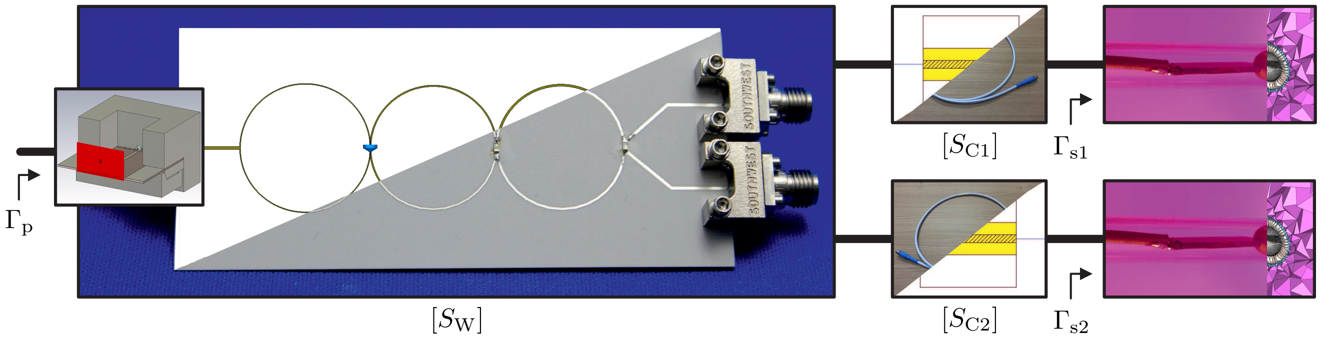
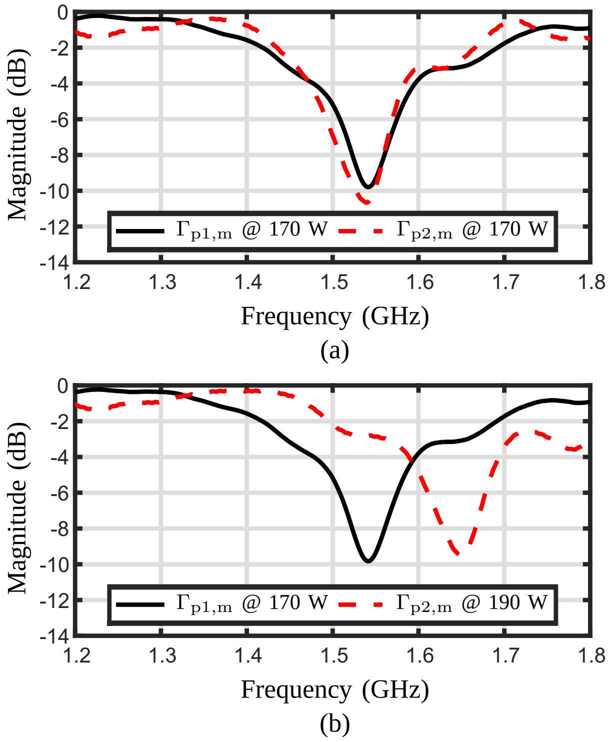


Fig. 1. Depiction of the parallelization concept for the simultaneous determination of the plasma density at two different positions, utilizing the MRP.



(a)

(b)

Fig. 2. Determined reflection coefficients by the parallel setup, utilizing two MRPs for two different setups: (a) Setup with constant excitation powers and (b) setup with varying excitation powers.

As expected, the same resonance frequencies can be observed for setup (a). Both curves are almost equal, which demonstrates the suitability of the realized divider and the applied signal processing. Setup (b) shows a frequency drift to higher frequencies affected by the rising excitation power. Hence, on the one hand a reduction of the excitation power can be derived by this measurement to equal both curves: The drift can be evaluated within a feedback control loop to sustain a homogeneous plasma density. On the other hand, if the curve history is tracked, the stability can be observed effectively.

Together with previously defined process limits, these results and their interrelation with the input power and gas pressure guarantee an effective feedback control.

IV. IMS2015 IMPRESSIONS

IEEE International Microwave Symposium (IMS) 2015 provided me the opportunity to present my research work and to meet experts and other young scientists of many different research fields. It was an excellent preparation for the challenges I have to face in my current and future work and it gave me a solid foundation for my personal and scientific development. I am looking forward to future IMS, to present my research work and to continue discussions to improve my work.

V. NEXT CAREER PLANS

My future plan is to continue as a postdoc and to continue my research in the field of RF sensors and radar systems. Additionally, I would like to sustain and extend my industrial connections, to allow a cross-fertilization between university and industry in emerging research fields.

Finally, I would like to mention that the MTT-S Graduate Fellowship Award has encouraged me to continue my research with even more effort.

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