Recording Spatially Resolved Plasma Parameters in Microwave-driven Plasmas

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Abstract In an almost cubical reactor 90 L in volume which is intended to deposit organic polymers by plasma-enhanced chemical vapor deposition (PECVD), microwave power is coupled into the volume via a quartz window which extends to approximately 1/10 of the sidewall area. Since the plasma is excited locally, plasma parameters like electron temperature and plasma density are expected to exhibit a spatial variation. The compilation of these plasma quantities has been accomplished with a bendable single Langmuir probe. To isolate the tungsten wire against its grounded housing tube, it was coated with polyparylene. After having compared this construction with our Langmuir probe, which has been now in use for more than a decade, we have taken data of more than half the volume of the reactor with argon and have found a definitive radial inhomogenity for all plasma parameters. To investigate whether this conduct can be determined applying optical emission spectroscopy, we improved our spectrometer which had been used for endpoint detection purposes and plasma diagnostics in chlorine-containing ambients where we could detect also a spatial dependence. This behavior is discussed in terms of Lieberman’s global model.

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1 Introduction

Chemical vapor deposition is performed by gaseous species which carry out a chemical reaction on cold surfaces. To that end, at least two different gaseous precursors flow into a reactor where the reaction takes place. In most cases, a carrier gas, often hydrogen, is applied to ensure stable reaction conditions. Therefore, the quality of the coatings can be influenced by the flows of these vapors (or gases) and the resulting pressure, their temperature, and the temperature of the surfaces. Further levers can be installed by application of a plasma (PECVD).

We distinguished between the external parameters, e.g., power output, power input, bias voltage at the powered electrode, and internal parameters, for example, plasma density \(n_p\) and electron temperature \(T_e\). It is these quantities which improve the quality of the coatings. Since they spatially vary across the reactor, they can also cause deviations from the uniformity. These plasma parameters are picked up by diagnostic tools, for example, Langmuir probes, spectrographs, \(V(I)\) probes, etc. However, only with the first method, can a spatial variation of plasma quantities be recorded. To that end, Langmuir probes must invade the plasma, and they must be constructed in a way so that all the positions within the reactor can be reached. In conventional Langmuir probes, a straight wire will eject out of a protecting shield for measurement. Its orientation is on-axis with respect to the vacuum flange. In a cylindrical reactor, this allows measuring the radial dependence of the typical parameters. The electron temperature, recorded with Langmuir probes, represents a quantity which is defined as mean kinetic energy (thermodynamic equilibrium). In particular, the electrons that are responsible for maintaining the plasma itself (temperatures beyond the ionization potential) are not measured but calculated. To measure their density and temperature, optical emission spectroscopy with traces of inert gases is employed (TRG-OES). This method, introduced by COBURN and CHEN as actinometry \([1]\), has evolved into a powerful tool after its refinement by DONNELLY and coworkers \([2]\).

It is the objective of this paper to report on spatially resolved investigations of \(n_p\) and \(T_e\) in the microwave-driven plasmas of argon used to dilute film-building plasmas of parylenes by applying these two methods which have been further improved.

2 Theoretical

2.1 Microwave-driven plasmas

Low-density plasmas generated by the absorption of microwaves are supposed to be spatially homogeneous