PLASMACHEMICAL ACTIVITY OF THE CONTACT REGION OF LOW PRESSURE MICROWAVE PLASMA SOURCE ARRAYS

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Abstract
An arrangement of two parallel sources of a planar microwave plasma source type was used to investigate the properties of the contact plasma region of plasma sources with minimum distance between each other by detailed optical emission experiments. It was shown, that plasma inhomogeneities can be suppressed and therefore the generation of planar microwave plasmas with large extension and good homogeneity in both plane dimensions is possible using multiple longitudinal planar source arrays.

Introduction

Microwave plasmas operated in the mbar pressure range without the support of a static magnetic field exhibit typical electron energies of about 1 eV - 2 eV, maximum electron densities about 10^{11} cm^{-3} and high densities of active neutrals approaching 10^{17} cm^{-3}. This makes them specially useful for plasmachemical processes. The propagation and absorption properties of microwaves in plasmas, however, prevent the generation of homogeneous large volume plasmas. Only the generation of long extended planar plasmas using the bounded propagation of microwaves on waveguiding structures seems to be promising. Some microwave field applicators for this purpose are known. Obviously, a principle of distributed coupling of microwave power is very useful to suppress the influence of strong microwave power absorption on plasma homogeneity. It was realized e.g. by tilted open traveling wave structures [1], slotted antenna structures on rectangular waveguides [2,3] or discrete, tunable coupling element arrays [4]. But the generation of homogeneous planar plasmas with large dimensions in both directions is still a challenging task. Basic problems are multimode electromagnetic field properties leading to plasma instabilities and the mechanical instability of large microwave coupling windows.
A solution of these problems can be attempted with arrays of long extended planar plasma sources, supposed the single plasma sources are homogeneous enough. However, small distances between the single sources will remain which are large enough to be comparable with characteristic plasma decay lengths and diffusion

lengths. Knowledge about the resulting plasma contact regions is therefore necessary. The present paper reports experimental investigations concerning this topic. Plasmas in mixtures of hydrogen, oxygen and hydrocarbons which are relevant for diamond deposition were chosen as object of investigation.

Experimental

The experiments were performed with an arrangement of two parallel sources of a planar microwave plasma source type which is based on a principle of distributed and tunable coupling of microwave power in conjunction with the use of additional smoothing interface waveguides which support in plane homogeneous plasma excitation. More detailed information about the excitation principle and resulting plasma properties type are given in [4,5,6]. Single sources of this type were succesfully extended to one meter lenght and arranged in certain distances to generate very large area plasmas for high rate plasma cleaning with moderate homogeneity [4]. The here used experimental device was designed to test source arrays with minimum distance between the single sources.

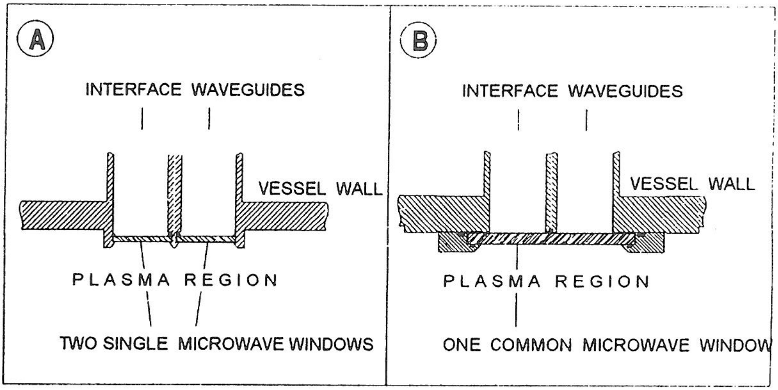

Fig. 1: Schematic cross section through the microwave coupling region of the investigated double plasma source. A: the mechanically favorable setup with two separate microwave coupling windows and a metallic brigde between them. B: the setup with a common microwave window.

The whole microwave applicator consists of three rectangular waveguides (see Fig. 2). Their dimension are close to WR 430 standard waveguides. That means, they are monomode H_{10}-waveguides for the used 2.45 GHz industrial frequency band. The here chosen double T-shape arrangement has then the advantange of an unambiguous configuration of the exciting electromagnetic field since the microwave windows are part of the narrow side of the interface waveguides walls which have a simple wall current distribution with constant in plane polarization. Following this, for the plasma a similar electromagnetic field configuration can be expected too. This is a more physical advantage. The advantage from the engineering point of view is that the device is very compact and stable against bending. Therefore, very long quartz microwave windows can be used without the risk of breaking. This mechanical stability is the precondition for obtaining large plasma areas by multiple arrangements parallel sources. A disadvantage of this kind of source arrangement is the remaining bridge between the single windows (see Fig. 1A). In the present case it was metallic and a few mm wide. It could be expected that this brigde would influence the plasma in its surrounding. First, its width is not small compared with the experimentally observed decay length of electron density [3] and electron temperature [6] in the microwave penetration direction normal to the microwave windows which are both somewhat less than 10 mm under typical plasma conditions. Second, its surface properties differ markedly from those of the quartz microwave windows.

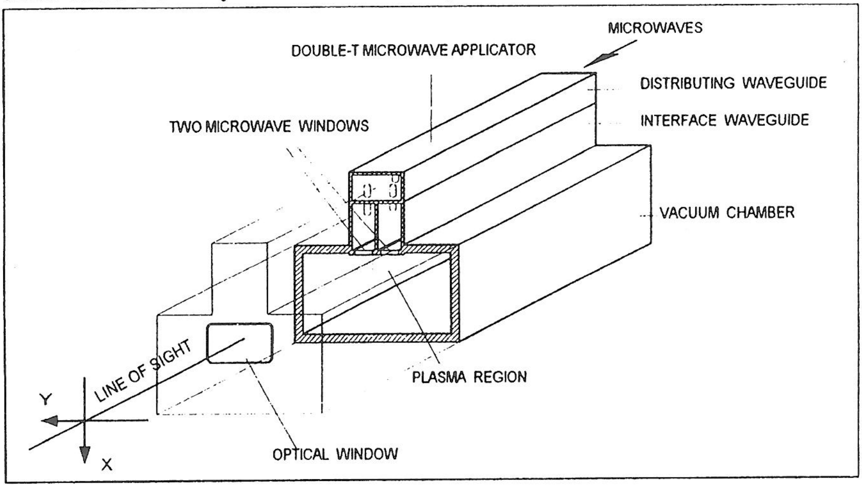

Fig. 2: Scheme of the complete discharge vessel with the double plasma source array on top. Also the configuration of the spatially resolved optical emission measurements is shown

The long extension of the single sources - in the present case the active plasma region was about 25 cm long - leads to high spectral flux densities for end on optical emission measurements. Therefore, spatially resolved measurements can be performed with high spectral and spatial resolution and directly refer to internal plasma property distributions (Fig. 2). This was used to study the properties of the contact plasma region between the two windows. For the measurements an optical multichannel analyzer (OMA-VISION) was used which was equipped with a 0.5 m grating spectrograph and a Peltier cooled, UV intensified, highly sensitive CCD matrix detector. This setup allowed molecular band analysis for all relevant species. Also excitation temperatures were derived from argon and hydrogen line distributions.
For the measurements gas mixtures of hydrogen, oxygen and methane and plasma conditions typical for diamond thin film deposition in plasmas were used since it is known that problems of plasma homogeneity and deposition area enlargement are still of considerable interest in this field of research.

Results and Discussion

In Fig. 3 results of actinometric measurements along a line just below the microwave windows in the setup of Fig. 1A are given. Obviously, there is a strong influence of the contact region on the distribution of active neutrals. In all cases it's spatial range

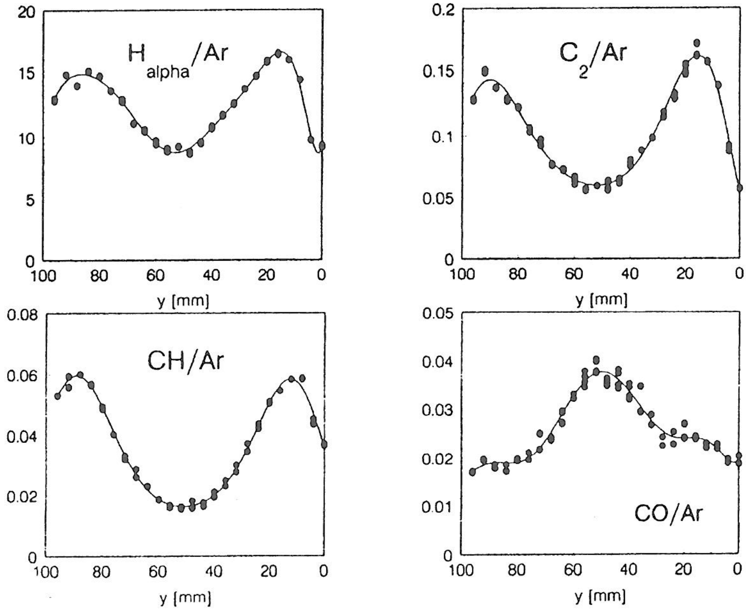

Fig. 3: Results of optical actinometry along a line 8mm below and parallel to the microwave windows in the plasma coupling configuration of Fig. 1A (20 sccm H_2, 25 sccm O_2, 40 sccm CH_4 and 7 sccm Ar, total pressure 1.5 mbar)

is nearly comparable to the width of the microwave windows. This result is rather surprising, since earlier investigations concerning atomic hydrogen distribution in the microwave penetration direction, i.e. the x-direction in Fig. 2 revealed a decay lenght of some centimeter [7]. Therefore, diffusion of active neutrals generated in the plasma region just below the windows should be strong enough to fill the small gap at the brigdes location.

The reason for the strong effect must be located in the properties of the contact region itself. One possibility is the inhomogeneity of the microwave field distribution at this place. However, this is not very likely since the microwave penetration depth and the brigde width are comparable. Indeed, different investigations concerning optical activation energy distribution along the same line as in Fig. 3 indicated only weak variations in the contact region (see Fig. 4). There is evidence that under the here relevant plasma conditions the activation energy determined from argon emission line distributions is comparable to the mean electron energy determined by probe measurements [6]. This energy is strongly correlated to the electromagnetic field strength. Therefore, it can be assumed that only small field variations exist in the

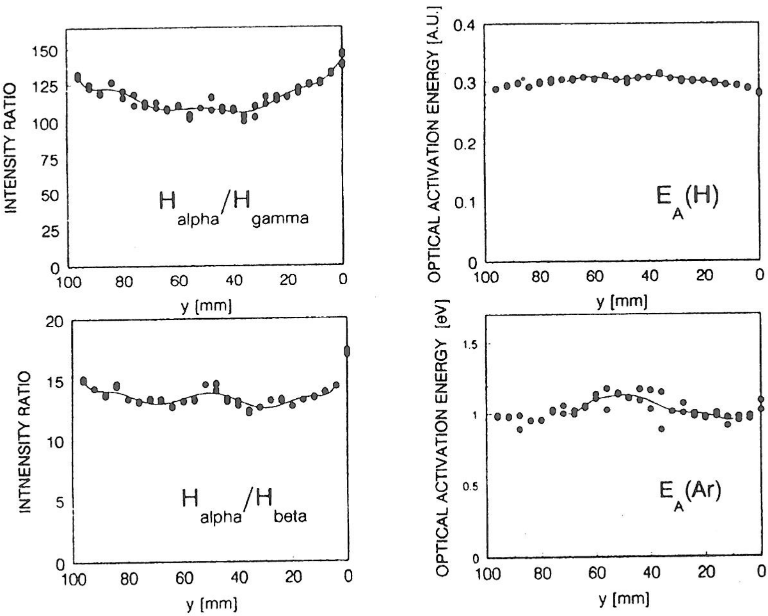

Fig. 4: Hydrogen line ratios and optical activation energy computation results for the same configuration and plasma conditions given in Fig. 3 .

contact region. The results given in Fig. 4 also support the applicability of actinometry, i.e. it can be assumed that Fig. 3 represents real density variations. The density variations are very similar in sign and tendency for atomic hydrogen, CH and C_2. For CO it has an opposite sign. This general behaviour can be explained in terms of the dominant neutral reaction scheme for these kinds of plasmas as it was discussed in [8] and [9]. A simplified version of these schemes is given in Fig. 5. Obviously, atomic hydrogen plays a dominant role for the reactions of C_xH_y-species. A reduction of it's concentration will reduce the concentration of both CH as well as C_2. Simultaneously, this can support the CO generation. Following the discussions above a reduction of the volume processes of atomic hydrogen generation is not very likely. More propable are enhanced surface losses. It is well known that surface recombination of atomic hydrogen is very effective on metal surfaces and less effective on quartz.

Conclusions

Following these experiments, the electromagnetic field configuration seems to be less effective for control of the contact region plasma properties than surface properties. To test this, in a further experiment the small aluminum brigde between the two

adjacent quartz microwave windows was removed (see Fig. 1B). Indeed, this resulted in a less disturbed contact region. For the optical activation energy the results were very similar to Fig. 4. The actinometric measurements revealed a reduced, but not completely suppressed influence of the contact region on the distribution of active neutrals. The latter is considered to be due to enhanced electromagnetic interferences between the single plasma sources. Electromagnetic tuning of the device was much more difficult than in the former configuration. A combination of real single line plasma sources instead of the double T-configuration should be more useful.
Summarizing, the experiments have shown that contact region plasma inhomogeneities can be suppressed and hence planar micorwave plasmas with large extension and good homogeneity in both plane dimensions can be generated using multiple longitudinal planar source arrays.

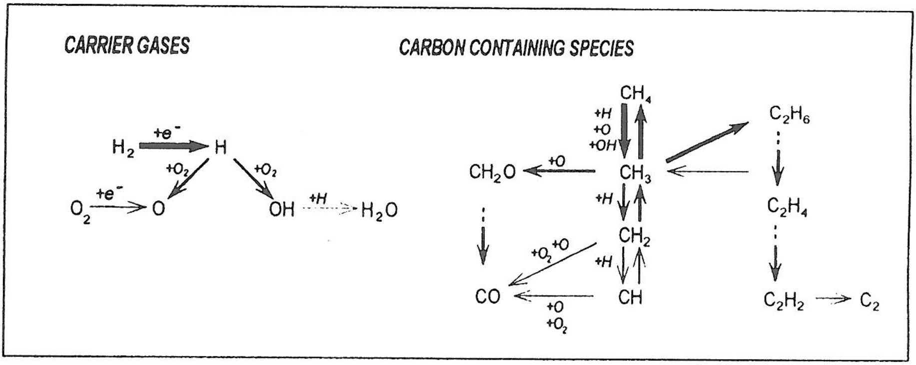

Fig. 5: Simplified scheme of of basic neutral particle reactions in the plasma (after [8,9], modified)

References

1. R.G. Bosisio, M.R. Wertheimer and C.F. Weissfloch, J. Phys. E: Sci. Instrum., 6, 1973, p. 628
2. T. Yasui, J. Kitayama, H. Tahara and T. Yoshikawa, Proc. ICRP-2/SPP-11, Yokohama, 1994, p. 367
3. J. Marec, pers. commun.
4. A. Ohl, in C.M. Ferreira (ed.), Microwave Discharges: Fundamentals and Applications, NATO ASI Series, Vol. B 302,Plenum, New York, 1993, p. 205
5. J. Röpcke and A. Ohl, Contr. Plasma Phys., 31 (1991) p. 669
6. J. Röpcke and A. Ohl, Contr. Plasma Phys., 34 (1994) p. 575
7. A. Ohl and J. Röpcke, *Diamond and Related Materials, 1*(1992), p. 243
8. C. Benndorf, P. Jöris and R. Kröger, Pure and Applied Chemistry, *66* (1994), 1195.
9. T. Lang, J. Laimer and H. Störi, Diamond and Related Materials, 3 , 1994, p. 470