N_2 – Ar Microwave Plasma Torch

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The development of microwave based plasma sources operating at atmospheric pressure is important for various industrial and scientific applications. Efficient applications of such sources depend on the ability to control the plasma properties. In the present work, an investigation of a surface wave (SW) driven N_2-Ar microwave plasma torch operating at atmospheric pressure is presented. The main plasma and wave characteristics are obtained in the framework of a self-consistent 2D model describing the spatial structure of this plasma source, which includes: Maxwell's equations; the dispersion equation of the surface mode; the rate balance equations for $N_2(X^1\Sigma_g^+, v)$, $N_2(A^3\Sigma_u^+, B^3\Pi_g, C^3\Pi_u)$, $N_2(a'^1\Sigma_u^-, a^1\Pi_g, w^1\Delta u, a''^1\Sigma_u^+)$, $Ar(3p^5 4s)$, $Ar(3p^5 4p)$, $N^+, N_2^+, N_3^+, N_4^+, Ar^+, Ar_2^+$, electrons, and $N(^4S)$ and $N(^2P, {}^2D)$; the gas thermal balance equation; the equation of mass conservation for the fluid.

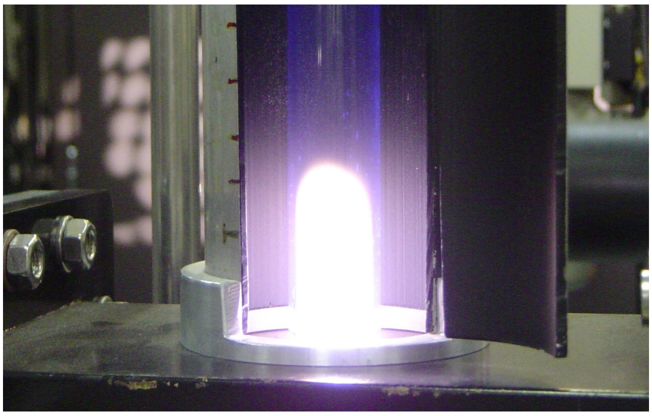

Fig. 1. Plasma Torch

The theoretical results have been compared to experiment. The SW-produced microwave (2.45 GHz) plasma torch (Fig.1) was created using a conventional surfaguide-based setup. A spectroscopic imaging system was used to measure 2D(r, z) profiles of emission intensities and line profiles (Fig.2.).

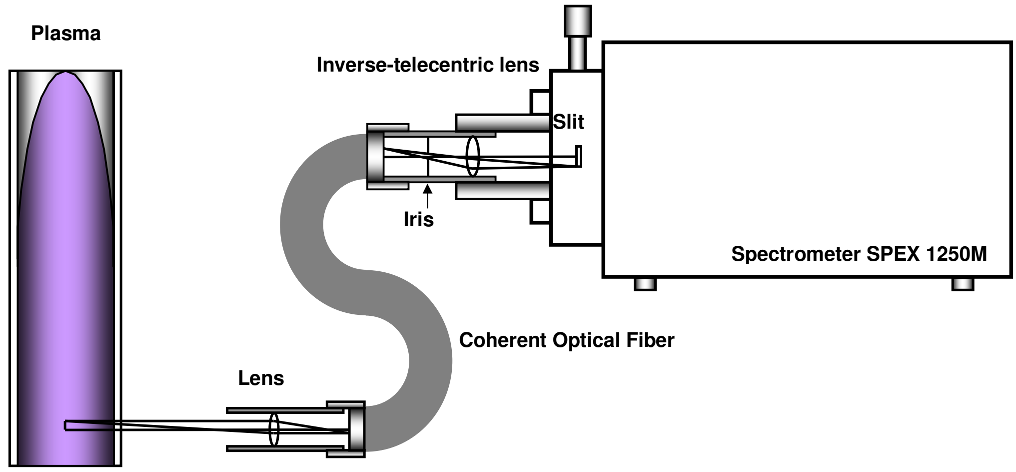

Fig. 2. 2D Imaging Optical System.

Abel inversion was applied to derive the radial profiles from side-on measurements. A small amount of H_2 was premixed with the N_2-Ar mixture before injection into the plasma torch. The H_β line profiles (Fig. 3) have been measured (Lorentzian components) to determine the electron density (Fig.4a).

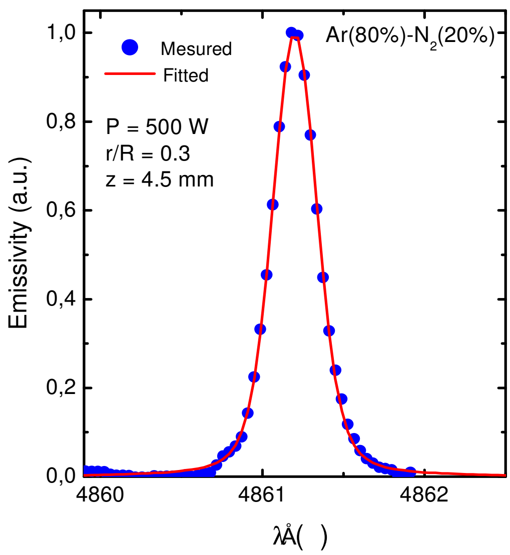

Fig. 3. Emission profile of the H_β line fitted with a Voigt profile.

The experimental 2D map of the electron density (Fig.4a) agrees well with the theoretical predictions (Fig.4b). The central electron density, close to the axis (up to *r/a* = 0.4), varies from about 2×10^{13} cm^{-3} to 10^{13} cm^{-3} up to 2 cm axial distance from the launcher.

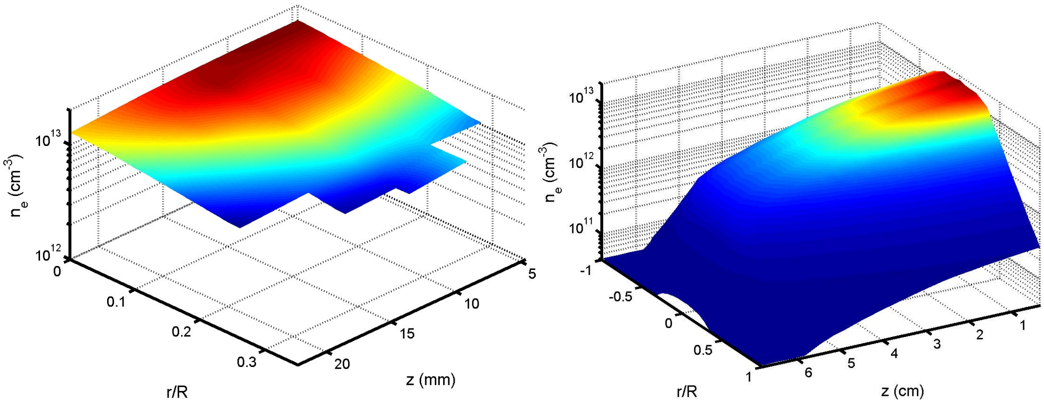

Fig. 4. 2D map of the electron density: (a) experiment; (b) theory.

As observed in Fig. 5, the theoretical gas temperature T_g decreases non-linearly towards the plasma column end, scaling as the non-uniform wave power absorption. The gas temperature radial gradient decreases towards the end of the generated torch. The axial gas temperature variations at the axis (*r/a* = 0) in the discharge zone are smooth.

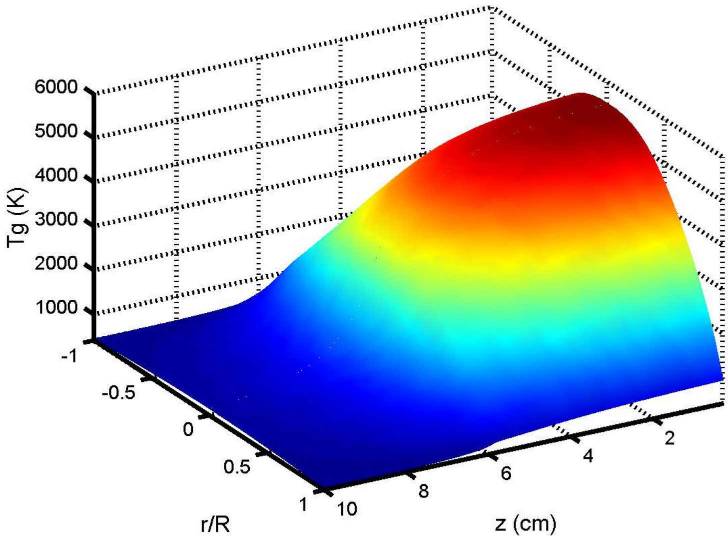

Fig. 5. 2D map of gas temperature.

The spatial variations of the populations of $N_2(A^3\Sigma_u^+)$ metastables and $N(^4S)$ atoms are depicted in Figures 6a,b. As seen, close to the launcher the $N_2(A^3\Sigma_u^+)$ relative population reaches levels higher than 4×10^{-3}. The axial decrease of the electron density and of *E/N* causes the decrease in $N_2(A^3\Sigma_u^+)$ and N(^{4}S) relative populations. Axial changes of the dissociation degree in the discharge zone are smooth but they are followed by a sharp drop of nearly 3 orders of magnitude in the post-discharge zone. The maximum dissociation degree (higher than 10^{-2}) is observed in the discharge zone close to the launcher

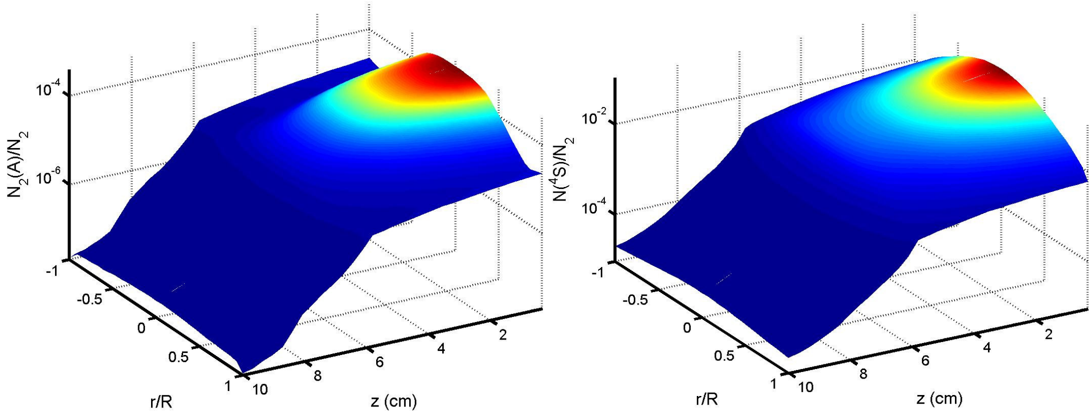

Fig. 6. 2D map of $N_2(A^3\Sigma_u^+)$ metastable (a) and N(^{4}S) ground state atom (b) densities.

Conclusions

An experimental and theoretical study of the spatial structure of a microwave (2.45 GHz) plasma torch driven by a surface wave in a N_2-Ar mixture has been performed. Spatially resolved emission spectroscopy techniques have been used. The experimental results have been analyzed in terms of a 2D theoretical model based on a self-consistent treatment of particles kinetics, gas dynamics and wave electrodynamics. This model determines the two-dimensional discharge structure, i.e., the radial and axial variations of the main plasma quantities. Strong correlation is shown to exist between the density distributions of plasma electrons and electronically excited states of molecules and atoms. High level of populations of molecular nitrogen metastables is predicted. A high degree of nitrogen dissociation, up to 5 %, is achieved. Along the main part of the plasma column there is only a small variation of the gas temperature, which remains close to 5,000 K at the plasma axis. This is followed by a sharp drop to about 400 K in the post-discharge zone (z > 6 cm). These results show that large radial gradients of the gas temperature do exist (~ 4,000 K difference between the axial and the wall temperatures). The measured 2D spatial profiles of the electron and positive ion densities are in good agreement with the theoretical model.

References

[1] C. M. Ferreira, E. Tatarova, J. Henriques, and F.M. Dias, J. Phys. D: Appl. Phys. 42, 194016 (2009)