Microwave driven air - water plasmas

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An experimental and theoretical investigation of a surface wave (2.45 GHz) driven atmospheric plasma source in air with an admixture (1-10 %) of water vapor is presented. The species of interest are detected by means of mass, FTIR and optical emission spectroscopy. The experimental results are analyzed in terms of a theoretical model based on a self-consistent treatment of particle kinetics, gas dynamics, and wave electrodynamics. Applications of this plasma source for biomass treatment, production of hydrogen and biomedical purposes are presented and discussed.

There exists growing interest in the potential applications of microwave plasmas at atmospheric pressure since such plasmas may enable lower facility and process costs for a variety of plasma processing and manufacturing techniques currently performed under vacuum conditions. Moreover, high-density plasma sources provide suitable conditions to dissociate molecules in abatement systems, to burn out chemical and biological warfare agents, and to atomize and synthesize materials in carbon nanostructures forming systems. In this respect, waveguide-based atmospheric plasma sources driven by surface waves (SWs) are an attractive alternative to classical sources, since they are compact, electrodeless, economical, and easy to operate.

In the present work we investigate both theoretically and experimentally a microwave driven air-water plasma as a source of active species of practical interest such as $O(^3P)$ ground state atoms, UV radiation, plasma-generated NO(X), etc. A theoretical model based on a self-consistent treatment of particle kinetics, gas dynamics, gas thermal balance, and wave electrodynamics is used to analyze the performance of this plasma source. The model includes coupled equations for the plasma bulk describing the kinetics of free electrons and of excited electronic states of molecules and atoms [$N_2(A)$, $N_2(B)$, $N_2(a')$, $N_2(a)$, $N_2(C)$, $N_2(a'')$, $N(^2D)$, $N(^2P)$, $O_2(a)$, $O_2(b)$, $O(^1D)$, $O(^1S)$], the chemical kinetics involving neutral molecules and ground state atoms [N_2, O_2, N, O, O_3, NO, N_2O, NO_2, NO_3, N_2O_5, H_2O, H, H_2, OH, HO_2, H_2O_2, NH_3, NH_2, NH, HNO, HNO_2, HNO_3], the kinetics of positive [N_2^+, N_4^+, O^+, O_2^+, O_4^+, NO^+, NO_2^+, N_2O^+, H_2O^+, H_3O^+, H_2^+, H_3^+, HN_2^+, NH_3^+, NH_4^+] and negative [$O^-, O_2^-, O_3^-, H^-, OH^-, NO_2^-, NO_3^-$] ions, the gas thermal balance and the equation of mass conservation for the fluid as a whole. The wave dispersion and power balance equations are further incorporated into the system of equations. This model describes both the SW driven discharge zone and its flowing afterglow, as integral parts of the plasma source considered. The predicted plasma-generated NO(X), $O(^3P)$ and singlet delta oxygen $O_2(a^1\Delta)$ concentrations, and the intensities of atomic oxygen lines and NO(γ) band radiation along the source are presented and discussed as a function of two external parameters, *viz.*, microwave power and water vapor percentage in the gas mixture. The relative concentrations of NO(X), HNO_2, NO_2 species in the exhaust gas stream of the source have been measured by mass analysis and Fourier transform infrared spectrometry and compared with the model predictions. Emission spectroscopy has been used to detect the plasma spectra emitted in the 250 – 850 nm range. The oxygen atomic lines at 777.4 nm, 844 nm and 630 nm, corresponding to the transitions $O(3p^5P \rightarrow 3s^5S)$, $O(3p^3P \rightarrow 3s^3S)$, and $O(2p^1D \rightarrow 2p^3P)$, respectively, and the NO(γ) band radiation in the range 230-260 nm (0-1, 0-2 and 0-3 vibrational transitions), corresponding to the electronic transition $NO(A^2\Sigma^+) \rightarrow NO(X^2\Pi) + h\nu$, have been detected. The rotational spectrum of the $OH\left(A^2\Sigma^+, v=0 \rightarrow X^2\Pi j, v=0\right)$ transition in the 306–315 nm range has been measured for the purpose of gas temperature determination.

The plasma source considered has been applied for the treatment of biomass and the production of hydrogen by plasma decomposition of alcohols. Results of the investigation carried out in these areas of application are presented. Potential biomedical applications of this source such as NO - therapy and plasma decontamination are also discussed.

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References

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