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COMPARISON OF PLASMAS GENERATED FROM N_2-O_2 AND NO BY AN Ar ION JET IN LOW PRESSURE REACTOR

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Abstract. The expansion of a supersonic Ar^+ ion jet in a low pressure (0.2 Torr) reactor filled with N_2-O_2 and NO, respectively, has been investigated by means of hydrodynamic modelling. The formation of different species through the molecular kinetics triggered by the collision of Ar^+ ions with N_2 and O_2 molecules, and NO molecules, respectively, in the three-dimensional reactor has been studied.

1. INTRODUCTION

Low pressure plasmas that contain N and O atoms, and excited NO molecules have a wide range of applications, such as metal surface cleaning, medical sterilization, etching and grafting of polymers, silicon oxidation, thin film synthesis, to increase surface adhesion, and textile material modification. In numerous cases instead of the active discharge region the remote post-discharge is used, where the density of charge species is negligible. In N_2 or N_2-O_2 discharges usually low N_2 dissociation degree (N_2 being less dissociated than the O_2 Kutasi et al. (2008)) can be achieved, e.g. in low pressure N_2-O_2 surface wave discharges depending on frequency and discharge tube radius the dissociation degree can be a few percent Pintassilgo et al. (2005), which further decreases in the afterglow due to the N atoms recombination. However, in the expanding thermal plasma (ETP) presented by van Helden et al. 2009 higher N_2 dissociation degrees may be achieved outside the active discharge region. The ETP consist of a high-pressure thermal plasma, here namely a dc cascaded Ar arc discharge, and a low-pressure process chamber, where the molecular gases to be dissociated are injected. The large pressure difference between the cascaded arc source (40 kPa) and the process chamber (typically 20-100 Pa) causes a supersonic expansion of the plasma from the nozzle of the cascaded arc into the chamber. The high velocity Ar ions so introduced into the vessel can strongly dissociate the N_2-O_2 molecules. Similarly the Ar^+ can contribute to the dissociation of NO molecules, therefore the Ar-NO ETP's can be used for the removal of the toxic NO. van Helden et al. (2009) have conducted mass spectrometry measurements on Ar-N_2-O_2 and Ar-NO ETP. The mass spectra were measured by sampling the gas through a controlled all-metal regulating valve con-

nected to the reactor through a metal tube. With this method the absolute concentration of the stable gas species N_2, O_2 and NO were determined. Ziljmans et al. (2008) have developed a model in order to reveal the creation mechanisms of the stable molecules detected. The aim of the present work is to give a detailed description of a low pressure reactor, where the plasma is sustained in N_2-O_2 and NO, respectively, by the externally generated Ar ion jet. Therefore, we determine the expansion of the plasma in the reactor, as well as the spatial distribution of the density of different species created in the reactor, due to the gas phase and surface processes.

2. SYSTEM SET-UP

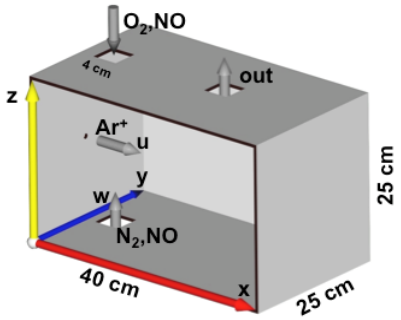

Figure 1: System configuration.

The system investigated in this work has a similar structure as that of van Helden et al. (2009). Here the plasma reactor is a parallelepipedic stainless steel chamber with the dimensions and structure shown in Fig. 1. The $4\times4mm^2$ square inlet, where the high velocity – 2000 m s^{-1} according to Engeln et al. (2001) – Ar^+ ions from the dc cascaded arc source enter the reactor is located in the middle on the left plate. Two more inlets of $4\times4cm^2$, which serve as inlets for the molecular gases, are located on the bottom and top plates, respectively, at about 2 cm from the left plate.

3. HYDRODYNAMIC MODEL

The three-dimensional hydrodynamic model developed by us is composed of: (i) the total mass conservation, (ii) the continuity equations for the different species, (iii) the total momentum conservation equation, and (iv) the total energy conservation equation. A detailed description of the model can be found in Kutasi (2010), together with a list of gas phase reactions for neutral species taken into account in the model. The neutral species kinetics in the reactor starts up with the creation of the active atoms, namely N and O-atoms. The N and O-atoms in the reactor can be created through the electron dissociative recombination of N_2^+, O_2^+ and NO^+ created in the charge transfer reaction between the molecules and Ar^+. The electron dissociative recombination of molecular ions is very fast, therefore we assume that the collision of Ar^+ ions with N_2, O_2 and NO result in the dissociation of the molecules (i.e. the molecular dissociation occurs in one step e.g. $Ar^+ + N_2 \rightarrow [Ar + N_2^+, N_2^+ + e]$ (N + N), producing ground state N(4S) and O(3P) atoms.

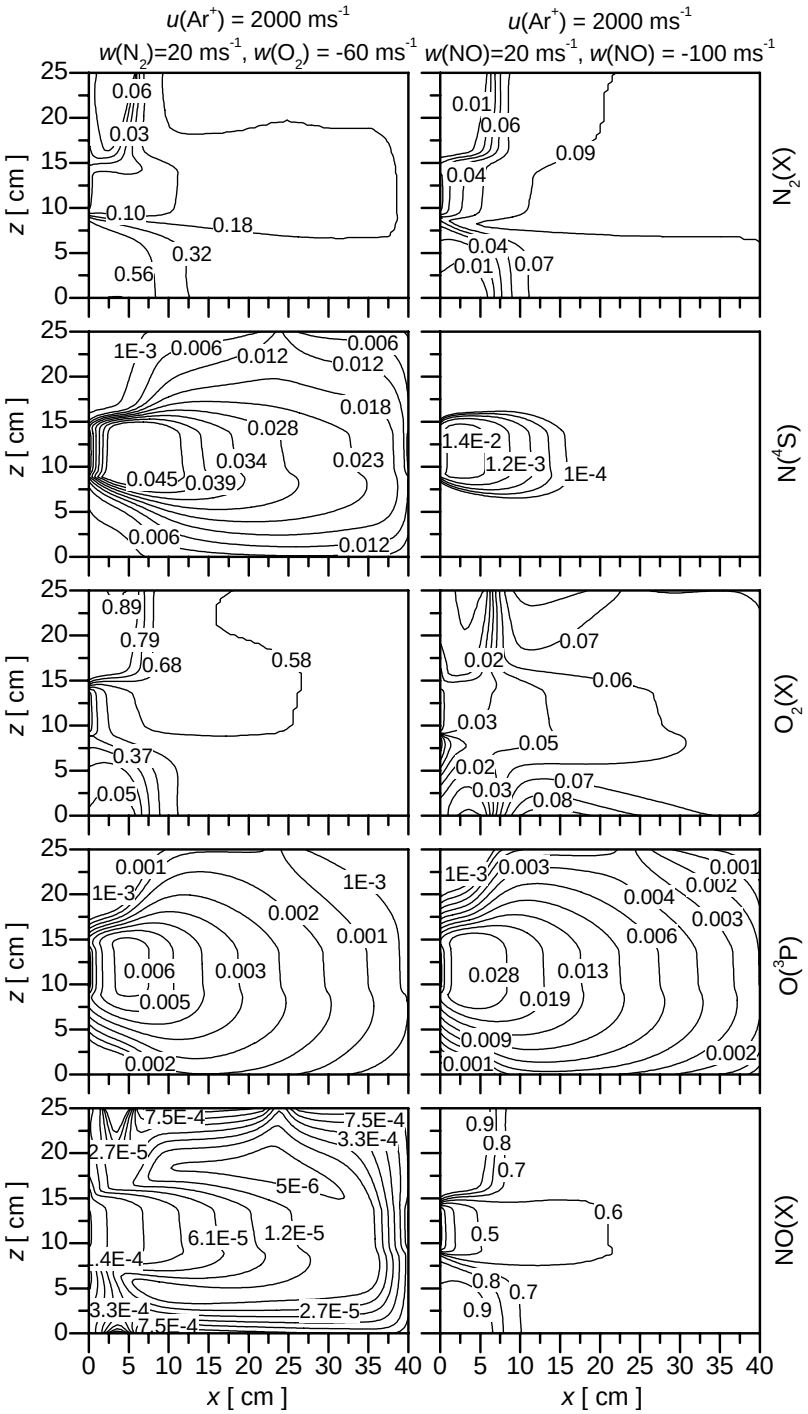

Figure 2: Species densities in case of reactors filled with N2 and O2 (first column), and NO (second column), respectively.

Besides the gas phase reactions important role are also played by the surface processes, such as surface recombination of N and O atoms resulting in the creation of N_2, O_2 and NO molecules, respectively. A detailed description of the surface processes can be found in Kutasi and Loureiro (2007) and Kutasi (2010).

4. PRELIMINARY RESULTS

Here we present the densities of most important species present in the reactor for two different cases (i) N_2 and O_2 are injected into reactor with $20ms^{-1}$ and $-60ms^{-1}$, respectively, and (ii) NO is injected through the two inlets with the same flow rate as the N_2 and O_2 in case (i). Fig. 2 shows that the dissociation of the molecules occur within 5-10 cm around the inlet, while in the other part of the reactor a homogeneous density distribution of the molecules is built up. In case (i) as the O_2 flow is three times higher than the N_2 inlet flow, its density becomes also higher accordingly. Since the O_2 is less efficiently dissociated than N_2 the N-atoms density in the reactor is higher than that of O-atoms. Both atomic densities decrease towards the walls due to the gas phase and surface recombination. In the surface recombination process N_2, O_2 and NO molecules are created. The surface production of NO molecules is well illustrated by its density distribution, which shows maximum densities near the walls. Changing the reactor feeding gases from N_2 and O_2 to NO, we can observe the variation of the plasma composition due to the different chemical kinetics of the system. Here the N-atoms created through the dissociation of NO are lost very fast in the $N+NO \rightarrow N_2+O$ process. Due to this here no N-atoms are present in most part of the reactor, while the O-atoms density becomes higher. The calculations show that the destruction of NO is not very efficient at the gas flows applied here, in order to achieve a much higher dissociation degree lower NO gas flow rates should be applied.

Acknowledgements

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