Experimental and theoretical characterization of the cascaded arc thermal plasma source in argon and hydrogen

EXPERIMENTAL AND THEORETICAL CHARACTERIZATION OF THE CASCADED ARC THERMAL PLASMA SOURCE IN ARGON AND HYDROGEN

Zhou Qing[1], E.B. Kulumbaev[2], V.F. Semenov[2], V.M. Lelevkin[2], D.K. Otorbaev[1,2], M.C.M. van de Sanden[1] and D.C. Schram[1]

[1]Department of Physics, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands.

[2]Kyrgyzstan Academy of Sciences, Chui prospect 265 A, Bishkek, 720071, Kyrgyzstan.

Introduction

The cascaded arc is an example of a wall stabilized thermal plasma and can be operated for a wide range of pressures and currents. As a simple and stable plasma source it has already been widely used both in fundamental research of non-equilibrium and non-ideal effects in the plasma, and in applications, such as a technique for surface modification, as a light source, as a source of ionizing particle (cf. e.g. [1]). To obtain a thorough knowledge of the cascaded arc, to optimize the design of the arc setup and to find new efficient regimes of arc operation, further experimental and theoretical investigations are required.

Experiment

The cascaded arc used consist of three cathodes, an anode plate with a nozzle, and several copper cascaded plates. The total length of the arc was either 30 or 60 mm, the diameter of the arc channel was 4 mm. The efficiency, the electric field strength, and the pressure gradients in the arc have been determined as a function of axial position in the arc and external parameters (arc current, gas flow rate, length of the arc). The local efficiency of the arc has been calculated by measurements of the cooling water temperature, the water flow to the particular plate and the potential of the plate. A special electric potential measuring device which consist of 12 channels is made for the measurements. The temperature of the cooling water and the pressure in the arc have been measured by calibrated temperature and pressure sensors, mounted to the cathode chamber and to the anode plate [2]. The results show, that efficiency and pressure gradients of the arc in hydrogen are lower, than the same characteristics of the arc in argon, whereas the electric field strength is higher. From the power balance measurements an average over the channel cross section electron temperature for the argon arc has been determined. The same procedure for the hydrogen arc is impossible due to effect of arc constriction (narrowing of the arc channel). The dissociation of the hydrogen molecules in the small flow range ($Q \leq 100$ scc/s) is almost complete, whereas in the large flow range ($Q \geq 100$ scc/s) it drops monotonically.

Modelling

The axial flow in a cylindrical channel of wall stabilized arc plasma gas flow is considered. The MHD conservation equations of energy and momentum, equation of continuity, the

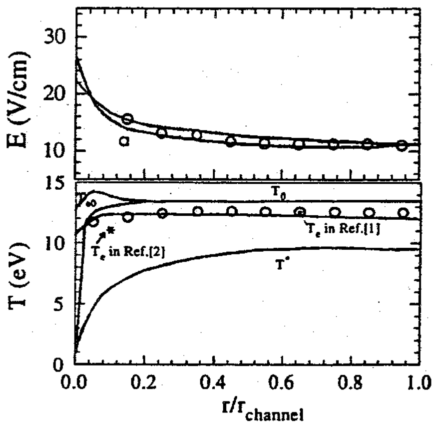
Maxwell equations and Ohm's law are used:

$$c\nabla(\rho\overline{\mathbf{V}}) = 0, \quad \rho(\overline{\mathbf{V}}\cdot\nabla)\overline{\mathbf{V}} = -\nabla P + \bar{\mathbf{j}}\times\overline{\mathbf{B}} + \nabla\tau_{ik},$$
$$\rho c_P(\overline{\mathbf{V}}\cdot\nabla)T = \nabla(\lambda\cdot T) + \bar{\mathbf{j}}\cdot\overline{\mathbf{E}} - \varphi, \quad \nabla\times\overline{\mathbf{E}} = 0, \quad \nabla\times\overline{\mathbf{H}} = \bar{\mathbf{j}},$$

The system of equations have been solved by a method described in detail elsewhere [3]. The main system of equations is extended by the equation of state, by the dependencies of the transport coefficients on the temperature and pressure, and boundary conditions. It is shown, that the characteristics of the thermal arc in hydrogen differs significantly from that in argon for similar arc settings. In contrast to the argon arc, near the axis of the hydrogen arc a sharp radial temperature gradient occurs: a strongly constricted high-temperature axial channel is realized. Because of the high thermal conductivity of H_2 fast gas cooling takes place. Near the channel walls the hydrogen plasma ionization and dissociation degrees are much lower in comparison with the corresponding axial values; the only flow of neutral molecular hydrogen occur. In the hydrogen arc the conductive heat flux on the walls of the channel exceeds the same value in the argon arc by more than order of magnitude [4].

Discussion

The experimental data on the efficiency of the arc, on pressure gradients, electric fiels strength and electron temperature were in a good agreement with the results of numerical modelling of the hydrogen and argon cascaded arc plasma. As an example Fig. 1 illustrate the axial distribution of an electric field strength and electron temperature in the argon arc, where the points are the experimental data, and the curves are the results of numerical calculations. Good agreement between theoretical results and experimental data shows that the discussed model could be used for a quantitative description of the parameters of thermal arc plasma.



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