

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

Citation for published version (APA):

Qing, Z., Kulumbaev, E. B., Semenov, V. F., Lelevkin, V. M., Otorbaev, D. K., Sanden, van de, M. C. M., & Schram, D. C. (1994). Experimental and theoretical characterization of the cascaded arc thermal plasma source in argon and hydrogen. In *ESCAMPIG 94 : European Sectional Conference on Atomic and Molecular Physics of Ionized Gases, 12th, Noordwijkerhout, The Netherlands, August 23-26, 1994* (pp. 428-429). (Europhysics conference abstracts; Vol. 18E). European Physical Society (EPS).

Document status and date:

Published: 01/01/1994

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

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

Zhou Qing¹, E.B. Kulumbaev², V.F. Semenov², V.M. Lelevkin², D.K. Otorbaev^{1,2},
M.C.M. van de Sanden¹ and D.C. Schram¹

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

²Kyrgyzstan 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

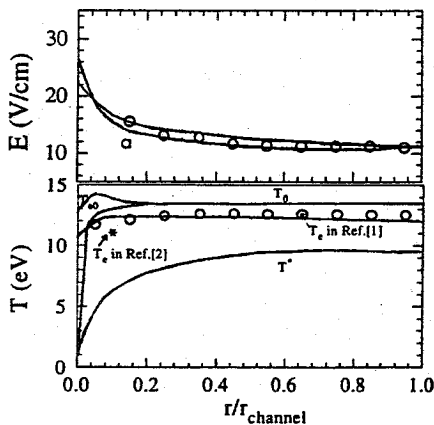
Maxwell equations and Ohm's law are used:

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

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 fields 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.



Acknowledgements. This work was partially supported under grant No. 713- 224 of NWO (Netherlands Scientific Society).

References

1. G.M.W. Kroesen, C.J. Timmermans and D.C. Schram, *Pure & Appl. Chem.* **60**, 795 (1988).
2. Z. Qing, M.J. de Graaf, M.C.M. van de Sanden, D.K. Otorbaev and D.C. Schram, *Rev. Sci. Instrum.* **65**, 1469 (1994).
3. V.M. Lelevkin, D.K. Otorbaev and D.C. Schram, *Physics of Non-Equilibrium Plasmas* (Elsevier, Amsterdam, 1992).
4. E.B. Kulumbaev, V.F. Semenov, V.M. Lelevkin, Annual Report of NWO-CIS-NL Research Program No.713-224, 1994.