Gas – Surface Interaction in Hollow Cathode Glow Discharge

Philipp J. Polikarpov*, Alexey P. Polikarpov*, Sergei F. Borisov*, Sergey P. Nikulin[†], Peter V. Tretnikov[†] and Denis V. Zubritsky[†]

**Physics Department, Ural State University, Ekaterinburg, 620083, Russia*
[†]Charged Particle Beam Laboratory, Institute of Electrophysics, Ekaterinburg, 620016, Russia

Abstract. Energy exchange between tungsten wire sample and low temperature plasma has been investigated in dependence on gas nature, discharge current and surface temperature. Experimental approach is based on low-pressure stationary Knudsen method adapted for plasma conditions that are obtained with the use of hollow cathode glow discharge. The data for air, argon and carbon dioxide are presented in the terms of power input and variable parameters of experiment.

Keywords: Gas-Surface Interaction**,** Heat Transfer, Hollow Cathode Glow Discharge.
PACS: 44.35.+c

INTRODUCTION

Gas-surface interaction problem takes on special significance in the case of plasma conditions. In particular, heat exchange in the system with partially ionized gas is complicated due to recombination process and heterogeneous catalysis. These processes determine temperature balance of space vehicles during their re-entry in planet atmosphere [1] and play an essential role in other applied problems.

To estimate contribution of different factors in heat exchange between the gas and the surface an experimental approach that realizes hot-wire Knudsen method [2] in hollow cathode glow discharge conditions has been developed.

Due to some advantages that provide energy accommodation measurements with sufficient microscopic information Knudsen method seems promising with respect to its realization for plasma conditions. Besides, heat transfer measurements from thin filament to plasma in cells of cylindrical symmetry are convenient for theoretical description of experiment and estimating contributions of different factors including heterogeneous catalysis.

The main goal of this research is to obtain experimental data on heat exchange between gases of different nature (air, argon, carbon dioxide) and tungsten surface for temperature range of (1000 - 1700) K with variable parameters of gas ionization.

EXPERIMENTAL SETUP

The experimental approach is based on low-pressure stationary Knudsen method that is adapted to hollow cathode glow discharge conditions. The hot wire realization is attractive due to its simplicity in heat management and temperature control of the sample by its electrical resistance.

The choice of Tungsten as a material for tested wire sample at the first stage is caused by the following reasons. First, Tungsten is a material with well integrated and known electrical and thermal/physical properties. Second, it belongs to refractory materials with high melting temperature of 3653 K that is convenient for providing measurements in a wide temperature range. Third, physical/chemical properties of this material permit to change surface chemical composition essentially (to clean it) by thermal heating treatment. Besides, Tungsten is widely enough used for gas/surface interaction study as a pure material and a base for preparing the surface of specified composition.

New approach in development of the technique consists in ionization of gas by the use of such well-known discharge system as hollow cathode one [3]. The main advantage of hollow cathode glow discharge in comparison with systems with flat electrodes is possibility of discharge operation at low gas pressure.

Arrangement of discharge chamber is schematically shown in Figure 1.

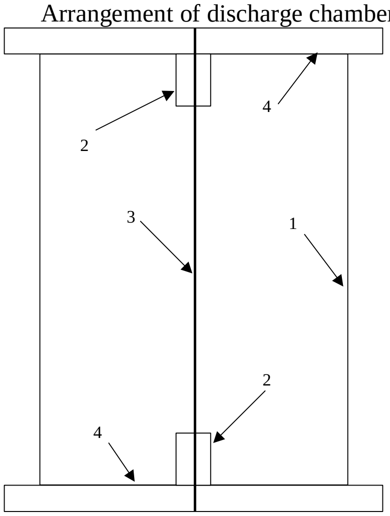

FIGURE 1. Scheme of gas discharge chamber:
1 - cathode, 2 - anode, 3 – Tungsten wire,
4 – assembly flanges with gas-tight electric joints.

Glow discharge is operated in stainless steel hollow cathode (1) vessel of 140 mm diameter and 210 mm length. Two stainless steel cylindrical anodes (2) are attached to dielectric holders of discharge chamber opposite flanges. The wire sample is tensioned along axis of cathode-anodes system for all its length. Such geometry was chosen to protect of wire ends from plasma and to guarantee definiteness and homogeneity of the area where plasma interacts with sample surface.

The gas pressure in discharge chamber of about 1Pa is provided by the use of gas flow regulator.

The discharge chamber is mounted on dielectric supports in vacuum chamber evacuated by diffusion oil pump. The residual gas pressure is about 10^{-2} Pa.

Suggested experimental approach gives opportunity to use single cylindrical Langmuir probe theory for describing plasma conditions that take place in experiment. The degree of ionization for used gases is about $3 \cdot 10^{-5}$ at discharge current of 100 mA. Volt-Ampere characteristic is presented in Figure 2.

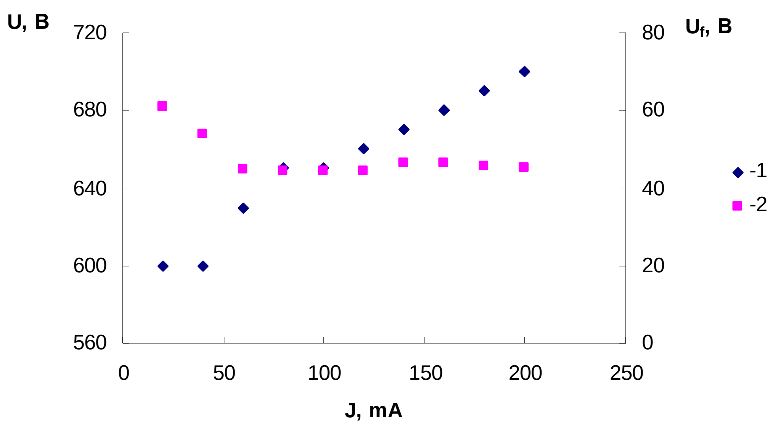

FIGURE 2. Discharge current dependences of discharge potential *U* (1) and floating potential U_f (2) on Tungsten wire in CO_2 plasma.

Experimental procedure consists in measuring electrical parameters of tungsten filament needed for obtaining power input that provides fixed temperature of the sample placed in plasma. Measurements are carried out by the use of special automatic device equipped with digital analog and analog-digital converters. Temperature of the sample is obtained from polynomial expression for electrical resistivity of tungsten [4]. It should be noted that tungsten wire had floating potential.

RESULTS AND DISCUSSION

The results of measurements for electric power input are convenient to express as a ratio of q/q_1, where q_1 is electric power input at sample temperature of 1000K (see Figure 3).

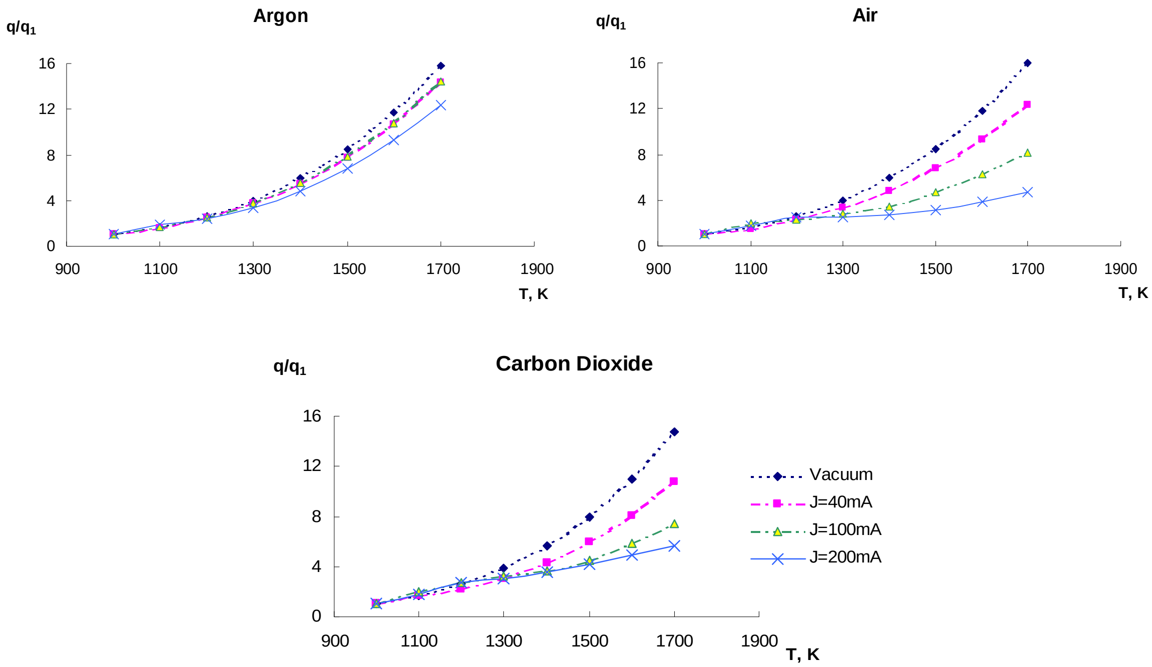

FIGURE 3. Temperature dependence of electrical power input to tungsten sample for various gases at different discharge current.

It seems interesting to compare presented above data for different gases but for the same parameters of discharge system. Corresponding diagrams are presented at Figure 4.

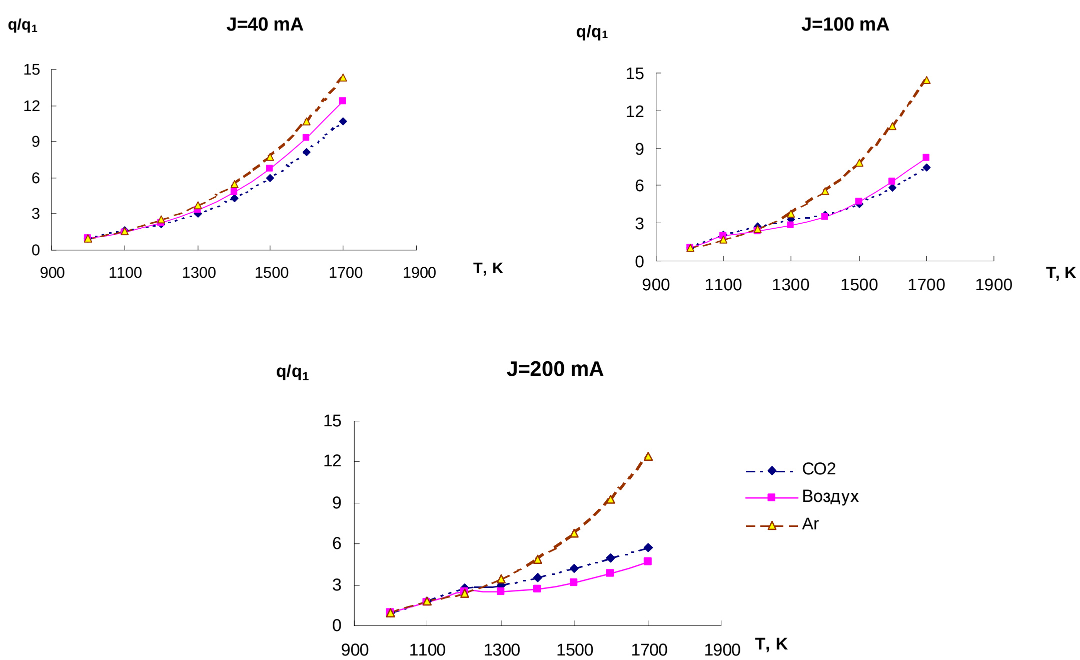

FIGURE 4. Temperature dependences of electrical power input to the tungsten sample for different gases at different discharge current.

As it follows from presented above figures the change in q/q_1 depends essentially on ionization rate for such gases as air and CO_2 but there is no dependence for Argon. This difference can be explained by possible chemical reactions, and in particular by heterogeneous recombination that definitely cannot take place in the case of Argon plasma.

To estimate energy exchange efficiency the recombination coefficient and accommodation coefficient for chemical energy should be calculated from experimental data.

It is known that coefficients of recombination g and chemical energy accommodation b depend on various microscopic parameters (the rate of surface coverage, near-surface concentration, rate of chemical reaction) that are not available in this experiment. The product of $\gamma\beta$ is the most convenient physical quantity that can be used for study of heat exchange without surface control.

$$gb = \frac{q_c}{m_{\downarrow} h_D}, \qquad (1)$$

where $m_{\downarrow}$ - mass of incident particles. q_c – heat released as a result of surface chemical reactions, for example, recombination, h_D – dissociation energy related to mass unit of recombined particles.

Relative change of gb with temperature is convenient for interpretation obtained results. The variation in heat exchange between wire and CO_2 plasma with the change of the surface temperature and the value of discharge current is shown in Figure 5.

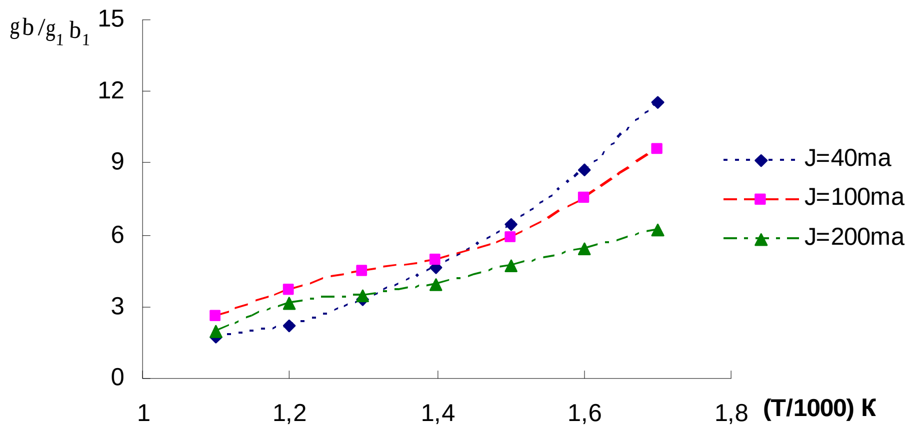

FIGURE 5. Temperature dependence of gb at different values of discharge current in CO_2 plasma.

Here γ_1, β_1 are coefficients of recombination and chemical energy accommodation at 1000K.

As it follows from Figure 5 heat exchange between wire and CO_2 plasma differs essentially for various values of discharge currents. One can expect that the use of numerical simulation of the problem and comparison it with experiment could help in extracting separate values of g and b .

Other result that follows from presented above experimental dependences and, in particular, connected with peculiarities of power input behavior in temperature range of 1000-1400 K looks unexpected and its interpretation requires additional study.

ACKNOWLEDGMENTS

The research described in this publication was made possible in part by Awards No: 03-53-5117 of INTAS/CNES and No: RUX0-000005-EK-06 (REC-005) of U.S. Civilian Research & Development Foundation for the Independent States of the Former Soviet Union (CRDF).

REFERENCES

1. T. Paulmier et.al. *Appl. Surf. Sci*., **180**, 227-245 (2001).
2. S.F.Borisov, “A Study of gas Molecules Energy and Momentum Accommodation on a Controlled Surface” in *Rarefied Gas Dynamics*, edited by A.E.Beylich, Proc. of the 17th Int. Symp. on Rarefied Gas Dynamics, VCH, Weinheim, 1991, pp. 1412 – 1418.
3. B.I. Moskalev, *Discharge with the hollow cathode*, Moscow: Energy, 1969, 184 p. (In Russian).
4. Desai P.D., Chu T.K., James H.M., Ho C.Y. *J. Phys. Ref. Data.* **13,** 1069 – 1096 (1984.).