Using two-chamber photoplasma for creating photovoltaic converter

S A Astashkevich, E A Bogdanov, G V Kirsanov and A A Kudryavtsev

Faculty of Physics, St. Petersburg State University, 3 Ulianovskaya Street, Petrodvorets, St. Petersburg, 198504, Russia

Department of Physics, Harbin Institute of Technology, Harbin 150001, China

E-mail: akud53@gmail.com

Abstract. Two-chamber photoplasma is developed for study photovoltaic converters. 2D simulation of conical geometry (similar to one of a solar collector) photoplasma parameters for Na-Ar gas mixture was fulfilled. The present study shows strong spatial non-uniformity of electron density and the electric potential distributions in the two-chamber cell that provides notable value of photo-emf.

1. Introduction

The importance of creating photovoltaic plasma converters is obvious from the point of view of diversification of energy, environment and responds to the global trend of increasing the relative share of renewable energy in the modern energy industry [1]. Such sources may have certain advantages compared to commonly used semiconductor solar cells [2, 3]. There are some approaches to convert solar energy into electrical energy based on photovoltaic effect in photoplasma [4, 5] containing a gas of an alkali metal (mainly Na and Cs): MHD generators [2], thermionic converters [6], and non-homogenous plasma [3]. In our recent papers [7, 8] it is shown that two-chamber 2D plasma cell allows obtaining large spatial gradients of electron density and temperature and thus create appreciable electric potential between chambers. So far the investigations of photovoltaic plasma converters (see [3] and bibliography in this paper) limited by one dimension case.

The aims of the present work are developing two-chamber plasma model for study photovoltaic plasma converters and 2D simulation of parameters photoplasma for Na–Ar gas mixture on the example two-chamber cell of conical geometry which conforms to one of a solar collector.

2. Model

2.1. Conical cell as an example of the photoplasma geometry

Let us consider conical two-chamber plasma geometry which conforms to one of a solar collector (see figure 1) and is similar the geometry of the experimental work [2].
2.2. Elementary photoplasma reactions
In the present work we study two-chamber resonance photoplasma for the Na–Ar mixture. The Ar as buffer gas serves to provide diffusive regime of destruction of the charged particles in both chambers. The list of main accounted reactions is given in table 1.

Table 1. Reactions taken into account in the present work.

| No | Reactions | Constants | Comments |
|----|-----------|-----------|----------|
| 1  | \( \text{Ar} + e \rightarrow \text{Ar} + e \) | Cross section [9] | Momentum transfer |
| 2  | \( \text{Na}(3s) + h\nu \rightarrow \text{Na}(3p) \) | \( \cdots \) | Resonance photoexcitation |
| 3  | \( \text{Na}(3p) + \text{Na}(3p) \rightarrow \text{Na}^{++} + \text{Na}(3s) \) | Reaction constant [10] | Excitation transfer |
| 4  | \( \text{Na}(3p) + \text{Na}^{++} \rightarrow \text{Na}^{+} + \text{Na}(3s) + e \) | Reaction constant [10] | Penning ionization |

2.3. Theoretical model
Two-chamber cell (\( \alpha \) is a chamber number: \( \alpha=1,2 \)) with open joint border (see figure 1 for the case studied in the present work) may basically have different cross profile both in shape and size. The continuity equation with the drift-diffusion approximation for each chamber \( \alpha \) (see e. g. [5]) is

\[
\frac{\partial n_j}{\partial t} - \nabla \left( D_{ja} \nabla n_j \right) = I_{ja} - R_{ja},
\]

where subscript \( j \) indicates \( j \)th specie, \( n \) is the density, \( I \) and \( R \) is creation and destruction rates, and \( D \) is the diffusion coefficient.

It was assumed that the spatial distribution of rate of resonance photoexcitation (reaction (2) in table 1) and electronic temperature has the following \((r, z)\)-dependence:

\[
s(r, z) = \begin{cases} S_1 e^{-\left( z - z_0 \right)^2 / z_1^2} \cos \left( \frac{\pi r}{2R(z)} \right), & \text{if } s(r, z) \geq S_0; \\ S_0, & \text{otherwise.} \end{cases}
\]

Here \( R(z) \) is the radial coordinate at the cell board for a given value of \( z \).

The electric potential is calculated using the Poisson’s equation.
3. Calculation and analysis
The conditions of 2D simulation are as follows: the Ar pressure $p_{\text{Ar}}=1$ torr; the ratio of Ar and Na pressures $p_{\text{Ar}}/p_{\text{Na}}=100$; the geometric sizes of the first and second chambers are $(L_1=10^{-2} \text{ m}; R_1=5\times10^{-3} \text{ m})$ and $(L_2=6\times10^{-2} \text{ m}; R_2=3\times10^{-2} \text{ m})$ respectively. The spatial profiles (Eq. 2) of the rate of resonance photoexcitation (for $S_0=0; S_1=1.6\times10^{24} \text{ m}^{-3} \text{ sec}^{-1}$) and electronic temperature (for $S_0=0.026 \text{ eV}; S_1=0.3 \text{ eV}$) for $z_0=5\times10^{-3} \text{ m}$ and $z_1=10^{-2} \text{ m}$ are shown in figures 2 and 3. The area of photoexcitation is mainly in the first chamber that corresponds concentrating of radiation in this chamber by means optical lens. 2D simulation was fulfilled in the COMSOL Plasma Module accounting equations (1)–(2) and reactions listed in table 1.

![Figure 2. 2D profile of the rate of photoexcitation reaction [m^{-3} sec^{-1}].](image)

![Figure 3. 2D profile of electronic temperature [eV].](image)

For the stationary case of Eq. (1) calculated 2D profile of the electron density is shown in figure 4 and one at the z-axis is given in figure 5. It is seen strong non-uniformity of electron density distribution through two chambers with the maximum in the second chamber.

![Figure 4. 2D profile of the electron density [m^{-3}].](image)

![Figure 5. The electron density at the z-axis [m^{-3}].](image)
The spatial distribution of the electric potential is shown in figure 6 and the electric potential at the cell border is given in figure 7. Calculated photo-emf for considered conditions $U_{12}$ is 1.28 V.

![Figure 6. 2D profile of the electric potential [V].](image1)

![Figure 7. The electric potential [V] at the cell border at points ($r=R(L)$, $z=L$).](image2)

4. Conclusions
The present study shows strong spatial non-uniformity of electron density and the electric potential distributions in the photoplasma two-chamber cell that provides notable value of photo-emf. The further research suggests more detailed accounting of photoplasma reactions and optimization of plasma geometry and conditions.

Acknowledgements
This work was supported by grant SPbGU 11.37.212.2016.

References
[1] World Energy Resources: Full Report 2016 (London: World Energy Council).
https://www.worldenergy.org/wp-content/uploads/2016/10/World-Energy-Resources-Full-report-2016.10.03.pdf
[2] Dunning G J and Palmer A J 1981 J. Appl. Phys. 52 7086
[3] Gorbunov N A and Flamant G 2015 Plasma Chem. Plasma Process. 35 799
[4] Beterov I M, Eletskii A V and Smirnov B M Sov. Phys. Usp. 1988 31 535
[5] Smirnov B M 2007 Plasma Processes and Plasma Kinetics (Weinheim: WILEY-VCH)
[6] Khalid K A A, Leong T J and Mohamed K 2016 IEEE Trans. El. Dev. 63 2231
[7] Kudryavtsev A A and Serditov K Yu 2012 Phys. Plasmas. 19 073504
[8] Bogdanov E A, Kudryavtsev A A, Ochikova Z S and Chirtsov A S 2015 Tech. Phys. 60 1570
[9] Phelps A V 1985 JILA Information Center Report 28 (University of Colorado)
[10] Mahmoud M A and Gamal Y E E 2012 Indian J. Phys. 86 659