Experimental installation to study the RF plasma flow at low pressures with experiment data synchronization

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Abstract. A diagram and description of an experimental setup for studying the properties of a stream of RF plasma at low pressure are presented. The setup is equipped with diagnostic devices that record the temperature, volt-ampere characteristics, and pressure in the chamber.

1. Introduction
Much attention is paid to the sources of cold plasma such as RF plasmas at low pressures (13.3 – 133 Pa) due to capabilities for material modification [1-5]. RF plasma sources is widely used for dry etching, plasma-enhanced chemical vapor deposition, and physical and reactive sputtering processes because they create a large volume plasma of low-energy low-intensity ions flows on a specimen surface.

The typical inductive discharge equipment for material modifications consists of a vacuum chamber and plasma torch. Low pressure inductive coupled (IC) RF plasma torch is a device which allows obtaining a plasma flow of 300-3000 K by temperature. The power of modern IC RF plasma setup is in range from 0.1 to 5 kW. A low-sized experimental setup made from dielectric materials for verification of mathematical model of low-pressure IC RF plasma [6-11] with an experimental data is constructed.

2. Experimental installation
The experimental setup is axisymmetric and has a base size of 90x90 mm and a total height of 470 mm, including the discharge and vacuum chambers. The RF plasma installation is mounted on an aluminum profile structure with a base size of 1000x1000 mm (Fig. 1). An argon cylinder, an oscilloscope, a vacuum gauge, and an RF generator are also attached to this design. No conductive parts were used in the installation to avoid their effects on the plasma.

The schematic diagram of the apparatus is shown in Fig. 1. The plasma torch consists of a quartz tube (1) of 30 mm by an outer diameter, 28 mm by an inner diameter, and 170 mm by a length, which is placed inside an inductor from a copper wire of 4 mm by a diameter (2). An alternating current with a frequency of 1.76 - 40.68 MHz is supplied to the inductor from the RF generator (3).

At the testing stage, a 40.68 MHz generator of 30 W by a power was used. As a result, an alternating electromagnetic field inside the discharge tube (4) initiates and sustains the discharge. Partially ionized gas flow enters a quartz vacuum chamber of 78 mm by a diameter (5). Gas from the vacuum chamber is evacuated by an oil rotary pump (Zensen VPA-3S).
Figure 1 – Schematic diagram of low pressures IC RF discharge set up (a) and the mounted set up (b).

Current and voltage probes connected to an AKIP-4115/5A oscilloscope (6) and a platinum thermocouple (type WRP 100s) (7) connecting with a computer by a microcontroller Arduino UNO R3 is used to obtain experimental data. The data synchronization system is built using an USB connector of B-type to send thermocouple data to a PC. The data from the voltage probe (model P6100) and the RF current probe (model PT-350) are synchronized with the PC via a connection to the oscilloscope, the vacuum gauge (testo 552) is connected to the PC via Bluetooth. All data is written to files with a prefix of the current time at executing a script that runs on a PC, thereby synchronize the device data. The list of controlled parameters is given in table 1.

Table 1 – The main parameters of the experimental installation

| Parameter                        | Range   |
|----------------------------------|---------|
| Voltage range, V                 | 0-1000  |
| Pressure range, Torr             | 0.6-760 |
| Frequency, MHz                   | 40.68   |
| The radius of the discharge chamber, mm | 14      |

3. Methods for improving installation efficiency

Experimental studies using RF currents are associated with several problems that are missed in direct current setup. One problem is voltage/current supply from the generator to the solenoid. A two-wire system with alternating current works is like a capacitor, so a «capacitive parasitic» is created. In addition, the proportion of radiation energy increases at increasing frequency, so the wires became antennas. Finally, the skin effect plays a large role for active resistance of the wires at high frequencies.

In order to reduce energy losses, the following requirements are imposed: the wire cross-section should be as maximum as possible for reducing losses due to the skin effect, the distance between the wires should be maximized, and the length of the wire should be minimized. Based on these requirements, two insulated wires of 500 mm by a length, 2 mm by a cross-sectional diameter, and 40...
mm by a distance between them, were used. The losses calculated by the equivalent straight-lined scheme (Fig. 2) is less than 3.6%, which is acceptable for the operation of the experimental setup.

**Figure 2** – Equivalent electrical circuit for supplying RF power via a two-wire unshielded cable and a temporary scan of the voltage at the input and output of the supply line.

The RF generator and the inductor are connected directly by the wires (Fig. 1). The inductor has only one turn, therefore no discharge was burn without assistance. So, a copper wire was used for ignition the discharge. After breakdown, the wire is diverted to a considerable distance from the discharge. Self-ignition of argon plasma occurs at a pressure of less than 3.4 Torr.

An important part of the installation is the vacuum system. The task is in selecting chamber materials that provide long-term pressure maintenance without leakage. It was established that PLA plastic does not affect the discharge and maintains pressure in the chamber; therefore, the top cover of the installation is made of PLA plastic. Chamber elements are connected by a silicone sealant.

PLA plastic has melting temperature 403 K, silicon-based sealing melts at 513 K. Therefore we did not use these materials in a space between plasma torch and main chamber (5). The space is filled by fluoropolymer which melts at 600 K, has low gas diffusion and adsorbs less gas than other types of plastics. To pump gas out of the chamber, we connected it with the pump by a reinforced gas hose; connections between fittings and hose is filled by PTFE sealing material tape. The same type of hose and the same material are used in connection join between an argon cylinder and the plasma torch (see Gas inlet on the Fig. 1). The operation of the RF plasma installation both in a non-flow and gas flow mode is shown on Figure 3.
Figure 3 – Operation of the RF plasma installation both in a non-flow (a) and gas flow (b) mode.

4. Acknowledgment

The study was funded by Russian Science Foundation, project № 19-71-10055.

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