SPATIAL DISTRIBUTIONS OF PLASMA PARAMETERS IN ICP REACTOR

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The results of systematic experimental researches of ICP reactor are presented. Experimental results on spatial distribution of local plasma parameters (plasma density, temperature and electron energy distribution function) and radial profiles of ion current to processed surface are presented for atomic (Ar) and molecular (N_2, CF_4) gases. Relation between the plasma density profile and the ion current density radial distribution is discussed. Comparison of the obtained results with the calculations executed using 2D-fluid model has allowed to reveal the main rules of the ion flux profile formation.

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1. INTRODUCTION

Last years ICP became the conventional basis for creation of various plasma technological devices, in particular for plasma-chemical etching in microelectronics. By the present moment great progress have been achieved both in the field of basic research of ICP physics and in the field of practical reactor design, and focus of ICP application is shifted to development of the technological devices optimized for specific micro- and nanotechnologies with high requirements to the device parameters. It is impossible to satisfy these requirements without detailed experimental researches and improvement of ICP mathematical models.

The results of systematic experimental researches of ICP reactor [1] are presented in this paper. Experimental results on spatial distribution of local plasma parameters (plasma density, temperature and electron energy distribution function) and radial profiles of ion current to processed surface are presented for atomic (Ar) and molecular (N_2,CF_4) gases. Relation between the plasma density profile and the ion current density radial distribution is discussed. Comparison of the obtained results with the calculations executed using 2D-fluid model has allowed to reveal the main rules of the ion flux profile formation.

2. EXPERIMENTAL SETUP

A schematic diagram of the experimental setup used in our investigation is shown in Fig. 1. The cylindrical discharge vessel has a radius R =7 cm and height L = 6 cm. The sidewall of the vessel is made of metal. The glass top cover and the inductive coil are cooled by air flow created by a fan. The vessel is evacuated by a turbo molecular pump down to a base pressure of about 10^{-6} Torr. The experiments are performed in the work gas pressure range 0.1…2000 mTorr.

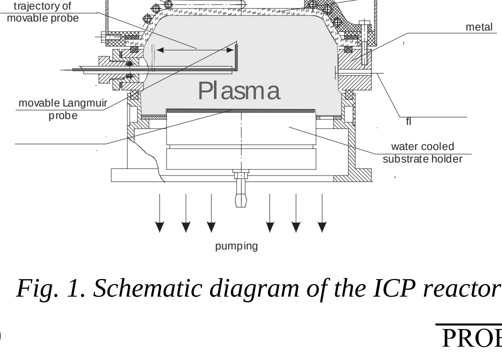

Fig. 1. Schematic diagram of the ICP reactor

The RF field is induced by a three-turn spiral copper coil with variable radius. RF power in the range 50…200 W at 13.56 MHz is coupled to the coil via a matchbox.

Measurements of the radial profiles of ion current density to the processed surface were done by a string of seven plane probes by square of 0.25 cm^2 arranged along the radius of the RF electrode. The negative plane probe bias of -25 V with respect to the chamber was used in experiments. Measurement of the radial distributions of the main plasma parameters of plasma have been led by means of the movable Langmuir cylindrical probe of diameter D_p= 0,1 mm and length of L_p = 2 mm. The probe was moved horizontally along the chamber radius 40mm higher the substrate holder. Measuring of the probe traces and the probe data processing was done using the “Plasmameter” device [2].

The RF field is induced by a three-turn spiral copper coil cooled by air. The capacitive coupling is damped by a grounded electrostatic shield. RF power in the range 50…500 W at 13.56 MHz is coupled to the coil via a matchbox.

3. EXPERIMENTAL RESULTS

Typical normalized radial profiles of the ion current density j at the substrate holder are presented in Fig. 2 at various working gases and pressures. Measuring were carried out at RF power of 100 and 200 W. It has been found, that in the power range 50…500W ion current density is proportional to the power, and profiles j (r) practically don't change.

As shown in Fig. 2, for low pressure range the normalized profiles of j are convex, maximizing at the discharge axis. For high pressure range the j profile becomes concave, with off-axis maximums. In this range the ratio of the peak density to the axis density increases with the pressure. There is relatively high uniformity of j in the region $r < 0.8R$ for medium pressure.

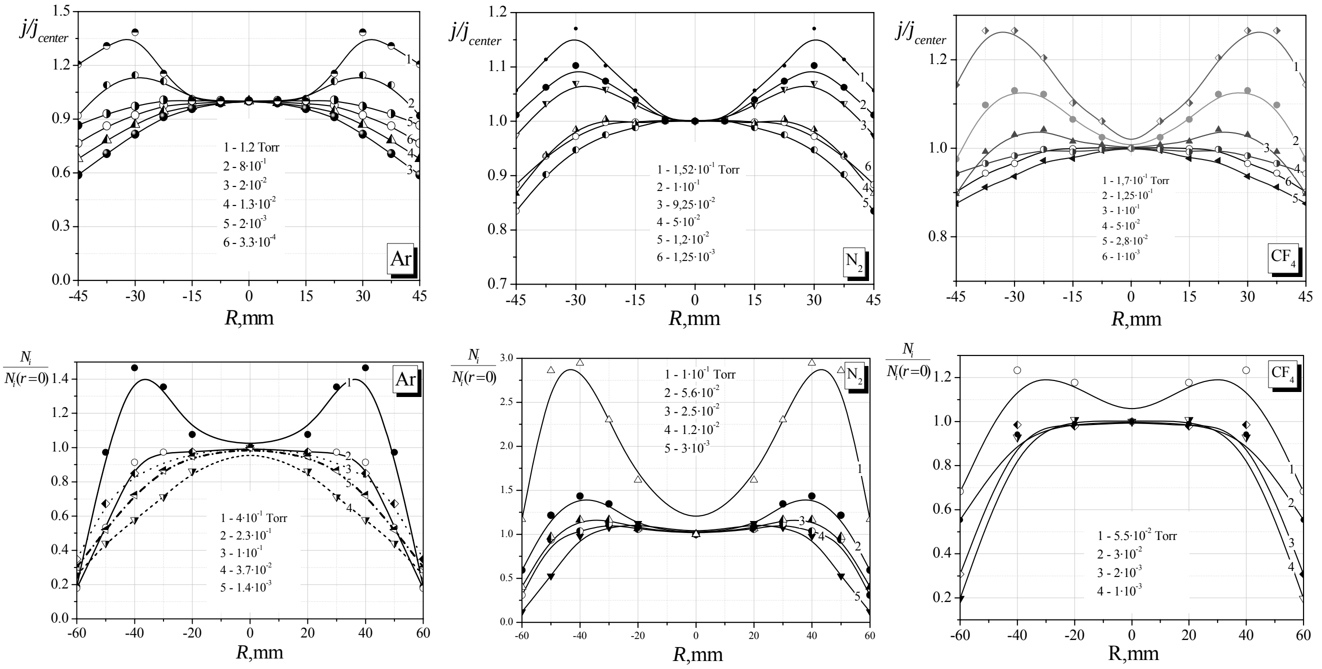

Fig. 2. Radial distributions of the normalized ion current density to the chamber bottom and the normalized ion density at h=40mm from bottom for work gases Ar, N_2, CF_4 (P_{appl} = 100 W)

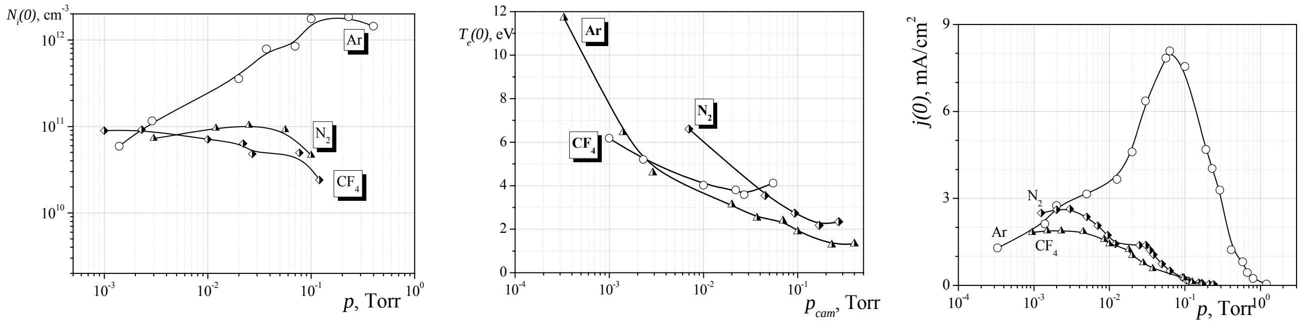

Fig. 3. Pressure dependencies of plasma density, electron temperature and ion current density at the chamber axis

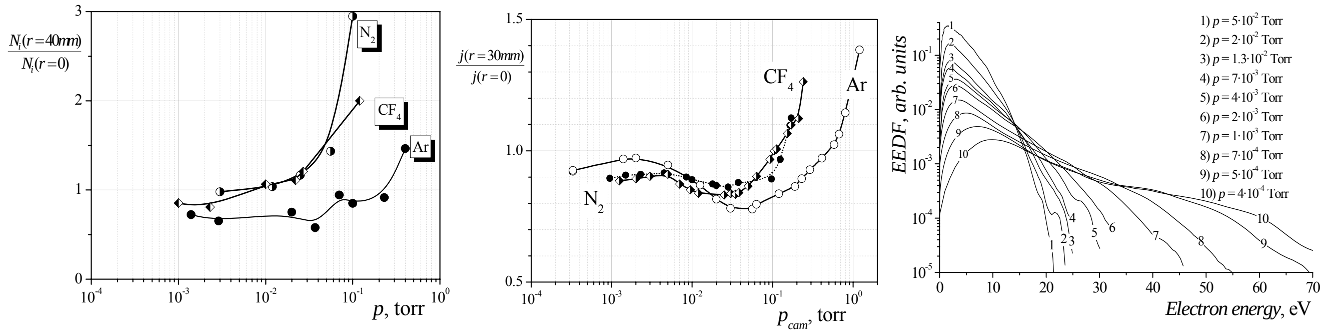

Fig. 4. Pressure dependencies of homogeneity factor for plasma density, ion current density and EEDF

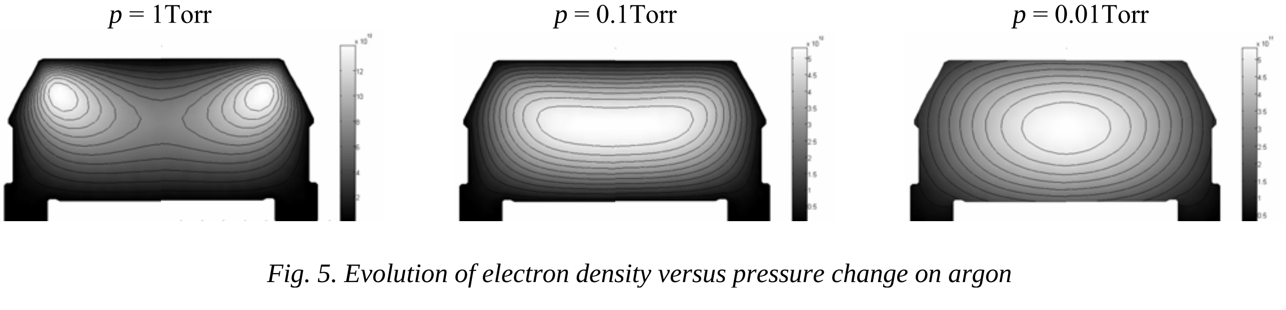

Fig. 5. Evolution of electron density versus pressure change on argon

It is discovered that for argon pressure $p < 350$ mTorr the radial current density profile is convex with the maximum at the discharge axis. For the pressures $p > 350$ mTorr the profile becomes concave with the minimum current density at the axis. It should be noted that the profile shape transformation with the pressure change isn't monotonic. At the pressure < 1 mTorr the profile is convex and shows poor uniformity. The best uniformity of the ion flow appears at the pressure 2 mTorr, then the uniformity becomes worth with the pressure growth to 60 mTorr. The further increase of the pressure leads to the uniformity improvement, but at the pressure >1 Torr the uniformity becomes poor again due to the local minimum appearing in the center.

The plasma density radial distribution shows analogous shape transformation with the pressure change. For the pressure 20 mTorr the distribution has the maximum in the center while at 60 mTorr the local minimum appears at the discharge axis. At the further pressure growth the maximum moves to the center again and for the pressures greater than 140 mTorr the profile becomes concave with the maximum near the inductive coil.

Dependencies of plasma density N_i and the electron temperatures T_e at the chamber axis on pressure of argon and CF_4, N_2 are shown in Fig. 3. It is obvious, that these dependences are significantly different for argon and molecular gases. With pressure increase a growth of T_e near the inductor is observed in the discharges in molecular gases. This gradient of T_e can be explained by the electron energy loss in inelastic collision with molecules.

As shown in Fig. 4, the radial distribution of the ion current density at the substrate holder repeats behavior of the radial distribution of the ion density in bulk plasma with a shift on gas pressure.

Also Fig. 4 shows evolution of electron energy distribution with pressure change. One can see the monotonic decrease of mean electron energy with the pressure growth. At pressures below 2 mTorr the electron energy spectrum became clearly two-temperature, at higher pressures it is Maxwellian with damped tail, and at highest pressures it have Druevestain-like shape. Fig. 4 shows two-temperature EEPF typical for low pressure.

In Fig. 5 the spatial distributions of plasma density calculated using 2D fluid model described in [3] are presented. The shown distributions demonstrate evolution of the plasma shape from toroid at high pressure to egg-like at low pressures.

ACKNOWLEDGEMENT

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ПРОСТРАНСТВЕННЫЕ РАСПРЕДЕЛЕНИЯ ПАРАМЕТРОВ ПЛАЗМЫ ИНДУКЦИОННОГО РАЗРЯДА В РЕАКТОРЕ ДЛЯ ПЛАЗМО-ХИМИЧЕСКОГО ТРАВЛЕНИЯ

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Представлены результаты систематических экспериментальных исследований реактора для плазменно-химического травления на базе ВЧ-индукционного разряда. Проведены измерения пространственных распределений локальных параметров плазмы (плотности плазмы, температуры и функции распределения электронов по энергии) и радиальных профилей плотности тока ионов на обрабатываемую поверхность. Измеренные зависимости существенно отличаются для инертного (Ar) и молекулярных (N_2, CF_4) газов. Поскольку диапазон давлений охватывал области бесстолкновительного и диффузионного режимов движения заряженных частиц в плазме, радиальное распределение плотности тока ионов и его абсолютная величина существенно изменялись. Проведено сравнение полученных результатов с расчетами, выполненными с использованием 2D-fluid модели.

ПРОСТОРОВІ РОЗПОДІЛИ ПАРАМЕТРІВ ПЛАЗМИ ІНДУКЦІЙНОГО РОЗРЯДУ В РЕАКТОРІ ДЛЯ ПЛАЗМОВО-ХІМІЧНОГО ТРАВЛЕННЯ

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Представлено результати систематичних експериментальних досліджень реактора для плазмово-хімічного травлення на базі ВЧ-індукційного розряду. Проведено вимірювання просторових розподілів локальних параметрів плазми (густини плазми, температури і функції розподілу електронів по енергії) і радіальних профілів щільності струму іонів на оброблювану поверхню. Отримані залежності істотно відрізняються для інертного (Ar) і молекулярних (N_2, CF_4) газів. Оскільки діапазон тиску охоплював області руху без зіткнень і дифузійного режимів руху заряджених частинок в плазмі, радіальний розподіл щільності струму іонів і його абсолютна величина істотно змінювалися. Проведено порівняння отриманих результатів з розрахунками, виконаними з використанням 2D-fluid моделі.