LARGE-AREA SURFACE WAVE PLASMA SOURCE

N.A. Azarenkov, A.A. Bizyukov, A.V. Gapon, A.Y. Kashaba, K.N. Sereda, A.Ph. Tseluyko, N.N. Yunakov
Kharkiv National University, Kharkiv, Ukraine, 61108,
E-mail: bizyukov@pht.univer.kharkov.ua

A surface wave plasma source for the production of a large-diameter, high electron density and low electron temperature plasma at low pressure without using a magnetic field for plasma processing and thin film preparation are. The DC or RF voltage with the frequency of 13.56 *MHz* can supply the source. The pumping-out of the source is carried out through the insulated substrate holder. The plasma source operates in a working gas pressure range of $3 \cdot 10^{-2} \div 10^{-4}$ *Torr* with changing the RF power in a range of 50÷1000 *W* during the discharge on surface waves with the mode 0 excited by a ring antenna. The plasma density has a homogeneous distribution over a diameter of 300 *mm* and varies in a range of $10^8 \div 10^{10}$ cm^{-3} at electron temperature of 2÷7 *eV* depending on external parameters. An ion beam density in the presence of the RF bias applied to the substrate holder reached 0.1 mA/cm^2 with homogeneous distribution over the diameter of 300 *mm*. The total ion current to the substrate holder with a diameter of 467 *mm* reaches the value of 2 *A* with average ion energy of 200 *eV*. Numerical analysis of electric field distribution over the processing chamber in linear approach was made and compared to experimental results obtained.
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1. INTRODUCTION

Low pressure (less than 10 *mTorr*), high-density (more than 10^9 cm^{-3}) plasma sources which produce uniform (less than 5%) densities of ions and radicals over large areas (more than 300 *mm* diameter) have recently been important for plasma etching and deposition technology in the fabrication of ultralarge-scale integrated (ULSI) circuits with deep submicron features [1, 2]. Among the various types of plasmas (inductively coupled plasma (ICP), electron cyclotron resonance (ECR) plasma, helicon, etc. [3]), surface-wave plasmas (SWPs) are one of the most promising candidates from the viewpoints of cost performance, compactness and feasibility of enlargment of high density homogeneous plasmas [4].

This paper presents a surface wave plasma source for the production of high-density plasma over large areas without a magnetic field for plasma processing and thin film preparation.

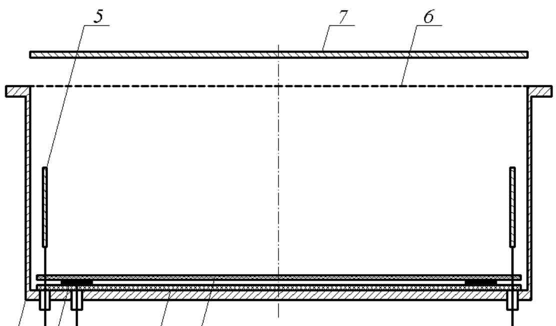

Fig. 1. Schematic diagram of the plasma source. 1 – housing ; 2-flat ring electrode; 3, 4 – dielectric plates; 5 – cylindrical ring electrode; 6 – gridded electrode, 7 – substrate holder

2. EXPERIMENTAL

The plasma source consists of a cylindrical housing made of stainless steel, flat and cylindrical ring electrodes, two round flat dielectric plates, high-frequency electrical vacuum lead-ins, insulated substrate holder. The internal diameter of the housing is 505 *mm*, height is 215 *mm*, thickness of end wall is 10 *mm*. The flat ring electrode, which geometrical sizes can vary, is placed on the interior side of the end wall between two round flat dielectric plates with the diameter of 502 *mm* and thickness of 4 *mm*. The cylindrical ring electrode with an internal diameter of 492 *mm* and height of 80 *mm* has a wall thickness of 3 *mm* and is arranged coaxially to the housing near the end wall. Both flat, and the cylindrical ring electrodes with excitation of surface waves with different modes can serve as antenna. The insulated substrate holder with the maximum diameter of 498 *mm* is arranged on an opposite end of the housing. In some experiments, to extract the ions from the discharge volume the gridded electrode with a diameter of 460 *mm* made stainless steel is disposed from above of the cylindrical electrode. The transparency of the gridded electrode is approximately 50%. The distance between the end of the cylindrical electrode and gridded electrode can also vary from 0 up to 100 *mm*. The DC or RF voltage with the frequency of 13.56 *MHz* can be supplied to flat or cylindrical ring electrodes. The plasma source is mounted on the modernized vacuum chamber of base vacuum installation such as UVN which allows to perform preliminary source evacuation to residual pressure 5×10^{-6} *Torr*. The gas inlet system allows to support working gas pressure in range of $10^{-1} \div 10^{-5}$ *Torr*.

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3. RESULTS AND DISCUSSION

The plasma source operates in a working gas pressure range of $3\cdot 10^{-2} \div 10^{-4}$ *Torr* with changing the RF power in a range of 50÷1000 *W* during the discharge on surface waves with the mode 0 excited by a flat ring electrode-antenna. In the selected geometry the conditions are suitable for launching of the surface wave sustained discharge. The probe measurements indicate that the plasma density has a homogeneous distribution over a diameter of 300 *mm* and varies in a range of $10^{8}\div 10^{10}$ cm^{-3} at electron temperature of 2÷7 *eV* depending on external parameters. Fig 2. shows plasma density distribution and electron temperature along radial direction of the system. Fig 3. shows dependence of plasma density and electron temperature on the input power. An ion beam density in the presence of the RF bias applied to the substrate holder, which was studied by the system of flat directional probes, reached 0.1 mA/cm^2 with homogeneous distribution over the diameter of 300 *mm*. In the case of applying the positive DC bias to the cylindrical electrode, the dependencies of ion current to the substrate holder at typical external working parameters of the plasma source has linear character within the range of DC bias from 0 to 1000 *V*. The spatial distribution of ion current density is homogeneous over a diameter of 300 *mm*. The total ion current to the substrate holder with a diameter of 467 *mm* reaches the value of 2 *A* with average ion energy of 200 *eV*.

The carbon films with the evident diamond-like properties was synthesized on the glassceramic substrate surface from a mixture of cyclohexane and hydrogen.

The calculation of an RF-field was carried out using the configuration similar to the planar reactor. In spite of the fact that an electric field is enough for ionization maintenance, the linear approach is traditional for amplitude distribution calculation and dispersion characteristics [4 - 6]. Since length of an electromagnetic wave in vacuum for used frequency $\lambda \propto 10\ m$ for frequency wave 13.56 *MHz* a quasistationary condition was satisfied ($\lambda >> L$, L - the size of considered region) and one can consider that electric field is potential.

Considering that the time dependence of unknown fields $u(r,t)$ is specified by applied RF field as $u(r,t) = U(r)\exp(i\omega t)$ (cyclic frequency $\omega = 2\pi\nu$, where ν - the generator frequency), the equation for an RF-potential can be written in the following view:

$$\nabla(\varepsilon\nabla\psi) + \frac{v_t^2}{\omega^2}\nabla^4\psi = -4\pi Q, \qquad (1)$$

where $\varepsilon = 1 - \dfrac{\omega_p^2}{\omega(\omega + i\nu_{coll})}$ - plasma permittivity, Q - extraneous charge density, ν_{coll} - effective electron collision frequency.

The regional conditions were chosen as in ref. [6]:

$$\vec{n}\nabla\left(\nabla^2\psi_p - \frac{\omega_p^2}{v_t^2}\psi_p\right)\Bigg|_S = 0, \qquad (2)$$

$$n\nabla\psi_p - \varepsilon_d n\nabla\psi_d\big|_S = 0, \qquad (3)$$

where n - normal line to an interface S, ψ_p - RF potential in plasma, ψ_d - potential in a dielectric.

The solution was found numerically using finite-difference equations obtained by a method of the streams [6]. Fig. 4 shows the potential distribution normalized by peak value for conditions similar to experimental one. The plasma permittivity varies in range from minimum value –100 up to the 1 near the boundary. Potential reaches the greatest value on the surface where the plasma resonance condition is satisfied.

Far from the antenna the potential distribution is nearly the natural solution of the equation (1). The significant voltage dropping toward the axis is distinct that has been found out experimentally. Taking into account electron pressure here is essential. The identical potential profile was calculated using cold plasma approach and is shown in Fig. 5 for comparison with previous one.

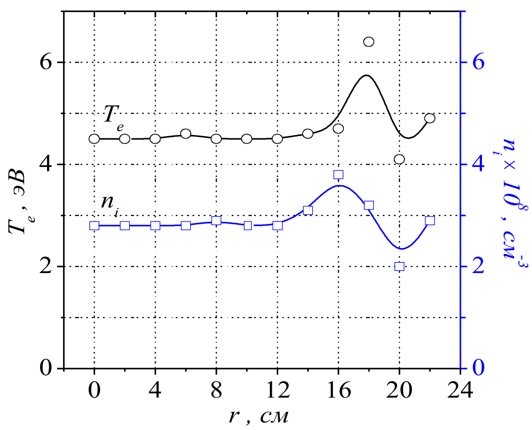

Fig 2. Ion density and electron temperature distribution along radial direction of the system. $p = 2\cdot 10^{-3}$ Torr, $P_{RF} = 100$ W, working gas was argon

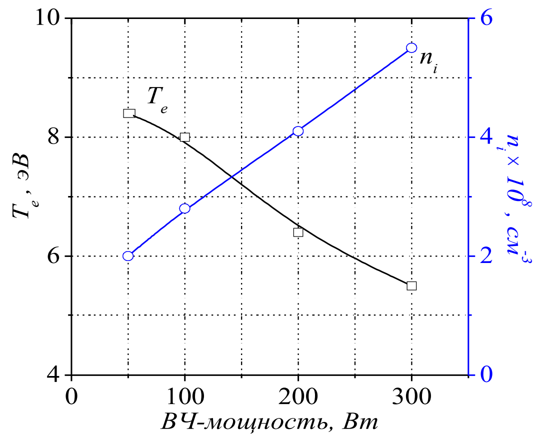

Fig. 3. Dependencies of plasma density and electron temperature on the input power. $p = 2\cdot 10^{-3}$ Torr, working gas was argon

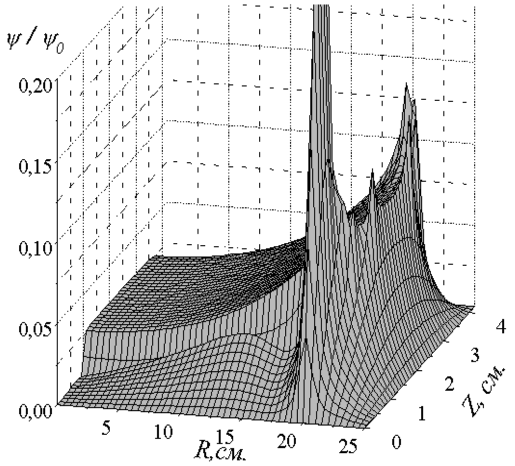

Fig. 4. Electron temperature T_e=5 eV, distance between glass disks d=3 cm, r_o=20 cm, z_o=0.4 cm

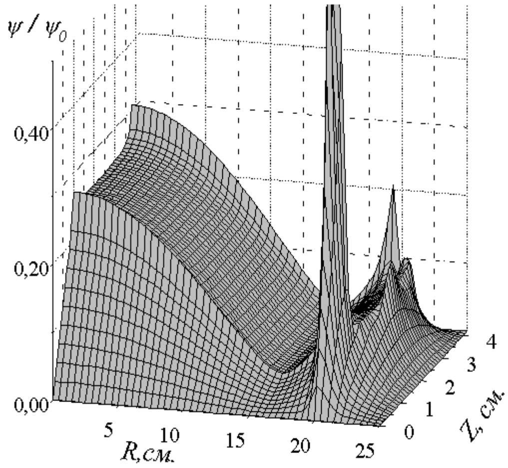

Fig. 5. Cold plasma approach. Geometrical factors see on caption for Fig.4

4. CONCLUSIONS

A surface wave plasma source for the production of a large-diameter, high electron density and low electron temperature plasma at low pressure without using a magnetic field for plasma processing and thin film preparation are. The DC or RF voltage with the frequency of 13.56 *MHz* can supply the source. Numerical analysis of electric field distribution over the processing chamber in linear approach was made and compared to experimental results obtained.

5. ACKNOWLEDGMENTS

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