SURFACE WAVE PLASMA SOURCE FOR BROAD-BEAM ION AND ELECTRON PRODUCTION

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The new type of multipurpose plasma source based on the surface wave sustained discharge is presented. The plasma in the source is generated by the RF surface wave discharge excited by the antenna system placed inside a cylindrical metal chamber. Charged particle acceleration is carried out by a quasi-stationary electric field due to DC voltage applied to the cylindrical electrode mounted inside the chamber. The source can be used for production and acceleration of ion as well as electron beams. The source has stable low-pressure operation in the range of applied RF power from 50 to 1000 W and produce ion beam having a density up to 0.3 mA/cm^2 in the energy range from 50 to 200 eV and 3% homogeneity on the 300 mm diameter.

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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 enlargement 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.

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 the end wall is 10 *mm*. The flat ring electrode, the geometrical sizes of which 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, the flat and the cylindrical ring electrodes with excitation of surface waves in different modes can serve as an 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 of stainless steel is disposed from above of the cylindrical electrode. The transparency of the gridded electrode is approximately 50%.

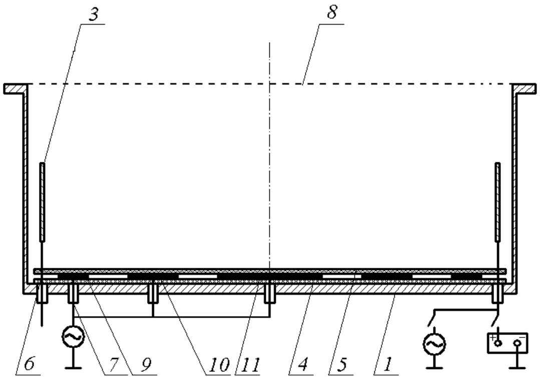

Fig.1. Schematic diagram of the plasma source. 1 – housing; 3 – cylindrical ring electrode; 4,5 – dielectric plates; 6,7 – RF vacuum input, 8 – gridded electrode; 9,10,11 – flat ring electrodes-antennas

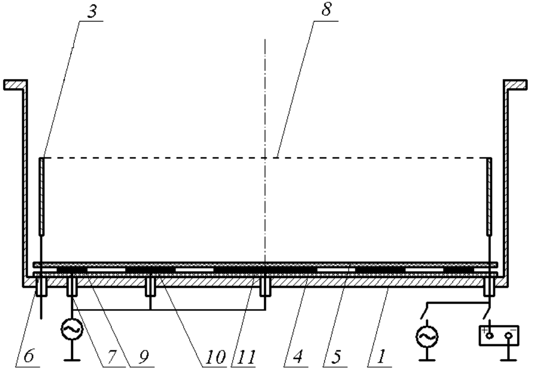

Fig.2. Schematic diagram of the plasma source 1- housings, 3-cylindrical electrode, 4,5 - dielectric gaskets; 6,7 - RF - vacuum feedthroughs, 8 – grid; 9,10,11 - antenna system

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 updated vacuum chamber of the base vacuum installation such as UVN which allows to perform preliminary the source evacuation to residual pressure 5×10^{-6} *Torr*. The gas inlet system allows to support the working gas pressure in range of $10^{-1}...10^{-5}$ *Torr*.

3. RESULTS AND DISCUSSION

The plasma source operates in a working gas pressure range of $3\times(10^{-2}\ldots10^{-4})$ *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 $10^8\ldots10^{10}$ cm^{-3} at electron temperature of 2…7 *eV* depending on external parameters. Fig.3. shows the plasma density distribution and electron temperature along the radial direction of the system. Fig.4. shows the dependence of plasma density and electron temperature on the input power.

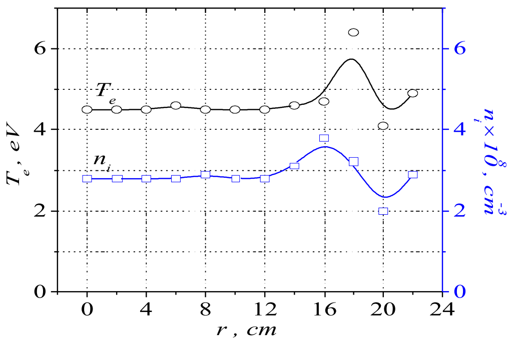

Fig.3. Ion density and electron temperature distribution along the radial direction of the system $p = 2\cdot10^{-3}$ *Torr,* $P_{RF} = 100$ *W, working gas was*

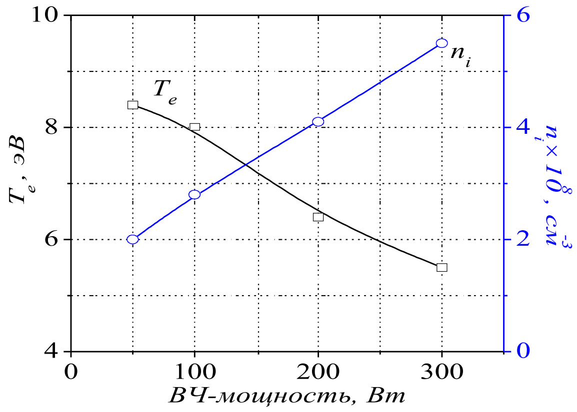

Fig.4. Plasma density and electron temperature versus input power. $p = 2\cdot10^{-3}$ *Torr, working gas was argon*

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 a 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 an average ion energy of 200 *eV*.

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

The wave identification problem needs for addition studying. Therefore we calculate the RF-field for 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 the electromagnetic wave length in vacuum is about $\lambda \propto 10\ m$ at the generator frequency 13.56 *MHz* the quasi-stationary condition is fulfilled ($\lambda >> L$, L is the dimension of the region under consideration) so we supposed that the electric field is potential one.

It was supposed that the time dependence of unknown values $u(r,t)$ is determined as follows $u(r,t) = U(r)\exp(i\omega t)$ ($\omega = 2\pi\nu$, where ν is the generator frequency), the equation for an RF-potential can be written in the following form:

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

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

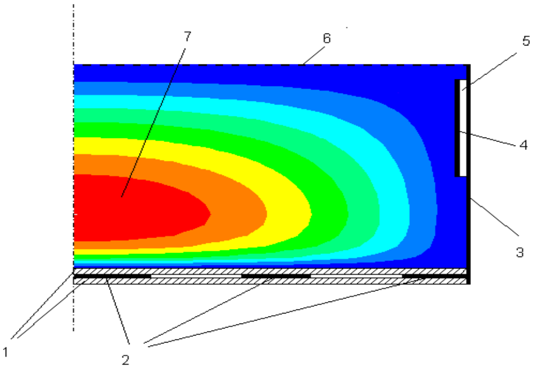

Fig.5. Calculated plasma potential profiles for the plasma source on the surface waves. 1 – glass disks; 2 –RF electrodes; 3 – metal housing; 4 – cylindrical ring electrode; 5 – isolator; 6 – gridded electrode; 7 – plasma

The boundary conditions were chosen in the following form [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 is the normal vector to the interface *S*, ψ_p is the RF plasma potential, ψ_d is the potential in dielectrics.

The solution of equation (1) was found numerically with the help of finite-difference equations obtained by the method of streams [6]. Fig.5 shows the calculated plasma potential profiles for the plasma source on the surface waves.

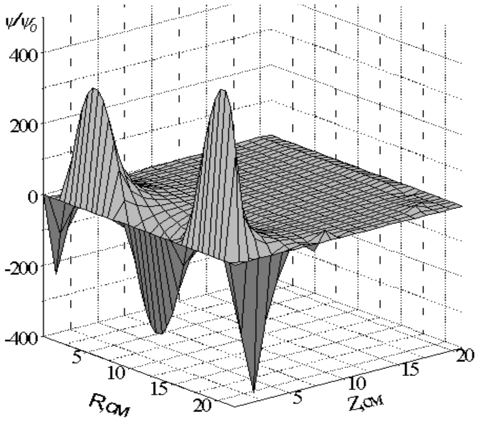

Fig.6. RF potential distribution normalized by the antenna potential for an optimized antenna geometry at electron temperature $T_e = 5\ eV$, $\overline{N}_e = 50\,n_{cr}$, n_{cr} is the resonance plasma density, for the generator frequency it is equal to $2.28\times 10^6\ cm^{-3}$

The plasma permittivity varies in the range from a minimum value –100 up to the 1 near the boundary. The plasma potential reaches the maximum value on the surface where the plasma resonance condition is satisfied.

At the far distances from the antenna the potential distribution is nearly the eigen solution of equation (1) with zero right part. The significant voltage dropping towards the axis is distinct that has been found out experimentally. Taking into account the electron pressure here is essential. The RF potential distribution normalized by the antenna potential for optimized antenna geometry is shown in Fig.6.

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 is considered. 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 the linear approach was made and compared to experimental results obtained.

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ПЛАЗМЕННЫЙ ИСТОЧНИК НА ПОВЕРХНОСТНЫХ ВОЛНАХ ДЛЯ ПОЛУЧЕНИЯ ИОННЫХ И ЭЛЕКТРОННЫХ ПУЧКОВ

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Представлен новый тип многоцелевого плазменного источника на основе разряда на поверхностных волнах. Плазма в источнике генерируется ВЧ-разрядом на поверхностных волнах, возбуждаемым с помощью антенной системы, расположенной внутри цилиндрической камеры. Ускорение заряженных частиц осуществляется квазистационарным электрическим полем за счет постоянного напряжения, приложенного к цилиндрическому электроду, расположенному внутри камеры. Источник можно использовать для получения и ускорения как ионных, так и электронных пучков. Источник стабильно работает при низком давлении в диапазоне приложенной ВЧ мощности от 50 до 1000 Вт и генерирует ионный пучок с плотностью до 0,3 мА/см^2 в диапазоне энергий (50…200) эВ при 3% однородности на диаметре 300 мм.

ПЛАЗМОВЕ ДЖЕРЕЛО НА ПОВЕРХНЕВИХ ХВИЛЯХ ДЛЯ ОДЕРЖАННЯ ІОННИХ І ЕЛЕКТРОННИХ ПУЧКІВ

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Представлено новий тип багатоцільового плазмового джерела на основі розряду на поверхневих хвилях. Плазма у джерелі створюється ВЧ-розрядом на поверхневих хвилях, що збуджується за допомогою антенної системи, яка міститься всередині циліндричної камери. Прискорення заряджених частинок здійснюється квазістаціонарним електричним полем завдяки сталій напрузі, яка прикладена до циліндричного електроду, що міститься у камері. Джерело можна використовувати для отримання та прискорення як іонних, так і електронних пучків. Джерело стабільно працює при низькому тиску в діапазоні прикладеної ВЧ потужності від 50 до 1000 Вт і генерує іонний пучок з густиною до 0,3 мА/см^2 в діапазоні енергій (50…200) еВ при 3% однорідності на діаметрі 300 мм.