PLASMA DEVICES FOR ION BEAM AND PLASMA DEPOSITION APPLICATIONS

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We describe the operation of some new axially-symmetric plasma devices based on plasma-optical principles and the plasma lens configuration. Plasma devices of this kind using permanent magnets can be applied in a number of different applications for ion treatment and materials synthesis.
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1. INTRODUCTION

Plasma-optical devices are a subset of a large class of plasma devices (plasma accelerators, magnetrons, magnetically-insulated diodes, thrusters) that use a plasma medium in crossed electric and magnetic fields with closed electron drift. Such devices are attractive for the production, formation and manipulation of high current beams of heavy ions. This is related to the fact that such beams cannot exist without electron compensation of their positive ion space charge. The electrostatic plasma lens is a well-developed plasma-optical device for focusing and manipulating high current, large-area, heavy ion beams, where the concern of beam space charge neutralization is critical [1,2]. Following an extensive program of investigation of the plasma lens at the IP NASU (Kiev), some collaborative work between the Kiev group and LBNL (Berkeley) was initiated, and the results of this joint work have been published [3,4]. In these investigations we demonstrated the value of application of the plasma lens for carrying out high dose ion implantation processing [5]. A vacuum arc ion source was used to form a wide-aperture (diameter 10 cm), moderate-energy (10–50 keV), heavy metal ion beam (Bi, Pb, Ta, Cu, Zn, Co), which was focused by an electrostatic plasma lens that had been designed, made and tested at the IP NASU. We showed that the ion beam current density focused onto the implantation target could be increased by a factor of 30–40. We explored the variation of the ion current density profile at the target as a function of plasma lens parameters, and preliminary tests of high-dose ion implantation (dose up to 5×10^{17} cm^{-2}) of C and Co into a silicon substrate were carried out. The lens used in these experiments employed a magnetic field that was formed by conventional current-driven electromagnetic coils. We noted an increase in the focused ion beam current density for specific low magnetic field strengths. We found a very narrow range of low magnetic fields for which the optical properties of the plasma lens improve significantly. Under these conditions, the plasma noise within the lens volume is drastically reduced, and high beam compression can be obtained. This opens up the attractive possibility of a new generation of compact, low-cost lenses that are based on the use of permanent magnets rather than conventional current-driven field coils. Such improved lenses, having low noise and minimal spherical aberrations, could be suitable for use in the injection beam lines of high current heavy ion particle accelerators, where there exists a severe concern of beam space-charge blow-up. Experimental investigations of the focusing properties of a plasma lens based on permanent magnets for establishing the required magnetic field configuration were carried out collaboratively both at the IP NASU and at LBNL [6]. The plasma lens used at LBNL is shown on Fig. 1.

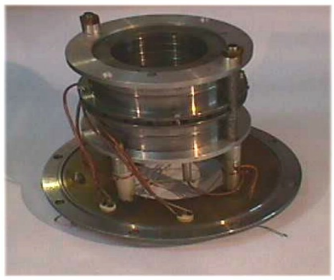

Fig. 1. Electrostatic plasma lens based on permanent magnets. Input aperture 10 cm, length 15 cm, number of cylindrical electrodes 11. The magnetic field strength formed by the Fe-Nd-B permanent magnets at the center of the lens is 300 G

One particularly interesting result to come out of this background work was the observation that the plasma lens configuration, involving crossed electric and magnetic fields, provides an inherently attractive method for establishing a stable plasma discharge at low pressure. Use of the plasma lens configuration in this way was further investigated, leading to a low cost, low maintenance, plasma device using permanent magnets and possessing considerable flexibility with respect to spatial configuration (planar, cylindrical, elliptical).

Here we describe the operation of some novel axial-symmetric plasma devices based on the plasma lens configuration, and summarize the results of some preliminary experiments in which their application for ion treatment was investigated.

2. ION TREATMENT PLASMA DEVICES

We made and tested one particular version of cylindrical plasma device based on plasma optic principles and the plasma lens configuration, designed for the ion treatment of substrates with complicated cylindrical shape. A simplified schematic of this device is shown in Fig. 2.

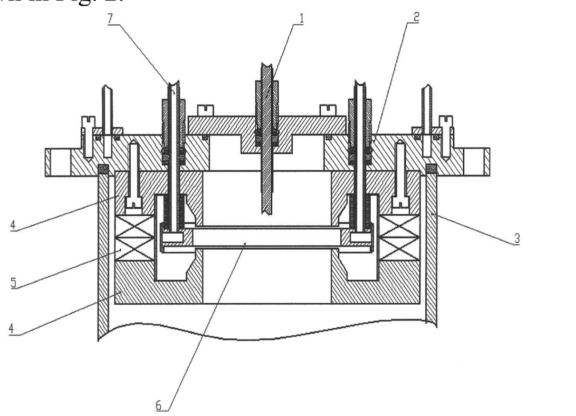

Fig. 2. Schematic of ion-cleaning plasma device. 1 - sample holder; 2 - flange; 3 - chamber; 4 - pole of the magnet system; 5 - magnets; 6 - anode; 7 - anode holder

The operation of this device was investigated experimentally. Device parameters optimized included the magnetic field strength and configuration, width and length of plasma channel, working gas pressure and manner of feed gas, value of anode potential and dependencies of volt-amperes characteristics for different pressures. We found that under optimal conditions this device can form an ion-plasma flow focused on a cylindrical substrate of diameter 10–40 mm with total ion current up to 10–30mA and energy in the range 300–2000 eV. The device operates reliability and reproducibly in the range of working gas (argon) pressure (6–12) $\times 10^{-4}$ Torr. Under these conditions the maximum cleaning (etching) rate is in range 0.5–3.4 nm/s depending on the substrate material. Determination of the etching

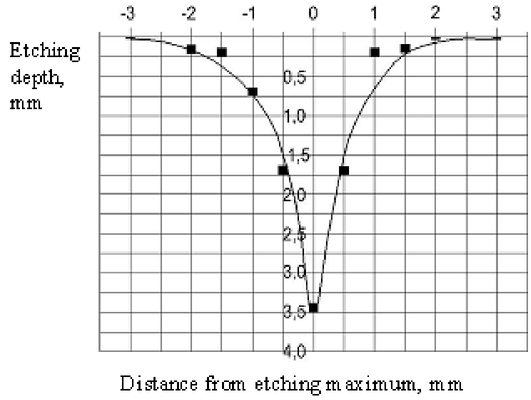

Fig. 3. Etching depth profile

rate was done for a range of materials including titanium, molybdenum, tungsten, copper, ceramics 22XC, and polycor. As an example, we determined the surface etching profile for a round titanium tubular substrate of 40 mm diameter. The following experimental conditions were used: gas pressure 9×10^{-4} Torr, discharge voltage 900 V, the ion treatment duration 60 minutes. The results of these measurements are shown in Fig. 3.

It can be seen that the width of the erosion trace at the sample surface spans about 5–6 mm. The most intense etching occurs over a ring-shaped region of 2 mm width at the center of the erosion trace. The etching rate at the center is ~1.0 nm/s. For other materials the following were measured: Mo ~1.3 nm/s; W ~1.7 nm/s; Cu ~3.0 nm/s; ceramic 22XC ~0.4 nm/s; polycor (polycrystalline aluminum oxide) ~0.15 nm/s. The working gas pressure also influences the etching rate, as clearly illustrated for the case of Cu: for an Ar pressure of 9×10^{-4} Torr the etch rate is ~3.0 nm/s; for a pressure of 8×10^{-4} Torr, 0.6 nm/s; and for 7×10^{-4} Torr, 0.5 nm/s. The etch rate also depends on the energy of the ions. Since, as the ion energy is varied, not only does the sputtering coefficient change but also the current density as well, thus the dependence of etch rate on energy is close to linear. The working parameters of this ion cleaning device allow this tool to be combined with a cylindrical magnetron sputtering system so as to form a single hybrid processing mode.

3. MULTIFUNCTIONAL VACUUM SETUP

To further test and develop our new plasma-optical and magnetron sputtering devices, a new multifunctional setup (Fig. 4), was made. The inverted cylindrical magnetron allows sputtering of the internal surfaces of cathodes onto all sides of three-dimensional substrates placed inside the tubular target. This enables coating deposition onto long-length articles, such as wires, fibers, rods, biomedical stents and implants.

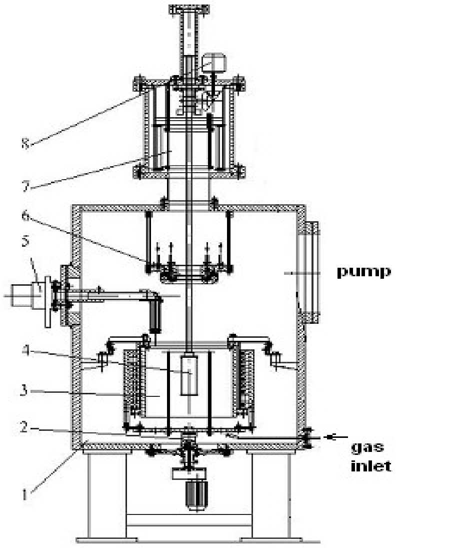

Fig.4. Multifunctional vacuum setup.
1 - vacuum chamber; 2 – rotational drive for magnetron magnetic system; 3 - magnetron; 4 - processed sample; 5 - optical monitor; 6 - ion cleaning plasma devices; 7 - heater; 8 - drive for vertical displacement of the sample

The cylindrical dc magnetron sputtering system includes a tubular water-cooled cathode with internal diameter 230 mm and height 200 mm, a rotating magnetic system using SmCo permanent magnets, power up to 8 kW, discharge voltage up to 700 V, and a rotating magnetic field system for increasing target material utilization. The anode system of the inverted cylindrical magnetron includes 9 rod electrodes made of non-magnetic material (molybdenum or stainless steel X18H10T), each 6 mm diameter and 140 mm long and placed like the magnetic system on a rotating table. This allows rigid fixing of the anodes with respect to the magnets, and provides minimum shielding of the flow of sputtered cathode material. Target material usage efficiency of up to 70% has been achieved.

The use of the ion cleaning device together with the magnetron sputtering system was complicated by the difference in optimal argon gas pressure needed for steady operation of each device (2×10^{-3} Torr and 9×10^{-4} Torr for magnetron and ion-cleaning device, respectively). In the process of experimental investigations we found some conditions for which pressure compatibility occurs for both devices at a gas pressure of about 2×10^{-3} Torr.

4. CONCLUSION

The plasma-optical devices that we have described can be used separately, for example for ion treatment of substrates, and in combination with each other for pre-cleaning surfaces and deposition of functional metal and nonmetal coatings on round substrates in a single processing cycle, for example on anilox rolls which are used in the printing and textile industry. The d.c. ion-plasma devices also allow reactive deposition of binary chemical compounds (e.g., nitrides, oxides, carbides) with nanostructure of interest for basic and applied investigations in the field of nanotechnologies.

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ПЛАЗМЕННЫЕ ПРИБОРЫ ДЛЯ МАНИПУЛИРОВАНИЯ ИОННЫМИ ПУЧКАМИ И ПЛАЗМЕННОГО ОСАЖДЕНИЯ

А. Гончаров, А. Демчишин, А. Добровольский, Е. Костин, О. Панченко, С. Павлов, И. Проценко, Б. Стеценко, Е. Терновой и Я. Браун

Описываются некоторые новые плазменные приборы, основанные на принципах плазмооптики и конфигурации плазменной линзы. Приборы такого типа, в которых используются постоянные магниты, могут применяться для ионной обработки и получения новых материалов.

ПЛАЗМОВІ ПРИЛАДИ ДЛЯ ВИКОРИСТАННЯ З ІОННИМИ ПУЧКАМИ ТА ПЛАЗМОВОГО ОСАДЖЕННЯ

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Описуються деякі нові плазмові прилади, основані на використанні принципів плазмооптики та конфігурації плазмової лінзи. Прилади такого типу, що використовують постійні магніти, можуть застосовуватись для іонної обробки та отримання нових матеріалів.