The Installation for Ion Treatment of Constructional Materials with Mixed Beam

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Abstract – The design and performance data of a 70 keV and total current of beams up to100 mA mockup of implanter for the modification properties of surface constructional materials are described. The two-stepped ion source TIS on low pressure in crossed ExB fields has been developed. Non-separated beam of charged particles gas G^+ and metal Me^+ is obtained in two chambers device of coaxial geometry. One step was a source of radial converging gas plasma flow for two steps – internal cylindrical chamber-ICC, where the axial isolated electrode SE is placed. ICC may be serves a) as expander for obtaining ion nitrogen and b) cavity for generation a multi-components plasma is created by means of sputtering Me target SE. TIS worked as bipolar diode with opened discharge ICC for obtaining broad beam of the gas or of the mixed ion beam. One with relationship roughly equal 1 for G^+/Me^+ was obtained by total current ~6 mA.

1. Introduction

A non separated beam of charged particles consisting of ions gas G and metal Me can be efficient tool for modification of the surface properties of materials [1, 2]. A stationary ion mixed beam with current greater 1 mA and roughly equal a fractions of ion G^+ and Me^+ may be obtained from gas-metal plasma [1, 3, 4] with total concentration $N_i \geq 10^{15}$ m^{-3}. Multi-component plasma MP can be obtained with sputtering Me electrode, by means of glow discharge d.c. [1, 3–6]. A sputtered electrode SE of required metal Me is introduced into discharge spacing with negative bias related to gas plasma potential. Ions are routinely extracted from region near sputtering target. This method of generation multi-component plasma presents a considerable difficulty.

A velocity of sputtered particles exceeds ther-mal one roughly an order of magnitude. Size of sputtered electrode and its potential makes influence on the structure and properties gas discharge in similar geometry [3–6]. A device with Me target placed in discharge spacing play a part either a big probe or another cathode [4–6]. Only singly or doubly charged ions permit to obtain beams of available intensity for modification surface properties. MP plasma is generated by sputtering Me target consist of ions with various charges. It can hold concentration Me^+ and G^+ required for formation mixed ion beam.

The problem of obtaining mixed ion beam of available intensity can be reduced in this case to the solution of two challenges: 1. Generation of dense gas plasma. 2. The creation of MP with required relationship of density ions G+ and Me+ by means of sputtering target with gas plasma.

2. Description of the Installation

A schematic diagram of the mockup implanter is shown in Fig. 1.

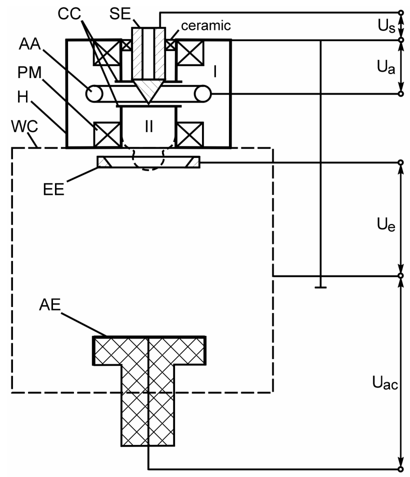


Fig. 1. Scheme is of installation witch two-stepped ion source. EAC-I, ICC-II respectively, external and internal chambers ion source; AA – annular anode, CC – cold cathodes; PM – permanent magnets; H – housing source; SE – sputtered electrode; EE, AE – extracting and accelerating electrode, respectively; WC – working chamber. U_a – discharge voltage; U_s – voltage of SE; U_e – extracting voltage; U_{ac} – accelerating voltage

One was designed for operation free of computer control. The installation consist of a target chamber WC 0,5×0,5×0,5 m^3 with a large access door and accelerating electrode AE on this vertical axis. In the front door and two windows allows visual inspection of the interior of the chamber. Stainless steel AE with diameters 0,2 m served as table for ion beam treatment samples simultaneously. On top of target chambers is mounted ion source TIS. WC and TIS is at ground potential. Design a two-stepped source on low pressure discharge in crossed $E{\times}B$ fields allows to solve challenges 1 and 2. The mixed ion beam of circular section can easily be obtained in device with coaxial position discharge chambers. The vacuum system of the installation is involved a 1500 l s^{-1} diffusion pump and a 10 m^{3}h^{-1} roughing pump. A pressure is of about $1{\cdot}10^{-5}$ Torr. achieved in the WC in approximately 1,5 h. During implantation the pressure rises to 1^{-2}–10^{-4} Torr. The gas supply system consisted of inlet needle valve supplied via a reducer. Fig. 1. External annular chamber EAC with cold cathodes-CC serves as the gas plasma source for internal cylindrical chamber ICC. These EAC and ICC are made from magnet steel. Annular anode AA made from nonmagnetic materials and cooled by water is forward biased to annular gap between cathodes. Gas plasma of discharge via annular gap penetrates into ICC. Gas plasma source efficiency is evaluated by density of penetrating plasma in ICC.

The cathodes system CC consist of two electrodes are made of magnetic steel symmetrical arranged on azimuth plane of anode. They build up annular gap for exit of the gas plasma in ICC. An active part of surface cathodes EAC are sharp edges facing to anode. The anode surface facing to cathodes is made in the form of electrode Felici, that for the electrical field near its surface to be uniform. The sources of magnetic fields EAC are annular permanent magnets. Uniform magnetic field B_0 in gap between cathodes and in discharge spacing can be slightly varied by means of moving them along the vertical. The magnitude of the induction measured in gap is B_0=(10÷100) mT. ICC with axial insulating electrode SE may be served as a) expander cup for obtaining gas ion beam b) cavity for generation gas-metal plasma by means sputtering of target SE for obtaining mixed ion beam. Diameter channel extraction approximately equals in magnitude dimensions ICC. Ion beam is shaped by means electrical fields of extracting EE and accelerating AE electrodes. EE made from stainless with diameter slightly over that one cylindrical chamber. Power supplies electrodes TIS (A, SE, EE) consist of commercial high voltage rectifiers with falling performance of BP-100. They are voltage up to 7 kV and current up to 1 A.

The construction of ion source (Fig. 1) has regulated heat-removal from SE. It is achieved by means of the change of cooling water parameters and heat resistance between solid target and axial heat-insulated electrode SE. The surface temperature of target may range from 300 °C to 1000 °C and more. The temperature of fusion for Al, Cu and different metals is easily achieved.

3. Operation of the Installation

The discharge of low pressure in EAC is initiated by either in ordinary magnetron (8). A glow discharge is initiated in crossed radial E_r and axial B_d fields at $pd{\geq}(pd)_{\min}$ (d – is the spacing in the region of the left branch of the Paschen curve) (7).

The EAC by pressure $10^{-4}{\cdot}10^{-2}$ Torr had two operation modes: a) the high voltage V_a=(1÷5) kV by current I_a<100 mA and *b*) low voltage U_a<1kV but high current I_a=(0,1÷0,3) A. The second mode is more essential for obtaining dense gas plasma. The current-voltage characteristics for cathodes made with triangle profile facing the anode are presented in Fig. 2. The continuous evolution operating regime of discharge in described conditions is possible only in direction indicated by arrow. The view of the current-voltage characteristics essentially depends on geometry discharge spacing [4, 5, 7, 8].

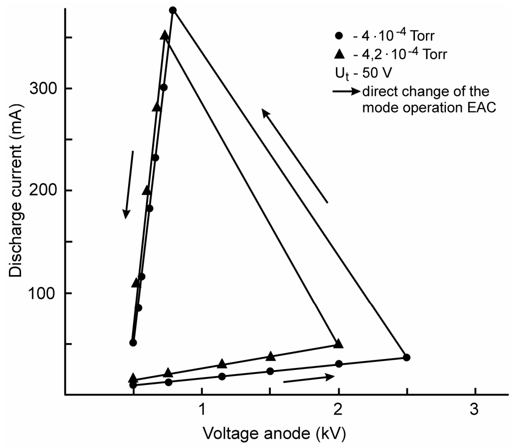


Fig. 2. Current – voltage characteristics of the EAC. U_t – voltage of the SE

The influence axial component B_a-field is essential for electrons. The oscillation electrons along lines of magnetic uniform field in the gap leads to increase density of plasma at exit of the ICC. If the size of gap is more than ion layer thickness on surface of cathodes then the plasma penetrates in ICC and encloses the SE. Penetration plasma flow in cylindrical cavity created in ICC plasma anode with surface – emitted of ions. In this case axial rode SE is immersed in plasma and can be: a) source of energetic electrons for gas plasma or, b) one atoms of metal target for creating gas-metal plasma GMP.

The pressure of vapor Me and concentration atoms of the solid target in ICC depends on: parameters of gas plasma a) density charged particles – N_i and temperature of electrons – T_e; b) total difference of the potential between the SE and plasma – ΔU; c) surface temperature of the solid target – T_s [4, 9, 10].

Efficiency sputtering of solid target depends upon energy of the bombarding gas ions – E_i and their concentration in plasma – N_i. The E_i – is determined by the total difference of the potential U_0 between the gas plasma and SE. The potential of plasma equals nearly to it of anode EAC, therefore all ions would acquire close to the electrode layer of a big probe.

$$E_i = eU_0 = e(U_a + U_s). \quad (1)$$

Here are U_a and U_s – the potentials of plasma and probe SE relative to housing EAC, respectively.

Thus the saturation current density for large negative probe SE at ionic density of gas plasma N_i=(10^{10}–10^{12}) cm^{-3} is range from j_i=(2,5 to 25) mA cm^{-2} it may be obtained at high partial pressure for various metals by means sputtering respectively. The most part energy of ions E_i (>90 %) goes into heating solid target, therefore resulting concentration N_m atoms Me in ICC depends on target sizes, gas pressure and also temperature of target – T_s also that is changed by means of regulating removal heat. One can avoid some of the difficulties with high velocities sputtered neutrals by means of injection atoms Me having thermal velocity for temperature of target – T_s. The N_m is determined by the composition energy spectrum sputtered and sublimated atoms Me [9, 10]. In conditions ICC the most part sputtered atoms with energy E>1 eV will deposit at walls at diffusive – free path operation regime. The use of sublimation because of heating target with plasma allows to essentially increase concentration atoms Me in cavity ICC. The losses of energetic sputtered atoms will be compensated by neutrals with thermal velocities.

4. Experimental results

The concentration penetrating of the plasma was estimated with a big ion probe. The wall of EAC was used as the basis-electrode in experiment. The axial rode with geometry SE served as ion probe. The data of measurements showed, that average in area of probe ion concentration nearly equals N_i~10^{15} m^{-3}.

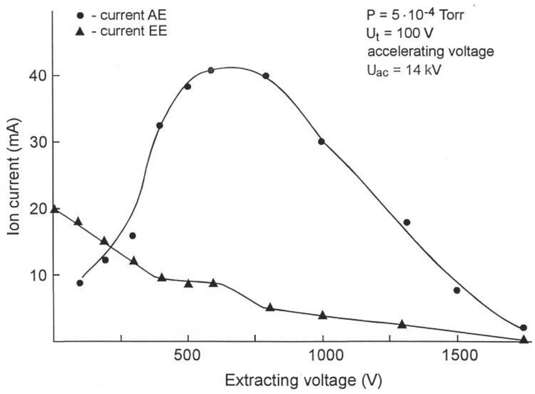
The installation (Fig. 1) operating in mode open discharge is aperture emission of channel extraction equal nearly in diameter ICC. The gradient of pressure between ICC and working chamber WC is only slight. The plasma inside of ICC builds up the form and position of emission surface according to the resulting external electrical field – E_0 which is a sum of electrical fields SE, EE and AE (11). Currents on the AE and the EE depends upon voltage on the latter is demonstrated on Fig. 3, *a*, *b*.

The convex surface of plasma with bubble on epy axis of TIS is set at little voltages (U_e<300V) in aperture emission of channel, fig. 3, *a*. The size of the plasma bubble is several cm in diameter and it is placed by approximately in plane the extracting electrode by small U_{ac}.

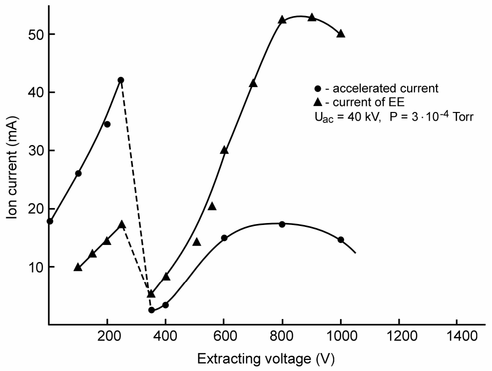
The increase the voltage on EE by U_e>300 V leads to total stopping of ion beam at low accelerating voltage for small ionic density. The emitting surface of plasma in ICC transfers to ringshaped gap EAC. In this case current of beam on the EE and AE is zero. The system plasma-layer can transform in given geometry of electrodes from one state to other by the action disturbance flows second particles knocked out ions from the EE and the AE. The spasmodic transition of system accompanies conversion of the plasma volume in ICC and redistribution of currents on EE and AE. The tolerance configuration of the volume of plasma in ICC determined from density of plasma – N_e and of the external resulting field E of electrodes.

The efficient of ionization atoms of the target, having velocity order thermal will depend on the electron concentration – N_e and their temperature – T_e for conditions specific geometry ICC free from magnetic field.

The Te can be increased by means of injection of energetic electrons in the plasma. The bombardment of the accelerated ions to energy E_i=(10–50) kV and I_i=(5–30) mA metal surface of the AE leads to knockout secondary electrons by coefficient ion-electron emission – K≈(2–3) [12].



a)



b)

Fig. 3, a, b. Distribution of the currents on the AE and the EE as function of the form and the position of emitting plasma surface

They are accelerated with the same electrical field and injected into MP plasma. The energy spectrum and concentration of electrons of plasma is changed essentially. Saturation vapor pressure in order 10^{-5} is achieved for a good many of Me at 1500 K. The availability a great deal of sublimated atoms Me in ICC leads to the establishment of resulting distribution on velocity with characteristic temperature in order it target surface. The efficient ionization of atoms-Me is increased in this case. Superposition sputtered and sublimated atoms Me allows to ignite forced discharge in vapor-gas mixture the ICC at fixed bias of probe – target SE. The results on the GMP is shaped free-drop mixed beam of charged particles Me^+/G^+ in mA range. The mass-spectrum ion beam on the AE is shown on Fig. 6. The results are consistent for diameter of plasma bubble. The relationship of charged components – Me^+/G^+ on periphery is decreased step by step.

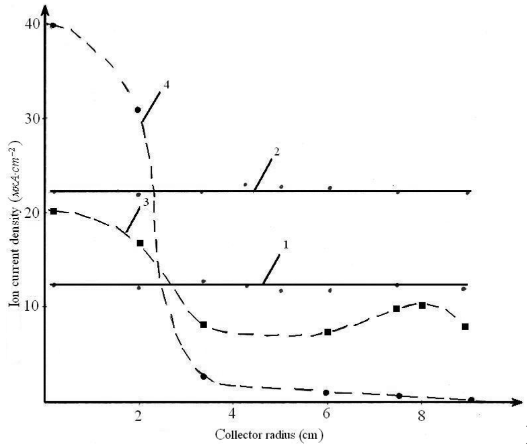


Fig. 4. Current density of the ions measured with a system small Faraday cup

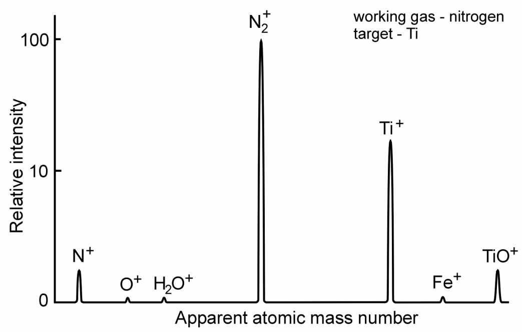


Fig. 5. Mass spectrum of the mixed ion beam

A non-separated drop-free beam of this source contains a high fraction atoms-Me. The flow of atoms-Me can prevail it of ions-Me^+ and G^+. A radial distribution of ions-Me^+ within the limits ±10 % is uniform for area respective to projection diameter of the plasma bubble on the AE.

5. Conclusion

A non-separated drop-free beam of charge particles consisting of G^+ and Me^+ allows to achieve relationship of charged component ~1 with total current of the beam ~6 mA.

The two-stepped source in coaxial geometry TIS can be used for research connected with implantation, mixing and deposition of intermediate layers and as model served for development process ion source.

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