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Bernas ion source discharge simulation[a]

I. Roudskoy, T. V. Kulevoy,[a] S. V. Petrenko, R. P. Kuibeda,
D. N. Seleznev, and V. I. Pershin
Institute for Theoretical and Experimental Physics, Moscow 117218, Russia

A. Hershcovitch and B. M. Johnson
Brookhaven National Laboratory, Upton, New York 11973, USA

V. I. Gushenets and E. M. Oks
High Current Electronics Institute Russian Academy of Sciences, Tomsk 634055, Russia

H. P. Poole
PVI, Oxnard, California 93031-5023, USA

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As the technology and applications continue to grow up, the development of plasma and ion sources with clearly specified characteristic is required. Therefore comprehensive numerical studies at the project stage are the key point for ion implantation source manufacturing (especially for low energy implantation). Recently the most commonly encountered numerical approach is the Monte Carlo particle-in-cell (MCPIC) method also known as particle-in-cell method with Monte Carlo collisions. In ITEP the 2D3V numerical code PICSIS-2D realizing MCPIC method was developed in the framework of the joint research program. We present first results of the simulation for several materials interested in semiconductors. These results are compared with experimental data obtained at the ITEP ion source test bench. [DOI: 10.1063/1.2823897]

INTRODUCTION

The joint research and development program is continued to develop steady-state ion source for ion implantation industry. In the framework of investigation of low energy beam generation for ion implantation the ITEP version of Bernas ion source is used.[1–3] As the technology and applications continue to grow up, the development of plasma and ion sources with clearly specified characteristic are required. Therefore comprehensive numerical studies at the project stage are the key point for ion implantation source manufacturing. Universal plasma models based on Vlasov-Boltzmann equation can be used to describe a wide variety of these sources. Recently the most commonly encountered numerical approach to solve this equation is the Monte Carlo particle-in-cell (MCPIC) method also known as particle-in-cell method with Monte Carlo collisions. In this paper we present the 2D3V numerical code PICSIS-2D realizing MCPIC method and the results of simulations applied to Bernas ion sources.

SIMULATION MODEL

The ion source plasma consisted of electrons and ions with different charge states is described by their distribution functions $f_k(\mathbf{x},\mathbf{v},t)$, where $\mathbf{x}$ is the particle position and $\mathbf{v}$ is the particle velocity. As usual the distribution functions f_k give the probability to find particles of sort k in a given volume of phase space. The neutral gas is treated as a uniform background of atoms or molecules with a constant temperature. The following processes are included into consideration: elastic electron-electron, electron-ion, and electron-neutral collisions; and inelastic ionizing and exciting collisions with neutrals and ions, elastic ion-neutral collisions and charge exchange collisions. The electric field $\mathbf{E}$ is calculated by solving the Poisson equation. The external static magnetic field $\mathbf{B}$ for simulation can be imported from either analytical solution or other simulation code or can be set as an experimental data table also. The influence of time varying magnetic field induced by currents of charged particles is neglected because it is much smaller than the one of other forces acting on the particles. To represent the distribution functions f_k, finite element or quasiparticle methods are used for the Monte Carlo particle-in-cell numerical approach. Trajectories of particles in phase space represent the evolution of the respective distribution functions and can be found by time integrating of the motion equations: The motion equations are solved using explicit time-centered leapfrog algorithm.[4,5] To solve the Poisson equation, the double fast Fourier[6] transformation in a two-dimensional (2D) geometry (plane or cylindrical) is used.

To choose a time between collisions, to pick up a particular event and to define postcollision velocities, the Monte Carlo technique is used. Elastic collisions with neutrals are regarded in hard sphere approximation. For inelastic collisions the respective analytical or experimental differential cross sections are applied. Binary collisions of charged particles are regarded in the way described by Refs. 7 and 8. To define an interaction range for colliding particles we use the

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[a] FAX: +7-(495)-123-3028. Electronic mail: kulevoy@itep.ru.

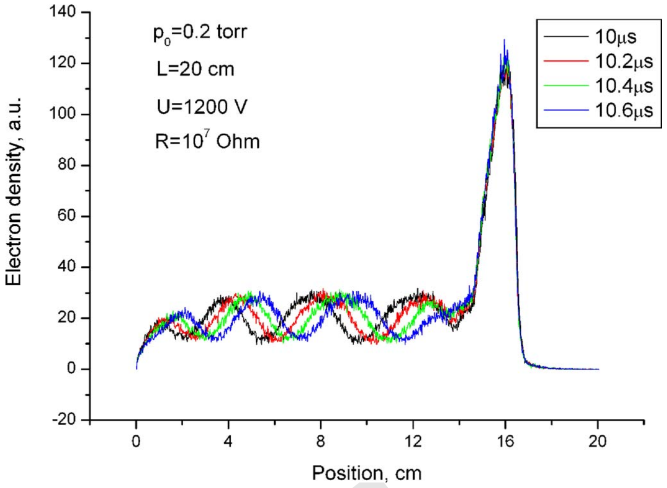

FIG. 1. (Color online) Time evolution of electron density in the discharge. Position of the anode $x=0$; cathode: $x=20$ cm.

same mesh as on solution of the Poisson equation. Small-angle scattering probabilities are supposed to follow the well-known Spitzer equation.[9]

NUMERICAL RESULTS

At first, the model described above was tested on the problems having analytical solutions: the development of two-beam instability, the ion charge state relaxation, the charged particle drift in crossed electric and magnetic fields, the momentum isotopization, and establishing of thermal equilibrium in plasmas. After that, the code was applied to the simulation of dc glow discharge. We have simulated the development of dc glow discharge in a tube of 20 cm long and 1 cm in diameter filled with hydrogen under the pressure of 0.2 Torr. It was assumed that the voltage of 1200 V was applied through the resistor of 10^7 Ω to the platinum electrodes. Elastic scattering, ionization, and excitation of vibration, rotation, and main electronic levels were taken into account as well as secondary electron emission from the cathode under ion impacts. All particles reaching the walls or electrodes are considered as killed. To initiate the discharge, it was supposed that the cathode can emit electrons with the temperature of filament (~0.1 eV). About 10^6 finite particles were under consideration. It was found that in 5 μs after the beginning the discharge became stabilize and steady-state discharge current remains approximately the same during all computational time (up to 50 μs). The values of cathode drop U_c (~280 V) and the thickness of cathode layer d_c (~5.1 cm) are in a good agreement with tabulated experimental data—276 V and 5 cm, respectively. Moreover the simulation showed the strata movement toward the cathode in accordance with experimental observations (Fig. 1). The more fine structure of the discharge (Aston and cathode dark spaces) can be also distinguished by analyzing of electron energy distribution.

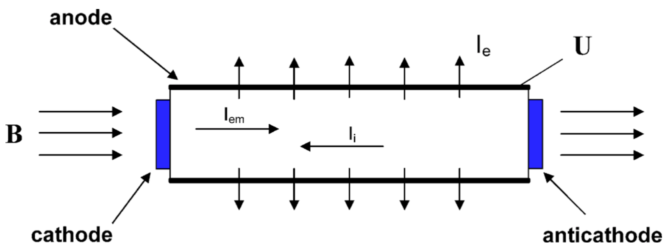

FIG. 2. (Color online) Pictorial description of Berna's ion source. Blue: cathode and anticathode; Black: anode; U: discharge voltage; B: magnetic field; I_{em}: electrons' flow cathode to plasma; I_e: electrons' flow from plasma to anode; I_i: ions flow from plasma to electrodes.

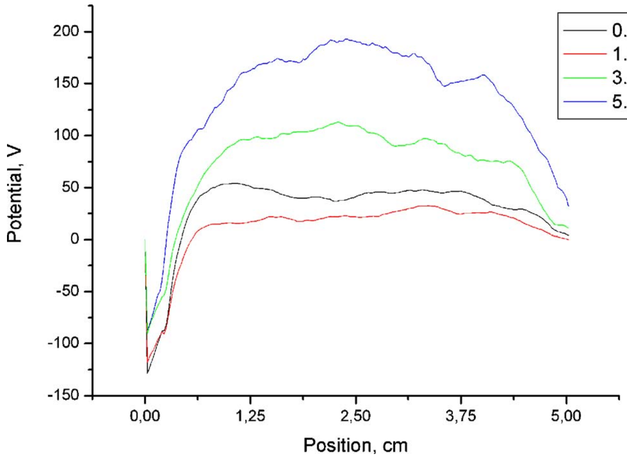

FIG. 3. (Color online) Electric field distributions in the ion source vs time: along the axis, (b) at the middle plane (L=2.5 cm). Sb, L=5 cm; R=0.5 cm; $n_0=10^{13}$ cm^{-3}; B=600 Gs; U=280 V; T_{em}=2700 K.

Finally, the code has been applied for simulation of Bernas ion sources operating in ITEP (sketch of model is shown in Fig. 2).[1] It was found that both the steady-state values of current discharge (I_d=260 mA) and the current of the extracted ions (I_1=10 mA for Sb^{+1}) are in a good agreement with experimental data.[3] In Figs. 3 and 4 the potential longitudinal and transversal distribution are shown. The 2D distribution in the discharge region is shown in Fig. 5. The simulated ion charge state distribution is in a good agreement with experimental data from Ref. 1 as well. The simulation of extreme parameters (high magnetic field into discharge region) showed that the discharge could not start due to significant suppression of electron emission by the negative space charge.

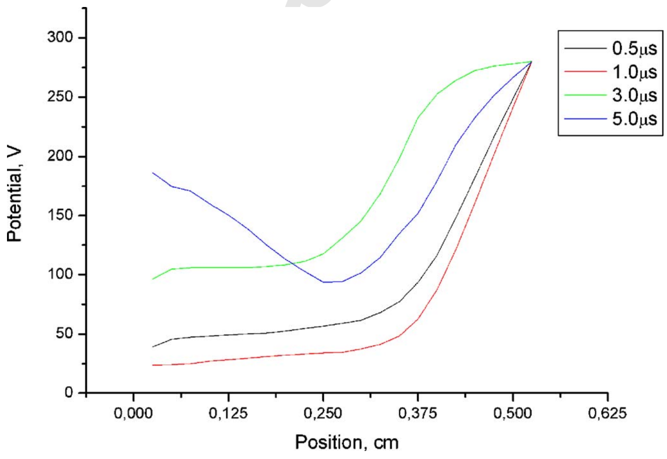

FIG. 4. (Color online) Electric field distributions in the ion source vs time: at the middle plane (L=2.5 cm). Sb, L=5 cm; R=0.5 cm; $n_0=10^{13}$ cm^{-3}; B=600 Gs; U=280 V; T_{em}=2700 K.

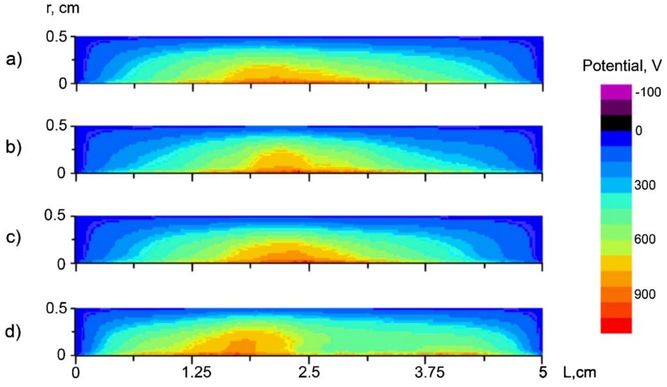

FIG. 5. (Color online) Steady-state 2D distribution of the electric field. (a) 5 μs; (b) 10 μs; (c) 15 μs; (d) 20 μs.

CONCLUSION

The results obtained clearly confirm that the numerical code developed in framework of the GRANT represents an adequate model of physical processes in the wide range of ion source plasmas. We use it for investigation of Bernas ion source for low energy implantation. As well we hope that after some modifications and improvements it will useful for electron cyclotron resonance ion sources modeling.

ACKNOWLEDGMENTS

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AUTHOR QUERIES — 165891RSI

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