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APPROBATION OF A HIGH-EFFICIENCY COLD CATHODE ION SOURCE AS PART OF AN ION IMPLANTATION SYSTEM BALZERS MPB-202

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The Institute of Applied Physics of the National Academy of Sciences of Ukraine has developed a design of a highly efficient ion source for ion implantation with Penning system cold cathode. Ionization of a solid-phase substance occurs due to interaction with fast oscillating electrons in a longitudinal magnetic field. A beam of ions of the plasma-forming gas and the sprayed solid-phase substance is extracted through a cylindrical hole of the emission cathode with a diameter of 1.6…1.9 mm. The ion source was tested on the BALZERS MPB-202 ion implanter at the V. E. Lashkaryov Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine.

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INTRODUCTION

Ion implantation is one of the basic methods of introducing impurities into solids during the manufacture of semiconductor devices. To implement this process, ion sources are used that can work with gaseous or solid materials. The ion source must provide the formation of high ion currents, have a simple and reliable design, be compact, use a simple power source, and also have a long period of continuous operation [1, 2]. Existing metal ion sources are classified into two main groups depending on the mechanism of ionization of atoms in the discharge chamber [3]. The first group includes hot cathode sources designed for the implantation of gaseous substances or solid materials with a melting point higher than the sublimation temperature [4]. The second group includes cold cathode sources of the Penning system, the principle of which is to spray a solid substance with plasma with subsequent ionization. One of the important requirements for such sources is the ability to effectively ionize substances with a high melting point, exceeding their sublimation temperature. Although hot cathode sources provide high ion currents, they are not suitable for implanting substances whose melting point is lower than the sublimation temperature. In this regard, the task of creating a highly efficient cold cathode source capable of providing effective ionization of materials arises. The design of such a source was developed at the Institute of Applied Physics of the National Academy of Sciences of Ukraine [5]. A description of the physical model and the algorithm for computer modeling of the extraction system and formation of an ion beam in a plasma ion source are presented in [6].

This work considers the adaptation of the developed source to the BALZERS MPB-202 industrial ion implantation system, which allows us to evaluate its performance in real operating conditions, determine the optimal power supply modes and stability of the plasma discharge.

EXPERIMENTAL RESEARCH

Fig. 1 shows a schematic representation of the BALZERS MPB 202 ion implantation system. It can be seen that the system consists of an ion source (1), an extracting lens (2), a focusing lens (3), accelerating electrodes (4), quadrupole lenses (5, 7), a mass-separator (6), a diaphragm (8), scanning plates (9), a deflector (10) and a target chamber (11). The designed cold cathode source of the Penning system was connected to the implantation system instead of a standard gas ion source. Sputtered inserts made of Be, Al, Ti and Cu materials were used as cathode and emission cathode materials for argon plasma excitation and ion beam formation.

To test the operating modes of the ion source and determine the operating time, the sputtering inserts (cathode and emission cathode) were made of Be, Al, Ti, and Cu. The accelerating voltage was 50 keV (ion extraction voltage from the source 21.3 kV, and the focusing lens voltage 14 kV) and 120 keV (ion extraction voltage from the source 25 kV, and the focusing lens voltage 17 kV). The adjustment of the elements of the ion-optical system (voltages on the extracting, focusing, quadrupole lenses and deflector) was carried out according to the principle of obtaining the maximum ion beam current for each of the energies. The vacuum in the chamber with the target was $3.5\cdot10^{-6}$ mbar, in the injector part $5\cdot10^{-6}$ mbar, during gas injection (Ar was used) the pressure was maintained at $8\cdot10^{-6}$ mbar. The optimal pressure range during discharge excitation was $(7\ldots9)\cdot10^{-6}$ mbar, which ensures a stable plasma discharge with relatively small losses of ion current due to scattering on atoms of the working gas (Ar), and also allows to avoid breakdowns in the middle of the accelerating tube and overloading of the extracting and focusing lenses. Schematically, the design of the BALZERS MPB-202 ion implantation system is shown in Fig. 1.

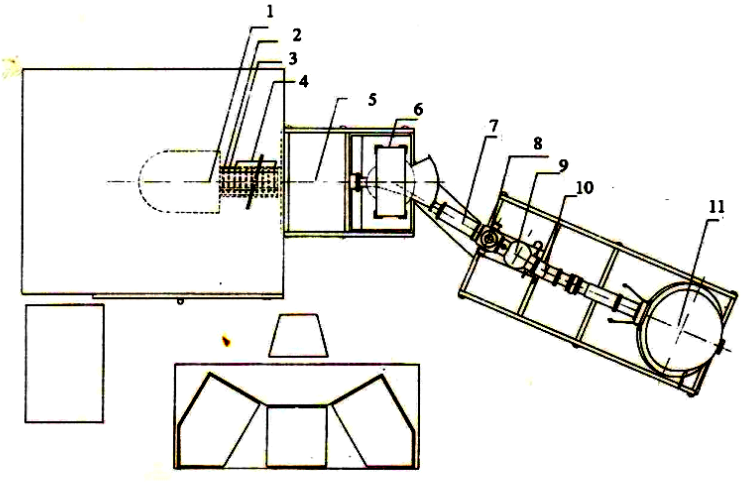


Fig. 1. Schematic representation of the ion implantation system BALZERS MPB 202: 1 – ion source; 2 – extracting lens; 3 – focusing lens; 4 – accelerating electrodes; 5 – first quadrupole lens; 6 – mass-separator; 7 – second quadrupole lens; 8 – diaphragm; 9 – scanning plates; 10 – deflector; 11 – target chamber

Since the supply voltage of the high-voltage terminal of the BALZERS MPB-202 ion implantation system is ≈110 V, and for the operation of the ion source, depending on the discharge current, a stable constant voltage of 300…480 V is required, for this purpose, an ion source power supply unit was developed, the power supply circuit is shown in Fig. 2.

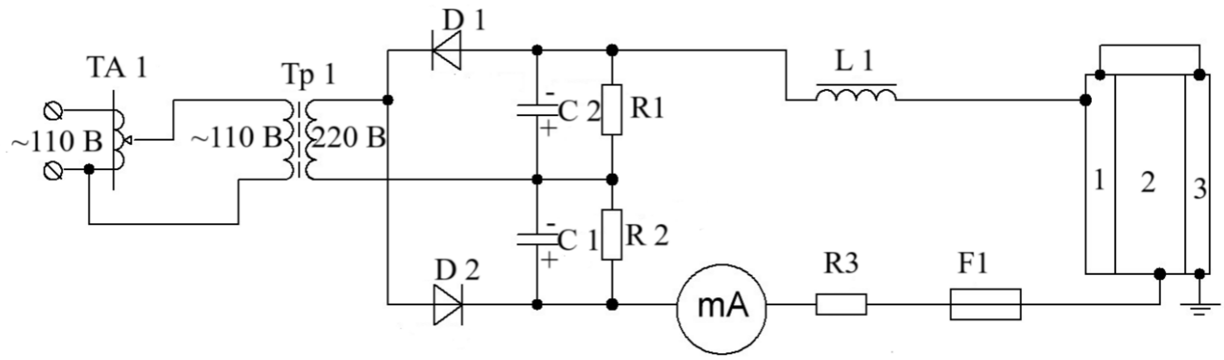


Fig. 2. Electrical diagram of the power supply for the ion source: TA 1 – autotransformer (~ 0…110 V), Tr 1 – step-up transformer (~ 0…110 V primary winding, ~ 0…220 V secondary winding), D1, D2 – diodes VA 10 – 10, C1, C2 – capacitors 1000 µF, 450 V, R1, R2 – resistors 82 kΩ, mA – milliammeter 0…800 mA, F1 – fuse 1.6 A, R3 – resistor 540 Ω, L 1 – choke 700 mH, 1 – cathode, 2 – anode, 3 – emission cathode

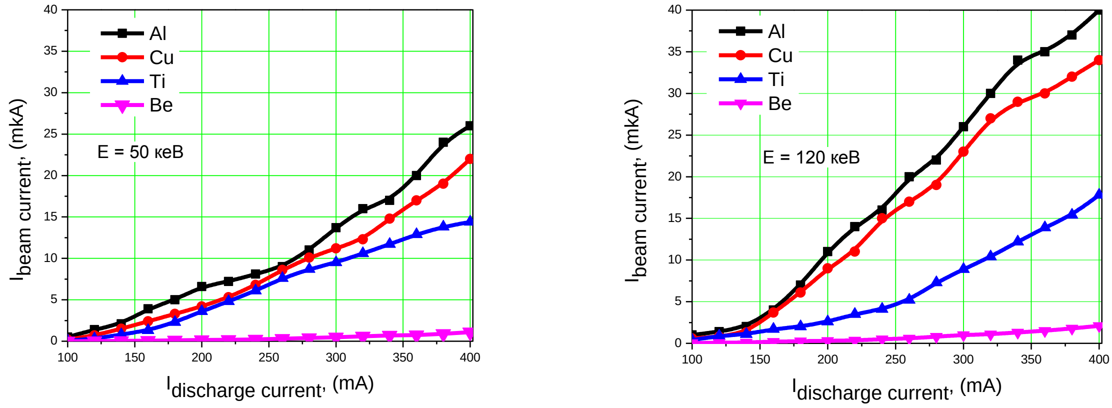
Using the autotransformer TA1 (regulation range ~ 0…110 V), the voltage in the secondary winding (regulation range ~ 0…220 V) of the step-up transformer Tr1 is controlled, part of the circuit – D1, D2, C1, C2, R1, R2 – a rectification and multiplication circuit with doubling by 2 times to 480 V. The resistor R3 – ballast and fuse F1 provide protection in the event of a short circuit, and the choke L1 – smoothes ripples and provides a stable constant voltage up to 480 V. This ensured stable operation of the source in a wide range of discharge currents.

RESULTS

To optimize the operation of the created ion source in the range of low and high implantation energies, the ion current of various elements was measured depending on the discharge current in the source. The current was recorded using a Faraday cylinder located after the mass separator, at two ion energy values – 50 and 120 keV.

Fig. 3,a shows the dependence of the ion current for the elements Al, Cu, Ti, and Be on the discharge current for ions with an energy of 50 keV. It can be seen that an increase in the discharge current to approximately 250 mA leads to a linear growth of the ion current of the elements. Reaching this limit causes a more intense growth of the current of Al and Cu ions, while the growth of the current of titanium ions remains moderate. The ion current of beryllium practically does not change, which indicates a low efficiency of ionization of the element.

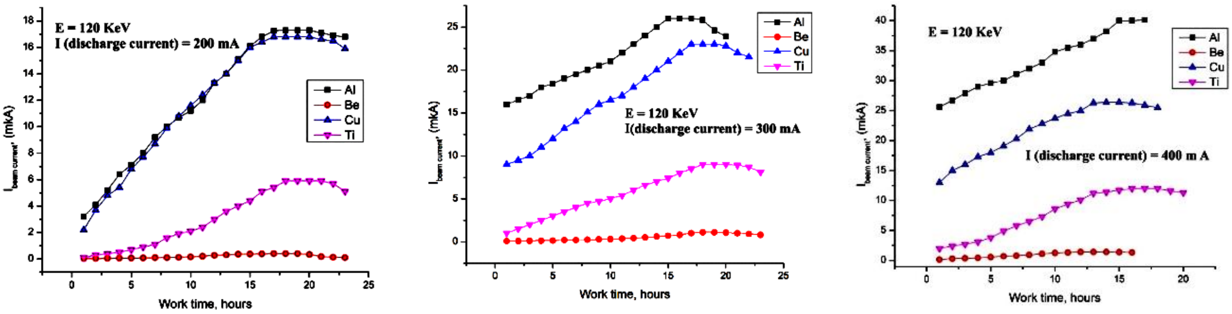
Fig. 3,b shows similar dependences for the ion acceleration energy of 120 keV. It can be seen that the currents of Al and Cu ions begin to increase noticeably already when the discharge current exceeds 140 mA. At the same time, the current of titanium ions continues to increase linearly up to 250 mA, after which its increase also becomes more effective. This behavior of the dependence may be associated with the transition of the discharge to the regime of increased plasma density. This situation is not realized in the case of beryllium, although the ion current of beryllium is somewhat higher than in the case of the energy of 50 keV.



a b

Fig. 3. Dependence of the ion current for the elements Al, Cu, Ti, and Be on the discharge current at an acceleration energy of 50 keV (a) and 120 keV (b)

Fig. 4 shows the changes in the ion beam current over time at an energy of 120 keV for different values of the discharge current: 200, 300, and 400 mA. It can be seen that with an increase in the discharge current, there is a significant increase in the ion current for all the studied materials. At 200 mA, the Al and Cu ion currents demonstrate close time dependencies. Increasing the discharge current to 300 mA leads to a more effective increase in the Al current compared to Cu. At the same time, the stable operation time of the aluminum cathode decreases faster than that of the copper one. At 400 mA, the Al ion current still increases, but is accompanied by a significant reduction in the cathode resource. Titanium is characterized by a less intense increase in the current with sputtering time, but the duration of stable operation of the source is longer. For beryllium, the beam current depends weakly on the discharge current, but the source lifetime decreases noticeably with an increase in the discharge current due to surface degradation.



a b c

Fig. 4. Dependence of the ion beam current on the ion source operating time at an energy of 120 keV for the discharge current Ip: 200 mA (a), 300 mA (b), 400 mA (c)

DISCUSSION

Fig. 3 shows that with an increase in the discharge current, an intensive increase in the ion beam current is observed, which is due to an increase in the amount of sputtered material and an increase in the plasma density in the discharge chamber. The latter is characteristic of Penning sources at high currents. At the same time, an excessive increase in the discharge current reduces the time of stable operation of the source due to cathode degradation. The nonlinearity of the growth of the ion current for Al and Cu after a current of ~ 250 mA indicates the onset of the plasma saturation regime. For beryllium, the low ion current in sources with a cold cathode of the Penning system is explained not only by the low ionization efficiency of Be atoms, but also by the formation of a BeO oxide layer on the cathode surface. The high work function of electrons (~ 5.6 eV) makes it difficult to maintain a stable discharge, which reduces the local density of Be^+ ions near the cathode and, accordingly, leads to the formation of a weak ion current. However, titanium exhibits a slower current growth, which corresponds to its higher lattice binding energy and lower sputtering coefficient.

Comparison of the results for energies of 50 and 120 keV shows that with increasing ion energy, their current in the beam increases due to reduced transport losses and improved ion focusing. Thus, the choice of source operating parameters should provide a compromise between high ion current and acceptable cathode operation time. For this purpose, an analysis of the beam current dependences on the source operation time was performed (Fig. 4,a–c). The difference between the current values for different materials is consistent with the sputtering coefficients of the materials calculated using the SRIM package: Be – 0.23 atom/ion, Al – 1.2 atom/ion, Cu – 2.13 atom/ion, Ti – 0.56 atom/ion. The larger value of the ion current for Al compared to Cu is explained by the isotopic composition of copper: the presence of two stable isotopes ^{3}Cu (69.17%) and Cu (30.83%). The ion beam passing through the mass separator consists of ^{3}Cu, while Cu ions are eliminated

The graphs in Fig. 4,a–c show that initially the ion beam current increases with time, reaching the saturation region, after which it gradually decreases until the discharge is completely extinguished. This is due to the sputtering of the cathode and emission electrode material, the deposition of sputtering products on insulators, and the development of surface circuits between the electrodes. Analysis of the curves shows that the optimal discharge current is about 300 mA, since under these conditions high ionization efficiency is ensured with an acceptable duration of the source operation. An increase in the current above 350…400 mA leads to rapid destruction of the cathode, while at a current below 200 mA the ion current is insufficient for technological use. Using the SRIM software package, the distribution profile of Be+ ions implanted with an energy of 20 keV into the InSb structure with a concentration of 1019 atoms/cm3 was simulated, and a qualitative depth distribution profile of beryllium was obtained using an Atomika 4000 secondary ion mass spectrometer [7]. This confirms the stability of the source and the good quality of the formed beam.

Thus, for Al and Cu materials, a stable operating region ("plateau") is characteristic, after which a sharp decrease in current occurs due to degradation of the cathode surface. For Ti, the current change occurs more smoothly, which affects the stable operation of the cathode. The decrease in Be efficiency is explained by the formation of an oxide layer of BeO, which blocks ion emission.

CONCLUSIONS

In this work a high-efficiency cold cathode ion source of the Penning system is successfully adapted to the BALZERS MPB-202 ion implantation system. The developed power supply unit ensured stable operation of the source in a wide range of discharge currents and allowed determining the optimal modes of ion beam formation for different metals.

Tests conducted using cathodes made of Be, Al, Ti and Cu showed that the efficiency of the source is determined by the physicochemical properties of the cathode mФaterial and the discharge parameters. Studies of the dependence of the ion beam current on the discharge current and the dependence of the ion beam current on the source operating time made it possible to determine the optimal discharge current in the source chamber (discharge current 300 mA) in accordance with the effective source operating time.

The results obtained can be used to improve ion sources in ion implantation systems and to develop technological installations for modifying semiconductor structures and thin films.

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АПРОБАЦІЯ ВИСОКОЕФЕКТИВНОГО ДЖЕРЕЛА ІОНІВ ІЗ ХОЛОДНИМ КАТОДОМ У СКЛАДІ СИСТЕМИ ІОННОЇ ІМПЛАНТАЦІЇ BALZERS MPB-202

О.В. Косуля, Б.М. Романюк, О.С. Оберемок, В.П. Мельник, В.А. Батурін, О.Ю. Роєнко, С.О. Єрьомін, П.О. Литвинов

В Інституті прикладної фізики НАН України розроблена конструкція високоефективного джерела іонів для іонної імплантації з холодним катодом системи Пеннінга. Іонізація твердофазної речовини відбувається за рахунок взаємодії з швидкими коливальними електронами у поздовжньому магнітному полі. Через циліндричний отвір емісійного катода діаметром 1,6…1,9 мм екстрагується пучок іонів плазмоутворюючого газу та розпилюваної твердофазної речовини. Апробацію джерела іонів здійснено на іонному імплантері BALZERS MPB-202 в Інституті фізики напівпровідників імені В.Є. Лашкарьова НАН України.