A Cathode Unit for High-Dose Implantation of Semiconductor Materials

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Abstract – The implantation of semiconductor materials in metals and alloys essentially extends the capabilities of modifying their superficial properties. However, the use of silicon or other semiconductor materials as a cathode in the existing designs of ion sources is complicated because of their low electric conductivity. The purpose of the given work was the development of a cathodic unit of an ion source where not only metals but also nonmetallic materials can be used as cathode materials to increase the stability of arc-firing and burning.

Ion sources such as DIANA, RADUGA, MEVA, etc., are most frequently used for metal and alloy modification by a high-dose ion implantation method. The ions in sources of this type are generated due to dispersion of the cathode under a vacuum arc burning. Hence it follows that the cathode should be made of conducting materials. Ions can be produced from semiconducting materials by means of ion sources of the VESUVII type or gas-metal sources. However, because of low speed of gathering a doze, the use of sources of the VESUVII type is expensive, and the use of gas-metal sources is accompanied by implantation of gas which is superfluous in solution of many problems.

Implantation of semiconductor materials in metals and alloys essentially extends the opportunities of modifying their superficial properties. For example, silicon carbide has hardness of 45 GPa, which exceeds that of titanium, hafnium, and zirconium carbides one and a half times. Our research into wear resistance and friction of steel 45 and α-iron has shown that the greatest increase in wear resistance is observed at implantation of silicon ions in comparison with implantation of molybdenum, carbon, lead, iron ions, etc. However, the use of silicon or other semiconductor materials as the cathode in the existing designs of ion sources is complicated because of their low electric conductivity.

Well-known is the design of a cathode unit described in [1]. The cathode is a cylinder made of an ionized material, an igniter electrode is located around the end of the cathode and separated from it by a thin (about 1 mm) corundum isolator. The design has the following drawbacks: during arc burning there is a primary burning out of ionized metal in the zone of its contact with the insulator, and the resulting plasma concentrates in a cavity between the ceramics and the cathode. This results in worsening the conditions of firing and limiting the operating time life of the cathode. The materials having low conductivity cannot be used as the high resistance of the cathode material allows no arc to be developed even in the case where firing has taken place.

There is a more complex design [2], where a composite molybdenum-lead cathode is used as a source of ions. In operating, the discharge is ignited on a substrate material (molybdenum), and, shortly, passes onto lead inserts. A drawback of the given cathode is the necessity to take into account the time of arc burning on one material (molybdenum) before its transition to the other material (lead) so that mostly lead ions are produced in the ion beam. Because initiation and burning of the arc occurs mainly in the area of contact of the isolator and the cathode material (molybdenum), the latter will be largely ionized.

The purpose of the given work was the development of a cathode unit of an ion source where it is possible to use not only metals but also nonmetallic materials having low electric conductivity as cathode materials and to increase the stability of arc firing and burning.

To solve the given problem, we suggest a cathode unit allowing ion implantation of semiconductor materials [4]. The essence of the solution is in that the sputtered cathode consists, as a minimum, of one basic and one auxiliary elements. Structurally, the elements of the cathode unit are located sequentially: an igniter electrode, an isolator, a basic electrode (semiconducting material), an auxiliary electrode (refractory-metal foil). On firing, the discharge occurs between the igniter and the auxiliary electrodes, and then passes onto the semiconductor material. The auxiliary electrode provides current to the surface of the basic cathode. The thickness of a basic element (elements) is chosen in view of the fact that the most probable place of formation of an arc spot ions are emitted from, is a small 1–10 mm area from the place of its contact with the isolator or the auxiliary element.

The use of such a cathode unit shows that it works steadily and provides an ion current comparable to that of a metal cathode. It should be noted that the auxiliary electrode will also be sputtered; however, a part of its ions will be insignificant because of its small thickness and selection of a material with a lower emission of ions. For example, we used a basic cathode made of a 4-mm silicon plate, and the auxiliary electrode was made of a 200-mm molybdenum foil. An analysis of the cathode unit after 1 hour of work, shows that it was mostly silicon that was sprayed.

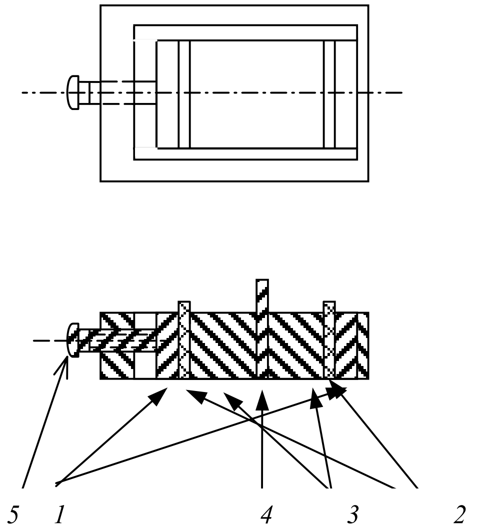

Fig. 1. The cathode unit of a rectangular form: *1* – incendiary electrode, *2* – insulator, *3* – basic elements, *4* – auxiliary element, *5* – spanning screw

Figure 1 shows a cathode unit of a rectangular form where *1* is the igniter electrode, *2* are the insulators, *3* are the basic elements of the cathode made of a material with a low specific conductivity, *4* is the auxiliary element of the cathode with a high specific conductivity, *5* is the spanning screw.

The prepared package was levelled in the plane where the initial electric-surface breakdown of the insulator should occur. Further the cathode unit is assembled. The prepared package is clamped in the holder *1* with the screw *5*. This is simultaneously the igniter electrode. Then the cathode unit is fixed in the implanter, providing necessary electric contact between the cathode electrode unit and implanter electrodes. The arc is ignited applying a pulse voltage between the auxiliary element *4* and the incendiary electrode *1*. The arc is extended and the ions are accelerated by imposing pulse electric fields according to a classical scheme adopted in [3].

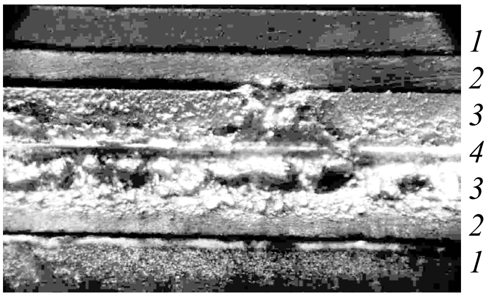

Fig. 2. A photo of the cathode unit of a rectangular form after work: *1* – incendiary electrode, *2* – insulator, *3* – basic element, and *4* – auxiliary element of the cathode

Figure 2 shows the photo of the cathode constructed according to a scheme shown in Fig. 1 after one-hour work. The irradiated area of 300 cm^2 was and the fluence was $2 \cdot 10^{17}$ ion/cm^2 . The basic elements 3 made of a silicon plate appear not to be completely run out at such fluence, while with silicon cathodes in the variants suggested in [1–3], it was often impossible to initiate the process of arc burning in general or the fluence made no more than 10^{16}–$3 \cdot 10^{16}$ ion/cm^2 at low ion currents.

Solving problems concerning hardening materials, it is possible to select thickness and elemental composition of auxiliary cathodes and thus obtain the desired composition in subsurface layers of hardened products.

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