Deposition of boron films using a discharge system with a hot boron anode

V V Shugurov and Yu F Ivanov
Institute of High Current Electronics SB RAS, 2/3 Akademichesky Ave., Tomsk, 634055, Russia

E-mail: shugurov@inbox.ru

Abstract. This work describes a discharge system for heating and evaporation of a boron powder target based on a non-self-sustained arc discharge with a filament, a hollow cathode and a hot combined anode. The measurements of the current-voltage characteristics of the discharge with a hot anode and the dependence of the anode temperature on the discharge parameters are presented. The modes of deposition of boron films have been determined.

1. Introduction
Boriding of metals is a promising method of surface hardening. Boriding can significantly increase wear resistance of machined parts. However, existing boriding methods have many disadvantages, e.g. the toxicity and explosiveness of volatile compounds during gas boriding, high energy consumption during electrolytic boriding, and difficulties associated with cleaning parts and outflow of the working solution with the parts during liquid boriding [1]. In this regard, the development of a new method of vacuum ion-plasma boriding is an urgent task.

Boriding is a thermal diffusion process. Therefore, it requires a sufficient concentration of boron on the surface of the part and the temperature of 800-1000 degrees Celsius. In the developed system, a boron film was deposited on the sample surface by evaporation of a hot anode. The system was heated by argon ions from the gas plasma.

2. Results and discussion
The experiments were carried out on the COMPLEX electron-ion-plasma setup for surface engineering. The setup was developed in the Laboratory of Plasma Emission Electronics, Institute of High Current Electronics SB RAS and included in the list of unique installations of the Russian Federation (UNIKUUM Complex, http://ckp-rf.ru/usu/434216/) [2].

Deposition of boron films by anodic evaporation of powder target required modernization of the discharge system in the PINK gas plasma generator [3]. A special anode was used as a discharge anode instead of a vacuum chamber. The anode of the discharge system had the shape of a cylindrical graphite crucible with the diameter of 40 mm and the height of 20 mm. The upper surface of the crucible had a recess with the diameter of 30 mm and the depth of 8 mm. A sample of boron powder was placed into the recess. The anode target was amorphous boron powder of grade A (TU 2112-001-49534204-2003) of the following composition (wt.%): B – 96.2, Mg – 3, Fe – 0.3, Si – 0.2, H₂O – 0.3. The crucible was located at the distance of 100 mm from the outlet of the hollow cathode of the gas plasma.
plasma generator. A holder with the samples was placed in the gap between the anode crucible and the cathode cavity of the gas plasma generator. The temperature of the holder and the sample was controlled by a chromel-alumel thermocouple. The discharge system is plotted in figure 1.

Figure 1. a) Scheme of the experiment: 1 – PINK gas plasma generator; 2 – samples; 3 – thermocouple; 4 – boron powder anode target; 5 – graphite anode crucible; 6 – electric screen; 7 – working vacuum chamber; b) appearance of the discharge system.

Figure 2. Appearance of the hot anode: a) current flows to the graphite crucible; b) current flows to a boron powder target.

To determine the optimal operating modes of the discharge system with a filament, a hollow cathode and a hot anode, the dependences of the discharge operating voltage on the filament current were investigated at various discharge currents. Argon was used as a working gas at the pressure of 0.3 Pa.
When the discharge was ignited, the primary current flew onto the graphite crucible. After the crucible with the powder were heated up to a temperature above 600-650 degrees Celsius, the discharge current switched to the surface of the boron powder. This happened because the resistivity of boron at this temperature becomes lower than that of graphite [4]. A further increase in the discharge current lead to an increase in the temperature of the boron powder anode target and to an increase in the boron evaporation rate. Figure 2 shows different stages of the discharge to the anode.

Figure 3 shows the dependence of the discharge voltage on the filament current at various values of the PINK discharge current (Ip).

Figure 3. Dependence of the discharge voltage on the filament current at various values of the PINK discharge current (Ip).

It can be seen from the graphs that the anode temperature changed insignificantly at a given discharge current and a change in the filament current. However, each dependence had a temperature maximum at large filament currents and low discharge voltages. A significant decrease in temperature at the discharge current of 25 A and the filament current of 123 A was associated with the appearance of an anode spot on the anode surface and the localization of the discharge current at one point. In that case, boron boiled off intensively in the place of localization of the discharge current, and the temperature decreased significantly on the rest of the surface. This is an emergency mode that limits the maximum discharge power in the configuration. The maximum anode temperature was revealed for each discharge current. Figure 5 shows the dependence of the discharge voltage on the discharge current at which the maximum anode temperature was observed.

It can be seen that the voltage at which the maximum anode temperature is reached decreases with an increase in the discharge current. This voltage corresponds to the maximum value of the anode drop and to the best conditions for heat generation at the anode.

Thus, the discharge current of 20 A at the discharge voltage of 43 V was chosen as the optimal mode for the deposition of boron films. Boron films with the thickness of 1 μm were deposited on samples in this mode at the deposition rate of up to 2 μm/hour.
3. Conclusion
A discharge system with a filament, a hollow cathode and a hot evaporated boron powder anode was developed. The operating modes of the discharge system and the dependence of the hot anode temperature on the discharge parameters were investigated. Boron films with the thickness of 1 μm were obtained in the optimal operating mode. The discharge system will be used to carry out future experiments on ion-plasma boriding of steels.

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