Non-self-maintained discharge with a hollow anode: characteristics and application

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Plasma parameters of non-self-maintained discharge with a hollow anode are presented. It is shown that such type of discharge may be effectively used for ion pumping, film deposition, ion etching, diffusion saturation of metallic materials, fusion and brazing of metals, and for combined application of above mentioned technologies in one process.

1. Introduction

Non-self-maintained gas discharge, in which the additional charge carriers are produced by a vacuum-arc plasma gun, is characterized by strong-current electron and ion fluxes and high values degree of ionization [1-3]. Such type of discharge may be easily excited in widely used vacuum-arc deposition setups. Between metallic cathodes and anode, power sources in such setups provide, as a rule, the arc current ranging from tens to hundreds of amperes at a voltage of a few tens of volts. With easy switching on such equipment one can obtain a discharge in a gas with almost the same values of current and voltage. Due to enhanced plasma density and degree of ionization, the processes of surface treatment in such gas discharge are much more intense than it is in a self-sustained glow discharge. The application of hollow anode instead of a plane one provides an additional opportunity for ion flux focusing [3-5]. As a result, the ion current density is increased by one order of magnitude that in turn increases the rate of etching, film deposition or diffusion saturation.

In this paper we discuss some technological methods of plasma surface modification with using the non-self-maintained gas discharge with a hollow anode.

2. Experimental setup

2.1. Apparatus

Figure 1 shows the scheme of Bulat-type deposition setup which is additionally equipped with switches and screens to produce a dense flux of gaseous ions. The plasma source 1 with anode 5 can work in two regimes: 1) as a usual electric-arc metal vaporizer with consumable cathode 7, i.e. as a source of metal ions, and 2) as a source of gas ions, when it forms together with anode 5 the hollow anode. In the first case, the switch SW1 connects the negative terminal of power source PS-1 to cathode 7 and positive terminal to the anode 5 and chamber 10. In second case, the switch SW1 connects the negative terminal of PS-1 to the chamber 10, and positive one to the anode 5, to cathode 7, and to additional ring anode 8. Since the output voltage of power supply PS-1 does not exceed 110 Volts, the gas discharge between hollow anode and chamber walls can not start. Its ignition at such a low voltage requires the presence of additional charge carriers.

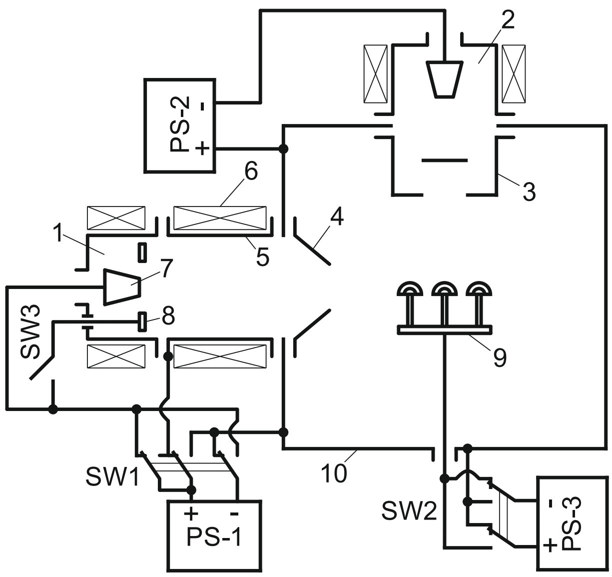

Fig. 1. Scheme of experimental setup.
1, 2 – vacuum-arc plasma guns; 3 – screen; 4 – diaphragm; 5 – anode; 6 – focusing coil; 7 – central anode (or cathode in deposition regime); 8 – additional ring anode; 9 – samples; 10 – vacuum chamber.
Power sources PS-1 and PS-2 supply arc and gaseous discharges; PS-3 is a bias voltage source

These charge carriers are produced by the vacuum-arc plasma gun 2. Its output aperture is overlapped by screen 3, which prevents the deposition of ions and neutrals on samples 9. At the same time, a small portion of electrons is scattered by the molecules of working gas, enters in the chamber and ignites the gas discharge between hollow anode (consisted of electrodes 5, 7, 8) and chamber 10. The connection of the ring electrode 8 to structure of hollow anode significantly reduces the minimal pressure at which the discharge is burning. The diaphragm 4 reduces the entrance hole of the hollow anode, thereby increasing the gradient of electric potential here. Sufficiently high electric field in this region, together with the magnetic field of focusing coil 6, enhanced the degree of ionization and forms the dense flux of gaseous ions emitted from the hollow anode into chamber 10. Such a flux may be used for intensive cleaning or surface etching of samples 9, depending on value of negative bias applied to them from power source PS-3. If the negative terminal of power source PS-3 is applied to the chamber 10 and positive one to the samples 9, one more non-self-maintained discharge is exited between walls of chamber 10 and samples 9. In this case the samples are heated by electrons of this discharge and may be subjected to diffusion saturation (without etching of its surface) in intensive ion flux, which is emitted from hollow anode, Figure 2.

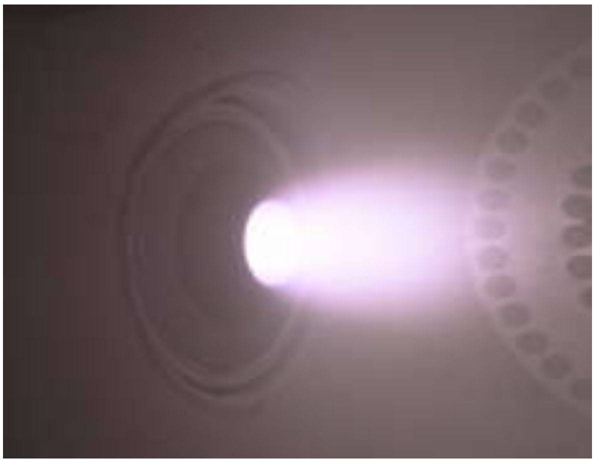

Fig. 2. The nitrogen ions beam emitted from the hollow anode

3. Results

3.1. Ion pumping

At the middle stage of evacuation of the vacuum chamber the excitation of non-self-maintained discharge in residual vacuum markedly increases the rate of pumping. In addition the vacuum chamber walls degasation and samples heating occurs. Applying a negative bias to the samples allows its cleaning yet during pumping. The connecting of the ring electrode 8 (see Fig. 1) to the hollow anode significantly expands the range of pressures under which the non-self-maintained discharge may exist.

As it is shown in Figure 3, the discharge current is increased by several tens of amperes. The main part of this current falls on the central electrode 7, whereas on the ring electrode 8 current does not exceed 6 Amps. Thus, the usage of non-self-maintained discharge allows significantly reduce the cycle time of plasma treatment.

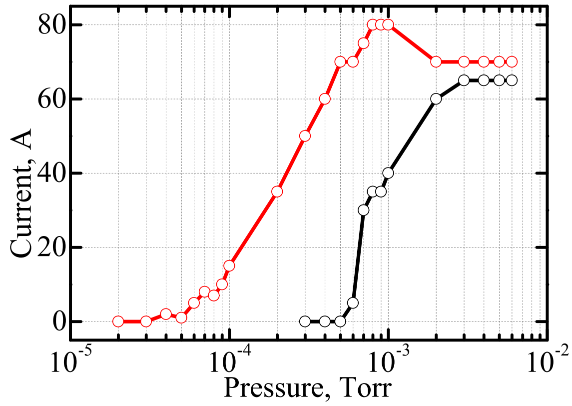

Fig. 3. Discharge current between hollow anode and chamber: black curve – without connection of ring electrode 8 to structure of hollow anode; red curve – the ring electrode 8 is connected to hollow anode

3.2. Diffusion saturation and film deposition

It is known that in non-self-maintained discharge the rate of diffusion saturation process, such as nitriding, oxidation, carburization, is much greater than, for example, the nitriding in glow discharge [6]. The excitation of such discharge with the hollow anode makes the saturation more intensive due to increase in ion current density. Figure 4 shows the microhardness distribution on a depth in titanium plate after 20 min exposition in nitrogen-ion flux at 850 ^{0}C. The plate surface was oriented tangential to ion flux. It can be seen that the back

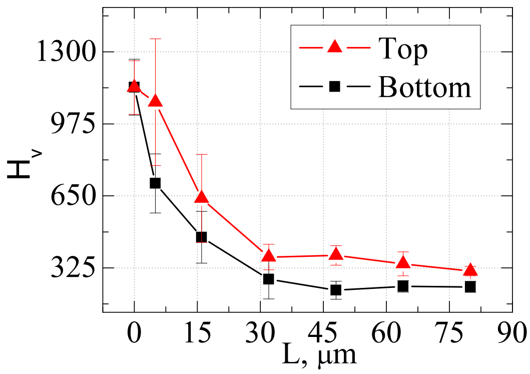

Fig. 4. Microhardness distribution along a depth of Ti plate after nitriding at 850 ^{0}C in tangential to the surface ion flux; $P=1\cdot10^{-3}$ Torr; Top - side turned to stream of ions; Bottom - back side, attached to the holder; time of nitriding is 20 min

side of the plate that was attached to holder was nitrided too. The hardness distribution on the depth not depend on whether the samples were heated by ions when were negatively biased, or by electrons, under corresponding positive potential.

The discharge with the hollow anode may be used also to produce thin films from a gas phase. For example, for the a-C:H films deposition the non-self-maintained discharge should be exited in propane-butane mixture [3].

3.3. Ion etching

The ion current density in discharge with hollow anode riches up to 50 mA/cm^2. Such a high density may be used for a high-speed etching of metallic samples. Figure 5 shows the etching rate versus pressure for stainless steel plate, placed at a distance of 10 cm from the aperture of the hollow anode. The surface of plate is oriented at an angle of 60 degrees to the direction of flux of argon ions. The curves were obtained for three values of bias voltage: -250, -500, and -1000 Volts.

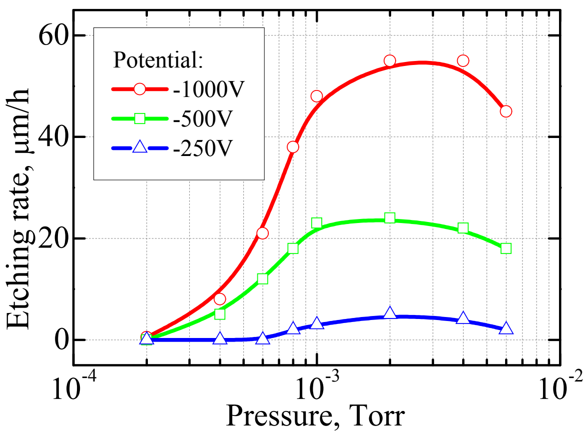

Fig. 5. The pressure dependence of etching rate of stainless steel sample by argon ions ejected from hollow anode. The surface of sample is oriented at the angle of 60 degrees to the direction of ion flux

3.4. Quenching, brazing and fusion

For specimens heating in vacuum furnaces mainly two methods are used: induction heating and indirect-resistance heating [7]. The induction heating heats up primarily the outer layer of specimen. As a result, the temperature is often overshot and non-uniform heating occurs. On the other hand, the indirect-resistance elements are expensive and oxidize easily. The heating in non-self-maintained gas discharge is free from these disadvantages. Power for heating is released directly on the specimen. The electron streams may be distributed correctly over the specimen for uniform heating. The rapid cooling of specimens is achieved by quick sending the inert gas into vacuum chamber.

Any two metals may be joined in non-self-maintained gas discharge by melting a thin layer of filler metal in the space between them.

Any metal in non-self-maintained gas discharge may be melted by concentrating the flux of electrons on specimen and by increasing the gradient of electric potential, using diaphragms and screens.

4. Conclusions

All of the above mentioned processing methods, together with the vacuum arc coating technology, may be implemented in a single technological cycle. The application of non-self-maintained gas discharge with the hollow anode significantly extends the technological capabilities of plasma treatment of metal products.

5. References

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