Automated Vacuum Ion-Plasma Setup "TRIO" for Making Nanostructure Coatings[1]

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Abstract – Principle of operation, construction and main parameters of new vacuum ion-plasma setup for arc nitriding and plasma-assisted deposition of such nanostructure coatings as TiAlN, TiCuN on metal substrate are considered. The new setup is assigned for scientific researches with multicomponent composite cathode for generation of strain-hardening and protective coatings on tools. The setup is fully automated for high repeatability of complex technological processes. The operating program has planning sheet which contains up to 300 steps in common technological process. The plasma source with heated cathode (PINK) and switch-mode power supply for high-voltage bias on substrate give the opportunity to carry out ion cleaning, etching and activation of substrate surface, arc nitriding of tools. There is the opportunity to operate by the inleakage of 2 different gases in necessary proportions. Switch-mode power supplies provide stable values of composite cathode currents and automatic discharge initiation in case of arc starvation. The setup main parameters, technical characteristics and supposed application fields are presented.

1. Introduction

Such types of ion-plasma treatment as surface cleaning, surface activation, formation of surface layers with modified chemical and phase structure, increased hardness and corrosion stability, deposition of different coatings are widespread in science and industry.

The most widespread types of surface treatment are ion etching and activation, ion-plasma nitriding [1], electroarc [2] or magnetron [3] deposition of coatings. Combination of these surface modification methods enables to improve consumer properties of work pieces and optimize certain features of modified surfaces for specified requirements.

In Institute of High Current Electronics earlier was developed special-purpose process installations "DUET" and "QUADRO" [4, 5] for the purpose of combination of different surface modification methods in single technological cycle. Automatic control system on the basis of industrial controller is built in installation for improvement of technological process control, accident prevention and treatment results reproducibility.

The new automated vacuum ion-plasma setup "TRIO" controlled by computer in this article is presented. The "TRIO" is developed in Laboratory of Plasma Emission Electronics in Institute of High Current Electronics. There is possibility to realize in single technological cycle up to 300 steps of cutting tool treatment in turn in this installation. These treatment operations are surface preheating and degassing, ion cleaning, surface etching and activation by arc plasma, chemicothermal treatment (nitriding) for formation of surface diffusion layer with increased hardness and corrosion stability (low pressure arc nonself-sustained discharge assisted), electroarc plasma-assisted deposition of single-layer or multilayer superhard (> 40 GPa) nanostructure coatings on basis of fine metals or their compounds (nitrides, carbonitrides, carbides). For these purposes the "TRIO" has 3 plasma sources: two arc evaporators and plasma source with filament cathode (PINK). The name of "TRIO" setup indicates the number of used plasma sources. Two arc evaporators with current up to 200 A is used for cathode material sputtering and deposition of coatings with evaporating rate up to 3 μm/h.

Plasma source "PINK" generates voluminous gas plasma which is used in such processes as surface cleaning, surface activation, ion-plasma nitriding.

2. Setup Description

The main technical parameters of setup "TRIO":

– technological module "TRIO" – 2100×1600×2120 mm;

– control rack – 2000×600×800 mm;

– sizes of the working chamber – ∅600 mm, length – 600 mm;

– speed of coatings deposition μm/h, on less – 3;

– power input, kW, on more – 40;

– working pressure – 0.05–1 Pa;

– water cooling – 2 m^3/h.

The general view of setup is shown in Fig. 1.

The "TRIO" includes: vacuum system, system of water cooling (heating), gas flow system, power supplies, technological devices, automation control system.

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Fig. 1. General view of complex vacuum ion-plasma setup "TRIO"

Water-cooled setup vacuum chamber is horizontal cylindrical-shaped vessel

The water-cooled setup vacuum chamber is made in the form of a horizontal cylindrical vessel with diameter 600 mm and length 600 mm with the lateral aperture closed by two doors from both sides of vessel.

There are flanges on the top of the vessel and on the doors for placing of plasma sources. There is flange for installation of the rotation mechanism on the bottom plane of the case. There are pipe branches and flanges for connection of vacuum system, system of cooling (heating), filling of working gas, watch windows on the case. There is a boss for installation of the temperature relay on the case.

The vacuum chamber is pumped by 2 fore pumps with pump speed 11 l/min and by turbo-molecular pump with pump speed 500 l/min. Vacuum system makes preparatory pumping and high-vacuum pumping.

Vacuum valves are electromagnetic and gate valve is electromechanical. High vacuum is measured by digital gauge on the basis of vacuum lamp PMI-51 and forevacuum in all parts of vacuum system is measured by 3 digital gauges on the basis of vacuum lamp PMT-2.

System of water cooling (heating) consists of input and output manifold blocks, inductive water heater and pipe ducts. All water-cooled setup units has separate cooling branches. There are water flow relays on the output manifold block which would turn on sound and light signal if flow of water were died out.

Water flow is regulated by valves on the output water collector. Hot water heating is used for degassing of inside chamber surface and doors. Water is heated by inductive water heater in closed circulatory system. Water circulation is realized by water pump. The chamber heat to 70 centigrade degrees is reached not more then 10 min.

Two-channel gas flow system enables to bring in "PINK" gas mixture that is used for deposition of super-hard composite coatings with using of composite cathodes.

The gas flow system consists of automatic leak valves with electronic control units. Gas inflow is realized in required proportions under desired working pressure. Maximum time of obtaining desired working pressure is 10 s.

The working gases in "TRIO" setup are nitrogen, argon or other inert gases for different types of treatment. The number of working gases leaking in chamber at the same is one or two.

Plasma source power supplies are controlled inverter current regulator and situated in one control rack structurally. There are three functional systems of supplies:

– system of PINK power supply, which includes water-cooling discharge power supply (15–60 V, 10–200 A), filament cathode supply (9–14 V, 40–200 A), magnetic coil power supply (10–150 V, 0.2–1.5 A);

– two systems of arc evaporator power supplies, which included discharge power supply (15–60 V, 10–200 A) and two magnetic coil power supplies (10–150 V, 0.2–1.5 A).

Discharge initiation power supply for arc evaporators builds in arc evaporator power supply. Every discharge initiation power supply operates independently and has voltage feedback with discharge. Discharge initiation power supply initiates discharge in case of casual arc starvation.

Negative electrical bias power supply is regulated constant-voltage source switched to load throw high-frequency regulated switch. Electrical bias power supply varies output bias voltage (0–1000 V), pulse frequency (2–40 kHz) and pulse duty factor (10–90%). Maximum average current on treated tools is up to 10 A.

The "TRIO" setup includes three plasma sources.

The "PINK" generates gas plasma of inactive gases such as nitrogen, argon and other inert gases. The "PINK" is plasma source on the basis of non-self-maintained arc discharge with filament cathode [6]. There is complex cathode consists of filament and hollow cathodes, located in magnetic field in this plasma source. Plasma density amounts to about 10^{10}–10^{11} cm^{-3} with electron temperature 3–4 eV. Category pressure range is 0.05–1 Pa in which discharge current gradually changes in the range of 0.1–200 A and discharge voltage changes in the range of 15–60 V.

There are two plasma sources for generation of metal plasma in this setup. Category pressure range is 0.05–1 Pa for this plasma sources, working current is in the range 30–200 A, discharge voltage is 30 V, Maximal speed of coatings deposition is 4.5 μm/h.

Treating tools is located on rotary holder – manipulator, which has 6 positions for fixing of treated tools. Every position rotates about its own axis during holder rotation. The rotation made by asynchronous motor controlled by regulated frequency converter. Holder rotary speed changes subject to technological regime of treatment.

Temperature control of tools is realized by means of thermocouple. There are two watch windows in chamber.

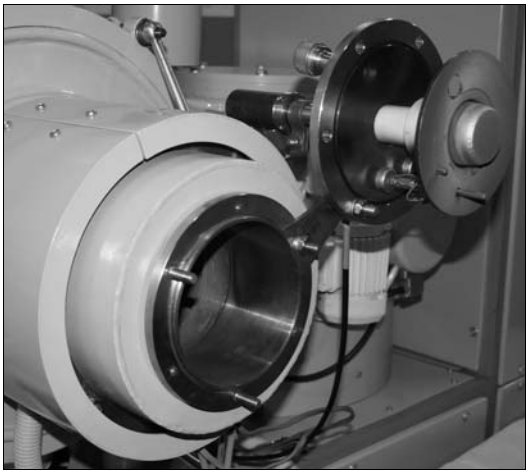

Fig. 2. Photo of arc evaporator

The system of automatic control of “TRIO” setup provides algorithms for automatic pumping (with possibility of manual control). There are pressure and cooling protections. There is protection for sequence of executive devices commutation. There are two types of protections: software-based and hardware-controlled.

Technological process control is realized in manual and automatic regimes with the possibility of setting of plasma sources parameters.

The system of automatic control of “TRIO” setup provides:

– algorithms for automatic pumping (with possibility of manual control) to high vacuum ($\approx 10^{-3}$ Pa);

– automatic temperature control of tools in the technological process;

– gas inflow of two gases in chamber in required proportions and automatic maintenance of working pressure in the range of 10^{-2}–1 Pa;

– choice and operating of specified working regimes of PINK and arc evaporators separately;

– control interception by operator on any step of technological process and carry out technological process in manual control regime;

– elimination of forbidden conditions capable of bring to waste of treating tools, setup break or its units. There are pressure and cooling protections. There is protection for sequence of executive devices commutation. There are two types of protections: software-based and hardware-controlled;

– emergency shutdown of setup in situations connected with possibility of technological cycle breaking or health hazard of operating personnel.

Temporal changes of all main parameters are displayed in the main window of software interface and also log.

The main execution unit of automatic control system is industrial controller ADAM-5000. The industrial controller operates of systems components by means of digital and analog signals.

The main window of operating program is shown in Fig. 3.

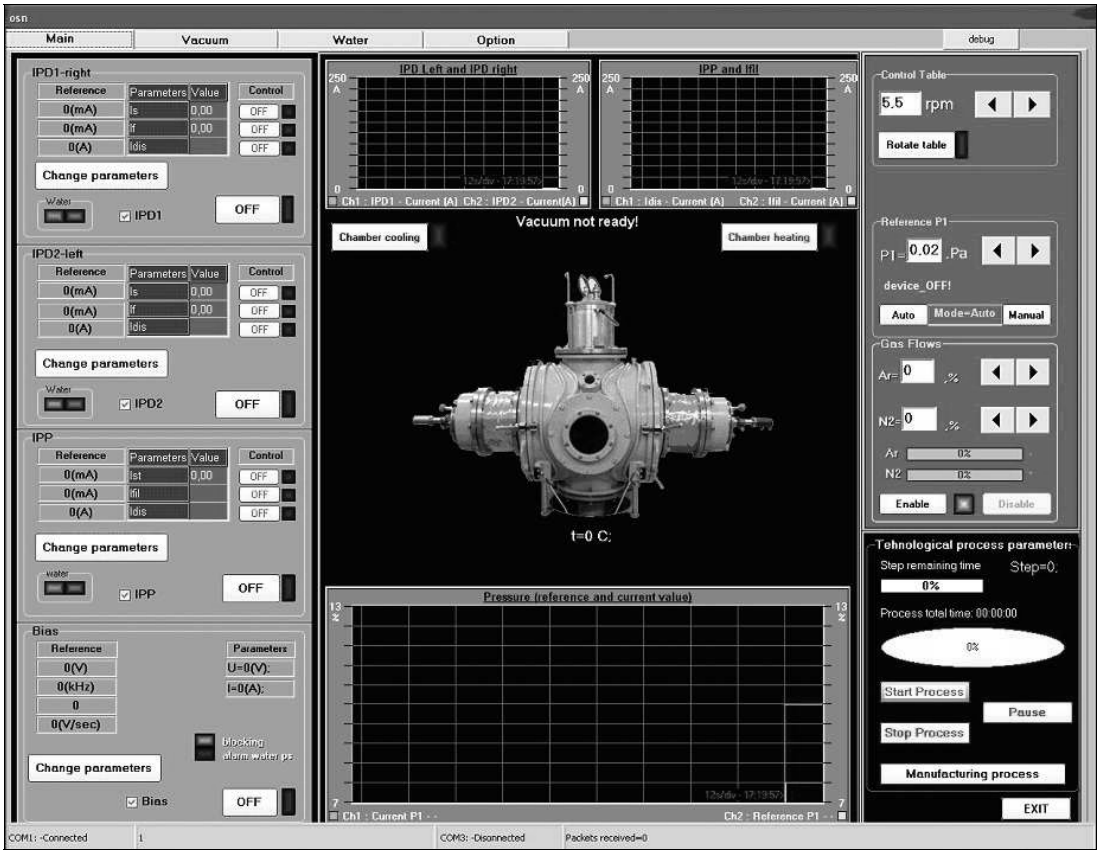

Fig. 3. The main window of operating program of “TRIO” setup

The new setup "TRIO" enables to realize complex processes of surface modification which include:

– finishing surface ion etching and activation;

– arc ion nitriding of tools;

– electroarc plasma-assisted deposition of composite super-hard coatings which includes nanostructure coatings with using of composite cathodes.

Such plasma treatment enables to increase wear resistance of cutting tools two times as much.

3. Conclusion

1. The new vacuum ion-plasma setup for complex surface treatment of cutting tools is developed. The setup enables to realize in single technological cycle ion etching, activation and electroarc plasma-assisted deposition of composite super-hard coatings ($\geq$ 40 GPa) with coating thickness of several μm and speed of coatings deposition – 4.5 μm/h.

2. Plasma sources used in this setup with their systems of power supplies and possibility of synchronous use of them give the opportunity to extend the parameters ranges of cutting tools treatment processes in comparison with known earlier.

3. The automatic control system of setup increases application safety and reproducibility of ion-plasma processes of cutting tools treatment.

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