Abstract – In the paper, the description of combined facility consisting of a source of low-energy, high-current electron beams and two magnetron sputtering devices mounted with an electron gun on the joint vacuum working chamber is given. The chamber is equipped with a manipulator which moves the worktable with the samples without breaking the vacuum, which allows one surface alloying on the samples in situ. Facility has an automated system for the control of pumping, filling the chamber with working gas, power supplies and synchronization of pulsed processes during the generation of electron beam, films deposition, the displacement of the sample, etc.

1. Introduction

Formation of surface alloys by pulsed liquid-phase mixing of “the film-substrate” systems is a promising method of modifying materials and products. Fusion of the pre-coating with the substrate can form a structure with needed physical and chemical properties, as well as radically solves the problem of adhesion of the coating.

For the deposition of coatings, the ion-plasma techniques based on magnetron or vacuum arc discharge are widely used [1, 2]. And for the alloying of the coating with the substrate it is advisable to use pulsed concentrated energy fluxes of particle beams or electromagnetic radiation. With the short pulse duration, the flux energy is released in a thin surface layer whose thickness is defined by heat diffusion during the pulse (several microns or tens of microns) or by particle penetration depth. The sources of wide-area (tens of square cm), low-energy (10–30 keV), high-current (up to 25 kA) electron beams (LEHCEBs) are very perspective types of concentrated particle fluxes. These sources distinguish by their simplicity, reliability, X-ray safety and low cost. The LEHCEBs sources developed in our lab have already found wide application for increasing the corrosion resistance of metals and alloys, electric strength of vacuum insulation, and finish polishing of metal parts [3–6].

Before the recent times, the LEHCEBs sources and ion-plasma deposition devices represented their selves the separate facilities that mean perfectly unneeded and even bad contact of the treated parts with atmosphere during their carrying over from one device to another. Recently, we have created the integrated facility “RITM-SP” consisting of LEHCEBs source and two magnetron deposition devices assembled on the joint vacuum chamber. The paper presents the description of the facility, its specifications and the results of testing.

2. Description of the facility

The general design of electron gun and vacuum chamber of the facility is given in Fig. 1. The main part of
the LEHCEBs source is an electron gun with explosive-emission cathode and plasma anode based on high-current reflective discharge [7]. The case of the electron gun is a stainless-steel tube of 320 mm in length and internal diameter of 156 mm. The gun is joined to the vacuum working chamber of diameter 251 mm and depth of 226 mm. The electron emitter is a multi-wire copper cathode made of RF cable braid. The braid roll is inserted into cup-shape holder made of stainless steel. The diameter of the cathode emitting part makes up 62 mm.

The plasma anode is produced by high-current (200–250 A) reflected discharge operated in argon at pressure $p = 0.03–0.07$ Pa. The discharge ignition occurred at application of a positive 5-kV voltage pulse to the anode. The anode was a thin-walled stainless-steel ring of inner diameter 62 mm and length 30 mm.

The working chamber is pumped with the use of vacuum pumping station HiCube Eco (“Pfeiffer Vacuum”) consisting of turbomolecular pump with pumping speed of 67 l/s and primary drug pump (0.25 l/s). To accelerate the pumping, the additional rotary pump with the speed 1 l/s is used. To avoid the oil vapors penetration into the working chamber, this pump is intercepted when fore-vacuum pressure $5 \cdot 10^3$ Pa is achieved. The residual gas pressure of $4 \cdot 10^{-3}$ Pa is achieved within 10–12 minutes.

The accelerating voltage pulse was formed during the discharge of an energy-storage capacitor (3 µF) through a pseudo-spark switch TDI1-50k/45 (“Pulsed technologies Ltd”, Ryazan, Russia). The storage capacitor is charged from high-voltage dc power supply HVPS-35/40 (35 kV, 40 mA).

A guide magnetic field of strength up to 0.25 T provides both operation of the reflective discharge and beam transport. A resistive voltage divider is used to measure accelerating voltage. The cathode current is measured with Rogowsky coil. Typical waveforms of pulses are presented in Fig. 2. Beam energy density is measured by calorimeter based on calibrated thermistor soldered to the back side of the copper absorber.

Deposition of the films is performed with the use of two planar water-cooled magnetrons operating in dc mode. The power consumption of each magnetron makes up 800–900 W at burning voltage of 400–450 V.

The treated samples and parts are placed on the movable working table driven along the guide rails with the use of chain transmission. The driving gear of the transmission is rotated by a step electromotor through the vacuum rotation input. When stopping of the working table under electron gun just before the irradiation, four copper rods are pressed to the back side of the table (from the bottom) providing high-current contact of the table with the “ground”. Driving of the rods (“up-down”) is performed electro-pneumatically.

![Fig. 2. Typical waveforms of accelerating voltage (Ch 1, 5.3 kV/div) and cathode current (Ch 2, 15 kA/div), $B = 0.24$ T, argon pressure is 0.04 Pa. Horizontal scale is 1 µs/div.](image)

The process of surface alloying is started from the cleaning of a sample (substrate) with several electron beam pulses at energy density sufficient for initial evaporation of the substrate material. Then, the samples are displaced to magnetron(s) where the film(s) of needed thickness is deposited on its surface. After this, a sample is returned under electron gun where the fusion of the film(s) with substrate is performed. The processes of deposition and fusion may be cyclically repeated. The control of pumping the chamber, its filling with the working gas, power supply units, synchronization of the pulsed processes during electron beam formation, motion of the treated sample from beam irradiation zone to deposition zone and back, driving the high-current contact is performed by automated control system from PC. Besides, the control system allows one to preset the pulse repetition rate and number of beam pulses in series, number of series (cycles) of irradiation and deposition, time period and mode of deposition, to keep the working minutes. The image of the control panel on PC monitor is given in Fig. 3.

Varying of the beam energy density is performed by changing the charge voltage of high-voltage pulsed generator, working gas pressure, the distance between the anode and the target as well as by focusing or defocusing of the beam by guide magnetic field. The characteristic beam autograph on the stainless steel plate is given in Fig. 4. It is clear that uniformly melted zone diameter makes up about 9 cm.

All supplying and control units have demonstrated their good noise stability in spite of high rate of the current varying in LEHCEBs source (up to $10^{11}$ A/s).

The tests have shown that vacuum station pumping speed is quite enough for the recovery of the pressure in working chamber at the installed level during the pause between pulses of electron beam, i.e. within 5 s, not more.
Fig. 3. Control panel of the “RITM-SP” facility

Typical specifications of the facility:
- Accelerating voltage – up to 40 kV;
- Electron beam current – up to 25 kA;
- Beam diameter – up to 9 cm;
- Beam energy density – up to 20 J/cm²;
- Beam pulse duration – 2–4 μs;
- Working gas pressure (argon) – 0.02–0.2 Pa;
- Residual gas pressure – (2–5) × 10⁻³ Pa;
- Pulse repetition rate – 0.1–0.2 pps;
- Deposition rate:
  - 290 nm/minute in case of copper;
  - 167 nm/minute in case of nickel.

Photo of the “RITP-SP” facility is given in Fig. 5.
3. Conclusions
Thus, we have developed and created the first facility for the surface alloying in situ which combines the LEHCEBs source and two magnetron deposition devices. Preliminary testing of the facility has demonstrated rather reliable and stable operation.

References