Journal of the Technical University of Gabrovo, Vol. 47'2014 (20-22)

ИЗВЕСТИЯ
на Технически университет
Габрово

VACUUM ION-PLASMA DEVICES AND THE PROCESSING TECHNOLOGIES OF STEEL IN THE MECHANICS

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Received 25 November 2013, Received in revised form 11 March 2014, Accepted 15 March 2014

Abstract
Ion treatment devices for vacuum surface were worked out. Coatings for steel based on chromium were formed. There has been studied the effect of process-dependent parameters on the coatings properties.

Keywords: vacuum, ion source, a magnetron, ion-plasma coating, steel.

INTRODUCTION

Many parameters of materials are determined by the properties of their surface layers, therefore the surface treatment technology and deposition have a significant value.

The vacuum plasma and beam surface treatment processes are very advanced in this respect. At the present time the vacuum deposition coating processes, pulsed-plasma exposure, ion implantation, radiation treatments, changing the physical and chemical parameters of the material surface, are used for the materials treatment.

Actual and promising direction of technics and technology development on modern stage is the vacuum coatings application.

EXPOSITION

The combination of a relatively simple technological devices in a vacuum chamber (sputtering device, ion surface treatment, equipment) essentially allows to create the complex composition and multi-layer coating structures.

It should be noted that the formation of vacuum coating with thickness of 10 nm to 10 microns (particularly metal surfaces) do not cause significant technological challenges.

By the optimal design of devices of ion-plasma sputtering and plasma (radiation) treatment can be formed a coating of a given composition and thickness with the high (5-6%) uniformity and adhesion strength.

Subsequent radiation treatment (ion-beam or laser treatment) can also change the structure of the coating - base system.

A perspective variant for ion processing apparatus at coating of the structure surface that combines any source of coating deposition and ion source with a cold cathode, built-into the vacuum chamber.

The worked out ion source was (one of the modifications) assembled on a steel flange (steel-3) with diameter 160 mm and thickness 12 mm. This flange is also a part of the magnetic system (magnetic) device. As magnet there has been used the cylindrical samarium-cobalt magnet (diameter 25.4 mm, height 35 mm). The main magnetic core is formed from the steel cylinder and the outer ring of steel.

Inside the magnetic core there is a chamber from Teflon-4 and the ring anode of stainless steel (diameter 60 mm, thickness 12 mm) mounted on racks. One of the racks (4 mm diameter) through the bushing insulators with a rubber seal is withdrawn outwardly and has a fixation of high voltage wire.

One of the designs of the ion source is shown in figure 1.

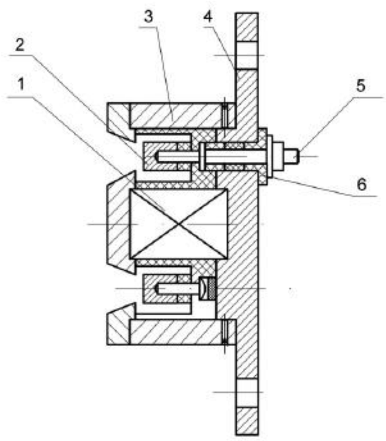

Fig. 1. *The ion source with a cold cathode and a divergent flow of plasma gas discharge*
1-cylindrical permanent magnet, 2-anode ring of stainless steel, 3 - magnetic core of stainless steel, 4- mounting flange to the vacuum chamber, 5 - electric high voltage bushing, 6 - teflon insulator

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ISSN 1310-6686© 2014 Известия на Технически университет Габрово

Photo of the ion source is shown in figure 2.

Fig. 2. *Photo of ion source with a cold cathode*

The power supply of the ion source with a cold cathode supplies a positive voltage up to +5 kV to the ring anode at load currents up to 30 mA (unit with "falling" external characteristic).

One more simple device for plasma surface treatment of pre-processed objects is a system of two discharge electrodes having an area of at least 100 cm^2 placed in different parts of the vacuum working chamber.

In particular, the electrodes represent themselves as rectangular plates of stainless steel sheets (1.5 mm) in size from 100x100 to 100x200 mm, mounted on teflon-4 insulators with ring sealing from the vacuum rubber or ceramic insulators (ceramics 22XC).

On the other side of the bushing insulators there is a controlled variable (50 Hr) voltage of step-up transformer which is supplied to the metal rack. The location of the discharge electrodes in a vacuum working chamber and equipment for samples processing is shown in figure 3.

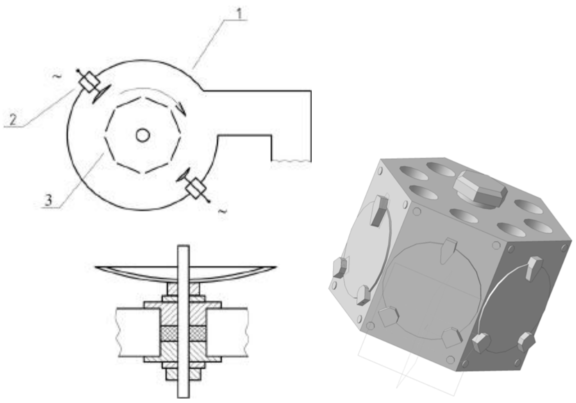

Fig. 3. *The discharge electrodes in a vacuum working chamber and accessories. 1 - working chamber,*

2 - electrodes, 3 - treated objects

The most effective device for nano-coatings deposition using the materials sputtering in the crossed electric and magnetic fields is a magnetron sputtering source with a disk-cooled cathode. The device allows to sputter the non-magnetic materials and as an option to treat the surface with a flow of ions.

Sputtering device was installed on a separate stainless steel flange and included the following parts: cooled cathode, cylindrical mountings, magnetic system, feed-in vacuum, the ring anode, gas supply line, a substrate holder, a unit for control and power supply.

The flange with sealing rubber was joined to the working chamber at an angle. The sputtering cathode from materials (Cu, Cu-Zn, Cr, Ti, Zr-Nb, Mo, Zn and manganese silicide) had a disc shape with a diameter of 80 or 130 mm from the end groove or hole. The optimum thickness of the disk for the cathode structure with 80 mm diameter was 3 mm, for the cathode with 130 mm - to 9-10 mm.

The cathode is fixed with semi-cylindrical screws or tie rods on a magnetic system, which is a single permanent magnet or magnet set of alloy. The back part of the magnetic system was connected with two 10-mm diameter tight inputs from stainless steel with sealed teflon insulators. Isolated tubes were output to the flange and were connected to the polymer tubes for cold water supply. Operating voltage was supplied to the tubes.

The line of working gases (Ar, N^2, O^2) was supplied to the working chamber, which included a gas vessel, oxygen reducer, gas purifying filter and needle valve disposed directly on the working chamber. Interchangeable cylindrical stainless steel anode was set around the cathode at a distance not exceeding 5 mm. As a rule the anode was grounded or had a positive potential to +50 V from a separate power supply.

The power supply system of the magnetron sputtering materials should provide a relatively high initial voltage at the ignition of the discharge, a stable discharge current at the operating voltage minus 300÷700 V, overcharge protection (at micro arc discharges) without interruption, as well as a short-circuit protection. The unit of BP-196 type is used to power the magnetron providing a discharge current up to 4.5 ÷ 5.0 A at 300-600 V and the initial voltage of 900 V.

The design of the magnetron sputtering device is shown in figure 4.

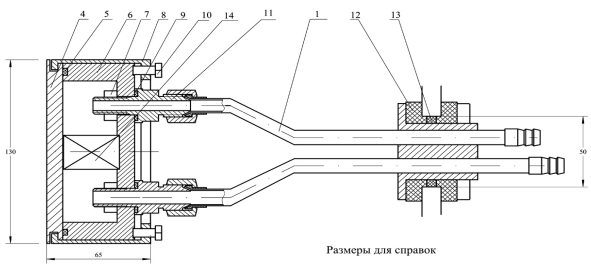

Fig. 4. *The design of the worked out device magnetron sputtering with a disk cathode, diameter of 130 mm*
4-water-cooled sputtering cathode, 6-magnetic system, 8-mounting system of the cathode, 1-isolated inputs for water and power supply, 12-teflon insulator

Figure 5 shows photographs of the magnetron sputtering device with different sizes of cooled cathodes.

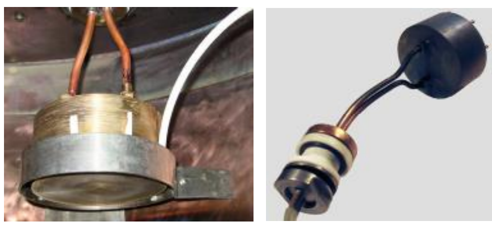

Fig. 5. *Photos of magnetron sputtering devices*

Magnetron sputtering device in combination with a source of ions differs from wide opportunities because they are operated with the same pressures of working gas ≈10^{-1} Pa, allow to adjust the intensity of the ion beam 10-2÷1 mA/cm^2 and to change the exposure time of the plasma (ions) flows from the source. The opportunity to change the coating deposition parameters appears in the zone of effect of the ion source with a cold cathode and magnetron sputtering device.

The studies have shown the capability of vacuum deposition of resistant coatings on carbon steel and tools.

Vacuum deposition Cr (as well as other coatings) for steel included the surface pretreatment in the ultrasonic bath with alkaline solution, drying with the hot air flow, the samples placing in a vacuum chamber, evacuating the chamber to "start" degree of vacuum, an ionic treatment of steel surface, magnetron deposition of the coating in the selected mode.

Cr deposition coating was carried out after the starting vacuum degree of about

$2{\cdot}10^{-3}$ Pa under Ar puffing to 10^{-1} Pa, the ion processing within 5-6 minutes, and the discharge current at the cathode of the magnetron 3-4 A.

The research parameters of Cr coatings on steel have shown that the thickness of formed coatings is proportional to the time of Cr-cathode sputtering. During 10-20 minutes of treatment it is possible to deposit coatings with thickness up to 2-3 microns. Uniformity of the coatings deposition is determined by the shape of items and improved by using equipment which provides the orbital motion of the items in chamber.

The ion treatment practically does not change the steel surface geometry, but allows before coating to extract the layer comprising hydrocarbon films. Research investigation of coatings adhesion strength by normal separation method of adhered rods has showed that the coatings tend to have the strength above 50 MPa.

The microhardness of steel samples after Cr coatings deposition with thickness 1.5 microns increases from 250-280 kg/mm^2 up to 270-300 kg/mm^2. The friction coefficient for the flat polished samples weakly depends from the coatings deposition and has the values of 0.11- 0.14.

The corrosion resistance of treated materials changes the most noticeable after the formation of coatings. The greatest resistance in acidic solutions show the Cr coated samples with thickness of 4-5 microns. The corrosion resistance to the solutions of nitric acid increases in 50-70 times.

The deposition of Cr coatings of 1.0-1.5 mm thickness on the tool (taps, drills) results in their service life increase in 2-3 times or more. The resistance to abrasion wear increases twice.

Investigations show that there are nanostructures (nanoparticles) of chromium having a particle size 60-200 nm in the vacuum coatings.

CONCLUSION

Vacuum organic ion-plasma processing of steels and tools allows to increase their corrosion resistance for several times and to improve the mechanical characteristics.

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