METAL SURFACE MODIFICATION BY A NANOSECOND DIFFUSE DISCHARGE IN NITROGEN

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The study demonstrates the feasibility of surface modification by a runaway electron preionized diffuse discharge (REP DD) at atmospheric pressures on a nanosecond pulse generator. It is shown that REP DD treatment provides an up to twofold decrease in carbon concentrations in the surface layers of steel and aluminum. It is found that both materials subjected to REP DD are involved in surface oxidation with the result that the oxygen concentration in steel surface layers increases three times and the surface microhardness of the material is enhanced at different depths, whereas the oxygen concentration in aluminum surface layers remains almost unchanged, and the surface microhardness of the material decreases due to the formation of an amorphous oxide layer.

KEY WORDS: *runaway electron preionized diffuse discharge, plasma modification of steel and aluminum, atmospheric pressure*

1. INTRODUCTION

Low-temperature gas discharge plasmas are widely used for surface modification of metals and dielectrics in microelectronics, nanotechnology, and medicine. The modification methods that use low-pressure gas discharges include plasma nitriding (Larisch et al., 1999), plasma spraying (Devoino and Okovity, 2013), and low-energy high-current electron beam treatment (Shymanski et al., 2013). However, most of the plasma sources used for such modification require special vacuum equipment which is to be integrated in production lines, and this increases the cost of the process. One of the alternatives is to use a nanosecond diffuse gas discharge at atmospheric pressure in an inhomogeneous electric field with attendant generation of a runaway electron beam and X-rays (Tarasenko, 2014). This type of discharge is formed in the gap between a plane electrode and an electrode with a small curvature radius and is termed a runaway electron preionized diffuse discharge (REP DD). In a REP DD, the grounded plane electrode experiences the action of a dense plasma, shock wave, and of a supershort avalanche electron beam (Baksht et al., 2006) as well as of optical radiation, including UV, VUV, and X-rays, from the discharge plasma. The polarity of applied voltage pulses and hence the direction of ion and electron motion define the type of treatment of the grounded electrode. Thus, this type of discharge provides the generation of a nonthermal bulk plasma at atmospheric pressure and allows low-cost surface modification on simple and easily operated equipment.

The aim of the study is to investigate the possibilities of surface modification of steel and aluminum in the plasma of a diffuse discharge in atmospheric pressure nitrogen.

2. EXPERIMENTAL PROCEDURE

In our experiments, we used an NPG-15/2000N high-voltage generator with a specific input power of up to 10 MW/cm^3. The incident voltage had a negative polarity, amplitude of about 30 kV, and FWHM of 6 ns; the discharge current was up to 100 A. The test materials were St3ps8 steel and AD-grade aluminum plates of dimensions 15 × 10 × 0.8 mm. The plates were treated in the plasma of a runaway electron preionized diffuse discharge (REP DD) in nitrogen in the repetitive pulsed mode at a frequency of 2 kHz; the gas flow rate was 5 sl/min. The discharge gap was formed by a plane anode (test metal plate) and a cathode with a small curvature radius (needle). The test plates were arranged in the discharge chamber at a distance of 8 mm from the cathode end. The number of pulses per plate was normally 10^5.

The microhardness and elastic modulus of the specimens were measured with a Berkovich diamond indenter on a NanoTest 600 system (Micro Materials Ltd., UK) at a load of 0.5, 1, and 2 mN by the Oliver–Pharr method (Oliver and Pharr, 1992). The concentrations of the main chemical elements in the surface layers were measured with a Shkhuna-2 Auger-spectrometer.

3. RESULTS AND DISCUSSION

Figure 1 shows the carbon and oxygen concentrations in the steel surface layers before and after diffuse plasma treatment in nitrogen.

It is seen from the figure that an oxide layer of about 50 nm in thickness is present on the surface of the initial steel specimen. After plasma treatment, the oxygen concentration in the steel surface layer of thickness 5 nm increases three times and the carbon concentration in this layer decreases two times.

Figure 2 presents Auger spectroscopy data for aluminum before and after diffuse plasma treatment. It is seen that the untreated aluminum surface (open symbols) is covered with a 10-nm-thick layer that contains carbon, aluminum oxide, and oxygen

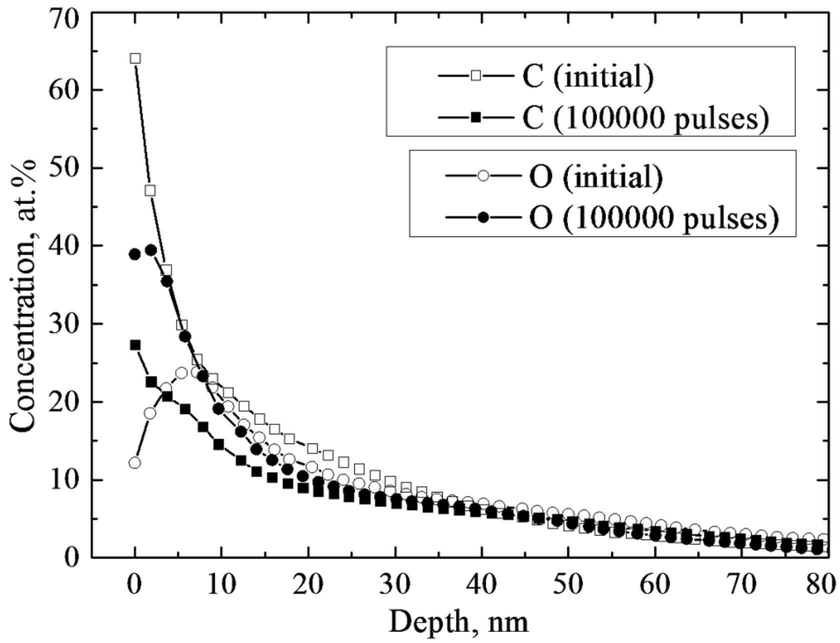

FIG. 1: Carbon and oxygen concentrations at a depth of the steel surface before and after diffuse plasma treatment in nitrogen

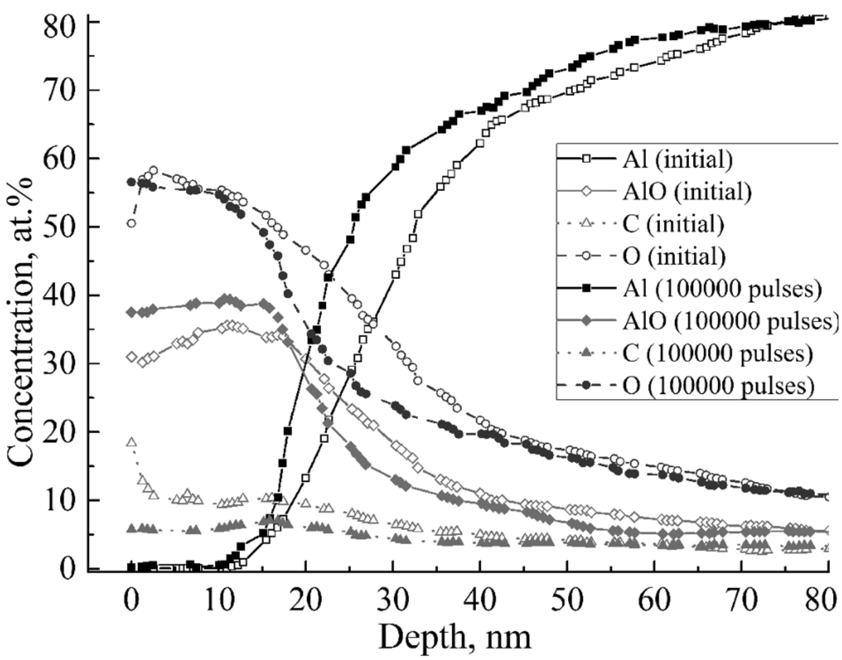

FIG. 2: Element concentrations at a depth of the aluminum surface before and after diffuse plasma treatment in nitrogen

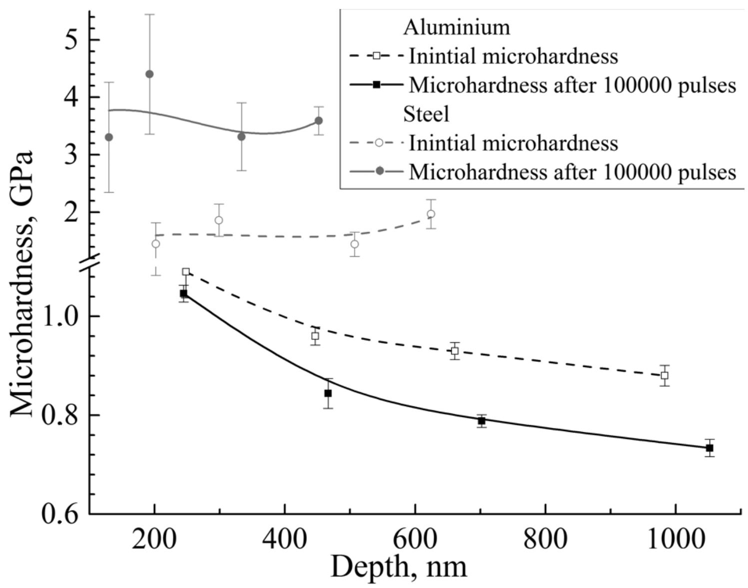

FIG. 3: Surface microhardness at a depth of the steel and aluminum specimens before and after diffuse discharge treatment

at a concentration of 20%, 30%, and 50%, respectively. At a depth of ≥20 nm, the concentrations of these elements in the untreated material decrease with increasing aluminum concentration. In the treated aluminum (solid symbols), the carbon concentration within a depth of 40 nm from the surface is two times lower than that in the initial aluminum. In a surface layer of 20 nm, the concentration of aluminum oxides increases by 30%, whereas the oxygen concentration remains almost unchanged.

Figure 3 shows the surface microhardness at a depth of the steel and aluminum specimens before and after diffuse plasma treatment. It is seen that the microhardness of the treated aluminum decreases slightly (by 10–20%) due to the formation of a thin amorphous Al_2O_3 layer on its surface, whereas the microhardness of the treated steel increases three times. In the initial steel, the scalar dislocation density determined by the intercept method (Utevsky, 1973) varies in the range $(1–2) \times 10^{10}$ cm^{-2}, whereas that in the treated steel increases substantially and measures about 4.1×10^{10} cm^{-2}.

4. CONCLUSIONS

Thus, the study shows that REP DD treatment in nitrogen provides surface cleaning of steel and aluminum from carbon contamination. At the same time, it is found that both materials subjected to REP DD are involved in surface oxidation that increases the surface microhardness of the steel two times but decreases the microhardness of the aluminum by 20% due the formation of a thin amorphous oxide layer on its surface.

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REFERENCES

Baksht, E. Kh., Lomaev, M. I., Rybka, D. V., and Tarasenko, V. F., Study of emission of a volume nanosecond discharge plasma in xenon, krypton and argon at high pressures, *Quant. Electron.*, vol. **36**, pp. 576–580, 2006.

Devoino, O. G. and Okovity, V. V., Plasma spraying of coatings from partially stabilized zirconium dioxide and nickel cermet on the fuel cell element with account for prediction, *High Temp. Mater. Proc.*, vol. **17**, no. 2–3, pp. 75–89, 2013.

Larisch, B., Brusky, U., and Spies, H.-J., Plasma nitriding of stainless steel at low temperatures, *Surf. Coat. Technol.*, vol. **116–119**, pp. 205–2011, 1999.

Oliver, W. C. and Pharr, G. M., An improved technique for determining hardness and elastic modulus using load and displacement sensing indentation experiments, *J. Mater. Res.*, vol. **7**, pp. 1564-1583, 1992.

Shymanski, V. I., Cherenda, N. N., Uglov, V. V., Astashynski, V. M., Koval, N. N., and Ivanov, Y. F., Phase composition modification of the Cr/Ti system by compression plasma flows and high-current electron beams, *High Temp. Mater. Proc.*, vol. **17**, no. 2–3, pp. 101–115, 2013.

Tarasenko, V. F., *Runaway Electrons Preionized Diffuse Discharges*, New York: Nova Science Publishers, Inc., 2014.

Utevsky, L. M., *Electron Diffraction Microscopy in Metal Science,* Moscow: Metallurgiya, 1973.