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Adhesion of Copper Surface treated by Runaway Electron Preionized Diffuse Discharge

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The work was performed in the framework of the State task for HCEI SB RAS, the project #9.5.2.

INTRODUCTION

Condition of metal surface, value and uniformity of the roughness are very significant quality factors, which have considerable influence on adhesive properties of the metal surface, decorative appearance and strength of the protective coatings. The best property has metal, with surface microgeometry characterized by microcavities and microasperities, which are chaotically located, but uniformly distributed on the different surface areas, at all other things being equal. Furthermore, adhesive properties of a coating are substantially depend on free surface energy of the substrate.

Surface microgeometry is set by preliminarily polishing of the surface with specified roughness values, usually realized by various mechanical methods using hydroabrasive and free abrasive powder [1, 2].

Currently, along with mechanical processing methods of the metal surface, electrophysical methods [3], such as ultrasonic and electro-discharge in pulse-periodic mode [4], are used. Surface treatment by runaway electron preionized diffuse discharge (REP DD) is one of the prospective method of plasma processing because it is engineering managed and environmentally friendly in contrast to mechanical methods, as well as high process efficiency, comparatively low price of the equipment and its simple maintaining as opposite to ultrasonic method.

The matter of REP DD treatment is cleaning and roughness changing of the metal surface layer under the action of diffuse discharge plasma formed in various gases at atmospheric pressure filling a gap between high voltage electrode (cathode) and processed metal surface (anode). Modified layer of the treated metal are formed under the action of low temperature diffuse discharge plasma and runaway electrons, which concentration gains 1014 cm-1 in the center of interelectrode gap. Such level of electron concentration in the discharge zone is achieved by using high voltage generator with nanosecond pulse duration.

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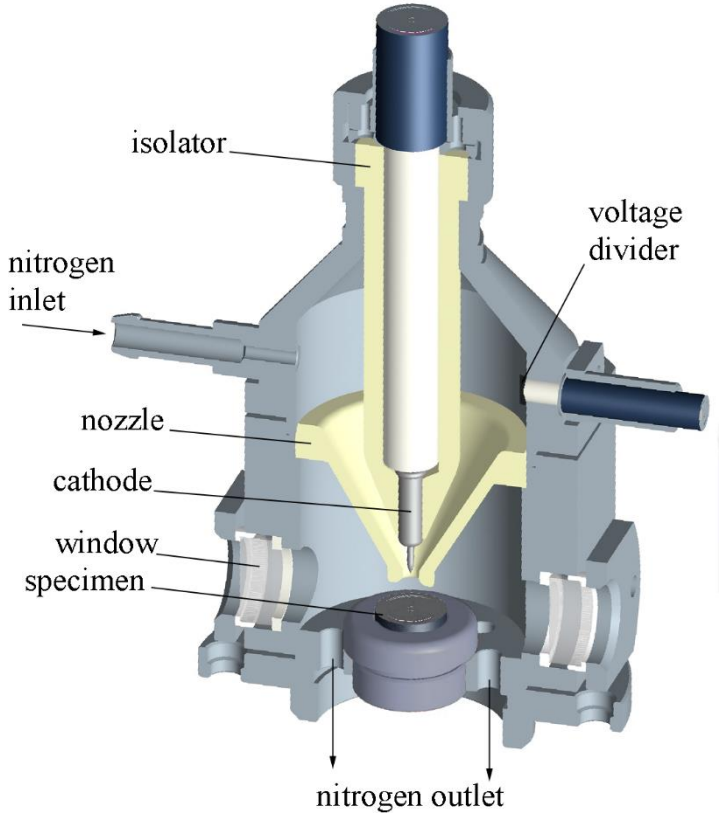
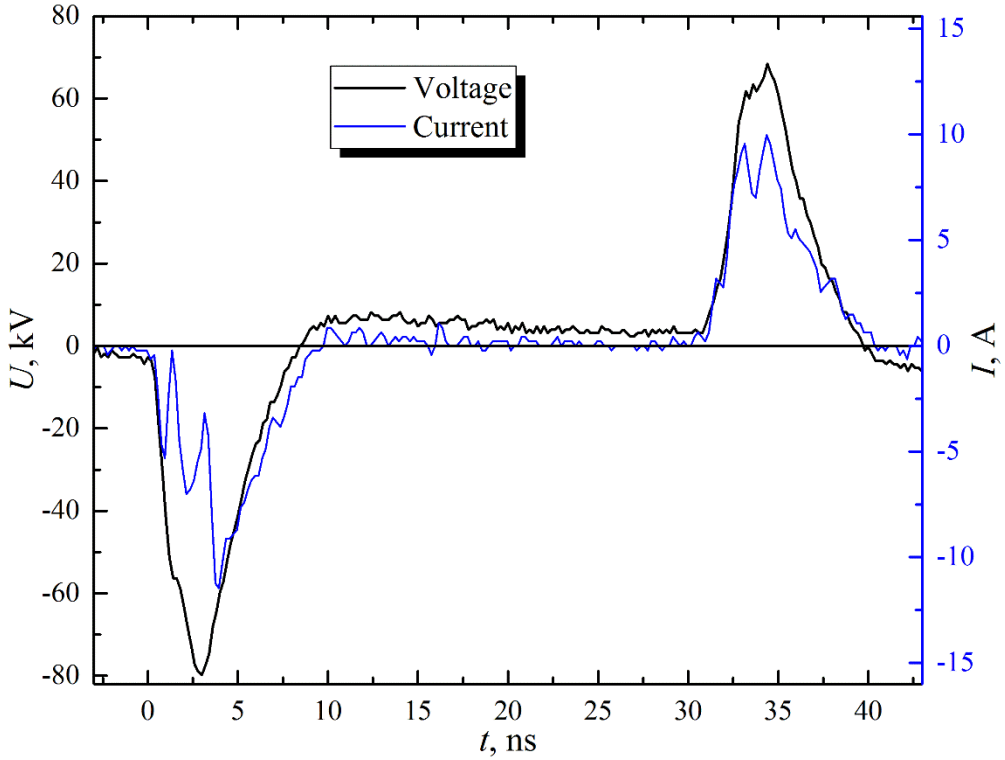
In [5], the microstructure of the spark prints and diffuse channels with anode spots was revealed at discharge with duration of several nanoseconds. The prints of such channels are a combination of up to 100 and more microcraters 5 – 100 μm in diameter. It was shown that, due to the short duration of the voltage pulse (less than 10 ns), a diffuse discharge can be realized, several pulses of which do not produce appreciable erosion on the plane anode or the coating deposited on it. Moreover, the effect of PER DD plasma in single shot pulses [6] or pulsed-periodic pulses [7] induces increasing of free surface energy: the study shows that REP DD plasma treatment with 105 discharge pulses provides ultrafine surface cleaning of the treated metals from carbon and increases their surface free energy up to 3 times.

The aim of this work was to study the possibilities of surface microrelief formation under the action of REP DD plasma and increasing of adhesive properties of the plane copper specimen.

EXPERIMENTAL SETUP





Generator voltage in the incident wave is U_{max} = -55 kV.
FWHM of voltage pulse 4 ns.
Voltage pulse rise time 800 ps.
PRF f = 10 - 1000 Hz.
The plane copper specimen was shaped as a cylinder of diameter 14 mm and height 2 mm.
The surface roughness was measured using a Micro Measure 3D Station (STIL, France).
Measurements of adhesion was made according to X-cut test (ISO 16276-2:2007) of aerosol paint KIM TEC (Germany) painted to the specimen's surface.

3D-topography and 2D-profilogram

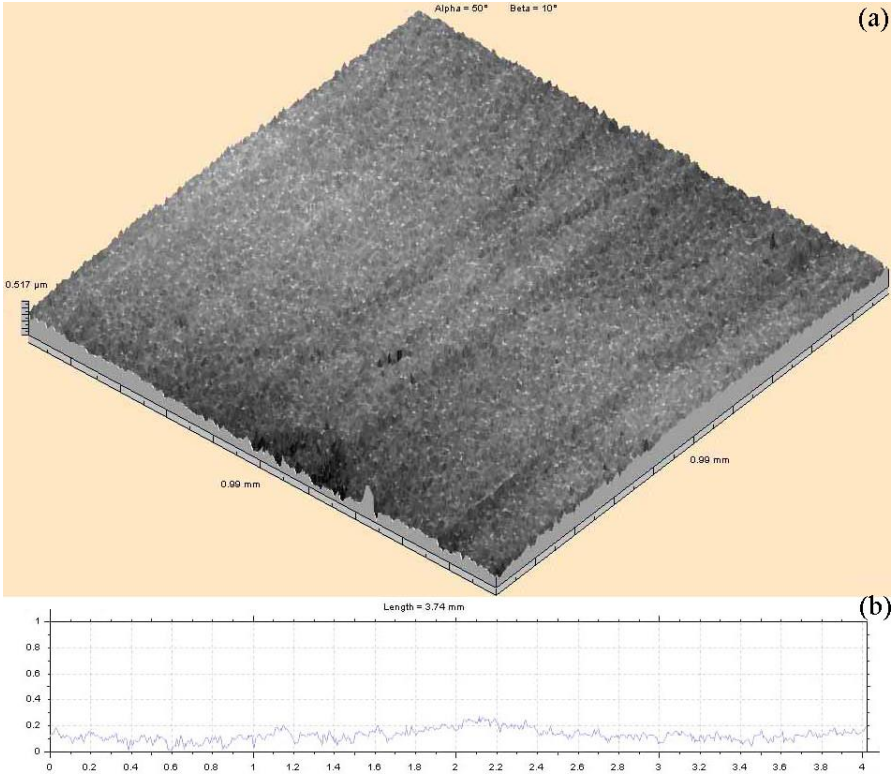


Fig. 1. 3D-topography (a) and 2D-profilogram (b) of copper surface before plasma treatment.

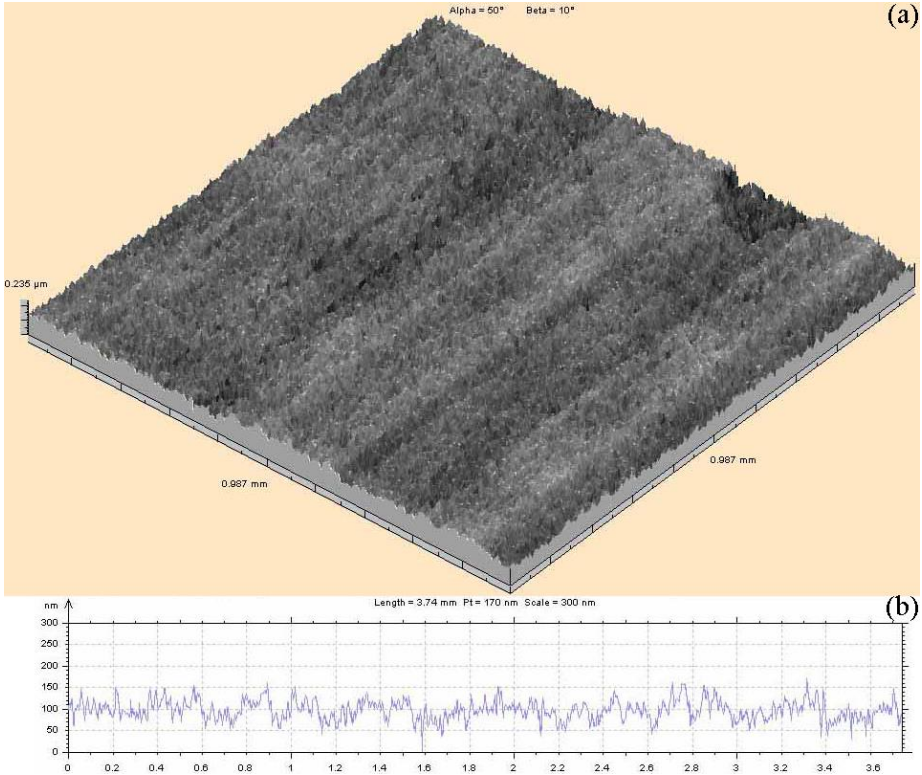


Fig. 2. 3D-topography (a) and 2D-profilogram (b) of copper surface upon the exposure to 40000 discharge pulses of REP DD.

The surface of the untreated copper specimen had many protrusions and the root-mean-square roughness R_q was 26.9 nm. After the REP DD plasma modification, the roughness value R_q considerably decreased to 22.3 nm. The roughness R_a value for the copper was 21.5 nm and it decreased to 17.7 nm under the action of 40000 discharge pulses of REP DD, which indicates that the size of bulges and grooves decreased. Moreover, the maximal height of the surface profile R_z was 137 nm and 124 nm for the untreated specimen and after plasma modification, respectively.

X-CUT TEST

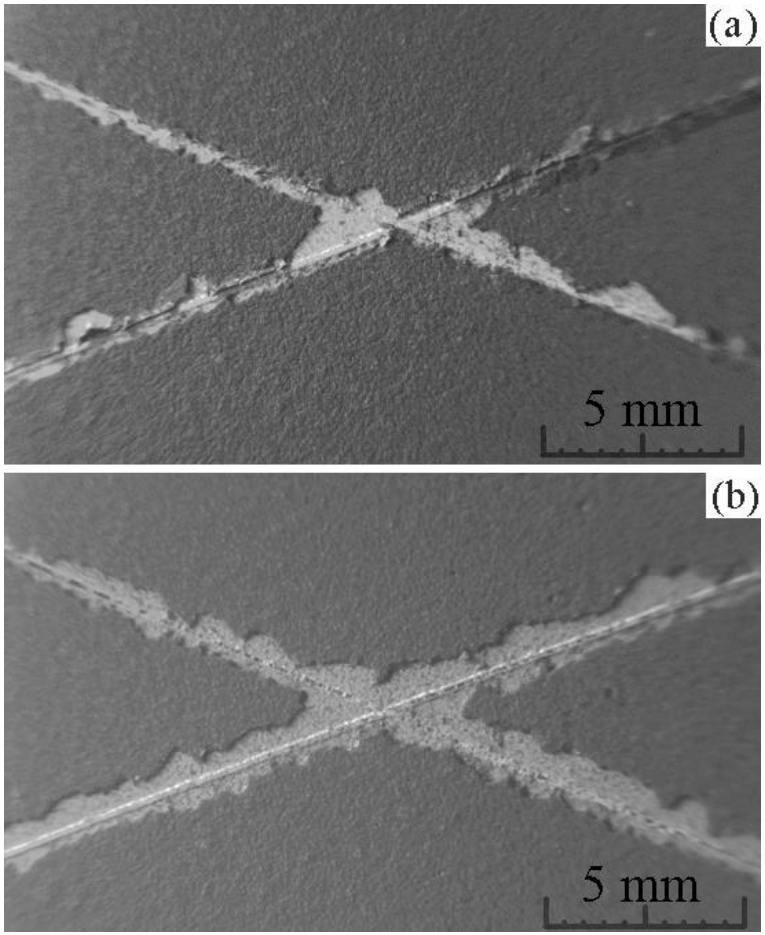


Fig. 3. X-cuts in paint on untreated copper specimen before (a) and after (b) tearing off adhesive tape.

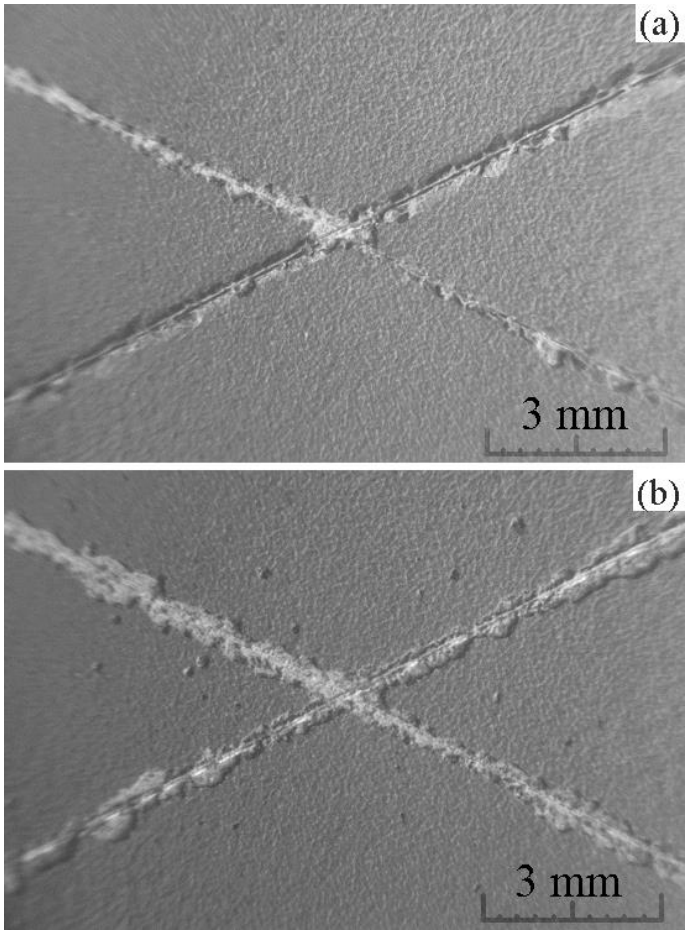


Fig. 4. X-cuts in paint on the treated copper specimen with 40000 REP DD pulses before (a) and after (b) tearing off adhesive tape.

Measurements of adhesion by means of X-cut test (ISO 16276-2:2007) have shown that adhesion of aerosol paint KIM TEC (Germany) on polished and rinsed in ultrasonic bath untreated copper (Fig. 3, (a) and (b)) specimens corresponds to 2 points, and increased up to 4 points after treatment by plasma of 40000 REP DD pulses (Fig. 4, (a) and (b)).

Conclusion

In summary, our research of microrelief formation under the action of REP DD plasma has shown the following. The roughness value Ra of the copper decreased after exposure to 40000 discharge pulses of REP DD, which indicates that the surface became smoother. Nevertheless, adhesion of aerosol paint on polished copper increased up to two times after the plasma modification due to increasing of free surface energy. These findings will have potential applications in the high adhesive coatings.

ACKNOWLEDGMENT

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