

Phase analysis study of the copper-aluminum contact pair obtained by plasma dynamic method

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Abstract. We obtained the contact pair copper-aluminum copper coating by using a magneto plasma accelerator. The process is realized during supersonic copper plasma jet flowing into the chamber filled with the air atmosphere. Copper jet is carried out of the accelerating channel towards the aluminum target. Plasma jet is generated by coaxial magnetoplasma accelerator (CMPA) based on copper electrode system. The CMPA is supplied from the pulsed capacitive energy storage with the maximum value of stored energy of 360 kJ. The obtained copper-aluminum contact pairs have been analyzed by X-ray diffractometry and Nano hardness tester. The copper coating on the aluminum surface is uniform with thickness about 100 µm. Also in this paper it is shown that transitional contact resistance of copper-aluminum contact pair is at 2,5 times less than a direct connection of copper and aluminum (test contact pair).

1. Introduction

In the place of joining dissimilar metals such as copper and aluminum, the contact is oxidized that leads to deterioration of its quality, the reduction of the useful life and the increase of the transitional contact resistance.

To join copper and aluminum contacts such ways as the using of bimetallic gaskets, copper-based powdered lubricants and copper-coating deposition on the aluminum surfaces are used [1-3]. However all of them have advantages and disadvantages. Bimetallic gaskets allow to join copper and aluminum contact but the resistance is increased due to the high quantity of boundaries. The method of cold gas-dynamic spraying is the most widely-used but the low adhesion of coatings negatively impacts on the long life of such contacts [4].

It was shown that it is possible to obtain a copper-aluminum contact pair by using the pulsed jet of the copper electro erosion plasma [5]. The jet is generated by the coaxial magnetoplasma accelerator with copper electrodes. This method allows to obtain copper-aluminum contact pairs with the high adhesion and the stability to dynamic loads [6].

To investigate the influence of the coating phase composition on the contact pair parameters such as hardness and transitional contact resistance, a series of experiments has been carried out.

2. Experimental

The coaxial magnetoplasma accelerator (figure 1) has been used as a source of copper plasma that influences on the aluminum surface. The power supply has been provided from the capacity energy storage.



Based on the terms of previous studies [7], optimal energy and constructional parameters for copper coatings deposition are as follows: a charging voltage $U = 3,5$ kV, a charging capacitance $C = 12$ mF, the charging energy $W_c = 73,5$ kJ, the diameter of the accelerating channel (AC) $d_{ac} = 12$ mm, the distance between end of the AC and an aluminum target $l = 270$ mm, the process is realized in the air atmosphere. The coating, obtained with these conditions, is uniform and the coating area is about of 130 cm².

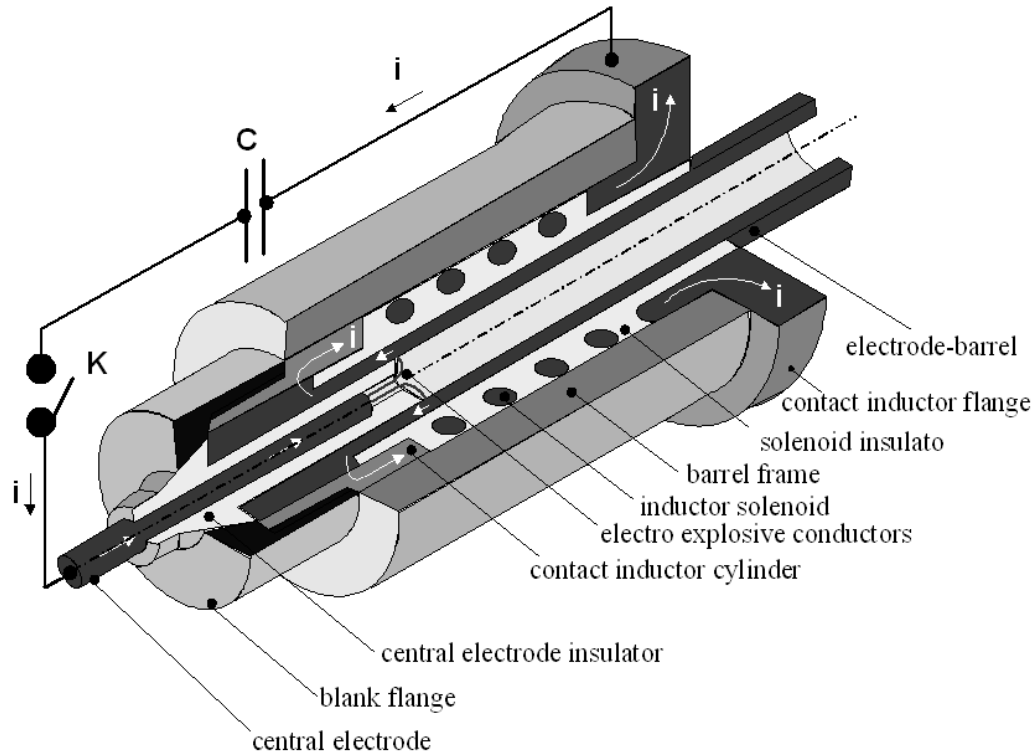


Figure 1. Coaxial magnetoplasma accelerator.

To investigate the phase composition of the copper-coated aluminum samples, the method of X-ray diffractometry (XRD) has been used by using the diffractometer Shimadzu XRD7000 with a $\text{Cu K}\alpha$ radiation. The analysis of XRD patterns has been carried out using the software “PowderCell 2.4” and databases PDF2 and PDF4+. The hardness of samples has been investigated using the NANO Hardness Tester NHT-S-AX-000X and Vickers hardness. The coating microstructure has been investigated with the optical metallographic microscope Olympus GX-71. The value of the transitional contact resistance has been measured by the volt-ampere method.

3. Results and discussion

The typical XRD pattern of obtained copper-aluminum contact pairs is shown in figure 2. It has been found the content of the main crystalline phase of copper Cu (Space Group (SG): $F 4/m - 3 2/m$) varies in the range $\sim 61 \div 83\%$ by depending on the coating conditions. Besides, such crystalline phases as copper oxide CuO (SG: $F 4/m - 3 2/m$) containing up to $\sim 25\%$, aluminum Al (SG: $F 4/m - 3 2/m$) up to $\sim 20\%$, aluminum nitride AlN (SG: $F 4/m - 3 2/m$) up to $\sim 20\%$ have been identified.

The aluminum phase presence in the coating is caused by its receipt from the substrate surface due to factors such as melting, hydrodynamic mixing and diffusion in the liquid phase at a high speed jet interaction with the surface. The crystalline phases of CuO and AlN are formed as a result of the process of the copper deposition in the air atmosphere. The absence of the aluminum oxide is the positive factor of the obtained copper-aluminum contact pair, because its presence deteriorates the contact quality.

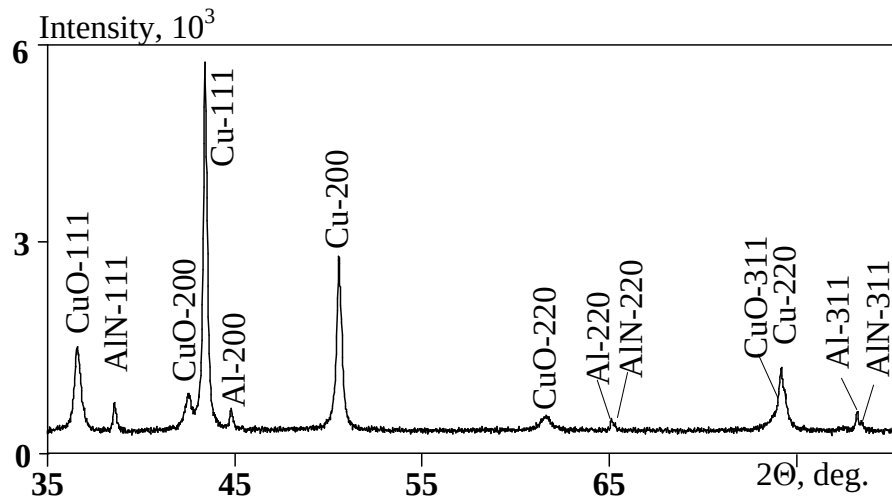


Figure 2. XRD pattern of the copper coating on the aluminum substrate obtained in the air atmosphere.

The comparative data analysis of the coating material phase structure and the nanohardness is shown in figure 3. There is also a correlation between the nanohardness of the copper surface and the presence of a harder phase of the aluminum nitride (AlN) and a less hard aluminum (Al) phase. The nanohardness increases like a linear function with the growth of the aluminum nitride presence in the above limits. An elevated presence of the aluminum phase leads to a significant reduction of the nanohardness.

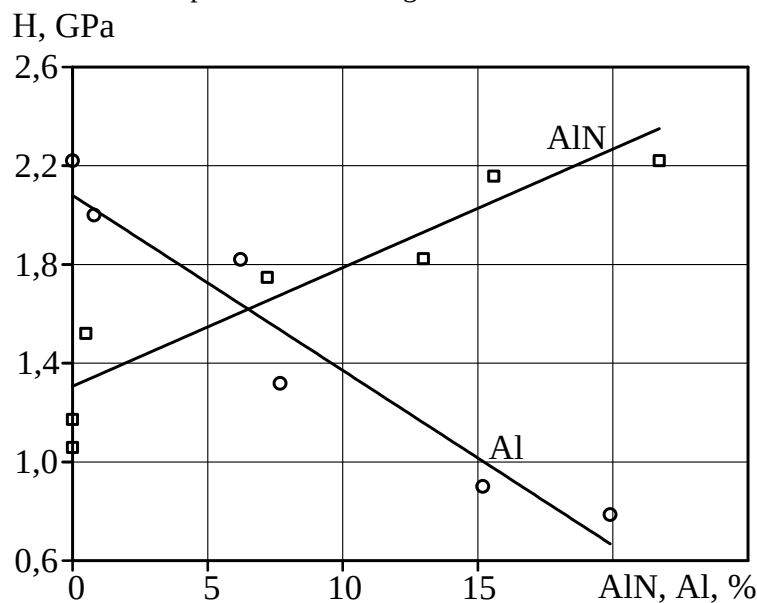


Figure 3. The dependence of nanohardness in the boundary layer on the phase concentrations.

It is well-known the transition resistance of the contact pair depends on the pressure load. The higher the value of pressure load is, the lower the transition resistance is [6-7]. However the dependence of the transition contact resistance on the nanohardness has been investigated (figure 4). It has been found, the transition resistance (R_{res}) reduces almost linearly with the growth of the nanohardness of the coating material, boundary and frontier layers of the substrate material.

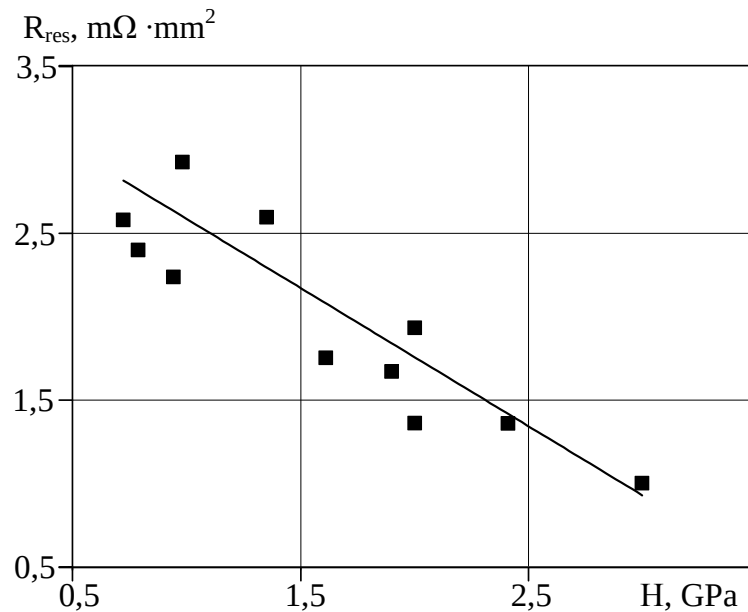


Figure 4. Dependence of the contact resistivity (R_{res}) on the nanohardness (H) of the coating.

The microstructure of the copper coating and the boundary layer has been analyzed by optical microscopy. Figure 5 shows the optical micrographs of cross-sections slice of aluminum sample with copper coating. Using the optimal energy and constructional parameters the uniform coating with the thickness of about 100 μm has been obtained. The cover adjoin tightly to the substrate replicating everything unevenness scope pairing. The boundary layer between aluminium and copper is absent according to micrographs. It is the positive feature of the method. The copper particles deeply penetrate into the substrate due to the hydrodynamic intermixing in the synthesis process. The hydrodynamic intermixing is the key factor of the strong adhesion between copper and aluminum. The transitional resistance of such contact pair is at 2,5 times less than a direct connection of copper and aluminum [8].

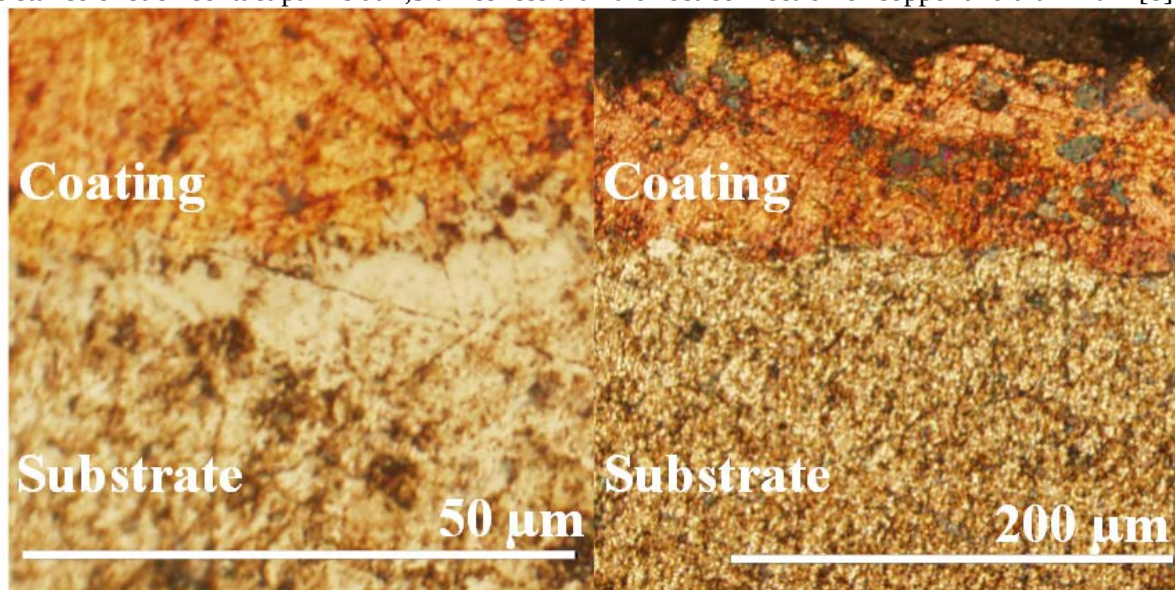


Figure 5. Optical micrographs of the cross-sectional slice of the aluminum sample.

4. Conclusion

It is shown the possibility of obtaining of the copper-aluminum contact pair with uniform copper coating with the thickness of about 100 μm by using the coaxial magnetoplasma accelerator. The phase composition of coating has been investigated and it has been found the presence of such crystalline phases as copper, aluminum, copper oxide and aluminum nitride. The dependence of the nanohardness on the aluminum nitride and the pure aluminum for the samples obtained by plasma dynamic method has been shown. The increase of the AlN phase leads to the increase of coating nanohardness. The increase of the nanohardness directly impacts on the reduction of the transitional contact resistance. Using the optimal energy and constructional parameters of the system based on the coaxial magnetoplasma accelerator, it is possible to reduce the transitional contact resistance of the copper-aluminum contact pair at 2,5 times.

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