NANOSTRUCTURED FORMATIONS AND COATINGS CREATED ON THE SURFACE OF MATERIALS EXPOSED TO COMPRESSION PLASMA FLOWS

V.M. Astashynski, S.I. Ananin, V.V. Askerko, E.A. Kostyukevich, A.M. Kuzmitski, V.V. Uglov*, V.M. Anishchik*, N.N. Cherenda*, Yu.V. Sveshnikov*, N.T. Kvasov**, A.L. Danilyuk**, A.V. Punko**

Institute of Molecular and Atomic Physics, National Academy of Sciences of Belarus, Minsk, Belarus, e-mail: ast@imaph.bas-net.by;
****Belarusian State University, Minsk, Belarus;***
*****Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus***

The paper presents the results of investigations on changing silicon and aluminium morphology under the action of compression plasma flows generated by the quasi-stationary plasma accelerator (magnetoplasma compressor type). The feasibility of spraying nanostructured metal films by compression flows was demonstrated. The resulting single-layer coating consists of spherical particles measuring 50 to 200 nm. Such particles bonded to each other cover a surface relief including flat areas and regular structures developing during plasma action. The state and composition of a sample surface were studied by SEM- and EXD-methods.

PACS: 52.40.Hf

INTRODUCTION

Nowadays a great attention is attracted to studies aimed at the formation of nanoscale structures and coatings from various materials. Of the approaches designed to modify material surface properties, the use of compression plasma flows [1-3] appears to be rather attractive one. For the most part this is due to high plasma parameters (such as velocity and density of plasma components) unattainable by conventional accelerators, which may be easily varied in a wide range of values. What is more, such technique makes it possible, aside from alloying a surface layer by plasma components, to use as a doping agent the substance purposely introduced into plasma flow.

Earlier we first obtained regular bulk structures on a surface of silicon wafers through exposing them to compression plasma flows generated by a quasi-stationary magnetoplasma compressor (MPC) [1, 2]. Considered in the present paper is the possibility for changing a surface topography of aluminium plates and spraying nanostructured metal coatings on a substrate.

EXPERIMENTAL

The experiments were carried out using MPC of compact geometry [3]. The peak of discharge current and discharge duration amounted to ~ 90 kA and 120 μs, respectively. Initial pressure of working gas (nitrogen) was equal to 400 Pa.

Under such conditions, typical parameters of a compression flow were as follows: plasma velocity - 40-70 km/s, charged particles concentration – $(5\text{-}10)\cdot 10^{17}$ cm^{-3} and temperature – 1-3 eV. Life time of a compression flow makes ~ 100 μs.

To investigate the microstructure and morphology of treated surface, Leo 1455VP scanning electron microscope (SEM) was applied. Using energy dispersive X-ray (EDX) microanalysis, the elemental composition of modified layer was found.

The action of compression plasma flow on a surface of silicon wafers measuring 10x10x0.3 mm^3 results in the formation of regular self-organizing structures 100-700 nanometers in diameter and up to 100 microns long (Fig.1).

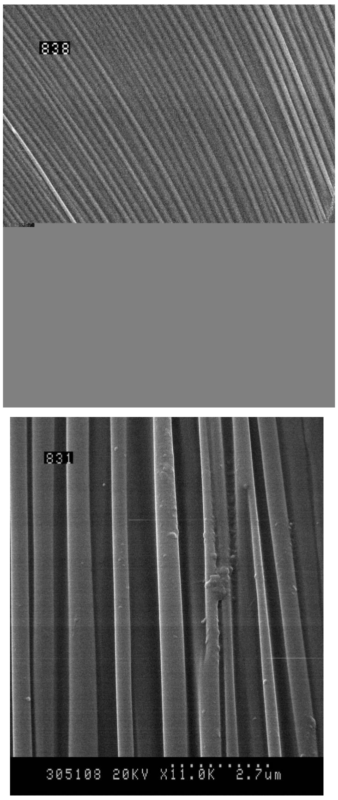


Fig. 1. Surface morphology a of monocrystal silicon wafer acted upon by a compression flow

Structural-phase surface changes are determined by a plasma power action, resulting in the fast heating and melting of a material surface layer, the spreading of plasma and, in its turn, of the melt throughout a surface (from a sample centre of to its edges) due to a compression flow dynamic pressure, gradients of plasma thermodynamic parameters in a shock-compressed layer, and finally to features of crystallization processes in conditions of fast cooling a surface in the presence of magnetic fields induced by swept-away currents.

The appearance of surface nano-scale structures developing on a sample subjected to a compression plasma flow is determined not only by conditions of the plasma/target interaction, but by a target material as well. In the case of processed sample from commercial purity aluminium, its surface morphology resembles that of processed silicon, with the difference, that there were no clearly defined cylindrical formations on aluminium sample. Surface structures typically observed are in the form of plates about 200 nanometers high located at certain angles to surface (fig. 2).

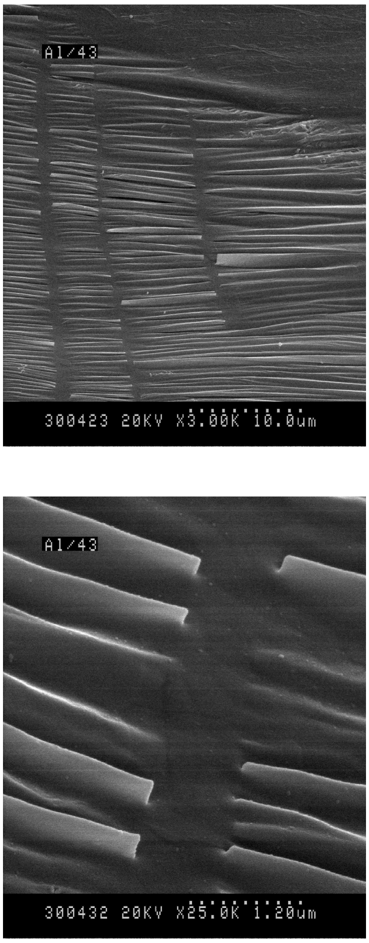
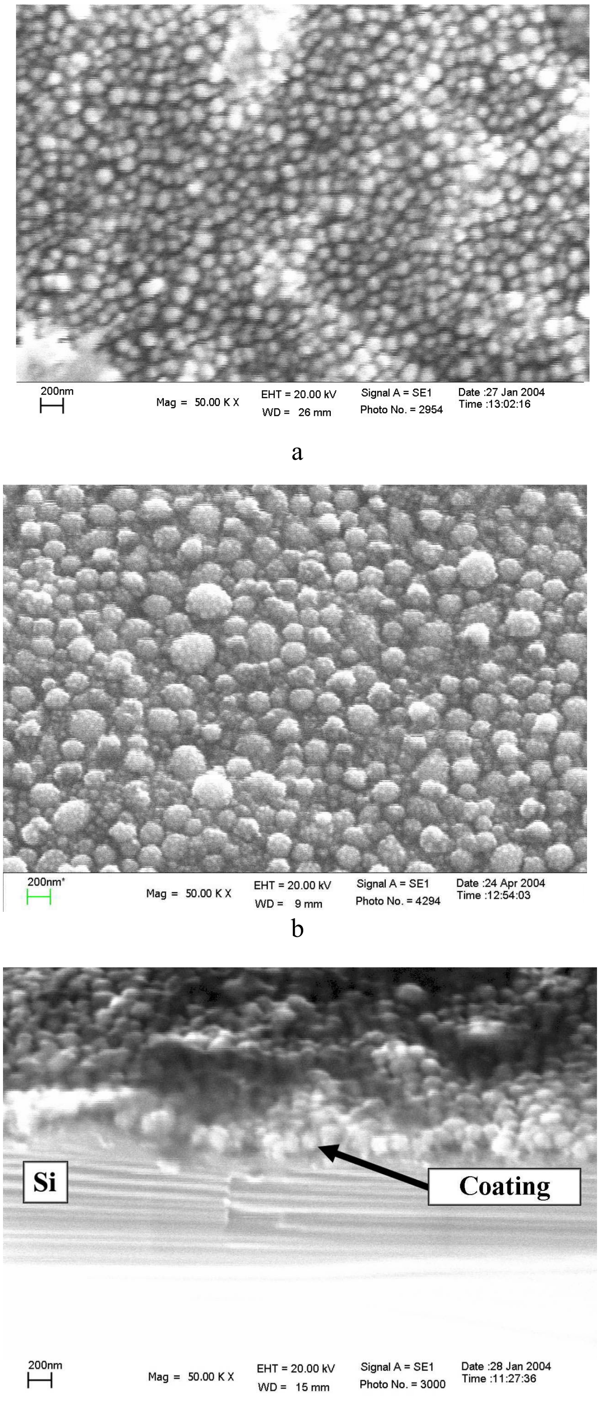


Fig. 2. Surface morphology of commercial purity aluminium processed by a nitrogen plasma flow

Compression plasma flows can also be used for obtaining nano-scale disperse coatings on various materials, including silicon. In this case a compression plasma flow is loaded by highly dispersed metal particles produced by the wire electrical explosion. Here, the plasma flow action results not only in the surface layer modification, but in the formation of a metal coating as well. Shown in Fig. 3 is the structure of a coating deposited on a silicon wafer by means of a compression plasma flow.



a

b

c

Fig. 3. A surface (a, b) and cross section (c) morphology of silicon wafer with the metallic coating deposited by a nitrogen plasma flow

The coating obtained looks like a monolayer of spherical metallic particles 50 to 200 nanometers in size linked to each other.

In such a combined mode of the MPC operation, metal particles comprising the nanostructured layer reach the sample surface towards the end of plasma flow action, thus covering various forms of plasma-modified surface relief, among them regular structures developed during exposure to plasma (Fig. 4).

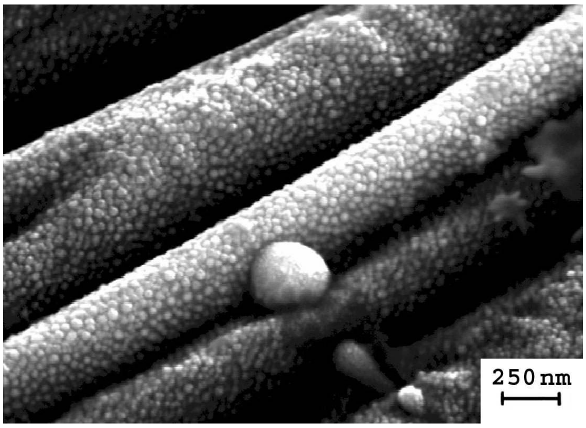


Fig. 4

When taken into account that the coating is a single-layer film comprised of closely packed nanoparticles, a possible mechanism for its formation may be as follows. The incidence of a head of supersonic compression flow on the sample initiates a shock-compressed plasma layer persisting throughout the discharge duration and shielding a surface from an incident flow. The near-surface plasma layer is mainly composed of target ablation products [4]. The location of its boundary is governed by a balance between dynamic head of incident flow and gas-kinetic (thermal) spread of near-surface plasma. Due to thermalization of the incident flow kinetic energy at the developed shock-compressed layer, the parameters of near-surface plasma are maintained at a high level throughout the discharge quasistationary stage life. The residual plasma shell keeps on existing close to the sample surface for some time upon decaying the compression flow.

Metal nanoparticles produced by the wire explosion move with relatively slow velocities and accumulate in the dense near-surface layer. Their deposition begins simultaneously with plasma shell disintegration and crystallization of substrate molten layer. These processes result finally in the formation of nanostructured metal coating. Large metal drops reach the target surface when the coating practically took shape.

CONCLUSION

A novel technique for modifying a material surface and spraying a finely structured coating on the modified surface is offered. The idea is to combine the action of the MPC-generated compression plasma flow on a target with simultaneous electrical explosion of metal wire. Plasma flow causes the target surface to change, whereas products of wire explosion deposit on the modified relief in a form of a monolayer of closely packed metal particles up to 200 nm in size. Using such a combined method, multicomponent metal-based coatings were obtained on sodium chloride monocrystals. By varying the material of wire and type of working gas, it is possible to change the coating composition.

REFERENCES

1. V.V. Uglov, V.M. Anishchik, V.V. Astashynski et al. Formation of Submicron Cylindrical Structures at Silicon Surface Exposed to a Compression Plasma Flow // *JETP Letters (74)*, 2001, No 4, p. 213–215.
2. V.V. Uglov, V.M. Anishchik, V.V Astashynski et al. The effect of dense compression plasma flow on silicon surface morphology// *Surface and Coatings Technology* v. 158-159C. 2002, p. 273-276.
3. V.M. Astashinskii, V.V. Efremov, E.A. Kostyukevich et al. Interference-shadow studies of the processes in a magnetoplasma compressor.// *Sov. J. Plasma Phys.* (Engl. transl.) *(17)*. 1991, No 9, p. 545-548
4. V.M.Astashynski, S.I.Ananin, V.V.Askerko et al. Materials surface modification using quasi-stationary plasma accelerators.// *Surface and Coating Technology* v. 180-181C, 2004, pp. 392-395.

НАНОСТРУКТУРНЫЕ ОБРАЗОВАНИЯ И ПОКРЫТИЯ, ФОРМИРУЮЩИЕСЯ НА ПОВЕРХНОСТИ МАТЕРИАЛОВ ПРИ ВОЗДЕЙСТВИИ КОМПРЕССИОННЫМИ ПЛАЗМЕННЫМИ ПОТОКАМИ

В.М. Асташинский, С.И. Ананин, В.В. Аскерко, Е.А. Костюкевич, А.М. Кузьмицкий, В.В. Углов, В.М. Анищик, Н.Н. Черенда, Ю.В. Свешников, Н.Т. Квасов, А.В. Пунько

Представлены результаты исследований изменения морфологии поверхности пластин кремния и алюминия при воздействии на них компрессионными плазменными потоками, генерируемыми квазистационарным плазменным ускорителем типа магнитоплазменный компрессор. Продемонстрирована возможность нанесения на подложки наноструктурных металлических покрытий с помощью компрессионных потоков.

НАНОСТРУКТУРНІ УТВОРЕННЯ І ПОКРИТТЯ, ЩО ФОРМУЮТЬСЯ НА ПОВЕРХНІ МАТЕРІАЛІВ ПРИ ВПЛИВІ КОМПРЕСІЙНИМИ ПЛАЗМОВИМИ ПОТОКАМИ

В.М. Асташинский, С.І. Ананін, В.В. Аскерко, Е.А. Костюкевич, А.М. Кузьмицький, В.В. Углов, В.М. Анищик, Н.Н. Черенда, Ю.В. Свєшников, Н.Т. Квасов, А.В. Пунько

Представлено результати досліджень зміни морфології поверхні пластин кремнію й алюмінію при впливі на них компресійними плазмовими потоками, що генеруються квазістаціонарним плазмовим прискорювачем типу магнітоплазмовий компресор. Продемонстровано можливість нанесення на підкладки наноструктурних металевих покрить за допомогою компресійних потоків.