# ELECTROCHEMICAL CODEPOSITION OF NANOSTRUCTURED MATERIALS FOR HIGHLY RELIABLE SYSTEMS

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***Abstract*** – This paper describes one of the approaches to solve the problem of wear and friction of mechanically moving and load carrying elements of micro and nano dimensions. The electrochemical electroplating technology of metals and alloys with inert hard nanoparticles is presented. Codeposition model of nanocomposite plating is developed. The influence of process parameters on the mechanical properties of particle-reinforced coatings is described. The use of nanocomposite materials to improve the mechanical properties of micro and nano components in modern integrated systems is investigated. The outlook of these materials and technologies for advanced micro- and nanoelectromechanical systems of high reliability and their application is considered. A method for manufacturing of holographic films with high runability for roll-to-roll technology is described.

## I. INTRODUCTION

Micro and nanosystems have become the integral part of human being. Such modern complex advanced systems and their production technologies require new types of material to be developed. These materials should be structured by shape and properties in nano and micro scale for fulfillment of requirements and further incorporation into the systems.

One of the approaches to solve the problem of wear and friction of mechanically moving and load carrying elements of micro and nano dimensions is the use of nanocomposite materials; in particular, codeposited metal and alloy with inert hard nanoparticles by electrochemical or electroless processes. The most exciting applications of plated nanostructured materials are microelectromechanical systems (MEMS), roll-to-roll and nanoimprint technologies.

## II. NANOCOMPOSITE PLATING PROCESS

Nanocomposite coatings containing ultra-fine particles were plated. Soft magnetic (NiFe, CoFeP, CoP) and hard magnetic (CoNiP, CoW, CoP) alloys as well as conductive matrixes of Cu and Ni were investigated. The thickness of the investigated deposits was up to 200 µm. Concentration of ultra-fine particles was varied from 0 to 10 g•dm$^{-3}$ (dry substance). Diamond, alumina and aluminium monohydrate ultra-fine particles and boron nitride microparticles were used. Average size of nanodiamond particles was 7 nm, alumina – 47 nm, aluminium monohydrate - 20 nm and boron nitride – 1 µm. Codeposition process was carried out in the electrolytic cell of flow type (Fig. 1).

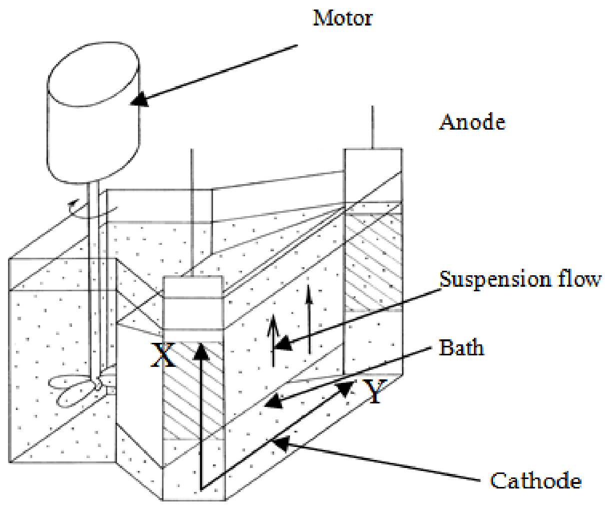



Figure 1 – Electrolytic cell for codeposition process

## III. Codeposition Model of Nanocomposite Plating

During the electrolytic codeposition, the suspended inert particles interact with the surface of the growing film due to hydrodynamic, molecular and electrostatic forces [1]. This complex process results in the formation of composite coatings.

Based on the experimental data [2], the qualitative codeposition model of the composite coatings with the ultra-fine particles was suggested. The peculiarities of the ultra-fine particles behavior are considered in the model. The model worked out is based on the assumption the codeposition of ultra-fine particles proceeds through the following stages:

1. Coagulation of ultra-fine particles in plating solution;
2. Formation of quasi-stable aggregates and therefore change of system dispersion constitution;
3. Transport of the aggregates to the cathode surface by convection, migration and diffusion;
4. Disintegration of the aggregates in the near-cathode surface;
5. Weak adsorption of ultra-fine particles and aggregate fragments onto the cathode surface;
6. Strong adsorption of dispersion fraction (embedment).

Behavior of dispersed systems is described by DLVO theory. Stability or coagulation rate of suspensions depends on sign and magnitude of overall potential energy of interaction between the particles. Structural investigations confirm proposed model of heterogeneous nanocomposite coating formation. Cross-sections show that ultra-fine particles are effectively incorporated into the meal matrix (Fig.2). These nanoparticles are distributed in the matrix volume uniformly. Small fragments of aggregates and separate nanoparticles form heterogeneous structure of nanocomposite.

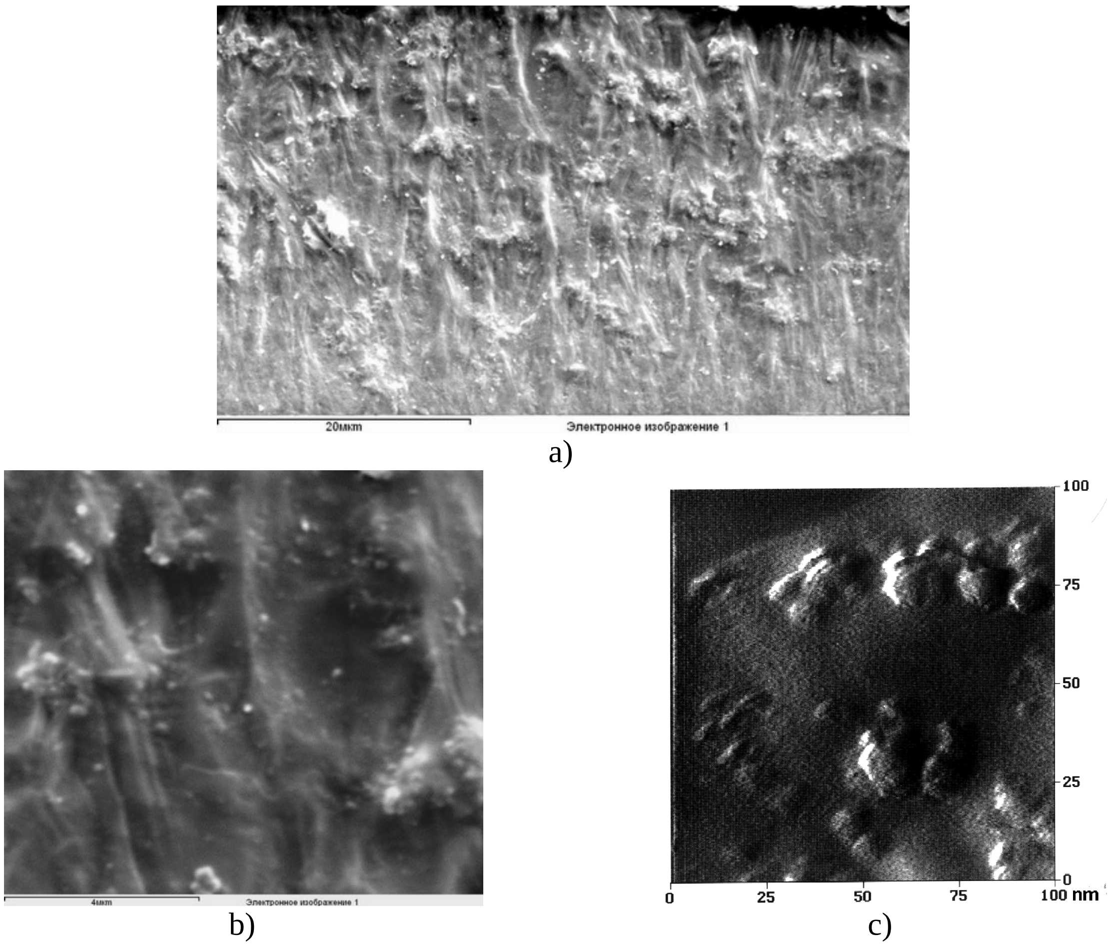



Figure 2 – SEM cross sectional images of Ni-$Al_2O_3$ nanocomposite film (a, b), AFM surface image of Ni-nanodiamond (c)

## IV. Nanocomposites for Highly Reliable Applications

Micro and nanosystems are the completed devices that combine into one sensor, electronic, and mechanical parts. Mechanical interaction between nano-, micro-, and macro world is the limiting factor for such a complex system. Three dimensional moveable structures should be integrated in micro and nanosystems from design and technology perspective. Moreover, in general reliability of the systems is determined by the reliability of the mechanical part.

Friction, wear and corrosion are the key problems for MEMS with real mechanically moveable elements. Codeposition processes allow getting nanocomposite elements with high operate reliability: wear resistance increased in 2-2.5 times, microhardness increased in 2 times, coefficient of friction and corrosion current were reduced factor 1.5 and 1.6 respectively. Developed technologies were tested on prototypes of the electromagnetic and pneumatic micromotors (Fig. 3).

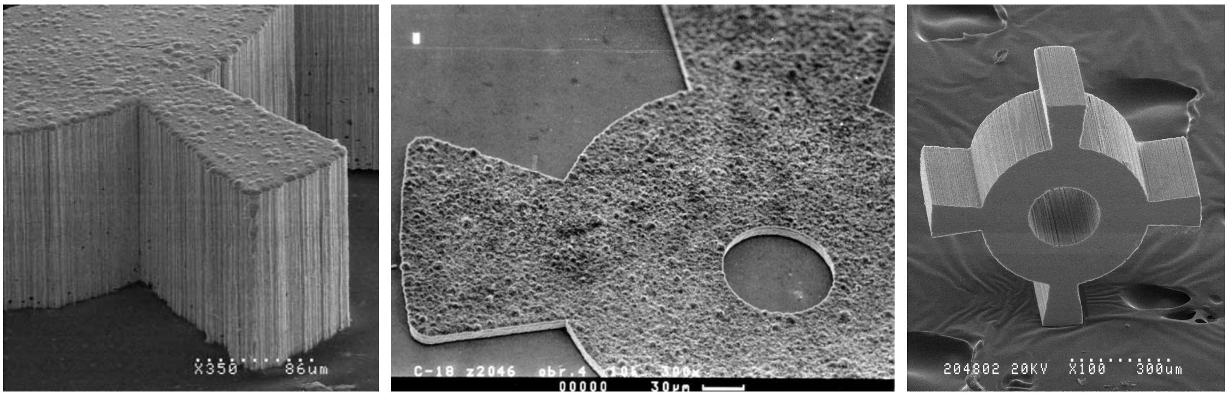
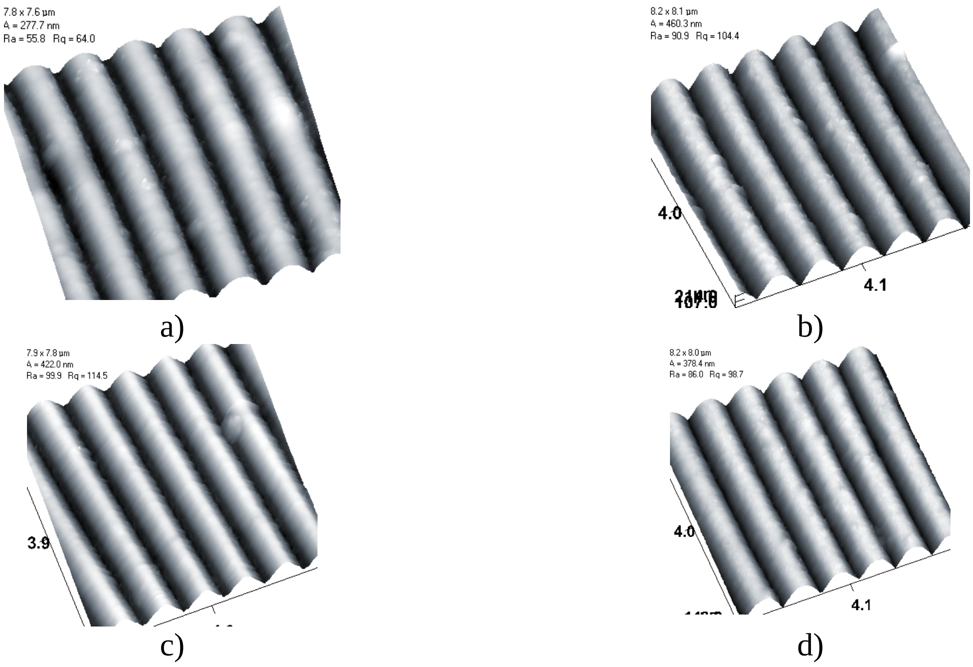


Figure 3 – Nanocomposite MEMS elements

Codeposition of thin composite coatings to improve the tribological properties of the contacting surfaces during roll-to-roll processing and nanoimprint lithography (NIL) is one of the most effective ways to achieve higher performance characteristics of devices. Another way is fully composite electrochemical foils with the one-side matrix profile to enhance the runability of working holographic matrixes.

Working nanocomposite nickel matrix was developed, as well as composite chromium protective coating deposited with nanodiamond particles on top of pure nickel matrix (Fig. 4).



a) b) c) d)

Figure 4 – AFM images of test nanocomposite samples of copies:
a – pure Ni, b – Ni with $Al_2O_3$, c – Ni with diamond particles, d – Ni with aluminum monohydrate

Test results show the increase of holographic matrixes runability on 60-400% with improved printed image quality.

Application of composite materials in NIL and roll-to-roll process is the right way to solve issues and improve reliability of templates and whole technology at all.

## V. Conclusion

This paper describes positive consequences of introduction of the nanocomposites in the advanced technologies. Application of nanocomposites in MEMS, NEMS, NIL and roll-to-roll technologies makes it possible to improve quality and reliability of these processes and end products.

Nanocomposite technology may be integrated in the systems technology by replacement of homogeneous pure materials by heterogeneous nanocomposites. This allows to improve set of physical mechanical properties, such as wear resistance, microhardness, corrosion resistance and friction coefficient. Nanocrystalline structure of nanocomposites enables to resolve sub-100nm features in MEMS, NEMS, NIL, and other advanced applications.

## References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