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NANOSTRUCTURED COMPOSITE MATERIALS FOR 3D ELEMENTS OF ADVANCED OPTICAL SYSTEMS

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Abstract. Nanocomposite materials electroplating for nano- and micro-fabrication with Si mold and LIGA-like technological process is proposed. UV lithography based on SU-8 photoresist for ultra-thick 3D structures is described. Two-stage process for high aspect ratio vertical metal structures fabrication is considered. Possible applications of the proposed technological approaches for advanced optical systems are described.

Keywords: nanocomposite electroplating, nanostructured material, optical system, photoresist

1. Introduction

Formation of various micro- and nanostructures plays an important role in the modern display and optical devices such as LCD, OLED-, PLED-displays, etc. Functional structures' pattering is achieved through the use of up-to-date technologies, which allow obtaining a light control systems [1]. Modern industry requires using high-end technologies, such as roll-to-roll (R2R) nanoimprint processing, 3D printing; application for optical elements manufacturing being profitable due to its high throughput, 3D shaping and low cost of production [2,3]. Application of nanocomposite materials with good wear resistance, high microhardness and good anti-sticking surface properties could improve lifetime of molds and heads, and reduce imperfection of these modern high accurate technologies. Application of high-grade coating with complex nanoscale geometry can improve electrical, optical characteristics and thus device performance of multiple optical systems.

Micro- and nano-electromechanical systems (MEMS and NEMS) and micro-optoelectromechanical systems (MOEMS) are the most promising state-of-the-art devices. Mechanical interaction between nano-, micro-, and macro-world is the limiting factor for such complex systems. Moreover, reliability of the whole systems is determined by the reliability of the mechanical part. The use of nanocomposite materials is the most promising method to solve the reliability issue [4-7].

In the context of the problem, the integration of nanocomposite materials electroplating with deep UV lithography based on SU-8 photoresist is proposed as a method of the solution.

2. UV lithography of SU-8 photoresist

To fabricate micromoulds in LIGA-like technology (Fig. 1), we use photoresists SU-8 2150 and SU-8 3050 on various substrates (glass, ceramic, metal, ITO, etc.). To remove all organic contaminants from the substrates, chemical cleaning and UV treatment were used. Chemical cleaning was carried out in peroxysulphuric acid, which is a mixture of a 25% hydrogen peroxide and 98% sulfuric acid in a one-to-two ratio. The more feasible method is

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UV treatment with the use of Photo Surface Processor PL16-110D. The cleansing process consists of three steps. The first is ozone generation from atmospheric oxygen at a wavelength of 184.9 nm. The second step is ozonolysis, when atomic oxygen is generated at a wavelength of 253.7 nm. The final step is decomposition of organic pollutants. Atomic oxygen has a strong oxidative activity which helps it to react with pollutants and to form reaction products. These products, such as water, carbon dioxide, etc., then are simply evaporated. Thin Omnicoat sublayer and thick photoresist layer was spincoated in two-stage mode by VTC-100 Spin Coater (MTI Corporation, USA). The dependence of coating thickness on rotational velocity, time, and temperature were determined.

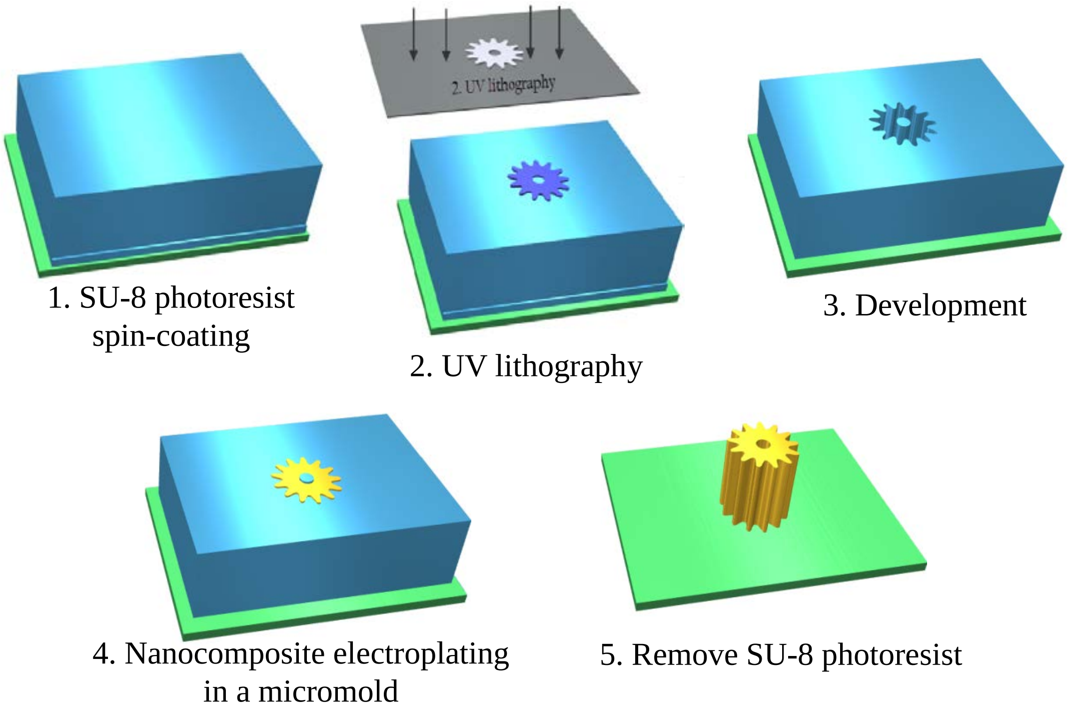

Fig. 1. LIGA-like technological process

One of the most important processes during the fabrication of thick micromoulds is soft baking. It provides evaporation of the solvent from the photoresist. The soft backing was conducted on a hot plate Wise Stir MSH-D (Labortechnik, Germany). Exposure of the SU-8 photoresist was performed by the contact lithography through a mask in the 365 nm wavelength. UV-LED module Lightningcure LC-L2 (Hamamatsu, Japan) was used as a light source. To expose photoresist layers with the thickness of 100-250 μm, the exposure energy was 250-300 mJ/cm^2. The post exposure backing (PEB) was carried out right away the exposure. During PEB the radiation absorption by an initiator occurs. It leads to local photochemical reactions that provide polymer crosslinking. The crosslinked regions are insoluble in the subsequent development process and uncured polymer removing.

To avoid spreading the structures because of melting and also to reduce mechanical stresses, the following temperature mode was selected. The substrate was placed on a hotplate preheated to 65°C for 5 min, was heated to 95°C at 15°C/min and then was stood at 95°C for 15 min.

To remove the unpolymerized parts of photoresist, the organic SU-8 Developer (Microchem Corp, USA) was used. After further hard backing at 150°C, the micromoulds become chemically and mechanically resistant. Farther nanocomposite coatings, containing ultra-fine particles, were electroplated into SU-8 or Si molds. Soft magnetic alloys such as Ni, Co, Cu, NiFe, CoP were codeposited. The concentration of ultra-fine particles was varied from 0 to 10 g/dm^{-3}(dry substance). Diamond and alumina ultra-fine particles, as well as boron nitride microparticles, were used. The average size of nanodiamond particles was 7 nm, alumina – 47 nm, aluminum monohydrate – 20 nm and boron nitride – 1 µm. The codeposition process was carried out in the electrolytic cell of flow type [1].

This procedure allows getting the micromolds with a thickness from 50 to 250 µm and minimum feature size of 1 µm for optical elements processing.

3. Nanofabrication for structures and interconnections of integrated optical devices

A promising way in the development of modern optical systems is the use of electron field emitters to improve their basic characteristics. Thus, the use of such emitters allows produce the displays with a high surface homogeneity and temporal stability; lighting lamps with an enhanced conversion factor of the embedded energy; portable X-ray sources with a high-scale temporal and spatial resolution; amplifiers of microwave radiation for satellite communication systems with reduced mass-dimensions characteristics [8]. High aspect ratio vertical structures with low specific resistivity should be obtained for effective field emission cathodes. This provides electrical conductivity between the conductive substrate and the array of emitting elements.

Metal conductive and catalytic channels were formed in insulating blind holes in 2 µm thick silicon oxide. The diameter of the holes is 0.35-3.5 µm, the pitch is 0.5-7 µm, and the matrix contains 20,000 to 750,000 contacts. The holes were filled with copper and nickel through vacuum technologies, electroplating and integrated processes. Such processes provide catalytic activity and compatibility with the integrated technological process.

High-grade and precise coating of the complex patterns is a serious problem in polarizers, functional optical layers, optical retarders and other optical elements with irregular shape. Addressing this issue metallic materials and alloys based on nickel (Fig. 2), cobalt (Fig. 3) and copper (Fig. 4) were electroplated in trenches.

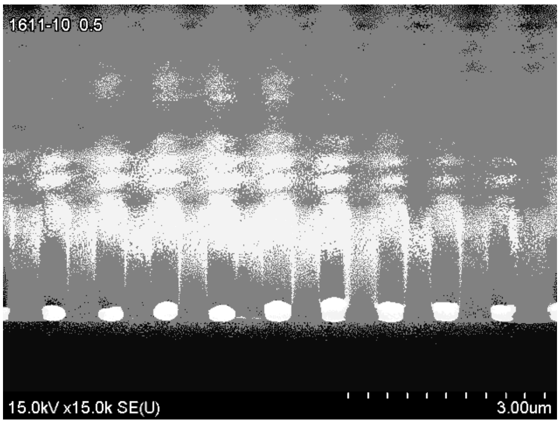

Fig. 2. Nickel-based coating

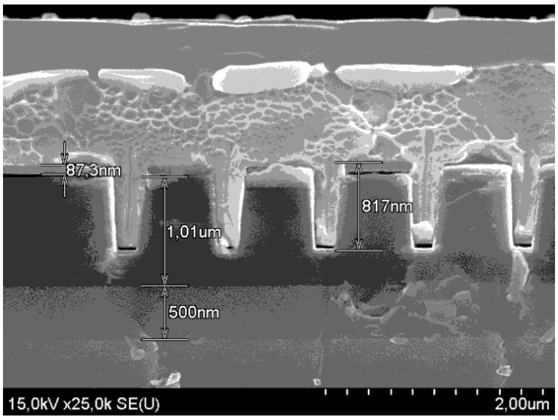

Fig. 3. Cobalt based coating with 170 nm wide patterns in Si wafer

Typical defects like voids, seams and reasonably coarse surface were not observed in the deposited coatings. The use of such coatings for optical systems interconnections reduces their return loss.

High aspect ratio vertical metal structures were obtained in two stages. At first, a layer with a high conductivity of 50 Å to 300 Å thicknesses was formed. On the second stage, electrochemical deposition was carried out using two technological regimes: potentiostatic and galvanostatic. The influence of hydrodynamic conditions on the filling of structures was investigated. It was determined that the filling quality is significantly improved by varying from static to laminar and, further, to turbulent regime. The samples were studied by optical and SEM microscopy. EDX analysis was performed to establish the chemical composition.

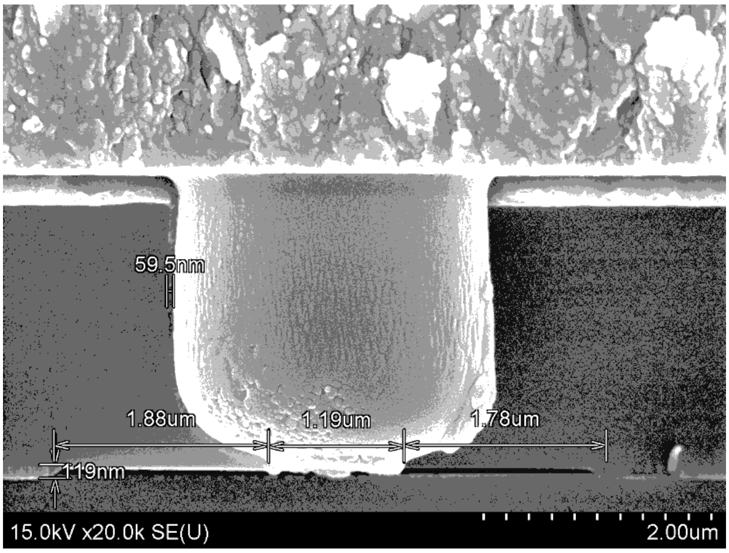

Fig. 4. Copper-based coating

4. Nanocomposites for reliable micro-optoelectromechanical components

Composite coatings for MEMS and MOEMS applications based on nickel and cobalt were electroplated with inert nanoparticles of ultradispersed diamond (UDD), alumina, aluminium monohydrate, boron nitride. The size of the dispersed phase varied from 7 to 50 nanometers. The nanoparticles were incorporated into the metal matrix (Fig. 5).

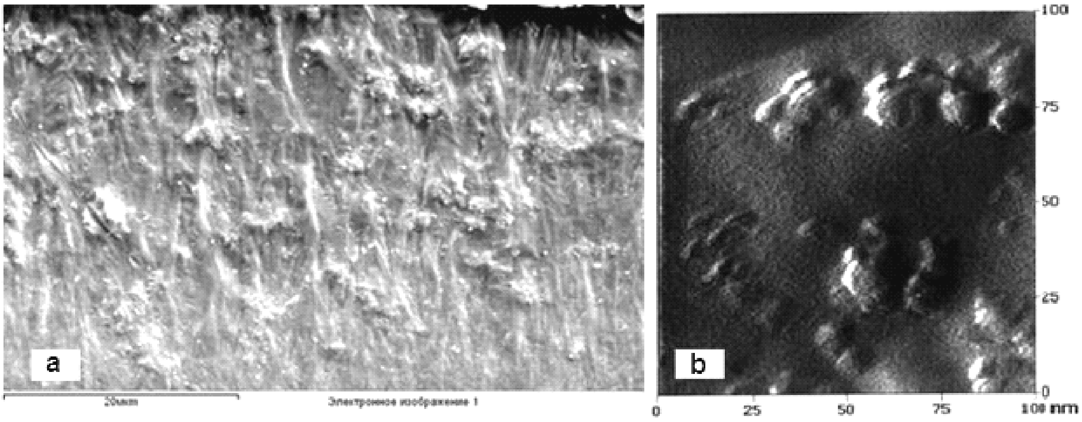

Fig. 5. Cross-section SEM (a) and AFM surface image (b) of nickel nanocomposite coating

The influence of nanoparticles concentration in the electrolyte (0-10 g/l), pH of the electrolyte and current density on the nanocomposite coating were studied. According to the behavior of dispersed phase in the electrolysis, a model for the joint electrolytic deposition of magnetic alloys and dispersed particles in a 3D matrix has been developed. In comparison with homogeneous coatings, nanocomposite coatings showed improved mechanical properties: The microhardness was increased by 20-80 %, the wear resistance was increased in 4 times, the friction coefficient was reduced in 2 times. Nanocomposite materials with such mechanical properties will improve the reliability of moving parts and the whole system of such MEMS and MOEMS as moving micromirrors, optical shutters, MOEMS-actuators, *etc.*

5. Conclusion

There are described positive prospects of nanocomposites and nanostructured electroplating introduced in modern technologies. Application in NEMS, MEMS, SOFC, ULSI, roll-to-roll, nanoimprint and other advanced systems and technologies makes it possible to improve quality and reliability of final products and enables their industrial development.

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