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Formation of Pt Cone-shaped Nanostructures by Laser Synthesis

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The present work is dedicated to the development of formation method for Pt cone-shaped surface nanostructures on silicon layer. For the formation of Pt nanoparticles fluxes the method of laser synthesis at air conditions is proposed. By the deposition of Pt nanostructures on solid layers, the cone-shaped surface nanostructures of Pt can be obtained.

Keywords: Laser synthesis, Cone-shaped metal nanostructures.

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1. INTRODUCTION

Nowadays nanoengineering is one of the most promising directions in the development of modern material science. High practical interest to this branch is caused by the presence of a number specific properties corresponding to nanostructures (physical, chemical, biological), which are not peculiar to massive objects, consisting of the same material. These features are caused by the presence of the so-called dimensional effects in materials, which are modified by structures with sizes less than 100 nm at least at one dimension. This, for example, allows upgrading the traditional media by metal nanostructures, thereby gaining new optical, magnetic and chemical properties.

An example of this practical problem is the obtaining of Pt surface cone-shaped nanostructures. Such structures can be actively used in organic and polymer chemistry, optical and photo elements industries. The present paper is devoted to the formation of Pt surface cone-shaped nanostructures on silicon layer in an air medium by the laser synthesis method and the investigation of the morphological characteristics of obtained structures.

2. PHYSICS OF LASER SYNTHESIS PROCESS

In the process of exposure of massive Pt planes to intense nanosecond laser pulses in a thin near-surface layer (~ 1 mkm) of the target, part of the irradiation is absorbed by free conduction electrons (electron gas). It should be noted that the initially high coefficient of reflection of optical radiation by smooth Pt surface ($R = 0.73$ for a light wavelength of 1000 nm) under intense laser action can sharply decrease, enhancing the integral dose of pulse energy absorbed by the target to 50-70 % of the total optical energy reaching the target surface [1]. In case of nanosecond pulse (with duration ~ 10 ns) implementation the leading edge time of laser pulse (~ 10^{-9} s) becomes comparable with the characteristic time of electron-ion thermal relaxation in metals (> 10^{-10} s). So the absorbed optical energy can not penetrate deep into the metal due to only electronic thermal conductivity, therefore the role of irradiative thermal conductivity significantly increases. As a result a macro-layer of the "solid–vapor" phase transition virtually without the formation of a liquid phase is formed under the influence of excess energy in the thin (~ 5-10 mkm) surface layer of the target [2].

This macro-layer can be comparable with an explosive layer, which detonation process is followed by two basic physical effects: formation of the metal vapor-plasma plume (rapidly expands to outer space) and generation of the intensive shock wave (propagates deep into the target) – so called "hydrodynamic" model. At the initial stage of its formation the vapor-plasma plume (due to the inverse breaking effect) begins to actively absorb the optical energy of the acting laser pulse, so increasing its internal energy and rapidly propagating into the atmosphere (according to the evaluations of [3] the initial velocity of vapor-plasma plume of Pt is 4.5 km/s).

After the finishing of the laser pulse due to cooling by adiabatic expansion in the vapor-plasma plume the local density fluctuations appears. which subsequently condense to drop-liquid particles. The result average sizes of Pt particles lie in the nanometric range (20-40 nm) and vary depending on the exposure conditions. This condensed phase of Pt is present in the surface region of the target over a rather long period: 500-600 mks after laser action [4]. Substantial roughness on the target surface (in the form of longitudinal scratches with transverse dimensions of ~ 50-100 mkm) increase the concentration of nanoparticles in the erosion plume by 2 orders (up to 10^{10} cm^{-3}) of magnitude compared to the smooth target surface (with irregularities of ~ 1-3 mkm). As a rule, under a single action of a high-power-density laser pulse on the Pt target, a rather small number of particles are formed (the total mass of particles of the carried-out condensed phase under a single-pulse action is equal to tens of micrograms).

In the case of multiple laser action without changing the localization of the focal spot we have observed the effect of a decrease in the concentration of metallic nanoparticles in the erosion plume for each subsequent pulse caused by surface smoothing. After 4-5 actions of this kind, the efficiency of nanoparticle formation is no different from the case of a smooth target irrespective

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of the initial level of roughness of the target. This fact, confirmed experimentally, must be taken into account with the aim of raising the efficiency of the method of laser synthesis of Pt nanoparticles by [4].

3. EXPERIMENT

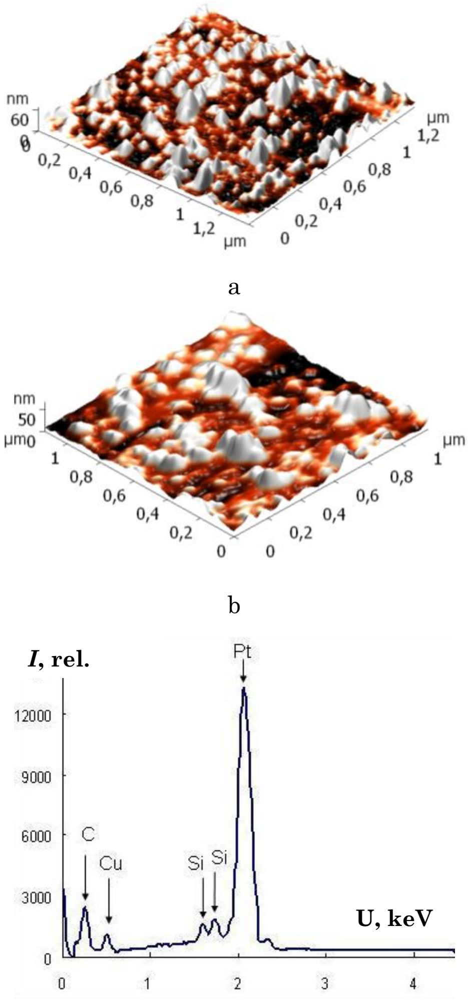
In the present work to form Pt cone-shaped nanosructures we used an Nd:YAG (λ = 1064 nm) laser generating pulses of duration 20 ns with a mean energy of 200 mJ, whose focusing into a spot with 3 mm diameter, so permitted obtaining a power density of ~ 0,1 GW/cm^2. The pulse repetition frequency was 5 Hz. The characteristic exposure time for obtaining samples containing Pt cone-shaped nanostructures was chosen to be equal to 2 min for one sample (600 pulses). The synthesis process proceeded in an air medium with subsequent deposition of formed Pt nanocones on silicon layer. For the target, we used massive plate from Pt, which chemical homogeneity has been confirmed by a state certificate.

In the present work, we used the following direct methods of diagnosing the parameters of the ultradisperse metal phase: atomic-force microscopy (AFM) and recording of the characteristic spectra of nanoobjects under their excitation by a sharply focused electron beam (electron probe).

The results of investigation of the samples using AFM (Fig. 1a, b) have shown the presence of cone-shaped nanoobjects. The spectrum of characteristic radiation of the particles on the carbon substrate (Fig. 1c) points to the fact that the material of these particles corresponds to the material of the target, i.e. to Pt.

4. CONCLUSION

On the basis of the method of laser synthesis, an industrial technology of Pt nano-drops fluxes formation can be developed. By the deposition of nano-drops on layers the Pt cone-shaped nanostructures can be obtained. The chief advantages of the given technological approach are the ease of the technological realization of the process, the low production cost, and high rates of synthesis of Pt nanostructures.



c

Fig. 1 – Results of investigation: AFM images (a, b), characteristic spectrum of nanocones (c)

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