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Laser Synthesis of Ag Island-Shaped Nanostructures at Air

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The present work is dedicated to the development of formation method of island-shaped nanostructures from Ag. For the formation of Ag nanoparticles fluxes the method of laser synthesis at air conditions is proposed. By the deposition of Ag nanoparticles on layers, the island-shaped nanostructures of Ag can be obtained.

Keywords: Laser synthesis, Island-shaped nanostructures, Scanning electron microscopy.

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1. INTRODUCTION

Currently, nanotechnologies and nanoengineering are one of the most promising directions in the development of modern science. Great practical interest to nanoobjects is caused by the presence of a number of specific properties corresponding to them (physical, chemical, biological), which are not peculiar to massive objects, consisting of the same material. The mentioned features are determined by the presence of the so-called dimensional effects in nanostructured materials. This, for example, allows to modify the traditional media by metal nanostructures, thereby gaining strength, durability, abrasion resistance, and so forth.

An example of this practical problem is the obtaining of Ag island-shaped nanostructures. Such structures can be actively used in organic chemistry, polymer chemistry, as well as in the photo element industry. The present paper is devoted to the formation of island-shaped nanostructures from Ag in an air medium by the laser synthesis method and the investigation of the spectral-morphological characteristics of obtained structures.

2. PHYSICS OF LASER SYNTHESIS PROCESS

The investigations of the erosion features of metals in an air medium under the action of nanoseconds (20 ns) high-intensity radiation pulses ($\lambda = 1064$ nm) have shown that ~ 20-60 ns after the beginning of irradiation (according to metal type) in the near-surface region of the target an unstable plasma formation is obtained. This erosion laser torch (ELT) propagates in the direction of the environment, absorbing, due to the inverse drag effect, some part of the energy of the rear front of the acting optical pulse and, as a consequence, is heated significantly. The characteristic velocity of propagation of the plasma formation at the initial time of its formation is 4-15 km/s depending on the type of the metal target material. When the intensity of the laser action decreases, the ELT begins to cool down slowly mainly due to the adiabatic expansion of the plasma at which in the spatial structure of the torch there appear density fluctuations of its vapors giving rise to condensation processes [1, 2]. As this takes place 1-1.5 μs after the beginning of the laser action, the vapor pressure in the ELT becomes equal to the atmospheric pressure, the plasma expansion practically terminates, and there appear prerequisites for stable condensation of torch vapors, due to which, near the target, surface conditions for the formation of fine droplets are created. Investigations of this regime of laser erosion in longer time intervals show [2] that the process of droplet formation goes on for 300-400 μs from the moment of laser action, which leads finally to the appearance over the target of fluxes of nanosized particles of the target material moving in the direction of the environment. In [3], the basic parameters of the ultradisperse phase of Ag formed under these conditions were estimated.

Investigations have shown that the sizes of the given particles lie in the nanometer range (20-90 nm), as well as revealed a high level of their concentration in the torch (10^{9}-10^{12} cm^{-3}). According to [4], the method of laser synthesis enables one to deposit the nanoparticles of metals formed in the ELT into an optically transparent solution and thus form colloidal systems of these metals.

In investigating the formation conditions of the liquid-droplet phase of a number of metals (Ag, Zn, Pb, Ni, Co), we revealed the effect of improvement of the droplet formation conditions with increasing roughness of the target surface for all materials. The particles of high-melting metals therewith have, as a rule, a smaller size and a higher concentration compared to low-melting metals, all other conditions of their laser processing being equal. Nanoparticles of the material of the laser-irradiated target are present in its near-surface region in a time internal of up to 500 μs, the mean velocity of their motion being 50-100 m/s depending on the type of the metal. These investigations have also shown that the coefficient of reflection of the laser radiation by metal targets has no determining role in the processes of laser erosion and subsequent droplet formation, since irradiation of the metal with intense optical radiation leads to the formation of a macrolayer of the solid-vapor phase transition in which absorption exceeds considerably the analogous parameter for a monolithic metal. The following parameters are dominant therewith: the acting radiation intensity, the melting and evaporation temperature, and the spe-

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cific melting and evaporation heat of the processed material. As a rule, under a single action of a high-power-density laser pulse on the metal, 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 depending on the type of the metal and the irradiation conditions).

Investigations [5] on the formation efficiency of the nanosized condensed phase of metals subjected to multiple laser actions without changing the spot localization revealed the effect of smoothing of the initial surface relief of the target, which leads finally to a worsening of the conditions for the formation of the condensed phase of the metal. Independent of the initial roughness (asperity sizes of up to 100 μm) of the metal target surface upon the action on it of tens radiation pulses, the conditions for the formation of the condensed phase of the target surface differ slightly from the erosion of the smooth target (with an average size of asperities of ~3 μm). From this point of view it is expedient to change regularly the site of spot localization in order to maintain the quantity of the condensed phase formed at a constant level.

3. EXPERIMENT

In the present work, to form Ag island-shaped nanostructures, we used an Nd:YAG ($\lambda = 1064$ nm) laser generating pulses of duration 20 ns with a mean energy of 200 mJ, whose focusing into a spot with $d = 3$ mm permitted obtaining a power density of ~ 0,1 GW/cm^2. The pulse repetition frequency was 10 Hz. The characteristic exposure time for obtaining samples containing Ag island-shaped nanostructures was chosen to be equal to 1-2 min for one sample. The synthesis process proceeded in an air medium with subsequent deposition of formed Ag nanoparticles on carbon layer. For the target, we used massive plate from silver, 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: scanning electron microscopy (SEM) 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 SEM (Fig. 1a, b) have shown the presence of island-shaped microobjects with composite internal structure. 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 silver.

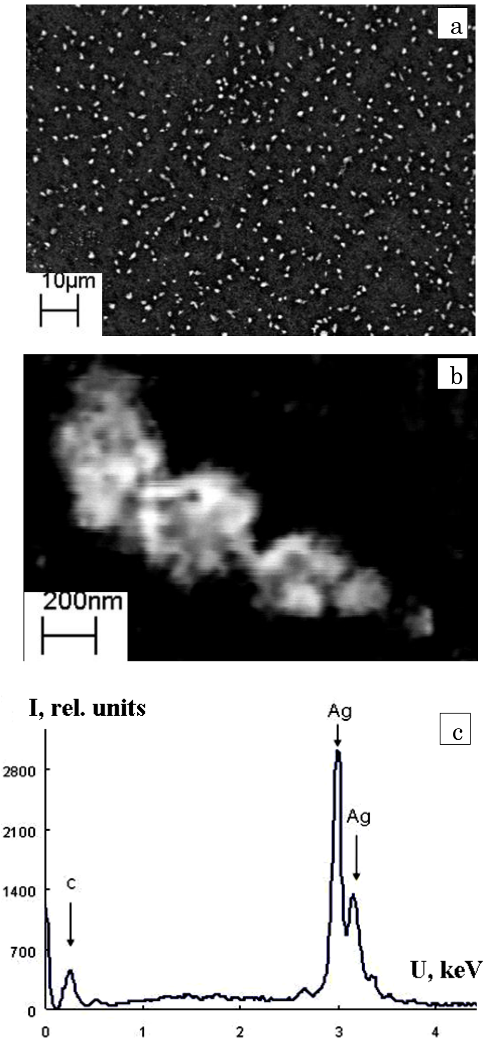

Fig. 1 – Results of SEM investigation: SEM images (a) and (b), characteristic spectrum of nanoobjects (c)

4. CONCLUSION

On the basis of the method of synthesis of metal nanoparticles in the air, an industrial technology of forming fluxes of Ag nanosized particles can be developed. By the deposition of those particles on layers the Ag island-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 metal nanoparticles.

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