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NANOSTRUCTURAL MODIFICATION OF Al–C–Ti-COATING ON AZ91D ALLOY USING MULTIPULSE NANOSECOND LASER ACTION

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Abstract. Multipulse laser action of Nd:YAG laser (λ = 1064 nm, τ = 20 ns, E = 200 mJ) as well as Nd-glass laser (λ = 1060 nm, τ = 85 ns, E = 2 J) on the AZ91D magnesium alloy with Al–C–Ti-coating was investigated. It was revealed the nanostructural modification of laser irradiated Al–C–Ti-coating on the sample of the AZ91D magnesium alloy. The grain size of the revealed structure was equal from 35 to 400 nm. It is shown that process of backward deposition of condense clusters formed in the plasma plume are taking part in formation of the discovered nanostructure on irradiated surface.

1. INTRODUCTION

In last years the interest to investigation of surface structure modification using laser radiation with nanosecond pulse length significantly increased (Petrovic at al. 2004, Xie at al. 2006). Using such approach the new method of nanostructural modification of Al–C–Ti-coating on the sample of the AZ91D magnesium alloy, based on the multi-pulse nanosecond laser irradiation with a melting of thin film together with higher deposition rates of nanoclusters from a plasma plume to target with forming of a nanostructures film are proposed by Xie, Guo, Hu, Chumakov, Bosak (2006). The properties of the alloy surface with the covering film are improved considerably. It is note that under the laser deposition of thin films and nanostructural coatings on the targets the expansion of the plasma plume to direct of a target and the backscattering of the condense clusters and the ejected particles have been experimentally observed by Pereira, Delaporte, Sentis at al. (2005). The number of the theoretical models of a laser ablation process for analysis of experimental data have been developed by Marine, Patrone, Luk'yanchuk and Sentis (2000), by Anisimov and Luk'yanchuk (2002). Some results was obtained using method of Monte Carlo for simulations of the processes of nanosecond laser ablation and the backward deposition of the condense clusters on the target, dissociation and recombination of molecules in plasma (Itina at al. 2006). Determination of possible mechanisms of surface structure formation is the subject of this investigation.

2. EXPERIMENT AND RESULTS

Q-switched Nd:YAG (or Nd-glass) laser with wavelength 1064 (1060) nm, pulse duration 20 ns (85 ns) and energy E up to 200 mJ (2 J) per pulse was used in experiments. The repetitions rate of laser pulses was about of 10 Hz for Nd:YAG-laser and up to 50 kHz for Nd-glass laser. The laser beam was focused on a sample in the spot of 5 mm in diameter. The Al-C-Ti-coating prepared by thermal coating method on the surface of the AZ91D magnesium alloy substrate was used as laser target. The irradiation of the samples by series of laser pulses with different power density q and number of pulses N from 5 to 5000 was made in air and in vacuum.

The surface morphology of original Al-C-Ti coating on magnesium alloy substrate was studied by means of scanning electron microscopy (SEM). The distribution of different elements contained in the coating was obtained by energy dispersive spectrometry. Obtained experimental data show that used samples was rough-surfaced and the typical size of inhomogeneous structure on the surface run into 5-10 μm. Elements Al, C, Ti were deposited as separate components and chemical reactions between them have not observed.

Irradiation of the samples by laser pulses was made in conditions of near-surface plasma formation at power density of laser radiation $q \geq 4\times10^{11}$ W/m^2. It was found that the laser action on samples leads to pronounced changes of surface morphology. The nanocrystalline film with size of grains equal to 30–160 nm was formed under the action of pulsed laser radiation (λ = 1064 nm, τ = 20 ns) with power density $q = 4.8\times10^{11}$ W/m^2 and number of pulses N = 5 on the Al–C–Ti-coating (Fig. 1, *a*). Increase of number of laser pulses N up to 4800 led to decrease of the size of grains to 10–35 nm and improvement of homogeneity of the film (Fig. 1, *c*). From the other hand increase of the laser pulse duration (τ = 85 ns, λ = 1060 nm and power density $q = 6.3\times10^{11}$ W/m^2) led to growth of the grain size to 100–400 nm (Fig. 1, *d*). It was established that the structure forming on irradiated surface depends on number of laser pulses, the pulse duration and the power density of radiation (Fig. 1).

3. EXPLANATION OF EXPERIMENTAL DATA

In conditions of the executed experiments presence of nanoclusters in plasma formation and their deposition on irradiated surface can be explained in the frames of condensation models advanced by Zeldovitch and Raizer (1966), Romanov and Pustovalov (1967), Anisimov, Imas, Romanov, Khodyko (1971), Itina, Sentis, and Marine (2006) etc. As you can see from Fig. 1, *d*, observed on experiment the large grains may achieve up to 400 nm in diameter. They consist of initial grains in the size ~ 30-100 nanometers. So, we can assume, that at expansion of evaporating substance of a target owing to condensation of target's vapors in plasma formation the clusters ~30-100 nm in the size are formed. Then at collisions they stick together, reaching more sizable ~100-400 nm, and then are deposited on a target.

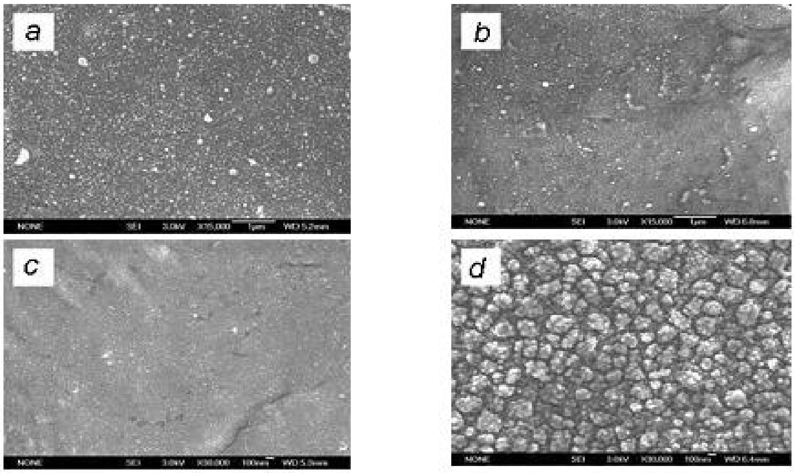

Figure 1: SEM microphotographs of the modified Al–C–Ti-coating on the AZ91D magnesium alloy, irradiated by 5 laser pulses (*a*), 200 laser pulses (*b*), 4800 pulses (*c*) Nd: YAG laser (λ = 1064 nm, τ = 20 ns) and 33 laser pulses (*d*) Nd-glass laser (λ = 1060 nm, τ = 85 ns).

At small number of pulses $N = 5$ and them concerning small duration $\tau \sim 20$ ns (Fig. 1, *a*, *b*) process of condensation of target's vapors proceeds for shorter time in comparison with a case which results are presented on Fig. 1, *d.* Therefore the sizes of clusters are smaller (~ 30-160 nanometers), than for a case represented on Fig. 1, *d* (100-400 nanometers). The effect of condensation in expanding vapor results in appreciable increase of absorption of laser radiation. Plasma starts to absorb laser radiation strongly. The clusters formed in plasma start to evaporate and decrease in part in sizes, and then to be deposited on a target surface. It is visible from Fig. 1, *b.* The number of the particles and large irregular-shaped droplets deposited back is much less, than for a case submitted on Fig. 1, *a.* It is connected with increase of the energy absorbed by a plasma cloud at rising number of laser pulses (N = 200, τ = 20 ns). Therefore the significant part of ejected particles which have got in a zone of plasma evaporates and the condensed earlier clusters decrease in sizes partially.

The real mechanism of nanostructures formation on laser target is caused by joint action of some processes, namely melting and recrystallization of a thin surface layer of a target, laser ablation of target and creation of a plasma cloud, dynamics of plasma expansion, condensation of vapors and association of condensed pair blobs in clusters in extending plasma formation, deposition of clusters from a plasma cloud and the particles which are ejecting from a target surface and coming back, and also condensation vapor on nucleation centre and aggregation its on a surface at cooling a target after action of each laser pulse.

4. CONCLUSIONS

Based on experimental results it was clearly shown that obtained modification of laser irradiated surface contain nanostructure with the more homogeneity and with the less dimensions of the grains than number of laser pulses is greater and length of laser pulses is smaller. The quality of nanostructural film formed on modifying Al-C-Ti-coating depends significantly on laser power density and number of laser pulses.

To explain the experimental results it is possible to offer physical model which would take into account processes of ablation from a target surface with backward deposition on target clusters of the condensed substance and ejected particles as well as formation of nucleation centers on a target surface and their joining with deposition clusters at cooling a target after the action of each laser pulse.

The proposed method of surface modification using multi-pulse nanosecond laser irradiation can find practical application due to creation qualitative nanostructural layer possessing good corrosion properties.

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