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Laser ablation studies of nanocomposites

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Abstract

The first experimental measurements of the threshold energy density values for the laser ablation of glass nanocomposites with nanodimensional coatings have been carried out under the action of the YAG–Nd laser power pulse radiation. The coatings in question were of different compositions and had been created by the sol–gel technology. The procedure for determining the laser ablation threshold energy density values was worked out on the base of the breakdown probability level of 0.5. The statistical processing of the measurement data over all the samples allowed obtaining the dependence of the ablation destruction threshold energy parameters on the coating physical and chemical properties such as the sample transmission in the visible region of the spectrum, coating thickness, the chemical composition of the film-forming solution, and on the pulse duration of laser radiation.

Keywords: Laser ablation; Glass nanocomposite; Nanodimensional coating; Threshold energy density; Breakdown probability; Transmission; Film-forming solution; Chemical composition.

1. Introduction

The materials laser processing technologies based on the laser ablation are widely used in high-tech industry operations such as microprocessing and modification of parts and their surfaces, thin-film coatings [1,2]. As it was noted by the authors [1,2], an important aspect of the problems associated with laser ablation is the probabilistic nature of destruction processes. There are several reasons for this: random spatial distribution of absorbing defects, different characteristics of these defects leading to different threshold laser breakdown values, probabilistic nature of the birth of seed electrons which initiate the development of plasma avalanche ionization, and the close relationship between the breakdown threshold and laser interaction area size (size effect).

Earlier works [3–6] were performed to study polymeric materials laser ablation under the action of high-energy pulsed laser radiation and to develop probabilistic methods for predicting the optical strength of such samples. This required a detailed study of the dynamics and mechanism of plasma generation during polymer laser ablative destruction in the range of laser pulse energy density up to 100 J/cm^2.

The aim of the present work is to study experimentally laser ablation threshold characteristics of some glass nanocomposites of different compositions, made by sol–gel technology [7], under the action of YAG–Nd laser pulsed radiation, and to study the dependence of

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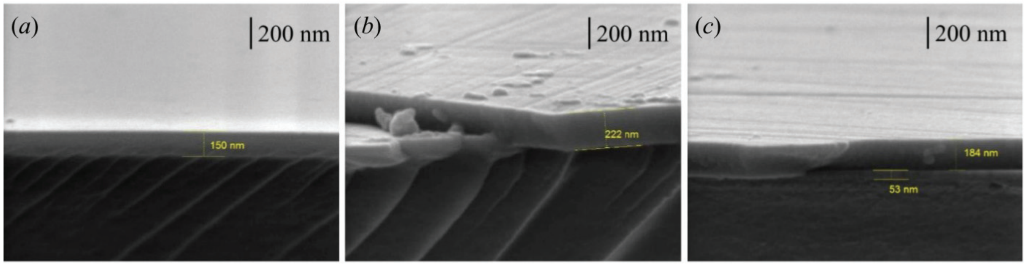

Fig. 1. Sectional microphotographs, obtained from X-ray phase analysis, of some oxides deposited on glass substrates: a thin film of SiO_2 (*a*), the same of TiO_2 (*b*), a layer of TiO_2 on the one of SiO_2 (*c*). The layer thicknesses are as follows: 150 nm (*a*), 222 nm (*b*), 184 nm and 53 nm (*c*).

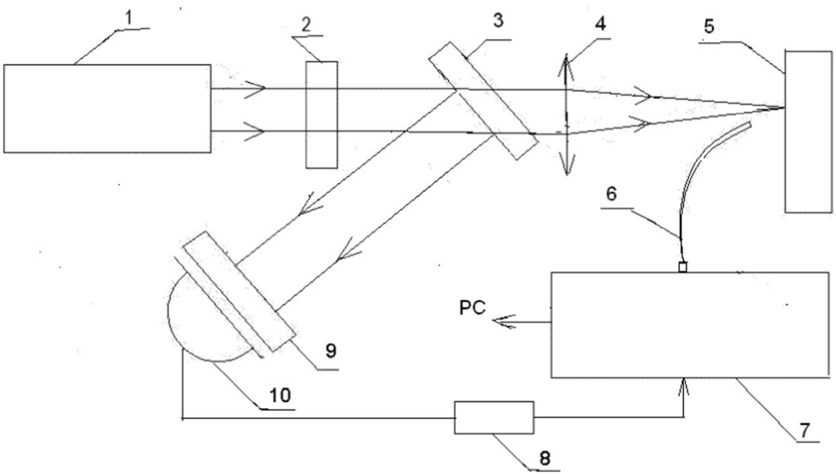

Fig. 2. Laboratory laser-ablation equipment: laser (*1*), neutral filter to change the energy of the radiation (*2*), glass plate (*3*), focusing lens (*4*), sample (*5*), optofiber (*6*), microspectrometer FSD-8 (*7*), delay line controlled by a PC (*8*), filter IRF-1 (*9*), photodiode (*10*).

these characteristics on the optical and physical properties of nanocomposites.

2. Experimental

All the measurements were carried out on nanocomposite samples which were rectangular plates sized from 4 to 7 cm and produced of clear float glass coated with different oxides: a single layer of SiO_2 or TiO_2, two or three layers of SiO_2, a double layer of $SiO_2 + TiO_2$. X-ray microphotographs of the first two and the last samples are shown in Fig. 1 as an example.

Since the coating produced from colloidal solution was deposited on cold glass, after coating the samples were kept in air and then fired in a laboratory furnace at the temperatures of 450–600 °C within 30 min.

For the experimental investigation of nanocomposite laser ablation, measuring the laser radiation threshold energy density was performed at which the breakdown of the sample surface started. Laboratory laser ablation apparatus was assembled on the basis of [3,5,6] experimental set-up and its structural scheme is shown in Fig. 2.

The radiation source was a laser (*1*). YAG–Nd laser generated pulses with the wavelength of 1064 nm of two types:

(a) the pulse duration was 20 ns, the pulse energy was up to 0.15 J;
(b) the corresponding values were 300 μs and 1.2 J.

Generation was produced in two modes of *Q*-switching and with different passive valves. The laser radiation was focused onto the nanocomposite surface by a special lens (*4*). The change in the laser pulse energy density in the range from 0.1 to 100 J/cm^2 was achieved by selecting the focal length of the lens (*4*) and by weakening the radiation by calibrated neutral filters (*2*). The presence of the breakdown was recorded via the appearance the laser plasma glow which was recorded by the microspectrometer (*7*) (type FSD-8, production of GPI RAS) with the fiber input (*6*). To control the laser pulse energy and to sync all the laboratory set-up, the