Study of Ruby Laser Beam Interaction With Glass

Bojana M. Radojković
Research Assistant
Institut GOŠA, Milana Rakića 35,
11000 Beograd

Slavica S. Ristić
Principal Research Fellow
Institut GOŠA, Milana Rakića 35,
11000 Beograd

Suzana R. Polić-Radovanović
Research Associate
Central Institute for Conservation,
Terazija 10,
11000 Beograd

This paper presents the results of the ruby laser light interaction with glass surface. The investigation was conducted in order to determine the maximum density of laser light energy (λ = 694.3 nm, t = 30ns) that can be safely applied in different laser systems used in nondestructive testing methods (NDT). The process of irradiation took place in atmospheric conditions. The results show that interaction of laser beams with glass materials is a complex phenomenon. It depends on many factors and it is associated with localized formation of plasma, heating of the material that leads to melting and transient stresses causing mechanical damages. The zones of laser light interactions were investigated by scanning electron microscope (SEM) with energy-dispersal unit for the analysis of X-ray (EDX). The results obtained by SEM and EDX analysis show that the maximum allowable energy density is 5 J/cm^2 for ruby laser light.

Keywords: *ruby laser interaction, glass, SEM, EDX.*

1. INTRODUCTION

Glasses are the most common optical material and have different applications in many areas of science, technology industry and in everyday life. Glasses have a lot of advantages over other optical materials because of their availability, cost and interesting properties such as chemical, weather and heat resistance and transparency in the regions of visible and near-infrared light. These characteristics and properties make them an interesting material for optical devices and technology.

Glass is treated in detail in a number of articles [1,2]. The composition, properties, and industrial production of glass are described, too. The physical and atomic characteristics of glass are treated in amorphous solid. The varieties of glass differ widely in chemical composition and in physical qualities. Commercial glasses are made by the three main materials-and (silicon dioxide, or SiO_2), limestone (calcium carbonate, or $CaCO_3$), and sodium carbonate (Na_2CO_3). Fused silica itself is an excellent glass, but the melting point of sand (crystalline silica) is above 1,700 °C.

The studies of laser-glass interaction contribute to a better and safely use of glass devices when they are exposed to the high energy laser light, whether they are glass components of the system with which testing are carried out, or glass samples that are subjected to testing. The surface absorption of the laser radiation energy depends of the glass preparation, cleanness of surface, the thickness and composition of layers, defect absorption centers on surface and glass subsurface. The morphology of damage induced by lasers in different materials has been studied by many researchers [3-17]. The investigations of laser–glass material interactions have potentials applications in optics, photonics and telecommunication and so on. These applications are based upon the change in the morphology and properties of the materials in the interaction zones.

Investigations on the morphology and the properties of the interaction zone help to understand the mechanism of the interaction. However, a comparison of surface morphological changes induced by the lasers have not been yet fully investigated. This paper provides some additional information on morphology of the interaction zones, induced by nanosecond ruby laser and mechanisms of the interaction processes.

The interaction of laser light with the surface of glass materials yields changes in their physical states or their properties locally [4-7]. The results depend of the laser pulse length, intensity and wavelength, too. For example, ultra-short pulsed lasers induced changes in the refractive index of glasses, damage inside the glasses through explosion, compaction and densification processes [8,12,15-18]. Short pulses induced damage on surfaces of materials via heating and ablation processes. Melting of glasses by nanosecond laser pulses have been also reported in literature [2]. The damage of glasses used in optical systems, upon multiple exposures to "pre threshold" laser pulses results from the gradual modification of glass properties toward a decrease in the optical strength. Depending on the radiation wavelength, the prevailing process before threshold can be either color center formation or the breaking of chemical bonds in the glass-forming network.

In recent years, many industrial processes and products are controlled by NDT methods such as holography, interferometry, electronic speckle pattern interferometry (ESPI), shearography, laser tomography, moiré technique and so on. Lasers are used as tools for machining of various materials, too. Irrespective of whether laser device is used for diagnostics, for cleaning or for cutting, laser light must have the parameters selected in such a way that the surface of glass optical components of testing device remains unchanged.

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Correspondence to: Slavica Ristić
Institut GOŠA, Milana Rakića 35,
11000 Beograd, Serbia
E-mail: s1avce@yahoo.com

The NDT of different objects can be performed using a divergent or parallel light beam, with a homogeneous energy density below a damaging threshold. However, when absorption centers/defects exist on the object surface, or complex geometry objects are tested (with prominent local concave surfaces), undesired focusing of laser light and a sudden increase of energy density above a damaging threshold may occur.

Holographic interferometry, ESPI, shearography, laser tomography and other NDT methods use ruby laser light (E = 1J, t = 30ns). Due to a large increase of laser systems application in different field of science, such as medicine, industry, and measurements, an incidental exposing of laser radiation on the used optical components may occur, causing rapid damages, especially in high laser power systems. It is useful, therefore, to determine the maximum energy density laser light with a wavelength of λ = 694.3 nm, which does not cause damage to glass components of optical systems.

This paper presents the results of testing the impact of ruby laser light, with different fluencies, on the surface of the glass. The results of the interaction were examined by a scanning electron microscope (SEM) equipped with energy-dispersion spectroscope (EDS). The minimum density of energy, which can be safely for use, was determined. Special attention was paid to morphological surface changes as a function of two fluence (intensity) regimes – medium and lower. Medium fluence regime, as a rule, is accompanied by the formation of plasma in front of the glass whereas the lower fluence regime can be considered as pure ablative process.

2. EXPERIMENT

The ruby laser (Appolo model 22, Imatex) [11], used in the experiment, operated in TEM_{00} mode, in Q-switch generation regime. The pulse length was t = 30 ns, λ = 694.3 nm. The coherent length was lc=1m. The cross section diameter of the output light beam was D =1.6 cm, energy E =1 J, density D_E = 0.5 J/ cm^2, with a Gaussian distribution. After focusing, the energy of laser beam, due to reflections, is decreased by about 10% and amounts to E_f = 0.9 J. The focal length of the lens focusing laser light was f = 0.1m. The tested sample was placed normal to the laser beam. The process of irradiation took place in atmospheric conditions, P = 0,997 MPa and T = 291 K. The change of the distance in the surface of the ceramics sample with respect to the lens caused a change in the density of energy, which was applied. The glass plate was no cleaned prior to laser irradiations.

Table 1 presents the parameters of interaction between the sample and the laser beam for each position of the interaction zone No.1 to No.3.

The results of the laser light and glass sample interactions were examined by Electron Micro Probe Analysis (EMPA), using a JEOL JSM–6610LV scanning electron microscope (SEM) connected with an INCA350 energy-dispersion spectroscope (EDS). An acceleration voltage of 20 kV was applied. The chemical composition of the cleaning zones and deposit (surface of the sample covered with the sediment) was determined by energy-dispersion spectroscope (EDS).

Before ion analysis, the glass sample was coated, in a ionization process, with a thin layer of gold 20 nm thick and density of 19.32 10^{-3} kg/m^3, with the aim of increasing electrical conductivity, i.e. to achieve a better quality image of the structure.

Table 1. Experimental parameters

Interaction parameters	Zones of interaction		
	1	2	3
Φ [mm]	2	3	4,0
S [mm^2]	3,14	7,0	12,6
E [J]	1	1	1
D_E=E/S [J/cm^2]	32	14	8

3. RESULTS AND ANALYSIS

The interaction of laser beams with materials is a complex phenomenon that depends on many factors. Energy density laser beam, time of irradiation, or pulse length, wavelength, and distribution of energy within the beam are related to laser characteristics. The coefficients of reflection and absorption, surface shape and roughness, homogeneity, temperature coefficient, melting point and point of vapour are related to object material. In nanosecond Q-Switched ruby laser and glass surface interaction, the prevailing processes are the selective explosive vaporization and the spallation induced by shock wave generation.

The laser-induced damage process is associated with localized formation of plasma, heating of the material leading to melting and transient stresses that instigate mechanical damage. Medium fluencies used in this work are obviously high enough to cause melting, evaporation and occurrence of plasma. These irradiation conditions are convenient for numerous potential applications, particularly surface elemental analysis, such as laser induced breakdown spectroscopy (LIBS). Reduction of laser intensity, on the other hand, allows cleaning on the surface of an optical material.

Irradiation of the glass with ruby laser at the wavelength of 694 nm for different moderate fluences and single applied pulse leaded to its surface modification. Damages generated using nanosecond laser sources, usually appears as a crater with rough surfaces that strongly scatter the incoming laser beam (Fig.1). Cracks originate at the bottom of the damage crater and on the surrounding of craters.

The zoomed photos of interaction zone center no. 1, are presented in figure 2. For higher fluence of 32 J/cm^2 central part of the damage shows intensive exfoliation and cracking.

The zone no. 2 is the result of laser beam, with energy density of 14J/m^2, impact on glass surface (Fig.3). Malting processes were occurred only in the center of the zone. Lower fluence of 14 J/cm^2 resulted in exfoliation without cracking, however the original glass structure is revealed.

The zone number 3 is result of interaction of laser light with fluency around 8J/cm^2. The cracks of glass are visible on the surface (Fig.4). During the impact of laser beam with energy density of 5 J/cm^2, appear no changes on the glass surface.

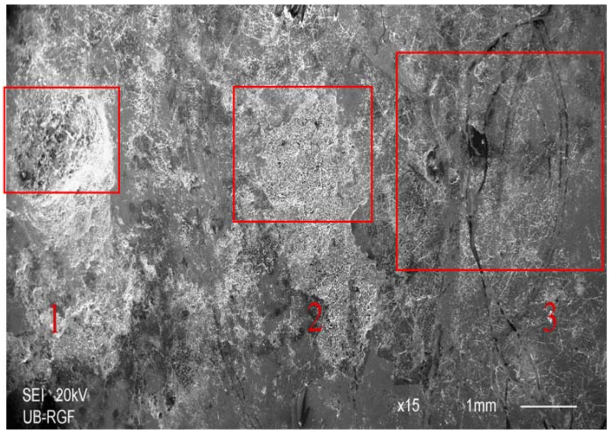


Figure 1. SEM of the three interaction zones

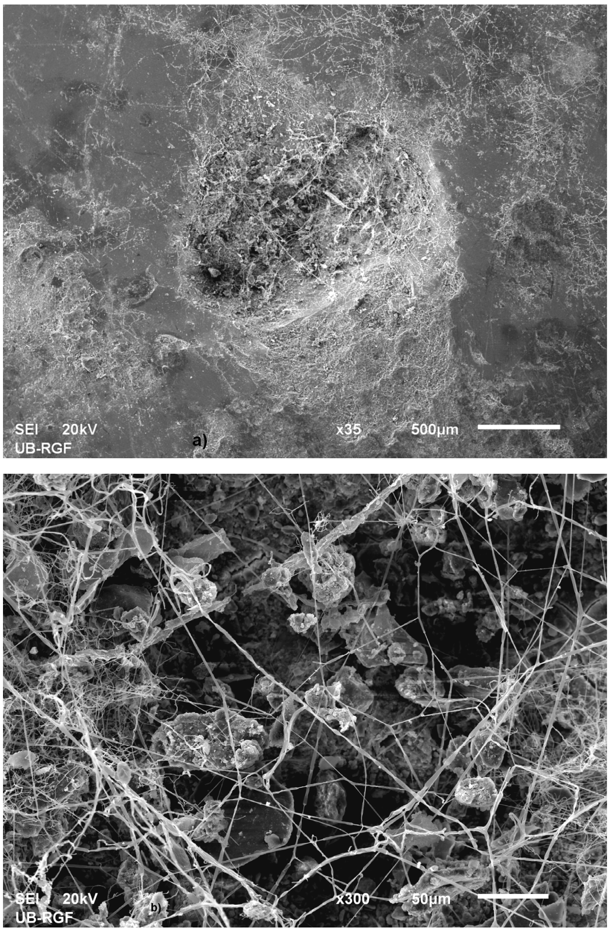


Figure 2. a - interaction zone 1, b- zone centre.

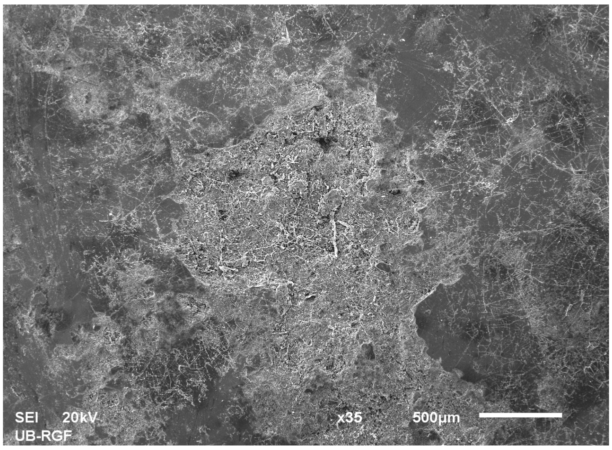


Figure 3. Interaction zone 2.

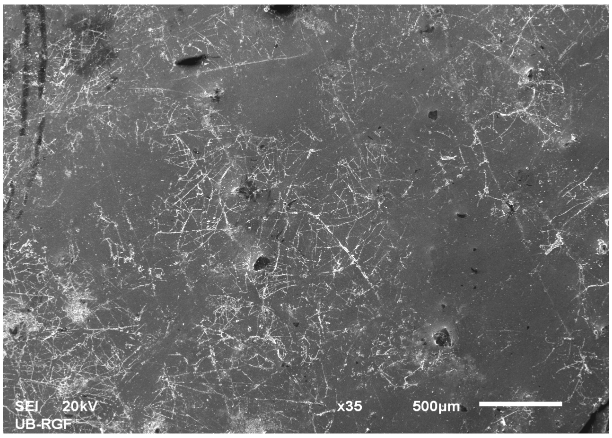


Figure 4. SEM of interaction zone 3 (center)

Figures 5 show the EDS spectrums of different regions in the zone of interaction no. 1 (Fig 5a). Spectrums no.1 and no.2 are taken in the centre of interaction zone; the spectrum no.3 is out of interaction zone. Chemical composition of glass, weight % is given in table 2.

Table 2. Chemical composition of glass, weight%

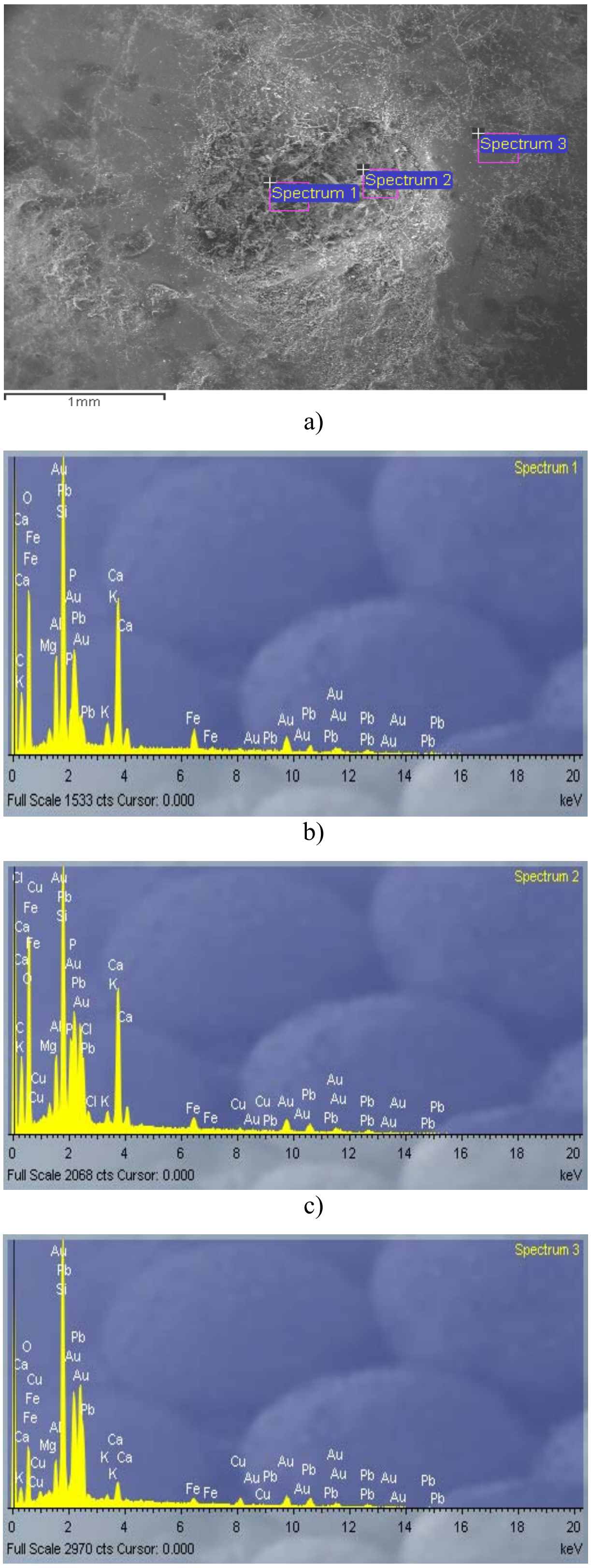
Spectrum	C	Na	Mg	Al	Si	P	K
Spectrum 1	17.12	0.00	0.42	2.33	7.43	0.89	1.02
Spectrum 2	16.34	0.00	0.36	1.28	4.93	1.81	0.39
Spectrum 3	10.51	0.00	0.32	1.69	12.33	0.61	0.58
Spectrum	Ca	Ti	Fe	Cu	Pb	O	Total
Spectrum 1	6.98	0.00	0.00	0.00	3.00	60.80	100.00
Spectrum 2	4.73	0.00	4.60	0.37	7.72	57.48	100.00
Spectrum 3	1.79	0.00	0.00	2.29	22.20	47.67	100.00

4. CONCLUSION

The interaction of nanosecond laser pulses with the surface of glass was studied. During the nanosecond laser irradiation, laser pulses with the energy of 32J/cm^2 induced crater on the surface of glass and pieces of glass were ejected from the interaction zone. The nanosecond laser with the energy of 32J/pulse induced damage on the surface through the sputtering process and ejected spherical fine powder from the interaction zone. The shock waves generated by more energetic nanosecond laser caused cracks on and sub glass surface. The nanosecond laser with energy of 14J/cm^2 induced damages on the surface which are the results of melting and cracks processes. If the energy is 8J/cm^2 is applied, only the cracks were appeared into the interaction zone.

During the impact of laser beam with energy density of 5 J/cm^2, appear no changes on the glass surface. Because of that, the recommended safety laser energy density for optical systems with ruby lasers is 5J/cm^2.

Generally, it can be concluded that the reported laser fluences above 5J/cm^2 at this laser wavelength and pulse duration can give modifications on the glass. Application of lasers with different wavelengths in NDT systems can, under given conditions, lead to undesirable modification of the glass surface. It is very important to determine the specific recommended safety laser energy density for optical systems with used lasers.



a)

b)

c)

d)

Figure 5. a-SEM of interaction zone and positions of EDS measurements D_E =30J/cm^2, b- EDX specter 1, c- EDX specter 2, d- EDX specter 3

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ИСПИТИВАЊЕ ИНТЕРАКЦИЈЕ РУБИНСКОГ ЛАСЕРА СА СТАКЛОМ

Бојана, М. Радојковић, Славица С. Ристић, Сузана Р. Полић-Радовановић

У овом раду је приказан део резултата истраживања која се односе на проучавање интеракције светлости рубинског ласера и површине стакла. Циљ испитивања је одређивање максималне густине енергије ласерске светлости (λ = 694.3 nm, t = 30ns), која може безбедно да се користи у различитим ласерским системима за испитивање без разарања (ИБР). Озрачавање стаклених узорака је вршено у атмосферским условима. Резултати показују да је интеракција ласерске светлости са стаклом веома комплексан феномен. Резултати интеракције зависе од више фактора и повезани су са формирањем локалне плазме и грејањем материјала које доводи до топљења и напрезања што причињава механичка оштећења. Зоне интеракције ласерске светлости са површином стакла су испитивани скенирајућим електронским микроскопом (SEM) и енергодисперзивним детектором рендгенских зрака (EDX). Резултати добијени SEM и EDX анализом показују да је $D_E = 5 \cdot \mathrm{J/cm^2}$ максимално дозвољена енергија за безбедан рад оптичких система који користе рубински ласер.