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Pulsed picosecond Nd:YAG laser irradiation of vanadium in controllable gas ambience

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***Abstract*— The interaction of a Nd:YAG laser, operating at 1064 nm wavelength and pulse length of 150 ps, with pure vanadium sample, in air and helium atmosphere was studied. The vanadium surface modification was carried out with a pulse energy of 15 mJ, with corresponding fluence of 20 J/cm2, and intensity 1.3×1011 W/cm2. The laser beam energy was partially absorbed and converted to thermal energy, which generated a series of effects, such as melting and vaporization, redeposition of material form gaseous phase, surface cracking, hydrodynamic effects and formation of laser induced parallel surface structures. Influence of the number of accumulated pulses was also studied. Following surface changes and phenomena were detected: (1) conical craters were formed in both atmospheres; (2) appearance of cracks and micropores in central zone (3) appearance of hydrodynamic effects and laser induced periodic surface structures on the periphery of damaged zone (4) formation of vanadium oxides in air and cleaning of surface in helium atmosphere.**

***Keywords*— picosecond laser, vanadium, laser surface modification, SEM-EDS, profilometry**

I. Introduction

One of the possible methods for precise processing and surface modification of metals is by lasers. Study of laser interaction with pure vanadium is relatively scarce in literature [1-3]. Vanadium is a transition metal, hard and ductile, with high corrosion resistance. Oxide passivation layer is formed on the surface at room temperature. It possesses four oxidation states, and can form various oxides. Vanadium is mostly used as an additive in steel and other alloys, as a catalyst, in batteries, etc.

The present paper studies the effect of picosecond pulsed Nd:YAG laser emitting in the infrared (1064 nm wavelength), with pulse energy of 15 mJ, fluence of 20 J/cm2, and intensity 1.3×1011 W/cm2, on the surface of pure vanadium sample, in air and helium atmosphere.

II. Experimental

A. Vanadium sample

Vanadium sample used in surface modification experiments was of dimensions 20 mm × 20 mm × 1 mm. Vanadium surface was prepared by a standard metallographic procedure. The sample was first mechanically polished by SiC grinding paper (1000-3000 grit) and by using diamond paste (1–0.25 µm), than ultrasonically cleaned and dried in hot air. After this, and also after irradiation, the sample was kept in desiccator. Before the laser irradiation experiment, sample was cleaned in ethanol..

B. Laser modification experiment

The sample was irradiated by picosecond Nd:YAG laser, model EKSPLA SL212P/SH/FH, with pulse duration of 150 ps, repetition rate of 10 Hz and was operating at 1064 nm wavelength. The laser beam was focused on vanadium target with quartz lens with focal length of 15 cm. The angle of incidence of the laser beam with respect to the target surface was ~90O. Irradiation was carried out in air and helium atmosphere. Helium gas was provided by the nozzle placed in front of the sample surface.

C. Characterization techniques

Sample surface was analyzed by JEOL JSM-7001F field emission scanning electron microscope (JEOL Ltd., Tokyo, Japan) coupled with Xplore 15 energy-dispersive X-ray spectrometer (Oxford Instruments, Abingdon, UK). Surface morphology was investigated by Zygo NewView 7100 (Zygo, Middlefield, CT, USA) non-contact optical profilometer operating in downward scanning regime.

III. Results and disscusions

Surface modification of metals including vanadium generally depends on the laser output parameters (pulse energy, intensity, pulse duration, wavelength, etc.), physicochemical characteristics of the material, and also irradiation condition (gas atmosphere composition and pressure) [4, 5].

Picosecond laser interaction with vanadium was accompanied by different processes, such as heating, melting, vaporization of molten materials, ionization od the vaporized material, creation of plasma, shock waves in the vapor and in the solid, deposition from gaseous phase, etc. Surface features generated during the interaction, can be described as following:

A. Air ambience

Initial experiments of irradiation of V target with picosecond laser were conducted in air, at atmospheric pressure. After 50 accumulated pulses, following changes were observed (Fig.1.): (1) crater depth was 4 µm, and with intense cracking of the surface in the central zone; (2) crater rim is not clearly defined and there are also cracks on the periphery; (3) Elemental EDS analysis (Fig.2., Table 1.) shows higher content of oxygen in the central zone (~9.5 wt%) than on periphery (~3.5 wt%), indicating possible formation of different vanadium oxides.

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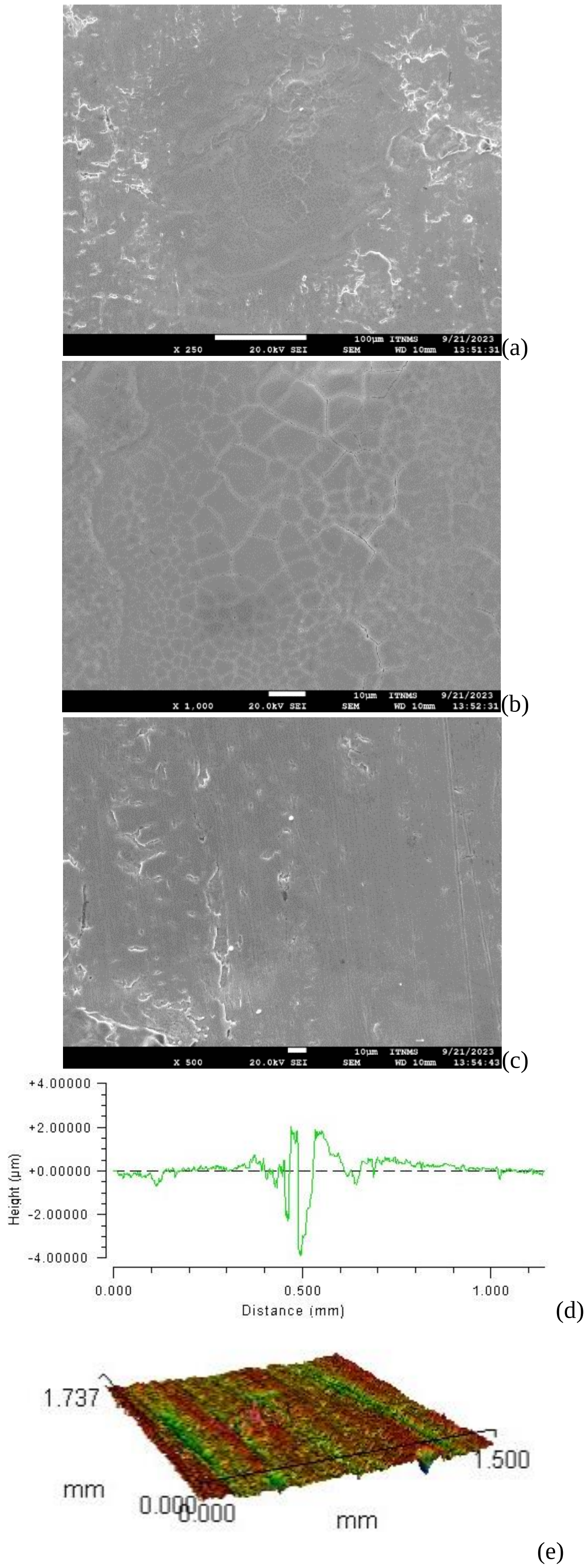

Fig.1. Vanadium sample irradiated with 50 picosecond laser pulses in air: SEM images of entire spot (a), detail from the central zone (b) and periphery (c); profilometric analysis, 2D cross section (d) and 3D view (e).

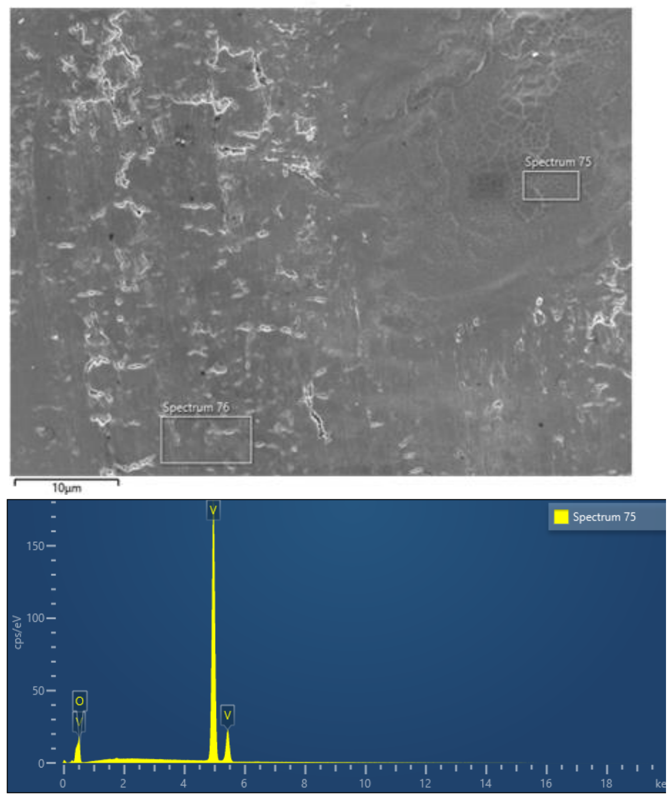

Fig.2. Elemental EDS analysis of vanadium surface irradiated with picosecond laser in air: SEM image with two locations where EDS spectra were taken, and EDS spectrum taken in the central zone.

TABLE 1. EDS ANALYSIS OF THE VANADIUM TARGET IRRADIATED WITH PICOSECOND LASER IN AIR WITH 50 ACCUMULATED PULSES

Element	Central zone [wt%]	Periphery [wt%]
O	9.48	3.43
V	90.52	96.57
Total	100.00	100.00

B. He ambience

Vanadium target was also modified by picosecond laser in helium, gas that reduces plasma shielding effect [6] and resulting changes after 50 accumulated pulses were: (1) Damaged zone is in form of conical crater (Fig.3.), with increased depth of 5 µm; (2) crater rim is clearly defined, with laser induced periodic surface structures (LIPSS) in periphery zone; (3) elemental EDS analysis (Fig.4.) of the surface shows that helium protects entire laser affected area from oxidation (Table 2.), and entire area is cleared from impurities.

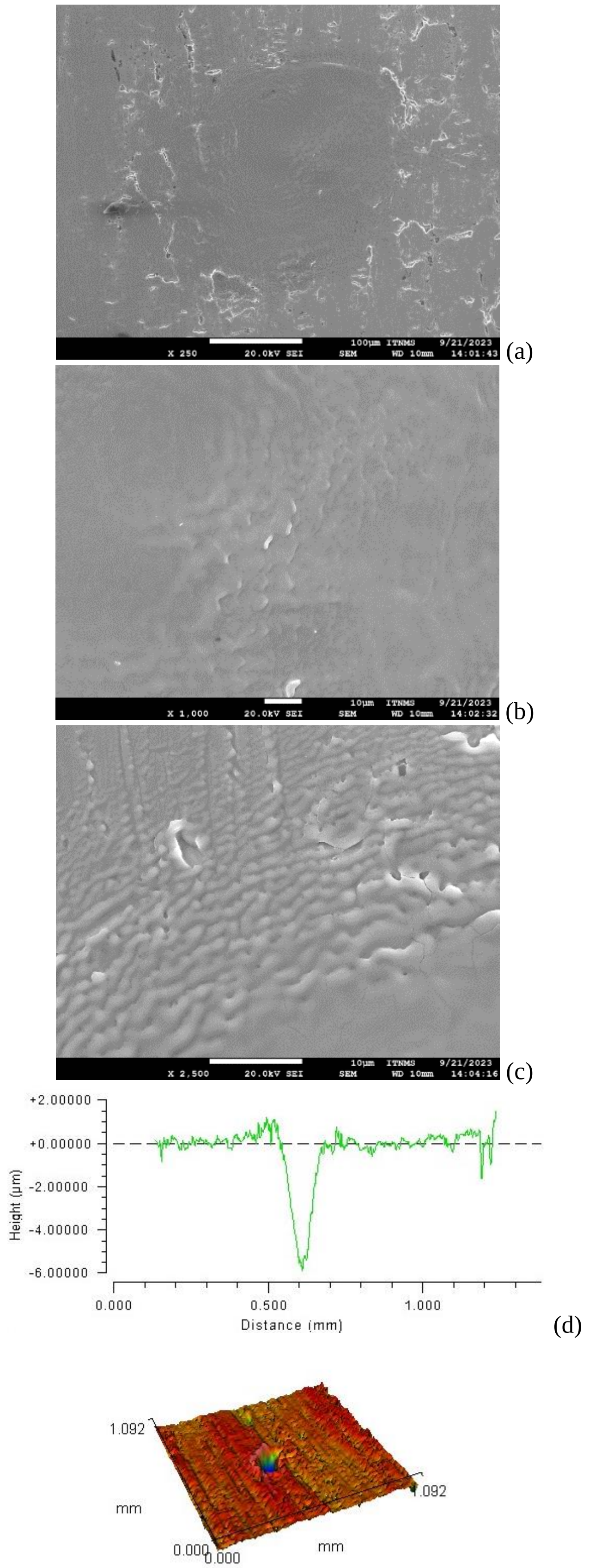

Fig.3. Vanadium sample irradiated with 50 picosecond laser pulses in He: SEM images of entire spot (a), central zone (b) and ripples on the periphery (c); profilometric analysis, 2D cross section (d) and 3D view (e).

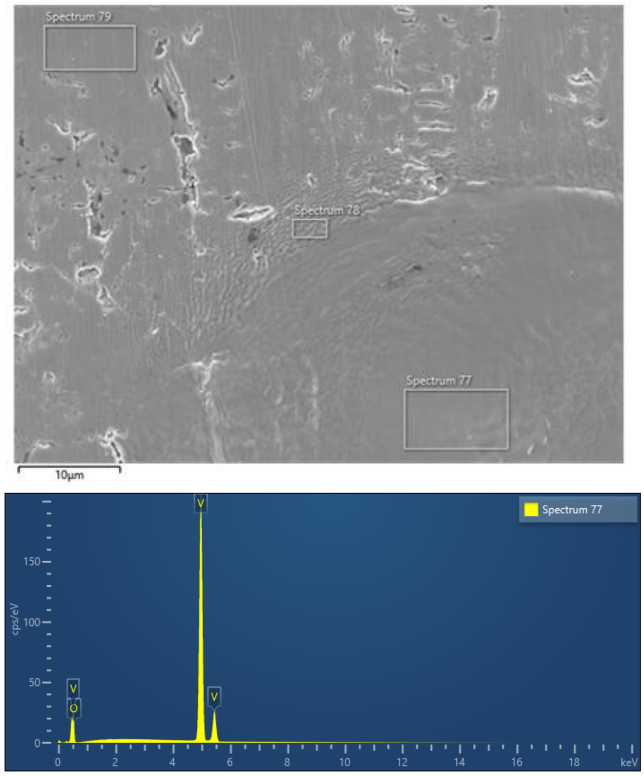

Fig.4. Elemental EDS analysis of vanadium surface irradiated with picosecond laser in helium: SEM image with three locations where EDS spectra were taken, and EDS spectrum taken in the central zone.

TABLE 2. EDS ANALYSIS OF THE VANADIUM TARGET IRRADIATED WITH PICOSECOND LASER IN HELIUM WITH 50 ACCUMULATED PULSES.

Element	**Central zone [wt%]**	**Close periphery [wt%]**	**Far periphery [wt%]**
O	0.00	0.00	0.00
V	100.00	100.00	100.00
Total	100.00	100.00	100.00

IV. CONCLUSION

Irradiation of vanadium sample by picosecond pulsed Nd:YAG laser in air and helium atmosphere results in significant morphological changes. Surface roughness increases, and crater-like damaged zones are formed. Vanadium oxides are formed in air. Helium reduces plasma shielding effect, prevents oxidation, and LIPSS are present. This shows that pulsed lasers can be used for precise modification of vanadium morphology and also changing chemical composition of the surface.

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