Available online at www.sciencedirect.com
ScienceDirect
Applied Surface Science 254 (2008) 4013–4017
applied surface science
www.elsevier.com/locate/apsusc

Surface modification of a WTi thin film on Si substrate by nanosecond laser pulses

S. Petrović [a,*], B. Gaković [a], D. Peruško [a], M. Trtica [a], B. Radak [a], P. Panjan [b], Š. Miljanić [c]

[a] *Institute of Nuclear Sciences, VINČA, P.O. Box 522, 11001 Belgrade, Serbia*
[b] *"Jožef Stefan" Institute, Jamova 39, 1000 Ljubljana, Slovenia*
[c] *Faculty of Physical Chemistry, Studenski trg 14-16, 11000 Belgrade, Serbia*

Received 29 November 2007; received in revised form 18 December 2007; accepted 18 December 2007
Available online 4 January 2008

Abstract

Interaction of a nanosecond transversely excited atmospheric (TEA) CO_2 laser, operating at 10.6 μm, with tungsten–titanium thin film (190 nm) deposited on silicon of n-type (1 0 0) orientation, was studied. Multi-pulse irradiation was performed in air atmosphere with laser energy densities in the range 24–49 J/cm^2. The energy absorbed from the laser beam was mainly converted to thermal energy, which generated a series of effects. The following morphological changes were observed: (i) partial ablation/exfoliation of the WTi thin film, (ii) partial modification of the silicon substrate with formation of polygonal grains, (iii) appearance of hydrodynamic features including nano-globules. Torch-like plumes started appearing in front of the target after several laser pulses.

PACS : 68.55.Jk; 52.38.Mf; 79.20.Ds

Keywords: WTi thin films; Laser ablation; Nanosecond laser pulse

1. Introduction

The research into laser-induced solid surface modifications is significant in many aspects. Understanding of physical and chemical mechanisms of interaction can be important both at the fundamental and technological levels. Some important aspects of the use of lasers in material processing, particularly those that involve material removal and heat driven processes, are: melting, vaporization, condensation of vapor in the gas phase, diffusion, segregation, resolidification, laser–plume interaction, etc. All of these factors are responsible for changes of the structure, composition and chemical state of the irradiated surface. Laser irradiation may modify surface composition and structure of metals and alloys, increasing their resistance to wear and corrosion [1,2]. With laser irradiation it is possible to process and modify localized surface areas [3]. Laser ablation has attracted much attention as a relatively new technique for material processing in forming stable nano-sized metal particles [4]. Nanoparticles have shown very promising applications in lubrication and magnetic recording media production [5].

Electrical contact and diffusion barrier of tungsten (W) and tungsten–titanium (WTi) thin films have been studied for microelectronic applications [6,7], development of gas sensors [8,9], functional coatings such as smart windows [10] and protective anticorrosive and oxidation resistant coatings [11]. Nanoparticles made of tungsten and titanium can enhance mechanical properties of metallic alloys, such as steel, by dispersion strengthening of the metallic matrix [5].

Earlier results with a WTi coating on a steel substrate [12] showed noticeable effects of the substrate on the morphology of the damage induced, even though the thickness of the coating was larger than in the present case. This indicates the importance of the substrate material in such systems.

Laser-induced surface modifications of a WTi thin film with thicknesses in the nano-domain have not been sufficiently reported in literature so far. The main objective of the present work was to study the surface modification induced by a TEA CO_2 laser (at 10 μm wavelength) of a WTi thin film deposited on a silicon substrate. Morphological changes at laser energy

* Corresponding author. Tel.: +381 11 8066425; fax: +381 11 8066425.
E-mail address: spetro@vin.bg.ac.yu (S. Petrović).

0169-4332/$ – see front matter
doi:10.1016/j.apsusc.2007.12.041

densities (fluences) ranging from 24 J/cm^2 to 49 J/cm^2 were investigated as a function of the number of accumulated laser pulses.

2. Experimental

The tungsten–titanium thin films were deposited by dc sputtering of the 90%W–10%Ti wt. target by Ar^+ ions. The substrate used in the experiment was silicon of n-type (1 0 0) orientation. Silicon wafers (0.5 mm thick) were polished and cleaned before deposition. Additional cleaning was also performed in the vacuum chamber by electron heating up to a temperature of 130 °C. The deposition was carried out by a Balzers Sputtron II vacuum system. The conditions during the deposition process were: acceleration voltage and current 1.5 kV and 0.7 A, respectively, partial pressure of argon 1.33×10^{-1} Pa. Under these experimental conditions the constant deposition rate was 0.14 nm/s, which produced a WTi thin film of 190 nm thickness, as measured by a Talystep I profilometer.

The laser used in the experiment was an ultraviolet preionized TEA CO_2 system [12]. It operated with a nontypical CO_2/X, X = H_2, H_2/N_2 gas mixture, which increased the efficiency of the laser. The laser pulse shape can generally be controlled by adjusting the gas mixture content [13,14]. Characteristics of the laser pulses were the following: working gas mixture $CO_2/N_2/H_2$ = 1/2.1/1.3 (1000 mbar total), output pulse energy up to 170 mJ, initial spike 120 ns at FWHM (with about 2 μs tail), transversally multi-mode (approx. 1 cm square array), wavelengths 10.5709 μm and 10.5909 μm, repetition rate 2 Hz.

Irradiation of the WTi thin film/Si system was carried out in ambient air atmosphere at a pressure of 1013 mbar. The laser beam was focused through a KBr lens of 6 cm focal length in a direction perpendicular to the sample surface.

Various analytical techniques, before and after laser irradiation, were used for target characterization. Optical microscopy (OM) was used for initial general analysis of the modifications obtained. Surface morphology was further observed by scanning electron microscopy (SEM) and atomic force microscopy (AFM). Topographic changes were characterized by a profilometer and AFM. Reflectivity of the target was observed in the wavelength region from 6.5 μm to 14 μm, by a Specord 75 IR spectrophotometer.

3. Results and discussion

An X-ray analysis of the initial non-irradiated WTi thin film showed its polycrystalline structure, composed of a bcc tungsten (W) phase with a presence of a hcp titanium (Ti)

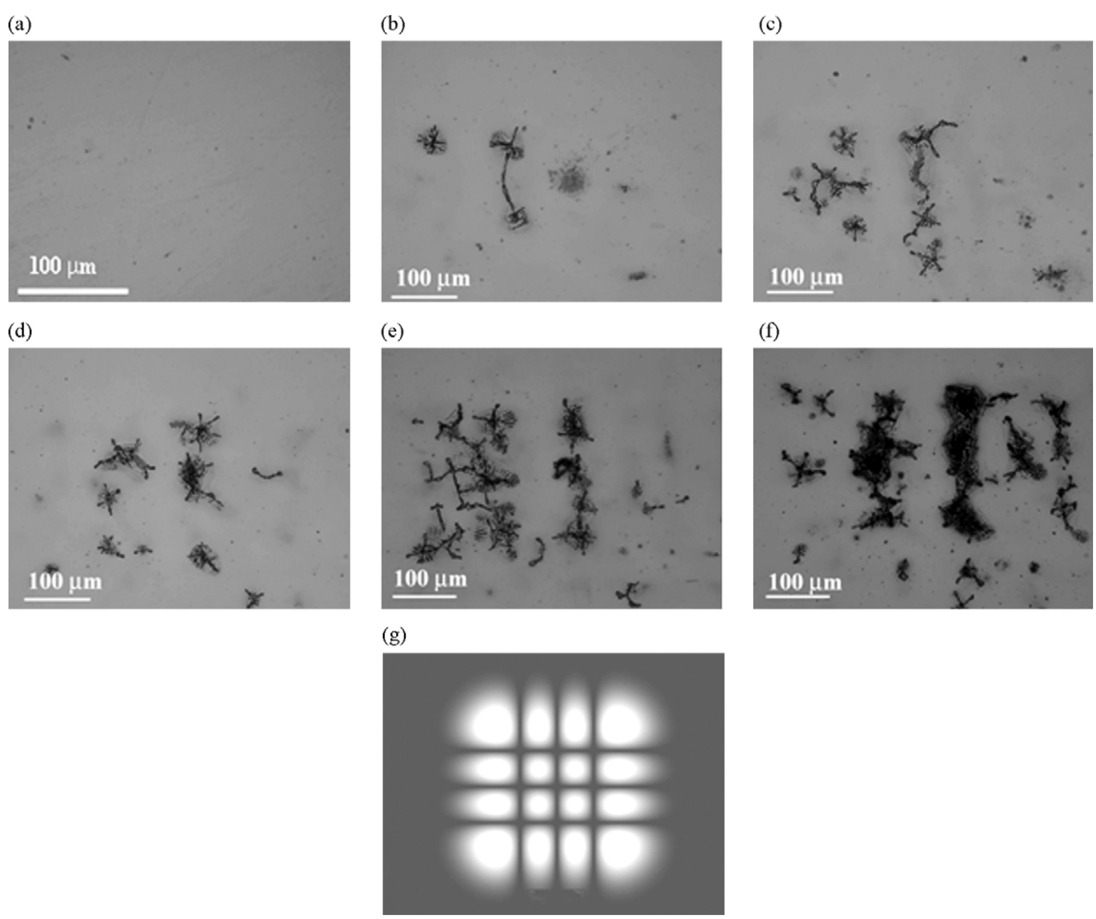

Fig. 1. Optical microscopy analyses of the WTi thin film/Si system after irradiation with TEA CO_2 laser. The laser operated in multi-mode regime, with fluences ranging from 24 J/cm^2 to 49 J/cm^2 in individual peaks: (a) WTi thin film on Si prior laser action; WTi/Si system after (b) 1, (c) 20, (d) 50, (e) 100, (f) 200 laser pulses and (g) schematic of the laser cross-section intensity.