MORPHOLOGY OF WTi THIN FILM PROCESSING BY FEMTOSECOND LASER

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Abstract. In this work we reported the effects of femtosecond laser on the morphology and structure of WTi thin film (thickness of ~190 nm) deposited on single crystal Si(100) wafer. Irradiation was performed in air by linearly polarized and focused femtosecond laser beam. The main characteristics of used laser system: pulse duration 40 fs, pulse repetition rate 1 kHz, wavelength 800 nm. The sample surface was irradiated using maximum energy of 7 μJ per pulse. The results demonstrate the possibility of laser induced periodical surface structures (LIPSS) formation on the thin film surface and on the Si substrate.

Introduction

The interaction of femtosecond, as ultra-fast/short, laser pulses with solid materials is a wide area of research for more than a decade because of a lot of potential in different applications /1/. Femtosecond laser pulses offer the possibility of high localization and extremely high heating rates in the illuminated area of the processed material /2/. By proper selection of the laser parameters, it is possible to produce preferred modifications of the deposited thin film surface and/or the substrate. Among others, lasers induced periodical surface structures (LIPSS), produced by multi-pulse fs laser irradiation, are useful for application in microelectronic and nanotechnology. Tungsten-titanium (WTi) thin film, has a wide usage in industry and technology, mainly in applications where high melting temperature, good thermo chemical stability, low electrical resistivity, high hardness and oxidation resistance are required. In this work we demonstrate the possibility of fs LIPSS formation on the WTi and on the Si substrate, as well as bump arrays (BA) on the Si substrate.

Experimental

Tungsten–titanium thin film was deposited on silicon a substrate by d.c. sputtering of a W/Ti (90/10 wt%) target with argon ions. As the substrate a n-type silicon (100) wafer (0.5 mm thick) was used. The deposition process was carried out in a Balzers Sputtron II vacuum system. The more details about the substrate preparation and the thin film deposition can be found in our previous publication /3/. The WTi thin films were deposited to a thickness of ~190 nm, measured by a profilometer.

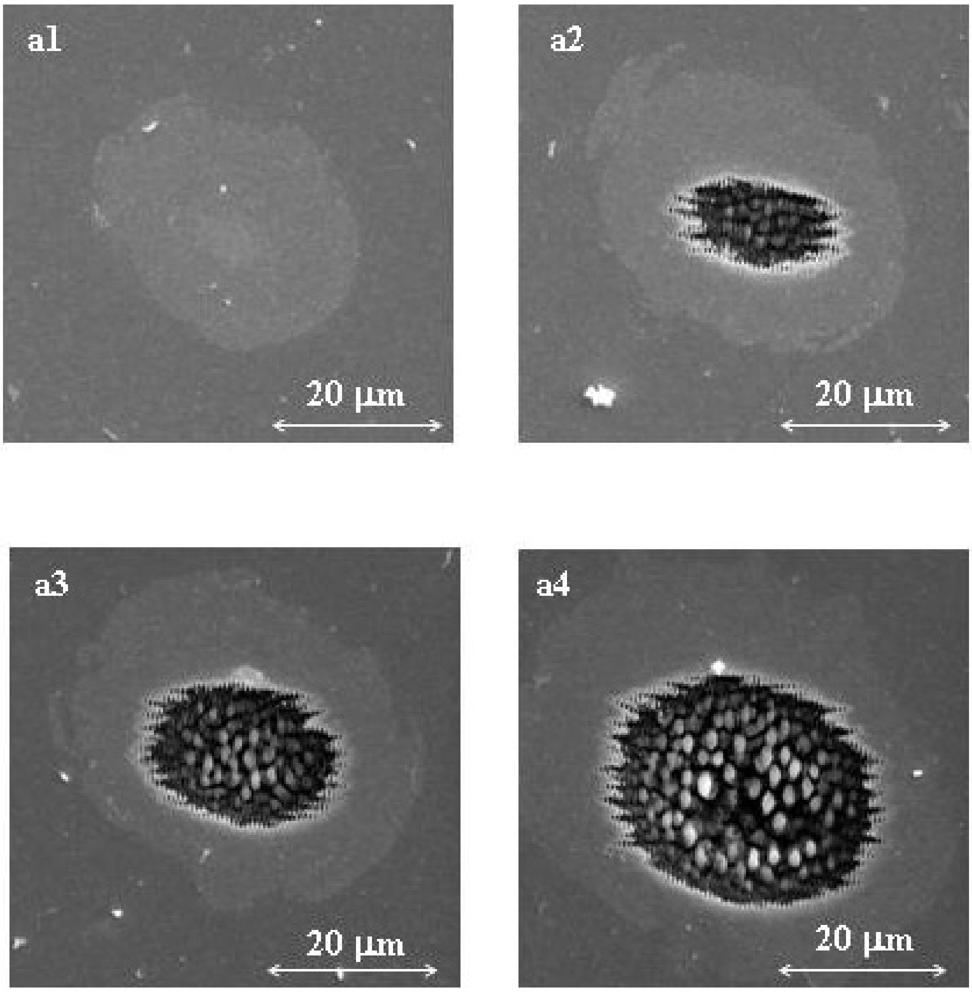
Irradiation of the sample was done with laser source (FEMTOPOWERTM Inc. COMPACTTM PRO) employed a multipass amplified Ti:Sapphite laser at $\lambda = 800$ nm wavelength. The pulse duration, and the pulse repetition rate were 40 fs and 1 KHz, respectively. The linearly polarized laser beam was focused with a quartz lens on the sample mounted to a computer driven translator with high precision in x,y and z directions. The surface of the sample was highly reflective for the used wavelengths. Because of that, the incidence angle of the laser beam was a few degrees different from the normal angle to the surface. Irradiations were carried out in air, at atmospheric pressure, and standard humidity. The laser beam waist at the lens focus was about 30 μm. The minimal and maximal pulse energy (E) per pulse used in the experiment were 0.8 μJ and 7 μJ, respectively. The corresponding laser fluence was calculated from applied pulse energy and beam radius /4/.

First inspection of femtosecond lasers induced morphology was done by optical microscopy. Composition and crystal phases of as deposited WTi thin film were identified by X-ray diffractometry. Surface morphology was monitored by optical and scanning electron microscopy. Scanning electron microscopy was connected to an energy dispersive analyzer (EDX) for determining surface composition of the targets.

Results and discussion

In case of applying to the sample surface number of laser pulses smaller than 100, in case of all used pulse energies, we have not registered any modification. Also, at the same location, action of 1000 pulses with energy less than 2 μJ, was not given any optically registered changes. Irradiation with 1000 pulses and energy equal and higher than that value, at the modification sites surface modifications were registered (Fig.1). In case of 2 μJ pulse energy, only color/brightness change was observed. Higher pulse energy caused morphological changes and thin film exfoliation in the central part of irradiated zone. At pulse energy greater than 2.8 μJ, morphological changes were appeared on the WTi thin film and on the Si substrate (Fig.1.a2-a4). SEM analysis discovered two different species of morphological changes: laser induced periodical surface structures (LIPSS) and bump arrays (BA). For strong absorbing materials such as metals or semiconductors in most cases, LIPSS are observed with a period Λ close to or somewhat smaller than the irradiation wavelength λ and an orientation perpendicular to the laser beam polarization. In our experiment $\Lambda \sim 700$ nm and orientation was perpendicular to the polarization. It is generally accepted /1,4/ that these LIPSS are cause by interference of the incident laser beam with a surface electromagnetic wave generated at the surface which might include the excitation of surface plasmon polaritons. BA are formed in the central area on the Si substrate at 4 μJ and higher pulse energy.

Figure 1. SEM micrographs of the WTi/Si after radiation with 1000 pul. Energy: (a1)



2.8 μJ, (a2) 4 μJ, (a3) 5 μJ and (a4) 7 μJ.

Except morphological examination, EDX analysis were done (Table 1).

Table 1. EDX compositional analysis of WTi/Si sample from three positions, non-irradiated area, from LIPSS and from BA in the crater (pulse energy 5 μJ)

	O	Si	Ti	W	Total
Non-irradiated area	1.02	30.47	7.57	60.94	100.00
LIPSS area	0.86	53.02	5.60	40.52	100.00
BA area	0.94	96.23	0.23	2.60	100.00

Processing option: All elements analysed (Normalised), all results in weight%.

Apart from irradiation of the sample surface at the same area with 1000 pulses, we performed surface irradiation using scanning mode, with laser beam linear movement (Fig, 2). Pulse energy was kept constant the same as in the previous irradiation and laser beam was moved with constant velocity of 0.5 mm/s. LIPSS were formed at the thin WTi film on the edge of scanning path. The period Λ was similar to previously observed.

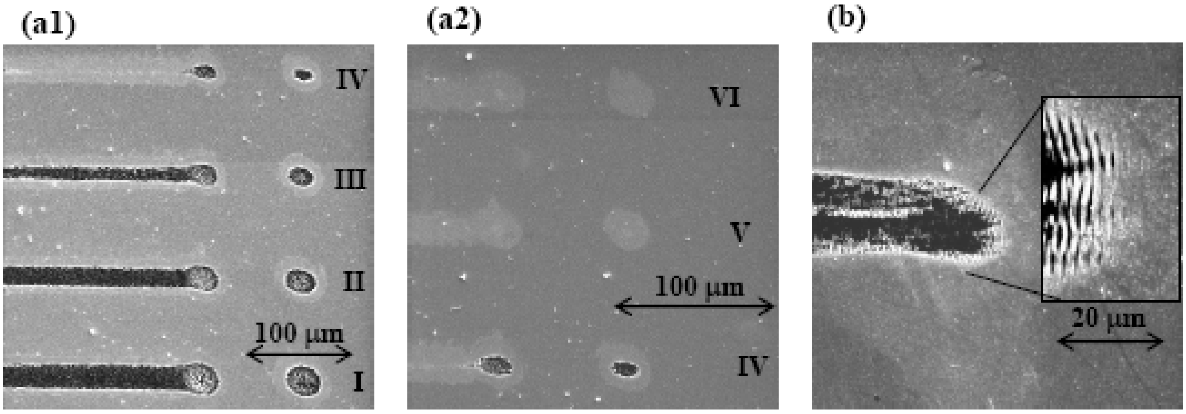


Figure 2. SEM micrographs of WTi/Si after irradiation in scanning and in static mode: (a1 and a2) I –VI lines (0.5 mm/s) and spots (1000 pulses) are produced with energies of 7, 6, 5, 4, 3 and 2.8 μJ, respectively. (b) Magnified part of the sample surface after action of 7μJ.

Conclusion

In this work we reported effects of 1000 ultra short laser pulses (40 fs) on the WTi/Si system. Thin WTi film, deposited on Si, was irradiated in air by linearly polarized and focused laser beam. The sample surface was modified with pulse energy from 2 to 7 μJ. The result demonstrate possibility of laser induced periodical structures formation on the thin film surface and on the Si substrate. Patterns in shape of bump arrays were formed on the Si substrate. In the experiment registered LIPSS period was close to the irradiation wavelength and orientation was perpendicular to the laser beam polarization. We also performed surface irradiation with laser beam linear movement with constant velocity of 0.5 mm/s. In this case LIPSS were also registered.

References

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