Modification of aluminium-titanium and nickel-titanium thin layers by plasma flow action

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Abstract

Morphological changes occurring on aluminum-titanium and nickel-titanium thin films, deposited on the silicon substrate, when treated with a compressed plasma flow have been investigated. The results of this type of interaction are compared with the results obtained in experiments where the interaction between the laser beam and the target was investigated. The energy density delivered to the surface is about 10 J/cm^2 in both types of interactions. Main similarities of compressed plasma flow treatment used here and laser beam treatment are surface uniform melting, perturbation action on melted surface layer and quenching of the produced surface wave structures.

1. Introduction

Titanium alloys are used in a wide variety of fields – in microelectronics, aerospace and biomedical industries. Systems and parts and their selection may be based on corrosion resistance or in strength features, with additional requirement, the biocompatibility, for biomedical implant applications. Aluminum-titanium (Al-Ti) and nickel-titanium (Ni-Ti) alloys have very good physicochemical characteristics that make them useful for high-temperature wear and corrosion protection in mechanical applications. For example, adding a Ti to Al-alloy can lead to the formation of a fine scale, equiaxed grain structure, which improves the mechanical properties, reduces hot tearing and eliminates porosity.

The main focus of this study is to analyze morphological changes occurring on Al-Ti and Ni-Ti thin films when treated with a compressed plasma flow (CPF) which was formed in the magnetoplasma accelerator and comparation of these changes with those obtained during the treatment with Er:glass and Nd:YAG laser pulses.

2. Experimental setup and procedure

Al-Ti and Ni-Ti multilayer systems have been created by alternate deposition of nanometer-thick layers (of Al or Ni on Ti) on a single silicon substrate, by sputter deposition method represented in [1]. The thickness of each individual layer is roughly 20 nm. Wafers of Si(100) was used as substrate. The deposited structures consisted of 10 alternate Al (or Ni) and Ti layers, five of each and 20 alternate Al (or Ni) and Ti layers, ten of each. The surfaces of the samples before plasma treatment are shown in Fig 1. The image was made by atomic force microscope (AFM).

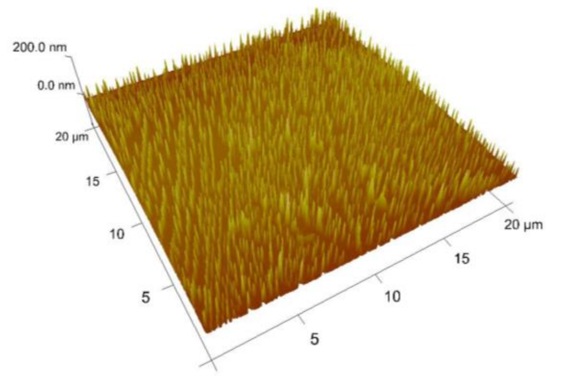

Fig. 1. AFM analysis of the 5x(Ni-Ti)/Si samples before plasma treatment.

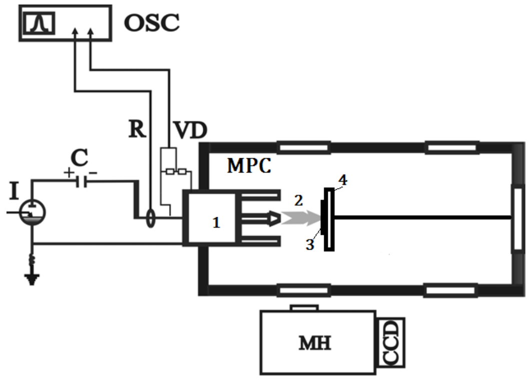

Fig. 2. Scheme of the experimental setup: 1. Magnetoplasma accelerator, 2. CPF, 3. Sample, 4. Sample brass holder.

The plasma source is a quasistationary plasma accelerator which operates in the mode of ion current transfer. The plasma acceleration by the Ampere force in MPC interelectrode gap is accompanied by formation of a compression plasma flow at the outlet of the discharge device. The plasma flow is compressed due to interaction of longitudinal current component with intrinsic azimuthal magnetic field (pinch effect) [2]. The stable CPF is formed 20 μs after the beginning of the discharge. Relatively high values of plasma parameters of the compressed plasma flows (electron density in the order of 10^{23} m^{-3}, and plasma temperature of 20000 K) together with large plasma flow velocity (of 100 km/s in hydrogen plasmas) and discharge duration (of up to 100-150 μs) makes them suitable and efficient for studies of surface modifications under high thermal loads. In addition, we are able to investigate the formation of specific micro- and nanostructures, the occurrence of morphological characteristics arising from the movement of the molten material pieces, and the formation of craters caused by ablation of the target. Scheme of the experimental setup is shown in Fig.2. In present investigation helium with addition of 5% of hidrogen was used as a working gas at 6 mbar pressure. Maximum current in discharge was about 50 kA with time duration of the plasma flow up to 150 μs.

Samples treated by the compressed plasma flows have been analysed by atomic force microscope (AFM) and scanning electrone microscope (SEM).

3. Experimental results and discussion

The energy density delivered to the surface is about 10 J/cm^2 [2] and surface is uniformly melted. Due to the fast cooling of the melted surface layer, the surface structures formed during melt phase are freezing (quenched) during a process of the melt resolidification. The central area of the treated surface contains craters with a diameter of 5 or 10 μm and mosaic structures with well-defined boundaries of the characteristic dimension of 1-2 μm (Fig. 3.). Orientation of these structures corresponds to the orientation of the silicon substrate. These microstructures originate from the redeposition of thin film materials on the partially destroyed structure of the Si substrate. The periphery area of the treated surface contains periodical structures which are smooth, homogenuous and sinusoidally shaped, as would be expected from the frozen capillary waves (Fig. 4.). Typical wavelength of the periodical structures is 10 μm.

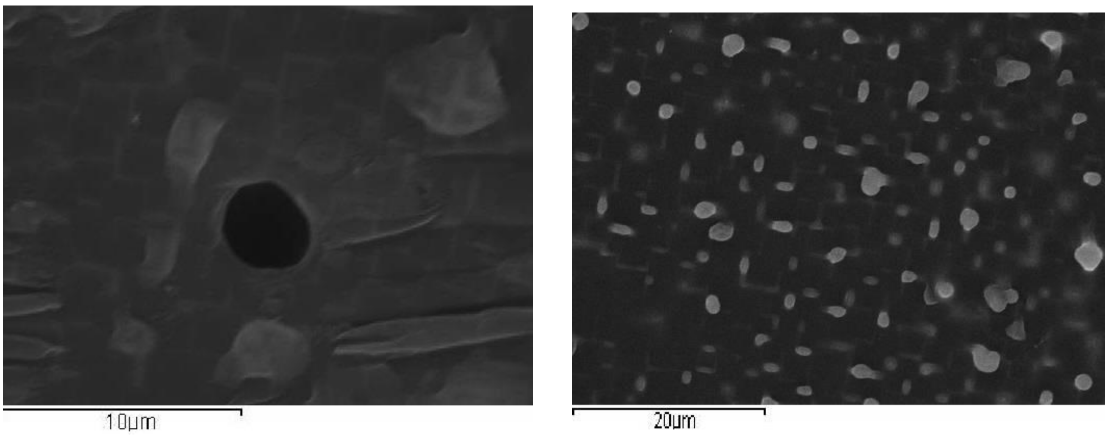

Fig. 3. SEM analysis of the 5x(Ni-Ti)/Si multilayer target after CPF treatment (a) crater (b) mosaik microstructure

These processes are comparable to the (Ni-Ti)/Si and (Al-Ti)/Si surface modifications during laser treatment [3, 4]. Typical wavelengths of the periodical structures in the periphery region are the same (10 μm). Mosaic structures formed in the central area are smaller in the process of laser treatment (100 nm).

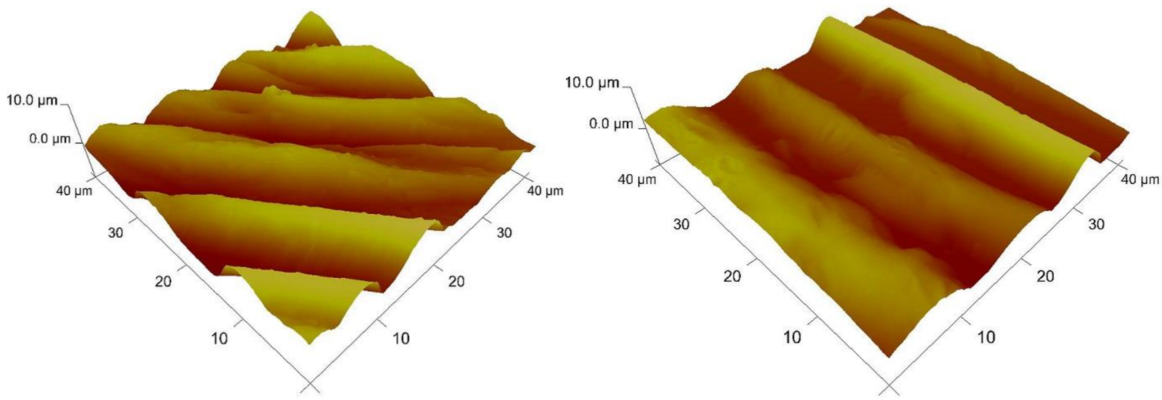

Fig. 4. AFM analysis of the multilayer target after CPF treatment: (a) 10x(Ni-Ti)/Si (b) 10x(Al-Ti)/Si

Results of silicon surface interaction with CPF have shown formation of the periodical structures very similar to those observed in present experiment. Wavelenghts of silicone periodical structures are 4-8 µm. Thikness of near-surface molten layer is estimated at 6-10 µm. It can be concluded that, in present experiment, periodical structures come from interaction of thin films with plasma, as well as from silicon – plasma interaction.

4. Conclusions

The basic effects of the CPF action on a solid target are surface melting, formation of different surface patterns and their freezing during fast cooling (quenching effect).

When a target is irradiated with a laser beam, most of the absorbed energy of the laser radiation is transformed into heat. Modifications of treated surfaces – craters, mosaic structures and periodical periphery structures, are similar to those formed by plasma flow-target interaction. Present study is important for investigations related with material of interest for mechanical applications, for fusion experiments, biomedical implant applications, etc.

References

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