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CONTENTS

FEMTOSECOND LASER ABLATION AND STRUCTURING OF A HARD BI-LAYERED COATING

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Abstract
We studied surface modification of a bi-layered coating (Al_2O_3/TiAlN/steel) induced by fs laser with single and multi-pulse irradiation. The laser pulses (λ=775 nm, τ=200 fs) were generated by a Ti:sapphire laser. The single pulse threshold fluence for ablation of the top Al_2O_3 layer was D_{ath}=0.56 Jcm^{-2}. Single pulse actions with fluence increased up to 16.47 Jcm^{-2} caused widening of ablated area without significant change of the TiAlN layer underneath. In case of multi-pulse irradiation, periodical surface structures (LIPSS) were induced on the TiAlN layer surface. The average periodicity of created LIPSS was 600 nm.

Experimental

The experimental sample was a hard coating produced by reactive sputtering in a commercial system [1]. The top alumina layer (Al_2O_3) of 1.7 μm and the underlying titanium aluminium nitride (TiAlN) of 1.9 μm were deposited on a polished steel substrate (Fig.1a). From XRD analysis, the alumina layer mainly consisted of the polycrystalline χ-Al_2O_3 phase (Fig.1b).

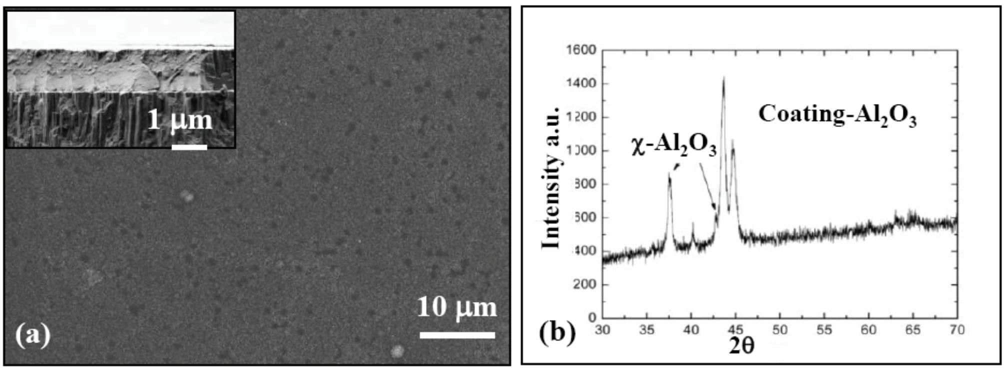

Figure 1. (a) SEM micrograph of the sample surface and cross section (insert) before fs laser pulse action. (b) XRD pattern of Al_2O_3/TiAlN/steel coating.

Laser used in this work was a Ti:sapphire laser source equipped with a chirped pulse amplification system (Clark-MRX 2101). Wavelength of the output beam was 775 nm, with a pulse duration of $\tau_p = 200$ fs [1]. Linearly polarized Gaussian beam was focused perpendicularly to the target surface. Irradiation was done in air with pulse energy E_p and fluence F ranged from 0.5 to 50 µJ and 0.1 to 16.47 Jcm^{-2}, respectively. For better statistics 3x3 spots were made with the same E_p. Surface morphology was examined by optical microscopy and scanning electron microscopy (SEM). SEM was coupled to an energy-dispersive analyzer (EDX) for determining the surface composition. X-Ray diffraction (XRD) was used for inspection of phase composition and crystalline structure of as deposited coating. Non-contact 3D surface profilometry was applied to map-out the geometry of the ablated/damaged area.

Results and Discussion

Interest for laser processing of materials, especially femtosecond laser systems is growing because of numerous possible applications in microelectronics, nanotechnology, tribology, medicine etc. LIPSS have been known since the 1960s. Much work has been done towards explanation of their origin [2,3] but it is still an area of extensive research, especially in the case of femtosecond lasers. Apart from fundamental importance, the damage threshold and the threshold of coating ablation are important parameters for ultra short laser pulse application.

Single-pulse effect. Damage threshold (D_{th}), the lowest fluence that causes irreversible surface modification, was found to be D_{th}=0.20 Jcm^{-2}. The damage appeared in the form of a doughnut shaped bulge on the surface of the top alumina layer with no composition changes. The ablation threshold (D_{ath}) the lowest fluence that causes removal of the upper alumina layer was determined too, D_{ath}=0.56 J cm^{-2}. Profilometry for all fluences (0.56 Jcm^{-2} - 16.47 Jcm^{-2}) showed that the depth of ablation region was 1.7 µm - the same as the thickness of the alumina layer, with clean, steep walls and flat bottom.

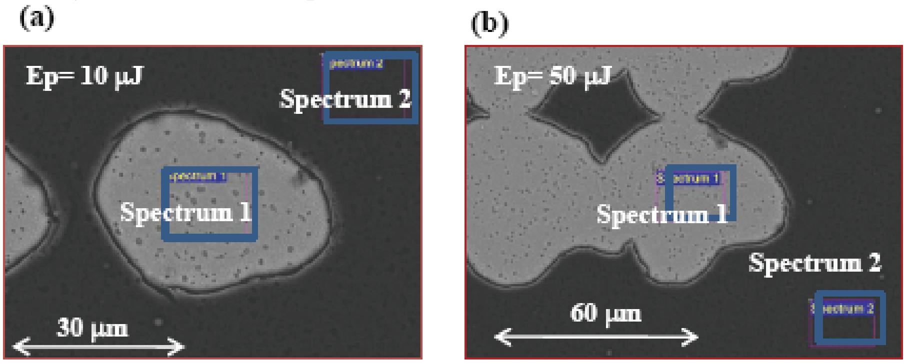

Figure 2. SEM&EDX analyses of Al_2O_3/TiAlN/steel coating after single fs pulse action: (a) pulse energy/fluence of 10µJ/1.86 Jcm^{-2} and (b) 50µJ/16.47 Jcm^{-2}.

Compositions of the ablated regions were checked by EDX (Fig.2). Data taken from blue squares on the Figs.2 a and b showed that the composition of the ablated areas (Spectrum 1) were the same in spite of different fluences (1.86 and 16.47 Jcm^{-2}) applied. Spectrum 1: N~28, O~2.3, Al ~27, Ti ~41 (all in wt%). Spectrum 2 corresponded to the composition of the original coating.

Multi-pulse effect. Irradiation of bi-layered coating (Al_2O_3/TiAlN/steel) by ten fs pulses and constant energy/fluence (10μJ/1.86 Jcm^{-2}) resulted in ablation of alumina layer from the underlying TiAlN and LIPSS formation on TiAlN (Fig.3).

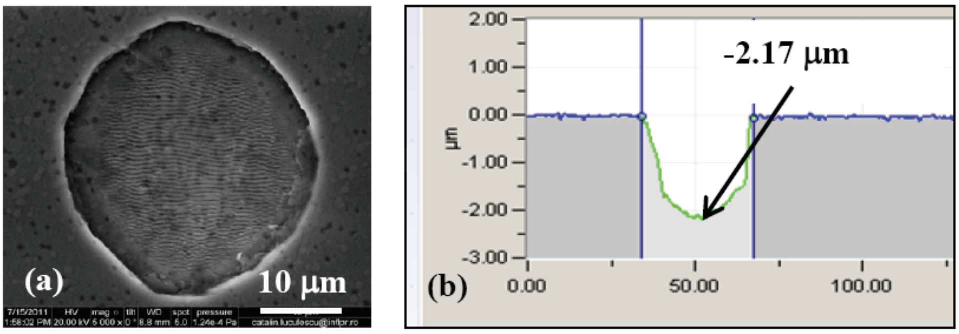

Figure 3. (a) SEM of 10 laser pulses action on Al_2O_3/TiAlN/steel. LIPSS are formed in the spot centre on TiAlN and (b) depth of ablated area obtained by profilometry.

The average periodicity value of the LIPSS formed was 600 nm. Among other explanations, their origin can be explained by interference of the incident laser beam with the so-called surface waves scattered on imperfections at the target surface [3].

Conclusion

Femtosecond laser pulses (200 fs), single and multi-pulse, were used for surface structuring of a bi-layered coating Al_2O_3/TiAlN deposited on steel. The value of single pulse ablation threshold, D_{ath}=0.56 Jcm^{-2}, was obtained for ablation of the top Al_2O_3 layer. A significant result is that underlying TiAlN layer remained unchanged after one pulse action (fluence up to 16.47 Jcm^{-2}). Multi-pulse irradiation (10 pulses) with the pulse energy/fluence of 10μJ/1.86 Jcm^{-2} caused Al_2O_3 ablation/exfoliation and appearance of LIPSS on the TiAlN.

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