THE EFFECT OF SURFACE LAYER ON NITROGEN DEPTH DISTRIBUTION IN IMPLANTED TITANIUM

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Abstract

Nitrogen implantation into titanium and its alloys significantly improves their surface hardness, sliding behaviour, wear and corrosion resistance. A thin surface nanolayer originating, e.g., from air exposure or from condensation of oil vapours modifies the ion energy distribution and causes a difference in the ion range. The effect of the thickness of the contaminant carbon layer on the nitrogen distribution was investigated. Titanium samples with a carbon nanolayer were implanted with nitrogen ions. An almost Gaussian experimental concentration profile was observed. The maximum of nitrogen concentration moves into the specimen with increasing thickness of the nanolayer. The experimental findings are in agreement with the theoretical calculations. These results can be useful for optimizing surface modifications of titanium materials by ion implantation.

Keywords: Ion implantation, concentration profile, surface nanolayer

1. INTRODUCTION

Ion implantation is a universal method for modifying the surface properties of the solids. Nitrogen implantation into the titanium and its alloys improves their surface properties such as hardness, friction coefficient, wettability, corrosion and wear [1-3]. Nitrogen distribution characterized by concentration profile in the implanted zone helps to clarify the mechanisms for improving surface properties [4]. The modified property can be controlled by changing the nitrogen concentration in the implanted surface area. The collisions of the accelerated nitrogen ions with target atoms deliver the energy in the sample surface. This leads to damage to the crystal lattice and a high concentration of lattice defects toward the surface [5]. The accumulation of these defects and their migration deform the concentration depth profile in implanted zone through radiation enhanced diffusion (RED) [6]. Owing to high affinity of titanium, surface adsorption of species causes the formation of thin contaminant layer. A residual atmosphere (e.g. oxygen and carbon) exists in vacuum chamber. If the contaminants adsorb or are co-implanted into the surface in large quantities, oxidation and carburization causes the microstructural changes of the implanted surface [7]. The chemical composition and the thickness of contaminant layer alter the depth distribution of implanted ions due to changes in the ion energy distribution [8, 9]. Tian et al. [10] observed skewing and translation of the nitrogen depth profile in implanted stainless steel due to surface contamination. Comparison experimental depth profiles and calculated depth profiles by Lacoste et al. [11] showed that they are consistent if no impurities are present in implanted titanium.

In this work, we present the effect of the thin contaminant carbon nanolayer on depth distribution of implanted nitrogen. Nitrogen depth distribution was measured by a glow discharge optical emission spectroscopy (GDOS). The experimental data shows a good agreement with the SRIM simulations.

2. EXPERIMENTAL PART

The substrates were made of Ti6Al4V titanium alloy in the form of a cylinder 14 mm in diameter and 3 mm in height. The samples were cut from a titanium alloy bar and were then ground with a series of waterproof

abrasive papers. Final polishing was performed with diamond paste. The samples were ultrasonically cleaned in isopropyl alcohol.

The experiment was performed in two steps. The first step was to deposit the carbon nanolayer by electron evaporation of a carbon tablet. The nanolayer thickness was 20 nm and 40 nm. Deposition rate and nanolayer thickness were measured by a quartz crystal monitor located in the vacuum chamber. In the second step, the coated samples were irradiated by nitrogen ions. The accelerating voltage was 90 kV and the maximum ion current density was approximately 1.5 μA·cm^{-2}. The fluency of implanted nitrogen atoms was about 1·10^{17} cm^{-2} for both series of the coated samples. The ion current was measured by the Faraday cup. An experimental arrangement of the modification process is illustrated in **Figure 1**.

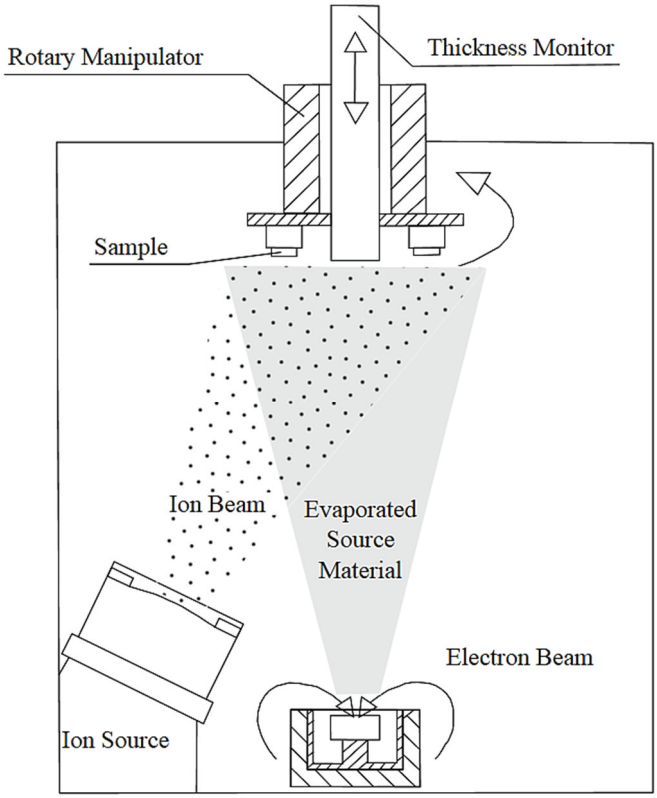

Figure 1 An experimental arrangement of the modification process

The chemical composition was measured by means of the glow discharge optical emission spectroscopy (GDOS) method. A LECO GDS850A optical emission spectrometer was used. Atomization of the sample surface was performed by the mechanism of cathode sputtering under an anomalous discharge. The process gas was argon. The spectrometer was calibrated using reference materials with a known composition and known sputter rates, and the “standard” calibration model was used [12].

3. RESULTS AND DISCUSSION

Figure 2 shows the typical nitrogen concentration profiles in the modified area of the implanted Ti6Al4V samples without a carbon nanolayer (sample Carbon 0 nm) and with a carbon nanolayer 20 nm in thickness and 40 nm in thickness (sample Carbon 20 nm and sample Carbon 40 nm). The distortion of Gaussian like concentration profiles are visible on top of the surface, due to nitrogen adsorption. The results in **Figure 2** show that the maximum of nitrogen concentration moves deeper into the sample with increasing thickness of the carbon nanolayer. The observed trend for nitrogen concentration maximum movement is in agreement with the SRIM simulation. The resulting SRIM nitrogen profiles are shown in **Figure 3**. According to the SRIM

simulation, the projected range of nitrogen ions is 80 nm for sample Carbon 0 nm, 85 nm for sample Carbon 20 nm, and 90 nm for sample Carbon 40 nm. This is in good agreement with the experimental findings.

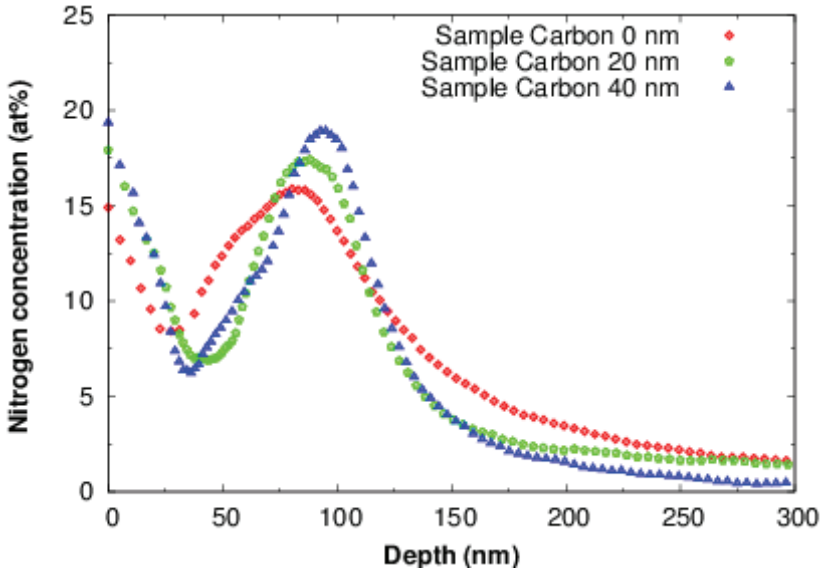

Figure 2 GDOS concentration profiles of nitrogen in the implanted Ti6Al4V alloy with and without a carbon nanolayer

The observed changes in the nitrogen concentration profiles are caused by the physical properties of carbon nanolayer. The ion range of implanted ions is modified by energy losses caused by collisions between the implanted ions and the carbon atoms. The relative atomic mass of carbon is approximately 4 times lower than that of titanium, and atomic density of carbon is approximately 1.6 times greater than that of titanium [8]. This causes the carbon nanolayer more penetrable for implanted ions in comparison with titanium. The maximum of nitrogen concentration shifts towards the carbon/titanium interface with increasing thickness of the nanolayer. However, towards the sample surface, the maximum of nitrogen concentration moves deeper into the sample due to the easily penetrable carbon nanolayer. The implanted ions after passing the surface nanolayer penetrate into the substrate in the modified projected range and modified longitudinal straggling which causes an increase in the maximum of nitrogen concentration in dependence on the thickness of the carbon nanolayer.

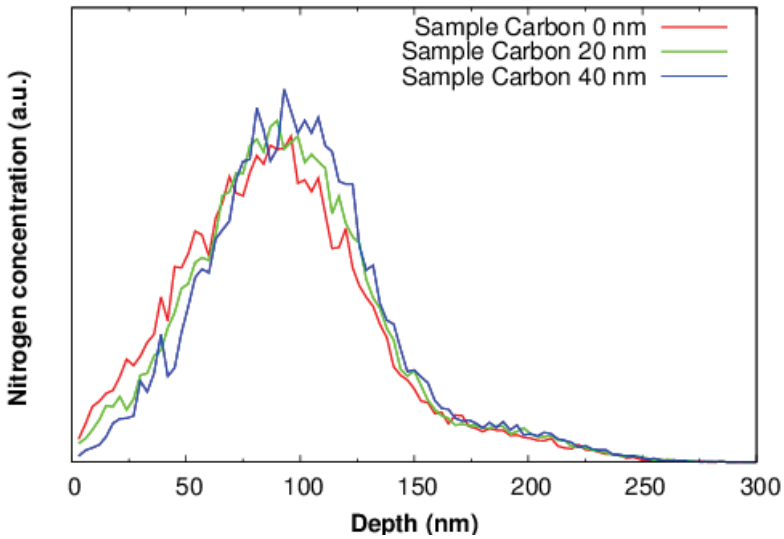

Figure 3 Comparison of nitrogen concentration profiles of implanted Ti6Al4V alloy with and without a carbon nanolayer calculated by the SRIM code

4. CONCLUSION

The effect of the thickness of the carbon layer on the nitrogen depth distribution was examined. It has been demonstrated that the nanolayer thickness deforms the concentration profile of implanted nitrogen. The maximum of nitrogen concentration moves into the sample with increasing thickness of the nanolayer. The implanted ions penetrate into the substrate in the modified projected range and modified longitudinal straggling which causes an increase in the maximum of nitrogen concentration in dependence on the thickness of the carbon nanolayer. The experimental findings are in agreement with the theoretical calculations from SRIM simulation.

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