Study of Plasma Interaction with Titanium Coated Ferritic Steel in IR-T1 Tokamak

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Abstract. Studies of plasma interaction with titanium coated ferritic steel is performed on IR-T1 tokamak. Titanium coating is one of the candidates for the plasma facing materials in a tokomak. Titaniumization is carried out by a sputtering method. Some of the samples were baked (3 hours at 460ºC) before sputtering. Atomic Force Microscopy (AFM) analyses before and after discharge in r/a=1.04 carried out. The samples (with distinctive titanium layers) were placed at different depths inside the vacuum vessel of the IR-T1 tokamak in the SOL region. A comparison of the titanium coated steel with bare ferritic steel exposed to plasma tokamak and glow discharges is made in this research. Depth of impurity penetration and retention, and the surface roughness are measured by using surface analysis methods. Rutherford backscattering method is used to measure the content of nitrogen, oxygen and titanium, before and after discharges. The result is shown a change in roughness with respect to position of samples.

Keywords: tokamak, plasma material interactions
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INTRODUCTION

Fusion material candidates are limited to reduced activation materials like as SiC/SiC composites, vanadium alloy and ferritic/martensitic steels. We use commercial type of ferretic steels that contains 22% Ni, 10%Cr. Titanium is applied as a coating on steel substrate. Titanium has acceptable aeromechanical properties as a wall in plasma generator (producer) system and fusion devices [1-3]. The first indication of the very good properties of titanium as getter for oxygen and as a protection against sputtering of metals from the limiters is the strong reduction of about a factor 2 of the impurity concentrations inside the plasma as measured by UV spectroscopy. The experiments carried out with a glow discharge and plasma shots. The main aim of this experiment is to understand effects of glow discharge and plasma on the edge surfaces positioned in the wall and limiter area of IR-T1 tokamak for future studies. In this experiment at first we run 500 shots, but the plasma removed all titanium over the samples, so we repeated the experiment by new samples with 55 shots.

EXPERIMENTAL SET-UP AND RESULTS

We use a RF sputtering method with power 400 W and deposit titanium layer on ferritic steel substrate, as a protection layer. Some of the steel substrates baked in 460ºC temperature and for 3 hours before analyzing them. Also, we installed some samples on a flange at different depth from plasma core (r=0) in IR-T1 tokamak in r_1=12.5 cm, r_2=13.2, r_3=13.5, r_4=13.8, r_5=14.2 cm, respectively. The samples positioned in parallel array. A baking process accompanies the coating technique to improve plasma purity. The oxygen inventory contents in titanium layer increased by the baking process. Figure 1 shows an array of samples inside the tokamak vessel. Comparison between samples with and without baking process show an increase in oxygen content and decrease in titanium content in baked sample. Oxygen gathering effect of Ti layer is clearly shown in Table 1. Oxygen content in titanium coating increased, because of tight bonds between titanium and oxygen impurity. Titanium in fact is very suitable for their chemical property to form tight bonds with oxygen and carbon that constitute the main contaminants on tokamak.

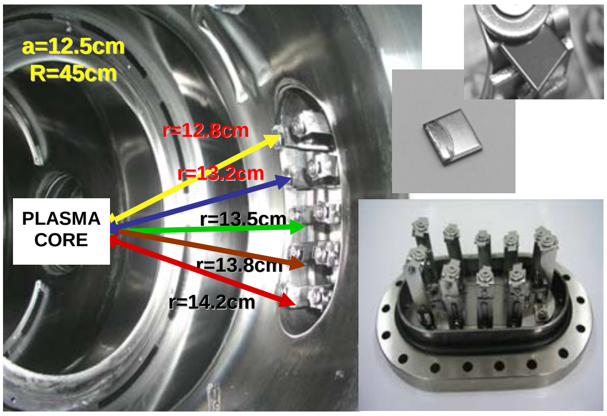

FIGURE 1. An array of samples installed inside the tokamak vessel.

TABLE 1. Oxigen gettering effect of Ti layer

Samples	Thickness (A°)	Ti (%)	O_2 (%)
Without Baking (r3186-1-Ti)	200	50	50
With Baking (r3188-2-Ti)	100	40	60
With Baking (r3191-4-Ti)	100	35	65

The samples were mounted on a flange and placed at different distances from the plasma core in the IR-T1 tokamak. After 15 minutes glow discharge cleaning and 55 plasma shots the titanium coating showed good performance in general. We expected protection against sputtering of materials from the wall, but the resolution of the detector did not allow to find a titanium coated layer after 15 minute glow discharge cleaning (GDC) and 55 shots. The coating was destroyed during operation. (As we had seen comparable erosion in samples with 500 shots and GDC for 20 hours). The coated layer at a different distance was sputtered, and it was not acceptable as a suitable layer. Probably, this destruction process was first initiated by the cracking of the coating layer due to steel composition for example chromium content in steel and difference in thermal expansion between stainless steel and Ti. (like for copper coating on tungsten substrate because of thermal expansion [3]).

Also, surface roughness decreased after 15 minute glow discharge cleaning and exposure to the plasma (55 shots). We can see an obvious decrease in surface roughness of samples placed closer to the plasma core due to sputtering by energetic particles. Figure 2 shows changes in roughness in samples before and after 55 plasma discharges and figure 3 shows profile of comparing roughness of samples before and after discharges.

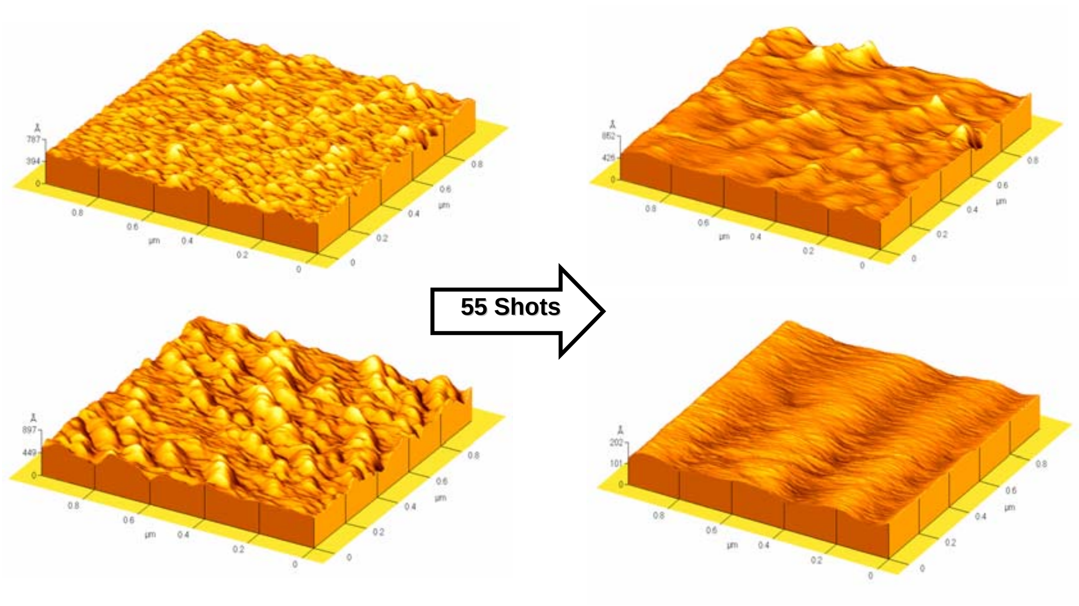

FIGURE 2. Changes in roughness at two different positions of the sample with respect to plasma core. Below one is closer to plasma core. Left figures are before discharges and right figures are after discharge.

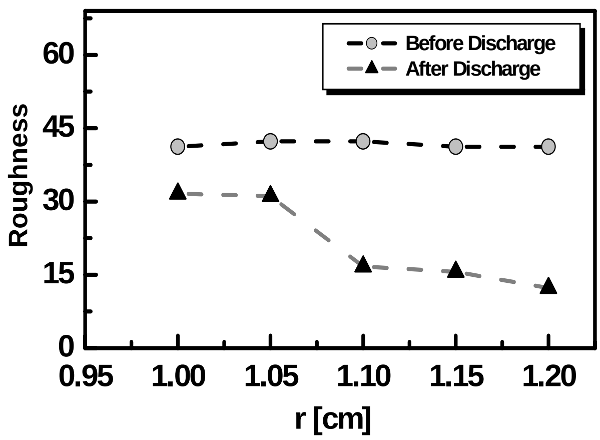

FIGURE 3. Profile of comparing roughness of samples before discharge and after discharges, where, *r* (normalized) is the position of samples with respect to plasma core.

Rutherford backscattering method has been used to measure the content of nitrogen, oxygen and titanium, before and after discharges. The Rutherford backscattering spectrometry (RBS) spectra shows lower oxygen content after plasma-surface interaction in titaniumized sample. It may be due to oxygen gathering of titanium properties. Figure 4 shows the analyses of RBS measurements with the SIMNRA Code. (Simulation Program for the Analysis of NRA, RBS)[4].

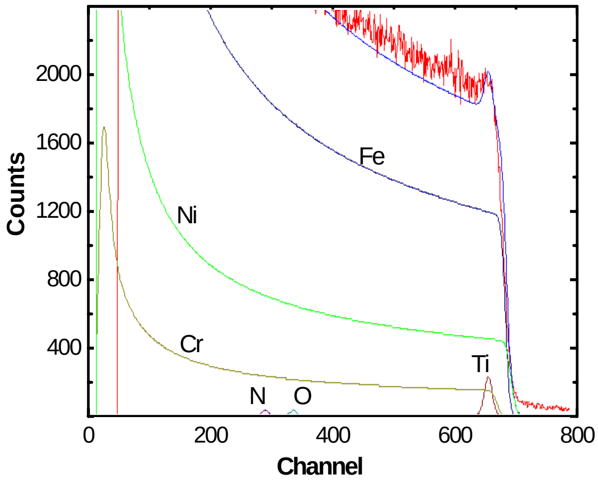

FIGURE 4. The analyses of RBS measurements with SIMNRA Code.

The titanium layer of the steel captures an amount of oxygen, and is eroded from surface because of surface defects. So, we can see lower content of oxygen in this sample, so that before titaniumization the concentration of oxygen is about 1.5×10^{18} and after titaniumization it is about 9.5×10^{17}. This result is not good for plasma purity, but shows lower oxygen penetration or permeability in steel and titanium impurity absorption.

CONCLUSION

The studies of plasma interaction with titanium coated ferritic steel is performed on IR-T1 tokamak. Atomic Force Microscopy (AFM) analyses before and after discharge in r/a=1.04 carried out. A comparison of the titanium-coated steel with bare ferritic steel exposed to plasma tokamak and glow discharges is made in this research. The depth of impurity penetration and retention, and the surface roughness were determined using Rutherford backscattering method, measuring the content of nitrogen, oxygen and titanium, before and after discharges. The results shown that the roughness changes with the position of samples, and that the concentration of oxygen decreases after titaniumization. This result is not good for plasma purity, but shows lower oxygen penetration or permeability in steel and titanium impurity absorption.

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