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MAGNETIC NANOSTRUCTURE OF THE Fe-Ti ALLOY LAYERS PRODUCED BY IMPULSE PLASMA DEPOSITION METHOD

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Abstract. The Fe-Ti layers were produced by the impulse plasma method (IPD) in two impulse plasma coaxial accelerators, each equipped with an internal electrode made of Fe or Ti, which functioned as the source of the alloying components of the layer material. The successive portions of Fe and Ti were deposited independently at separated time intervals, according to the schedule that specified the number and proportion of the impulses generated by each accelerator.

The magnetic nanostructure and the morphology of the deposited Fe-Ti layers were investigated by Magnetic Force Microscopy (MFM) and Scanning Electron Microscopy (SEM) techniques, respectively.

Magnetic structure was obtained for the layers in accordance with the Fe/Ti ratio= 5/1 and 2/1. The surface morphology is very similar to the magnetic contrast in the layers. It is interesting to note that the magnetic domain size in the magnetic contrast is related to the characteristic size in the surface morphology. We suppose that the light and dark contrasts in the magnetic structure correspond to the ferromagnetic phases i. e. α-Fe or bcc-Fe(Ti) and to the paramagnetic phases i. e. Ti or inter-metallic phases, respectively.

1. INTRODUCTION

In the impulse plasma (IPD) method, the impulse plasma generated in a coaxial plasma accelerator under quasistationary conditions is the only source of mass and energy during the entire process of the synthesis of the layer material [1,2]. This 'single –source' character ensures that a close relation exist between the IPD process parameters and the quality of the layers (the phase and chemical composition, morphological defects, kinetics of growth, adhesion to the substrate) [3,4].

During the impulse plasma deposition the plasma is generated in the form of discrete packs with a life-time of about 100 μs. The consecutive plasma packs are generated at a specified frequency and ejected from the accelerator toward the substrate at a velocity of about 10^4 m/s [5,6].

Characteristically, the layer growth mechanism in the IPD method involves the uncompleted coalescence of the clusters formed in the plasma itself and delivered onto the cold surface of the substrate [7].

In spite of the pulse character of the mass and energy supplied to the substrate, we know from our previous investigations, that during the IPD growth of the layers, short-distance diffusion takes place between the separated iron and titanium clusters [8,9].

2. EXPERIMENTAL

The Fe-Ti layers were produced in the IPD apparatus, equipped with two independent impulse plasma accelerators operated alternately. The sources of Fe and Ti were the internal electrodes of the accel-

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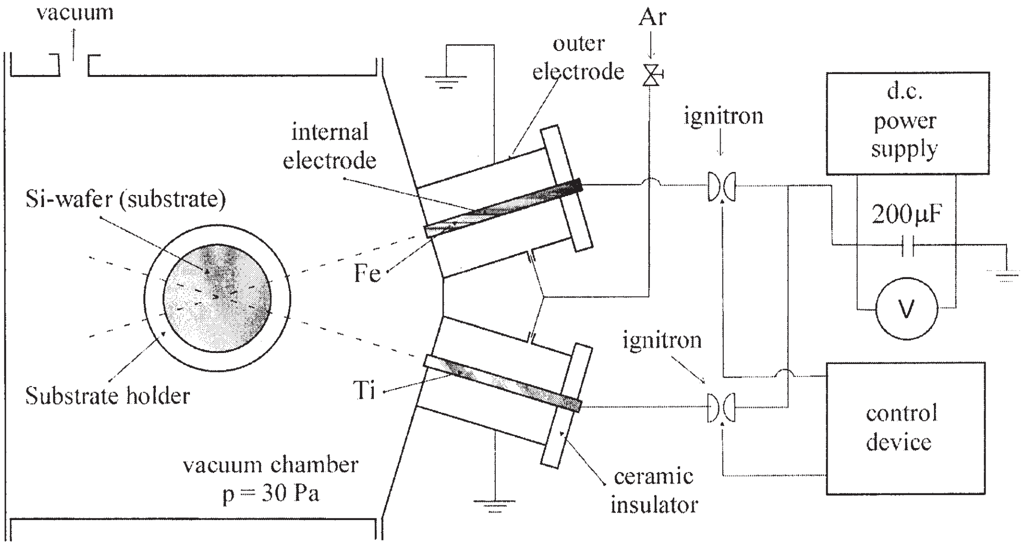

Fig. 1. A schematic view of the multi-accelerator apparatus for the fabrication of the Fe-Ti layers.

erators, made of titanium and iron. Fig. 1 shows schematically the apparatus of this type. The plasma processes were carried out in a hydrogen atmosphere under a dynamic pressure of 20 Pa, with the total number of plasma impulses equal to 3000. The layers were produced on silicon substrates. The substrates were installed in parallel to the axis of the accelerator electrodes. The plasma generation rate was 0.2 Hz. The routine impulse ratio in the alternate operation of the accelerators was: Fe/Ti =5/1, 2/1 and 1/1. This for example means that each 5 plasma impulses generated from the accelerator equipped with an iron electrode were followed by 1 plasma impulse generated from the other accelerator equipped with a titanium electrode (the Fe/Ti ratio =5/1). The successive portions of Fe and Ti were deposited independently and separately, according to the specified number and proportion of the impulses generated by each accelerator. The work of the accelerators was controlled by a microprocessor system.

The examination techniques included:

- Morphology was determined by High resolution Scanning Electron Microscopy (SEM) — Leo 1530.
- Topographic and magnetic features were investigated by Magnetic Force Microscopy (MFM) – Nanoscope IIIA Digital Instruments.

During the MFM measurement, the microscope collected simultaneously the topographic image (in the Tapping Mode) and the image of the magnetic interaction between the microscope tip and the sample surface (in the Lift Mode). The system operates in the non-contact mode, detecting the changes in the resonant frequency of the cantilever due to the variation of the magnetic field according to the tip-to-sample separation. Which effect dominates depends upon the distance of the tip from the surface, because the interatomic magnetic force is active up to greater tip-to-sample separations than the van der Waals force. If in the region where standard non-contact AFM is operated the tip is close to the surface, the image will be predominantly topographic. As we increase the separation between the tip and the sample, magnetic effects start to predominate. One of the ways in which the magnetic affects can be separated from topographic effects is to collect a series of images at various tip heights.

The lift Mode scan was used in the Phase Detection. The MESP-LM tips employed were coated with a cobalt alloy.

3. RESULTS AND DISCUSSION

Fig. 2 shows a SEM image of the morphology of the Fe-Ti layers. The morphology of the layers with the Fe/Ti ratios= 5/1 and 2/1, shows anisotropy in the layer perpendicular to the direction of plasma propagation, which can be seen in Figs. 2a and 2b. The morphology of the layers also depends on their

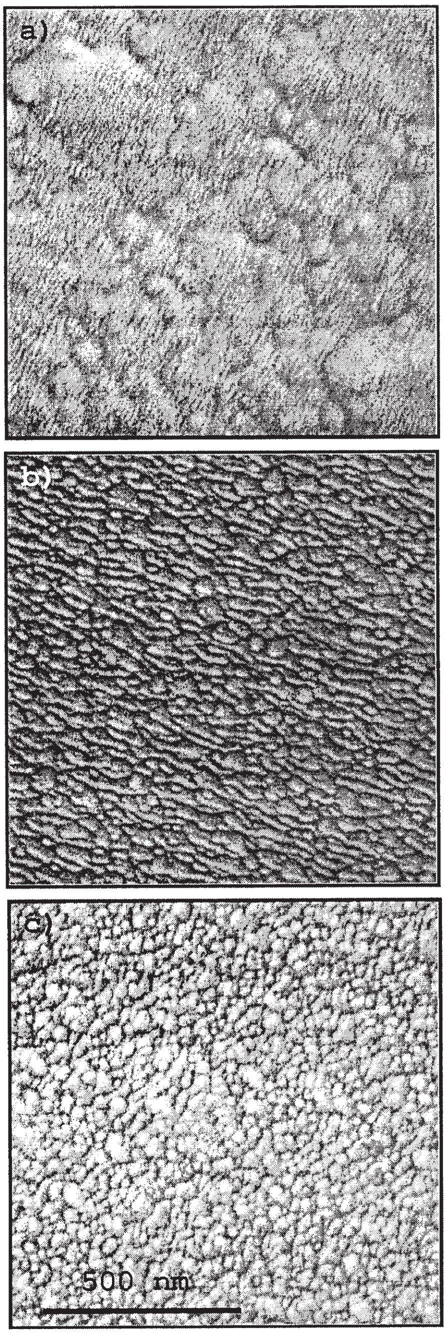

Fig. 2. SEM morphology of the Fe-Ti layers with various Fe/Ti ratios: a) 5/1, b) 2/1, c) 1/1.

chemical composition: at a Fe/Ti ratio of 1/1, the surface morphology is globular, without any visible anisotropy (Fig. 2 c).

Figs. 3 and 4 show the topographic and the domain structures of the Fe-Ti layer determined by MFM. In the layers with the Fe/Ti ratio=1/1, no image was registered, probably because of the predominance of the paramagnetic phase in the layer.

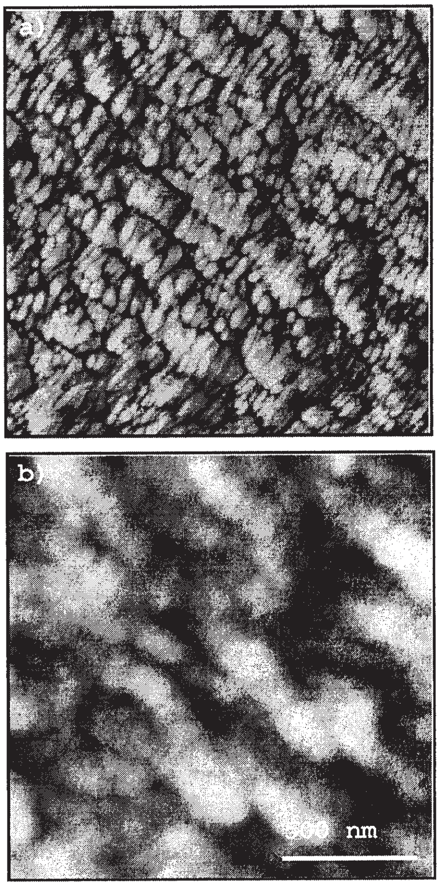

Fig. 3. Scan of MFM domain image (a) and AFM topographic image (b) of the Fe-Ti layer with the Fe/Ti ratio= 5/1.

We can see that the magnetic patterns are relatively regular, and consist of sharp light and dark contrasts. The light and dark contrasts correspond to the strength of the stray-field gradient on the sample surface. The lighter colour represents a larger frequency shift of the MFM tip vibration in which the magnetization of the samples and of the MFM tip is repulsive.

The surface morphology is very similar to the magnetic contrast in the layers. It is interesting to note that the magnetic domain size in the magnetic contrast is related to the characteristic size in the surface morphology. It is possible that, the size of the magnetic domains corresponds to the region built of a single-domain [10]. The dark nonmagnetic regions and the light magnetic regions are characterized by regular long, dense and parallel domain regions. In addition, we can see that the magnetic regions (light regions) are surrounded by a nonmagnetic matrix (dark region), and these two phases

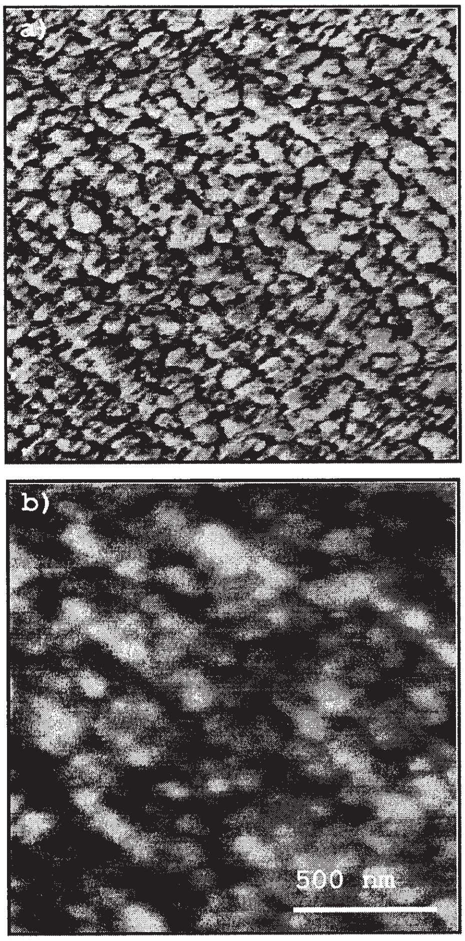

Fig. 4. Scan of MFM domain image (a) and AFM topographic image (b) of the Fe-Ti layer with the Fe/Ti ratio=2/1.

seem to be quite effectively separated from one another.

The results obtained thus far show that, during the IPD growth of the layers, short-distance diffusion takes place between the separated iron and titanium clusters [8,9]. The magnetic structures shown in Figs. 3a and 4a seem to confirm the possible mechanism of the formation of the alloy on the substrate, at the interface between the clusters. We can thus suppose that the light contrasts in the magnetic structure, corresponds to the ferromagnetic phases, i. e. to α-Fe or bcc-Fe(Ti) whereas the dark contrasts correspond to the paramagnetic phases, i. e. to Ti or inter-metallic phases.

4. CONCLUSIONS

The magnetic structure of the Fe-Ti layers, with various Fe/Ti ratios, was examined by Magnetic Force Microscopy (MFM). The magnetic structures were only obtained in the layer with the Fe/Ti ratios= 5/1 and 2/1. We can conclude, that the observed magnetic contrast is defined by the structure of the Fe-Ti layer itself, and it illustrates a possible mechanism of the alloy formation. The light and dark contrasts in the magnetic structure correspond to the ferromagnetic phases i. e. α-Fe or bcc-Fe(Ti) and to the paramagnetic phases i. e. Ti or intermetallic phases, respectively.

Moreover, the magnetic domain sizes in the magnetic contrast are related to the characteristic sizes in surface morphology.

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