Available online at www.sciencedirect.com
SCIENCE DIRECT
Vacuum 77 (2005) 287–291
VACUUM
SURFACE ENGINEERING, SURFACE INSTRUMENTATION & VACUUM TECHNOLOGY
www.elsevier.com/locate/vacuum

Impulse plasma deposition of magnetic nanocomposite layers

Katarzyna Nowakowska-Langier[a,*], Emil Wierzbiński[a], Krzysztof Zdunek[a], Michał Kopcewicz[b]

[a]Faculty of Materials Science and Engineering, Warsaw University of Technology, Woloska 141, 02-507 Warsaw, Poland
[b]Institute of Electronic Materials Technology, Wólczyñska 133, 01-919 Warsaw, Poland

Received 12 August 2004; accepted 17 October 2004

Abstract

The most characteristic feature of the IPD method is that the synthesis proceeds in the impulse plasma itself, with the participation of ions. The IPD growth mechanism, originating from clusters of constituent materials, makes this method particularly suitable for the fabrication of nanocomposite layers.

The material synthesised in the present experiment was an Fe–Ti alloy. The sources of Fe and Ti were the internal electrodes of two independent impulse plasma accelerators operated in an alternate mode. It appeared that the Fe–Ti alloy forms at the interface between the Fe and Ti nanocrystals as a result of the surface diffusion due to the coalescence of the nanocrystals.

Keywords: IPD method; Fe–Ti alloy; CEMS; MFM; SEM

1. Introduction

The genesis of the present study was derived based on the following two prerequisites:

- the IPD method is particularly suitable for the synthesis of high-melting nanocrystalline materials, since nucleation occurs there with the participation of ions, and
- the physical properties of magnetic materials with a nanocrystalline structure are determined by size effects.

The IPD method has been developed at the Faculty of Materials Science, Warsaw University of Technology, in the 1980s [1]. It has been described abundantly in the literature, in both the fundamental and applicative aspects [2–4]. As is known, this method utilises the impulse plasma generated and accelerated in a coaxial generator

*Corresponding author. Tel.: +48 22 660 8549; fax: +48 22 660 87 05.
E-mail addresses: kaha@inmat.pw.edu.pl (K. Nowakowska-Langier), zdunek@inmat.pw.edu.pl (K. Zdunek).

0042-207X/$ - see front matter
doi:10.1016/j.vacuum.2004.10.005

by the Ampere force [5]. The consecutive packs of the plasma with a lifetime of about 50–100 μs are generated at a specified frequency and ejected in the form of ion packs from the accelerator toward the substrate at a velocity of about 10^4 m/s. The structure and dynamics of impulse plasma has already been described in our earlier publications [6,7]. For the purposes of the present experiment, the most important features of the IPD process are

- the plasma is fully ionised and remains in state of deep unequilibrium,
- nucleation occurs on the ions within the plasma itself,
- no external sources of force fields (electric or magnetic) are used for the energy activation of the gaseous phase,
- no external heat source for heating the substrate is installed—in macroscopic terms, the substrate is cold during the entire layer deposition process,
- the source of the vapours is an eroding internal electrode of the coaxial plasma accelerator, and
- the layer is deposited through the coalescence of clusters and critical nuclei that form in the plasma; the layer thus obtained is solid and continuous.

Good examples of materials with the properties determined by the size effects are magnetic alloys. As is known, if the particle sizes in those regions of the material that are liable to spontaneous magnetisation are of the order of nanometres, the formation of the domain walls is not possible from the thermodynamical point of view [8]. As a result, these particles constitute single magnetic domains. Alnico, a metallic alloy having the properties of a hard magnet, acquires its final nanocrystalline structure through a spinodal decomposition of the saturated solid solution Fe(Co,Ti,Ni,Cu) into two coherent isomorphic phases α_1 and α_2 differing essentially in their chemical compositions [9]. The former phase mostly contains Fe and Co, whereas the latter contains mostly Ti, Ni and Cu. The chemical compositions of the two phases α_1 and α_2 are established as a result of the short-range diffusion that proceeds during the long-term (several tens of hours) heat treatment at a temperature between 600 and 500 °C. In effect, characteristic magnetic structures form, corresponding to the single-domain ferromagnetic regions of the α_1 phase isolated from one another by the non-magnetic matrix of the α_2 phase. The high-energy mechanism of remagnetising such a magnetic structure consists of simultaneous rotations of the spins within the entire single-domain ferromagnetic region [10].

The pilot experiment, described below, was aimed at determining the preliminary conditions required for the fabrication of multi-phase nanocomposites using the IPD method. The Fe–Ni nanocomposite, potentially able to form the single-domain structure through synthesis from the gaseous phase, was chosen for the present experiment as a suitable material for accomplishing the aim formulated above. Alloys of similar compositions have already been fabricated by other methods of plasma-assisted surface engineering.

2. Experimental

A schematic view of the multi-accelerator apparatus for the fabrication of Fe–Ti layers by the IPD method is shown in Fig. 1. The internal electrodes of each of the two impulse plasma coaxial accelerators installed in this apparatus were made of iron and titanium, respectively. The plasma processes were carried out in an argon atmosphere under a dynamic pressure of 30 Pa. The layers were produced on typical one-side polished silicon substrates of a diameter of 55 mm. The substrates were installed in parallel to the axis of the accelerator electrodes. The plasma generation rate was 0.2 Hz. The chemical composition of the layer was specified so as to correspond to the Fe and Ti contents of the α_2 phase in the Alnico alloy. To achieve this, each of five plasma impulses generated from the accelerator equipped with an iron electrode were followed by one plasma impulse generated from the other accelerator equipped with a titanium electrode. What we called the 'thin' layers were produced using 1,500 plasma impulses, whereas the 'thick' layers were produced using 4,500 plasma impulses. The magnetic structure of the layer material was