OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 4, No. 12, December 2010, p. 2048 – 2051

Structural characterization of MgO-Co multilayers prepared by thermionic vacuum arc method

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We investigated the MgO/Co multilayers deposited by thermionic vacuum arc technique on glass and brass substrates. Morphology, chemical composition, microstructure and crystallographic properties of the films were analysed by scanning electron microscopy, energy dispersive X-ray and transmission electron microscopy. These analysis showed nanostructured, smooth thin films with grain structure.

(Received November 4, 2010; accepted November 29, 2010)

Keywords: Multilayers, MgO-Co, TVA, SAED, EDAX

1. Introduction

Developments in the understanding of how materials behave enable us to design material structures to display specified properties.

Multilayered materials are considered as systems in which new properties, not found in their constituents in bulk form, can emerge. It is only by properly understanding the behaviour of materials that we can design their structure to fully exploit their properties and explore promising new materials combinations.

Recently, advanced studies in generating, manipulating and detecting spin/polarized electrons have stimulated interest in new types of devices called spintronics devices. The key component of many spintronics devices is the magnetic tunnel junction(MTJ), which consists of a sandwich of two layers of ferromagnetic (FM) electrodes (for example Co) separated by a tunneling barrier (for example MgO) [1].

Multilayered materials can be produced by a variety of deposition techniques among them RF and DC sputtering [2], magnetron sputtering [3], ion beam sputter [4]. In this case it was used the thermionic vacuum arc method (TVA) [5-7].

The aim of this paper is to analyze the nanostructured MgO-Co multilayers deposited by thermionic vacuum arc method. Succesive depositions of two different types of thin films in vacuum have been done to generate multilayers with different parameters from both pure materials used. To produce such nanomaterials it was used as deposition TVA method. The deposition was done in high vacuum conditions only in the presence of the vapors of the material contained in the anode (a crucible). There were used two anodes with MgO powder and, respective, Co pellet. Firstly, the accelerated electron beam was sent on one anode; the evaporated material generated a plasma and deposition on the substrate take place. Afterwards, the electrons accelerated by high dc voltage, sent on the second anode, determined the evaporation, the plasma generation and the deposition of the second material. By repeating these steps were obtained MgO-Co multilayers.

2. Experimental

The MgO and Co powders, to be evaporated, were in two graphite anodes at 3 mm distance between them. The distance between the cathode filament and the two anodes was 1 mm. The distance between MgO anod and Co anod to the substrate was 20.5 mm and, respective, 21 mm (Fig. 1).

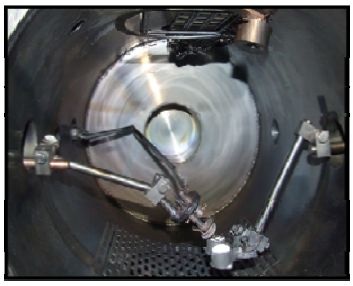


Fig. 1. Deposition system (graphite crucible).

In the case of MgO/Co multilayers deposited on Si substrate, the intensity of the heating current of the cathode filament was between 26÷34 A. The intensity of the TVA current and the voltage for the vapor discharge were I_{desc}= 1÷540 mA and U_{arc}=0.2÷2.5 kV. The pressure

inside the reaction chamber was maintained below 7.5×10^{-5} Torr using turbo and rotary pumps.

In the case of MgO/Co multilayers deposited on brass substrate, the heating current of the cathode filament was between 21,3÷37,2 A. The intensity of the TVA current and the voltage for the vapor discharge were I_{desc}= 1÷103 mA and U_{arc}= 0,2÷9,4 kV. The pressure inside the reaction chambre was $>7\times10^{-5}$ Torr .

The thickness of each MgO thin film was 1nm and of each Co thin film 10 nm and were measured by weight difference method, considering the densities $\rangle_{MgO}$ = 3.563 g/cm^3 and $\rangle_{Co}$ =8,9 g/cm^3, using a Cressington equipment.

The multilayers structure and superficial morphology were studied with TEM (Transmission Electron Microscopy), SEM (Scanning Electron Microscopy), EDAX (Energy X-ray Dispersion) and optical emission spectra.

3. Results and discussion

The EDAX spectrum of TVA deposited MgO/Co multilayers on glass substrate in Fig. 2 showed the presence of Mg, Co,O peaks.

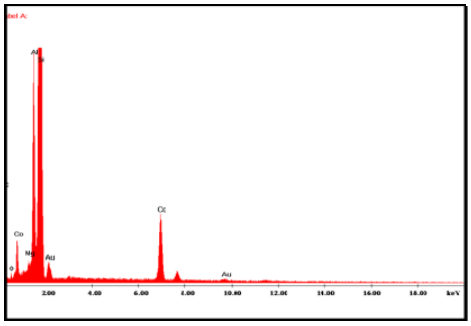


Fig. 2. EDAX spectrum of MgO-Co multilayers deposited on glass substrate.

The presence of Si was given by the substrate nature and Al, Au by the elements of reaction chamber. No presence of anod material was detected because of the TVA method characteristics.

Fig. 3 shows the surface morphology of MgO/Co multilayers deposited on glass substrate. From the SEM micrographs, it is observed that in the as-deposited films, the distribution of nanoparticles is uniform throughtout all region.

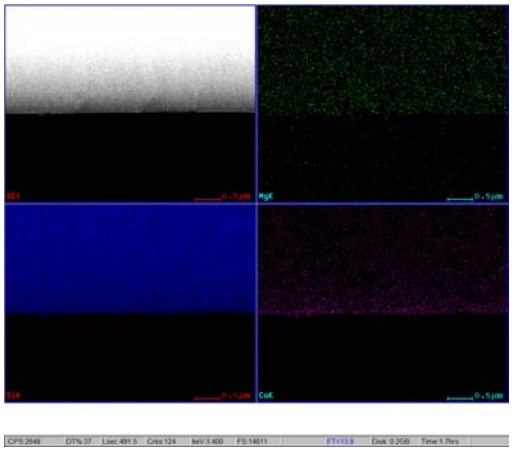


Fig. 3. SEM images of MgO-Co multilayers on glass.

The samples were examined, also, in cross-section (Fig. 4) with diferent magnifications showing the compactness of the nanostructures, as follows:
(a) P_1(160000x,tilt-3^0), (b) P_2(150000x,tilt-3^0),
(c) P_3(150000x,tilt-3^0), (d) P_4(300000x,tilt7^0),
(e) P_5(300000x,tilt 7^0), (f) P_6(240000x,tilt -3^0).

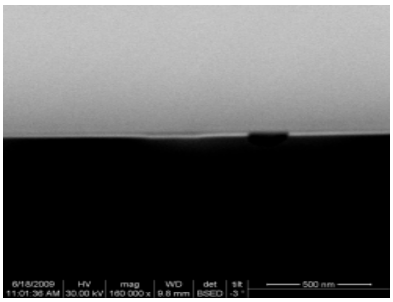


Fig. 4.(a) P_1 sample.

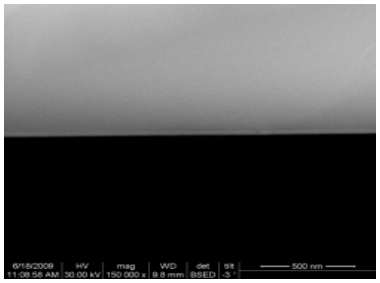


Fig. 4.(b) P_2 sample.

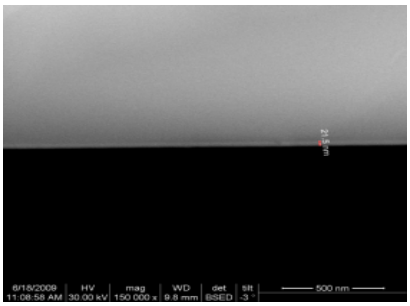


Fig. 4.(c) P_3 sample.

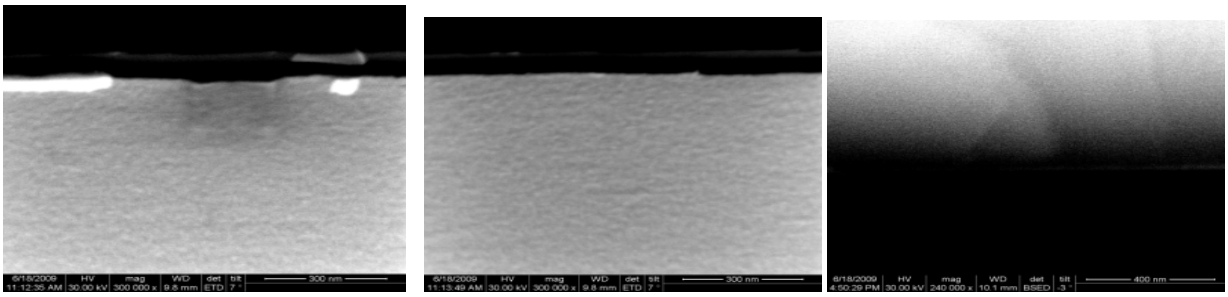


Fig. 4.(d) P_4 sample. *Fig. 4.(e) P_5 sample* *Fig. 4.(f) P_6 sample..*

Fig. 4. Cross-section SEM images of the probes.

Optical emission spectra (OES) of the samples are presented in Fig. 5.

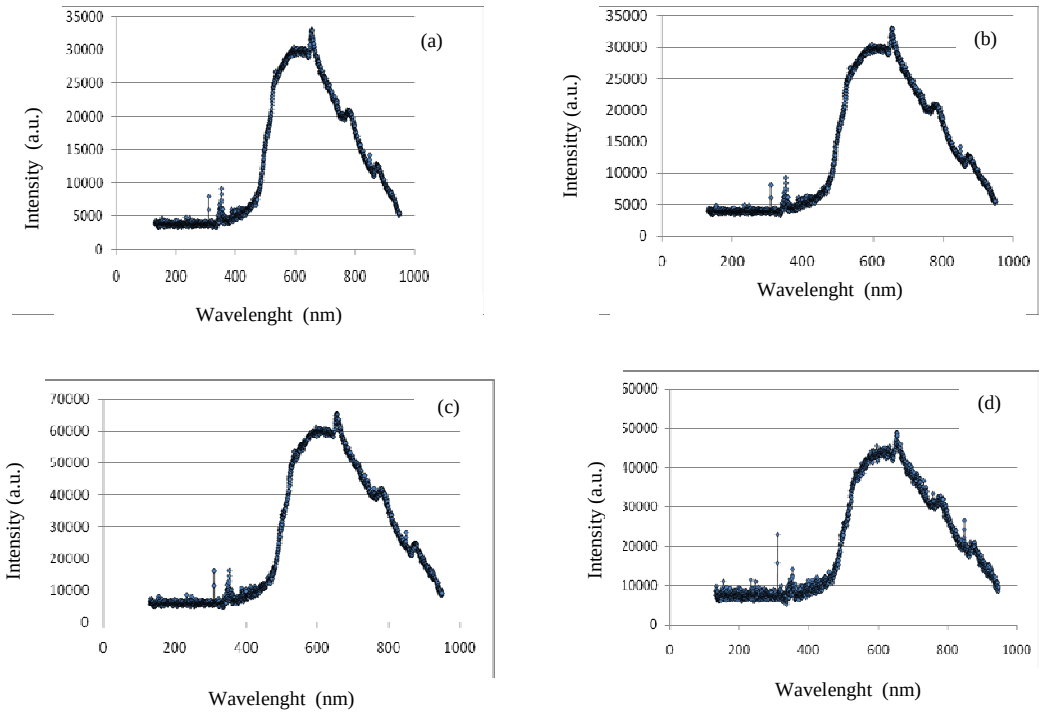


Fig. 5. Optical spectra of the probes: (a) P_1 ,(b) P_2, (c) P_3, (d) P_4.

From examination of the plotted curves it is observed that the major lines are λ_1=654.6479 nm for P_1 and P_2, and λ_2=655.8875 nm for P_3, P_4. Other secondary spectral lines coresponde to λ_3=310,4458 nm, λ_4=353,2438 nm and λ_5=848.9900 nm. Table 1 summarize the more important emission lines of each sample.

Table 1. Principal lines of OES.

Probe	λ (nm)
P_1	654,6479
P_2	654,6479
P_3	655,8875
P_4	655,8875

TEM measurements were made using a higher resolution electron microscope, Philips CM 120 ST, operating at an accelerating voltage of 120 kV and capable of a resolution of 2 Å.

The well definite diffraction rings from selected area electron difraction (SAED) pattern (Fig. 6a and Fig. 6b) indicate the polycrystalline state of the thin film investigated.

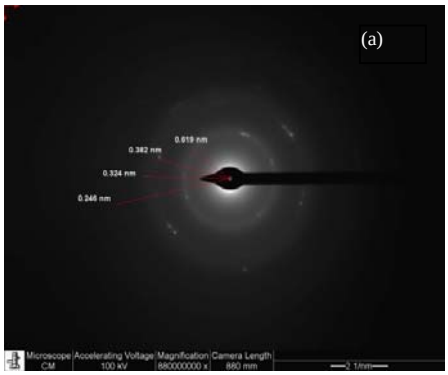


Fig. 6.(a) Diffraction rings.

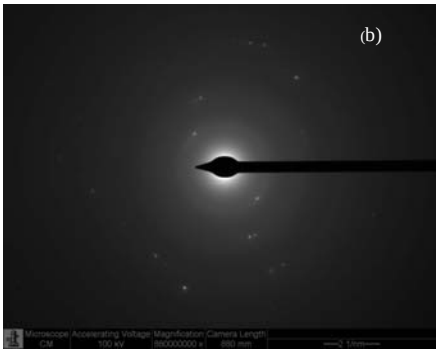
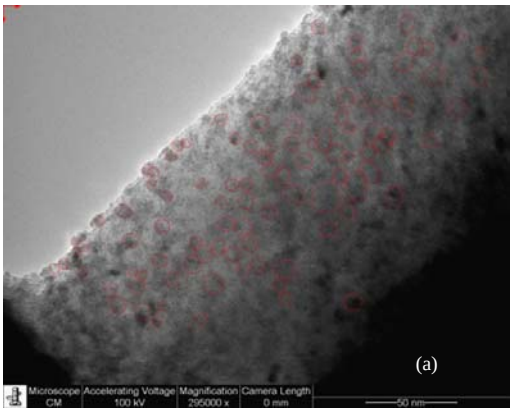


Fig. 6.(b) SAED image.

From the BF-TEM images of the film (Fig. 7a and Fig. 7b), we can say that the samples investigated have a grain structure, which consist in many small grains of relatively uniform size forming a morphologically homogeneous film.



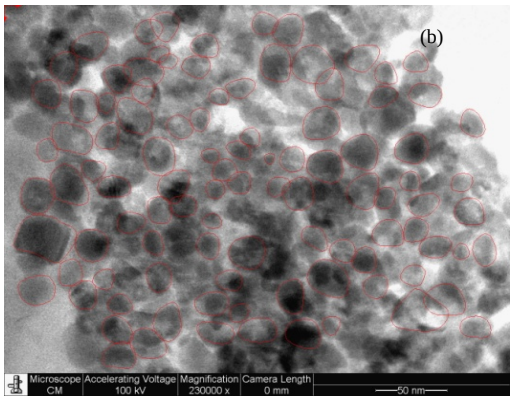


Fig. 7.(a),(b) BF-TEM images.

The diameter of the grains is in a range between 15 nm and 40 nm.

4. Conclusions

This study shows the manufacturing of MgO/Co multilayers using TVA method. The films were deposited on silica and brass substrates. It has been observed that good quality films can be prepared by TVA method.

Scanning electron microscope (SEM), transmission electron microscope (TEM) techniques and energy X-ray dispersion analyses were applied to observe the nanoscale structure.

MgO-Co multilayers deposited on glass were found to be of polycrystalline nature, consisting of nanosized grains.

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