Obtaining and stuying of thermionic vacuum arc deposited Cu and Co nanostructured multilayers on ceramic substrate

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In this paper we present an approach of the obtaining and study of nanostructured materials with special resistive magnetic properties. The Cu and Co thin films are grown by a physical thermionic vacuum arc method (TVA). Successive layers of Cu and Co were deposited on ceramic substrates using tungsten crucibles each containing Cu and Co metals, respectively. The morphological and structural investigations were achieved by means of electron microscopy technique: TEM (Philips, CM120ST). The compositional analysis of the films was performed by an X-ray spectroscopy and correlated to the electrical resistance.

1. Introduction

In this paper we are study the obtaining and studying of thermionic vacuum arc deposited Cu, Co nanostructured multilayers. The thin are grown by TVA method. The TVA method consists of generating plasma vapour of pure metal. We can get plasma vapour in conditions of high vacuum, between heated cathode and an anode. The heated cathode is an electronic gun with a tungsten filament. The anode is made from a crucible of high-melting material. The electron beam is accelerated to a high anodic voltage. It causes the vaporization of material anode. In the vacuum conditions, of a constant evaporation rate of metal between cathode and anode, the vapour density is great enough, for a high voltage, between electrodes, an electrical discharge to be ignited in the evaporated pure material [1 - 5].

Fig. 1. The spins orientation of the magnetic layers in the external magnetic field; (a) low resistance; (b) high resistance.

The sample magnetoresistance with alternate layers, magnetic (Co) and nonmagnetic (Cu), can be interpreted in tow ways for external magnetic field:

(a) the two magnetic layers have the spines oriented parallel (Fig 1. a) resulted that the resistance is low.

(b) the two magnetic layers have the spines oriented antiparallel (Fig 1 b) resulted that the resistance is high.

The magnetoresistive effect ΔR can be described:

$$\Delta R = [R(H) - R(0)] \qquad (1)$$

where $R(H)$ is the resistance in the presence of an external magnetic field; $R(0)$ is the resistance in the null magnetic field. The relative magnetoresistance is [6-8]

$$\eta = \frac{\Delta R}{R(0)} = \frac{[R(H) - R(0)]}{R(0)} \qquad (2)$$

2. Experimental

We deposited successive layers of Cu and Co on glass, silicon and ceramic substrate. In these paper, we study the thin film on ceramics substrate. We have used two tungsten crucibles, each containing Cu and Co metals, respectively (Fig. 2).
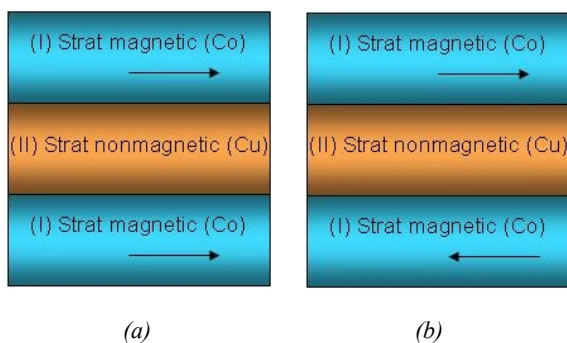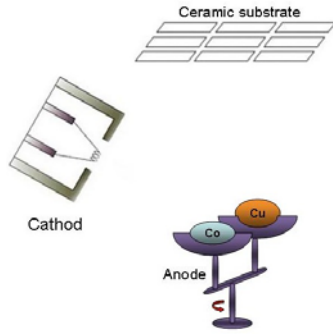
Fig. 2. The scheme of the experimental set-up.

We have used a Cressington quartz balance monitor mtm 10 to control the deposition thickness. The thickness of Cu was about 4 nm and for Co was about 10 nm. To control of the deposition thickness, we must know the density of the two materials Cu and Co: ρ_{Cu}= 8,93 g/cm^3, ρ_{Co}= 8,71 g/cm^3 and the melting temperature and vaporization temperature: copper (melting temperature is 1495^0C; vaporization temperature is 2870^0C); cobalt: melting temperature is $1083,4^0$C; vaporization temperature is 2593^0C.

The conditioners of deposition was ($I_{filament}$=24 A, pressure was $4 \cdot 10^{-5}$ torr) (Table 1):

Table 1

Nr. of layers	Metal	Anodic voltage (10^3A)	I_{anode} (mA)	Thickness of layer (nm)
I	Co	1,2	100	11
	Cu	0,8	80	3,9
II	Co	1,6	132	10,4
	Cu	0,8	80	4
III	Co	1,6	121	10,1
	Cu	0,8	80	5
IV	Co	1,6	120	3

The morphological and structural investigations were achieved by means of electron microscopy technique: TEM (Philips, CM120ST).

The circuit used for the measurements in electric and magnetic field is indicated in figure, where G - DC source (Keithley 224), V_x - voltmeter which measures the voltage on the sample (Hewlett Packard hp), V_e - voltmeter which measures the voltage on the standard resistance (Nanovoltmeter 2128). A - ammeter which measures the electric current on the circuit (Fig. 3).
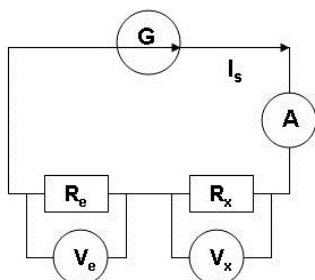

Fig. 3. The scheme of experimental electrical set-up.

The measurements were made at different temperatures and different values for magnetic field, perpendicular to the sample. The sample was mounted in a circulation cryostat (Cryospec CF-759). The standard resistance (R_e) is of manganin and R_{e0}=1 KΩ.

For a some temperature:

$$R_x = R_e \frac{U_x}{U_e} = R_{e0}\left[1 + \alpha\left(t - 20^0 C\right)\right]\frac{U_x}{U_e} \qquad (3)$$

where α is the coefficient of variation of resistance with the temperature.

3. Result and discussion

TEM measurements were made using a higher resolution electron microscope, Philips CM 120, operating at an accelerating voltage of 100 kV and capable of a point - to - point resolution of 2Å.

From the BF-TEM image of the film (Fig. 4), we can say that the probe has a grain structure, which consist in small grains of relatively uniform size forming a morphologically homogeneous film.
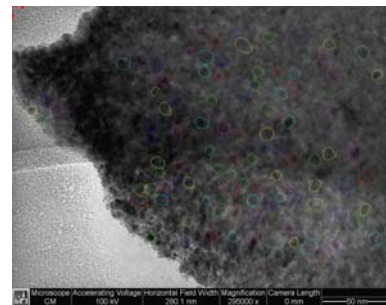

Fig. 4. The BE - TEM image.

Of the histogram of distribution of the grains size we can observe that the most likely size of grains is 8,3 nm (Fig. 5).
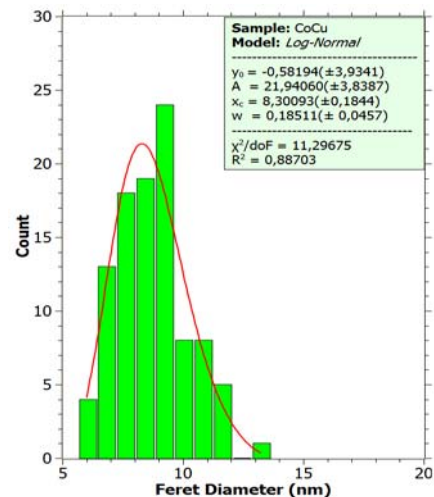

Fig. 5. The distribution of grain size.

From the SAED image (Fig. 6) we can identify the Cu and Co elements, who are in the cubic symmetry class and the Table 2, compared the experimental measurements with the theoretical data [9] and to the indexing result of cubic structures for spatial group with space group F m3m and unit cell: a_{Co}=3.5480 Å, a_{Cu}=3.6150 Å. The unidentified lines are from Table 2, correspond to the oxides of Cu and Co.
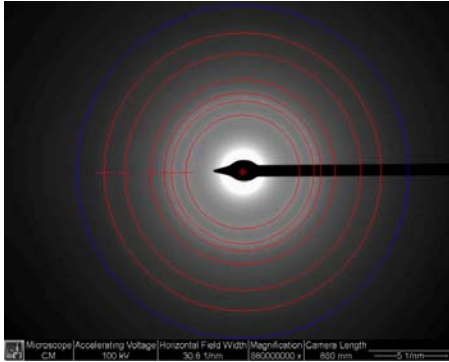

Fig. 6. The SAED image.

Table 2

Nr. peak	Value of d (Å)	Identified elements
1	2.5768	-
2	2.0544	Co(111)/-
3	1.8567	- /Cu(200)
4	1.5829	-
5	1.2322	Cu(220)/Co(220)
6	1.0522	-

Using the scheme of experimental electrical set-up (Fig. 3), from different temperatures (T_1=299K, T_2=309K, T_3=319K, T_4=329K) and B=0T, we plotted the current-voltage characteristics (Fig. 7).
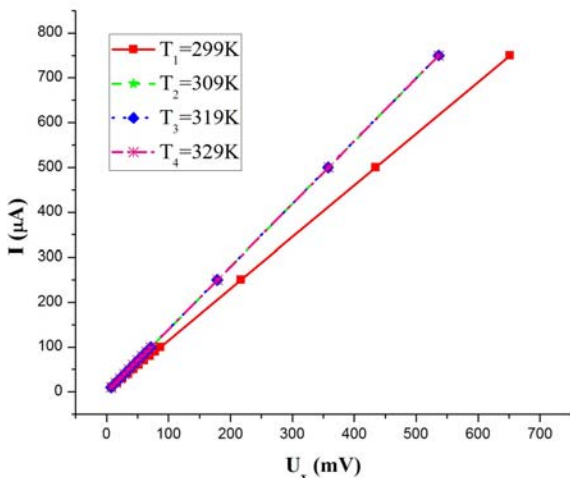

Fig. 7. The current-voltage characteristics.

The values from R_x and G_x are show in the Table 3.

Table 3

B=0T		
T (K)	R_x (Ω)	G_x (S)
299	869.014	0.001151
309	716.067	0.001397
319	714.949	0.001399
329	715.926	0.001397

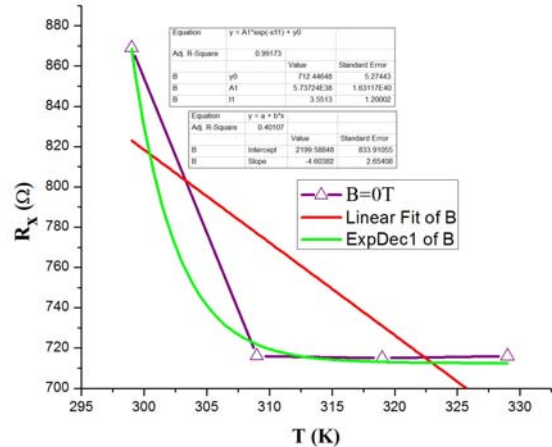In the Fig. 8 is presented R_x=f(T) and in the Fig. 9 is presented G_x=f(T) for B=0T.
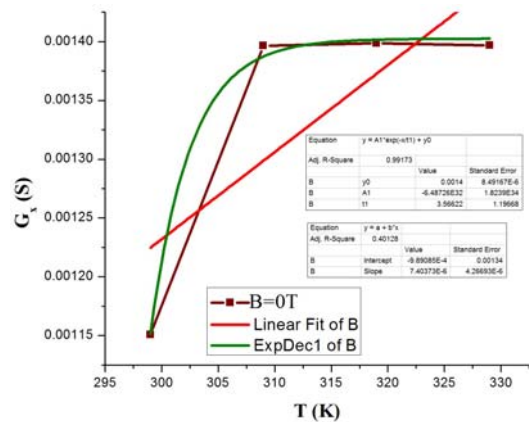

Fig. 8 - R_x=f(T).

Fig. 9 - G_x=f(T).

From the values of T_4=329K, I=10μA and U_e=9,99mV, we measured the U_x value on the sample for different values of the magnetic field and calculated the values for R_x and G_x of sample (Table 4).

Table 4

T_4=329K, I=10μA, U_e=9,99mV			
B (T)	U_x (mV)	R_x (Ω)	G_x (S)
0.55	8.72	872	0.001147
0.54	8.72	872	0.001147
0.53	8.73	873	0.001145
0.52	8.73	873	0.001145
0.51	8.73	873	0.001145
0.50	8.735	873.5	0.001145

In the Fig. 10 is presented R_x=f(B) and in the Fig. 11 is presented G_x=f(B). For the values of T_4=329K, I=10μA and U_e=9,99mV the value of the sample resistance is $R_x(0)$=715Ω. In the Table 5 is presented the values for η at a few values for the induction of magnetic field on the sample.
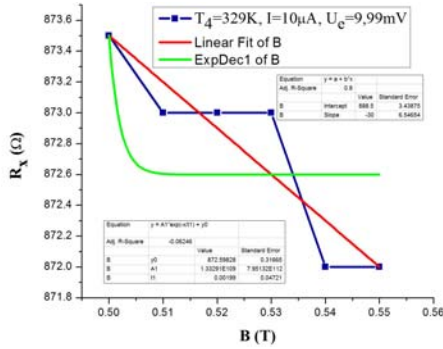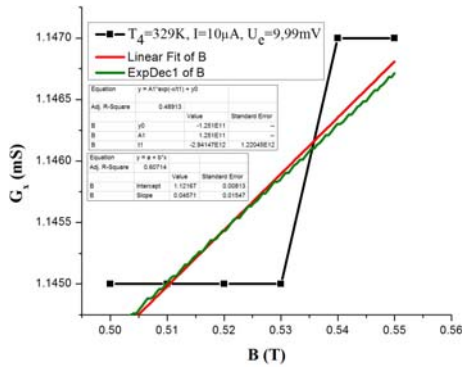

Fig. 10 - R_x=f(B).

Fig. 11 - G_x=f(B).

Table 5

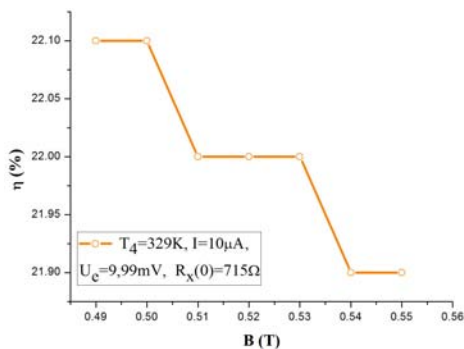| B (T)	$R_x(H)$ (Ω)	η (%)
0.55	872	21.9
0.54	872	21.9
0.53	873	22
0.52	873	22
0.51	873	22
0.50	873.5	22.1
0.49	873.5	22.1

In the Fig. 12 is presented η=f(B).

Fig. 12 - η=f(B).

4. Conclusions

From the BF-TEM image of the multiplayer CoCu we were able to observe a morphologically homogeneous film, with small nanocrystalline grains, having he mean grain size approximately 8.3 nm and this multilayer thin film is nanostructured. From the SAED image have been identified the elements Cu, Co and oxides of Cu and Co respectively.

From the measurements in the electric field (B=0T) was found that the sample resistance decreased with the increase of sample temperature. The value of sample conductibility increased with the increase of temperature.

Form the measured in the magnetic field was found that the sample resistance, for T=cst., decreased with the increase of the induction of magnetic field on the sample. The sample conductibility increased with the increase of the induction of magnetic field on the sample.

For the values of T_4=329K, I=10μA and U_e=9,99mV the value of the sample resistance is $R_x(0)$=715Ω. It was found that the magnetoresistance value decreased with the increase of the induction of magnetic field on the sample. The relative magnetoresistance value is approximately 22%. We can say that the sample has GMR effect.

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