Romanian Reports in Physics, Vol. 62, No. 4, P. 771–779, 2010

MATERIALS SCIENCE

OPTIMIZATION OF THERMIONIC VACUUM ARC PLASMA USED FOR MULTILAYER GMR/TMR FILMS PREPARATION*

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(Received June 30, 2009)

Abstract. Optical and electrical behavior of Giant Magnetoresistive (GMR)/Tunneling Magnetoresistive (TMR) multilayer thin films were controlled adjusting thermionic vacuum arc plasma parameters. Smooth, dense and adherent films were prepared using optimized plasma conditions.

A new setup for simultaneous depositions of pure materials was made, having inside the vacuum chamber three simultaneous discharges. To obtain the discharge all of the tungsten filaments of the thermionic vacuum arc guns were heated by a 45-55 A current. The emitted electrons were focused on a tungsten coated carbon crucible anode, filled with Cu, and the others crucible anodes filed with MgO, Co and Ag, respectively. The anode applied voltages for Cu, MgO Co and Ag were up to 1500 V, 1700V 1800V and 820V respectively. An optimization of the geometrical parameters as the distance between the cathode and the anode, and of the external parameters as the discharge voltage and the heating current of tungsten current filament was performed.

Structural and morphological properties of the prepared films were analyzed by scanning electron microscopy (SEM). The behavior of the obtained films was first analyzed in a Magneto-Optical Kerr Effect (MOKE) experiment. The electrical resistance behavior of the prepared films was determined in a magnetic field which values varied from 0.4 T to –0.4 T. The important changes in the values of the electrical resistance of the films were observed and correlated to the plasma conditions.

1. INTRODUCTION

The combinative multilayer thin film deposition brings a new interest in obtaining special electromagnetic structures with a wide range of applicability like IT, automation and science. The GMR effect is very sensitive to preparation parameters and theoretical estimations suggest that it is intimately related to the density and size distribution of the magnetic clusters. Indeed, when the cluster density is low, their magnetic behavior is super paramagnetic like, and the GMR effect increases when the cluster number increases up to the so named percolation

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* Paper presented at the Annual Scientific Session of Faculty of Physics, University of Bucharest, June 5, 2009, Bucharest-Măgurele, Romania.

threshold when the reciprocal interaction of magnetic domains leads to GMR decrease. There is an optimum concentration of the magnetic material inside the nonmagnetic structure (GMR effect) or of the isolating structure (TMR effect). If this concentration is small, there are few domains to contribute at the resistance variation. If the concentration is greater, the domain distance is small. The optimum concentration is on the range of 30%-40% for the magnetic material. For obtaining such kind of materials, an optimization of the TVA plasma parameters has been made.

Thermionic Vacuum Arc (TVA) is a new type of discharge which ignites in vacuum conditions in the vapors of the anode material, continuously generated by the electron bombardment of the anode [1-5]. The electrons, emitted from a heated tungsten cathode, are accelerated towards the anode, by a d.c. high voltage applied across the electrodes. At switch on, the anode material first melts and afterwards starts to boil, a steady state metal vapor atoms density being established in the interelectrodic space. At further increase of the applied high voltage, a bright and stable metal vapor discharge is established [2]. Because the deposition of the thin films using TVA technology is obtained in high vacuum conditions and also under the energetic ions bombardment of the depositing thin films, we may expect a high quality of such obtained films, namely, high purity, increased adhesion, compact and nanostructured films.

2. EXPERIMENTAL SET-UP AND METHOD

The experimental arrangement is shown in Fig.1 and consists of: a) three cathodes - tungsten wires with ϕ=0.8 mm, mounted inside of three separate Wehnelt cylinders; b) anodes – two graphite disks on which are mounted four graphite crucibles, each with a different material, and a separate centered fixed one. The crucibles are mounted on the graphite disk using some tungsten "legs", obtaining in this way a good transmission and less heat loss. The movement of the graphite disk can be done using an external rotator arm which moves it in small steps. Each of the graphite disks has its own rotator device. Also, the position of the heated gun can be controlled using an exterior rotator device.

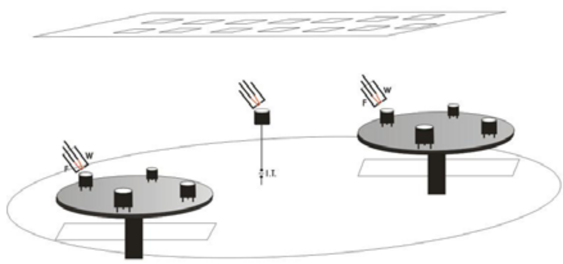

Fig. 1 – Schematic draw of the TVA multilayer ensemble.

It can be seen from Fig. 1 that the possibility of getting a great number of different combinations is high. For multilayer magnetorezistive structures is essential for the separation limit between two layers to be clear. For this a molybdenum plate has been used to cover the materials which were not supposed to be evaporated at that time. Over the top of the three deposition devices an iron plate with four rows and 12 rectangular 15mm/15mm holes was set. For the substrates, glass and silicon probes were used. Other geometrical parameter is the distance d between the electrodes. The external parameters of the discharge were the current value that heats the cathodes and the drop voltage for each anode. The whole electrodes assembly is mounted inside of a large vacuum vessel, provided with a glass window.

The studied discharge was in silver, cobalt, cooper and magnesium oxide vapors. In order to achieve a correlation of the discharge parameters, was used an electronic signal conditioning and data acquisition for current and anodic voltage. The software to program the devices was LabView.

The ignited heated cathodes arcs were running stable and smooth. The working parameters were: cathode filament heating current for each gun was 45–55 A, anode bombarding electron beam current: 140 mA for tantalum, 95mA for cobalt, 200mA for cooper 40 mA for MgO and 70 mA for silver, the applied high voltage were 1,700V for tantalum, 2,500 V for cobalt, 1,200V for cooper 1,800 V for MgO and 700V for silver. The pressure in the deposition chamber was 1×10^{-5} torr.

3. RESULTS AND DISCUSSION

In the multilayer magnetoresistive thin film structures, obtained by TVA method, it is no need for having a high energy plasma, because, for this kind of discharges the deposition rate is too large. For these structures the thickness of the layers must be of a few nanometers. A TVA discharge is equivalent with a deposition rate of 5–20 nm/s. For having the total control of the deposition rate, the energy supplied for the thermo emitted electrons from the heated cathode had to be diminished to values for which the deposition rate to be of few angstroms/s, implied by the variation of the anode voltage drop and the heating cathode current. The actual deposition was established by adjusting the external parameters of the TVA discharge. The optimization consisted in getting the deposition to start at the point of ignition, but no further more, obtaining in this way the total control for the deposition rate.

In Figs. 2 and 3 it can be observed the current-voltage characteristics for cooper discharge.

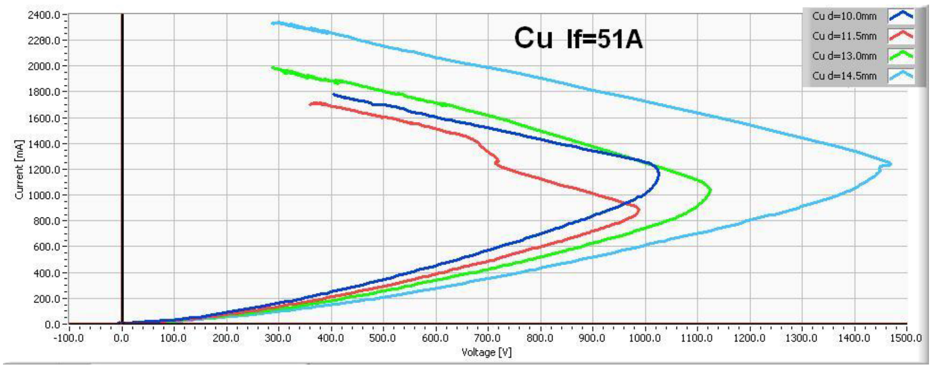

Fig. 2 – I-V characteristics for same heating filament current, different inter electrodes distance.

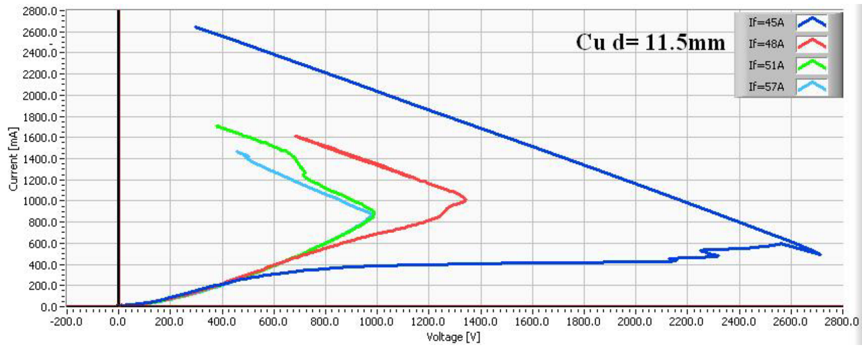

Fig. 3 – I-V characteristics for same inter electrodes distance, different heating filament current.

For the same heating filament current (Fig. 2) the plasma ignition for smaller inter electrodes distances needs a smaller energy contribution. On the other hand, a big inter electrodes distance is equivalent with a larger energy amount put into the system. This can be explained; for a greater inter electrodes distance the vapor pressure between the anode and the cathode is smaller than in the case of a smaller distance. So, the necessary dropping voltage to ignite the rarefied metallic gas is greater. Likewise for the case of the same inter electrodes distance (Fig. 3). A greater heating filament current ignites the plasma faster that in the case of a lower heating filament current.

The multilayer structure is shown in Fig. 4. Using glass and silicon substrates, a first layer of tantalum was coated. The second layer was of a combination implying cobalt, silver and magnesium oxide, the last two materials being deposited in the same time from two different sources. A final layer of tantalum completed the film structure. For the GMR/TMR measurements, an initial cooper layer has been coated on the glass, the purpose of that being for making the electric contacts.

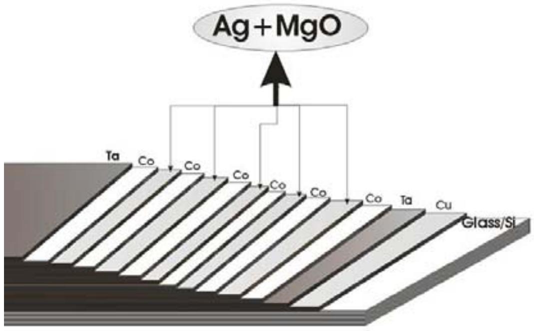

Fig. 4 –Multilayer structure view.

The SEM analysis (Fig. 5) shows that the multilayer thin film obtained by the TVA method is compact and has no major imperfection.

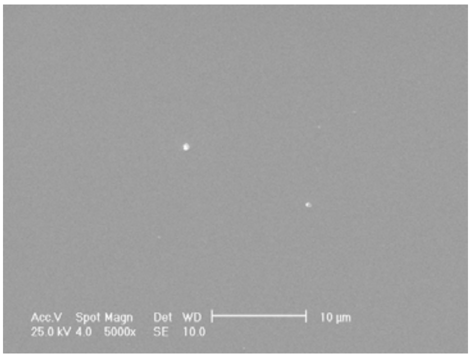

Fig. 5 – SEM analysis of the multilayer thin film.

Because of the substrates position, a large variation of concentrations was obtained. Each concentration can be studied, in the idea of getting different effects for different concentrations. (Figs. 6–8).

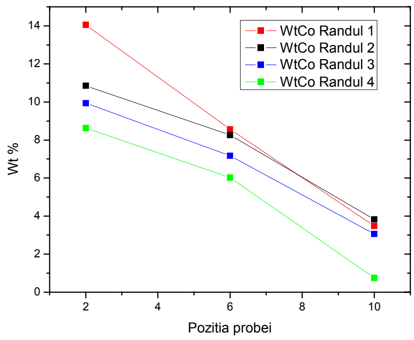

Fig. 6 – Cobalt concentration in respect with the substrate position.

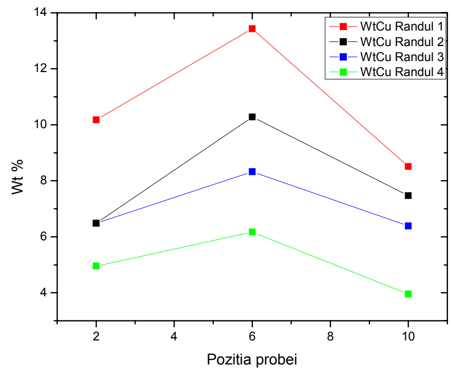

Fig.7 – Cooper concentration in respect with the substrate position.

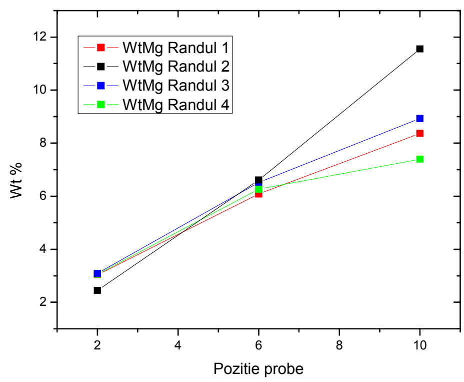

Fig. 8 – MgO concentration in respect with the substrate position.

As it expected the concentration of the materials vary with the distance between the ignition point and the position of the substrates. As Figs. 6-8 show, the concentration of each material is greater for the smallest distance. Indeed, cobalt had the left hand side position, cooper the center position and magnesium oxide the right hand side position.

For the GMR/TMR measurements a four point measuring system was made, in this way the error that could appear at the contacts between the probe and the film was eliminated. Two of the contacts were for imputing through the thin film structure a constant DC current, the other two contacts were for reading the drop voltage on the film. A schematic electric structure is shown in Fig. 9.

Before the actual measurement, a MOKE experiment was made on the probes (Fig. 10) to observe the field interval for which an electromagnetic effect would take place. The MOKE measurements showed that the filed interval was of –0.4 T up to 0.4T for the TMR obtained structure.

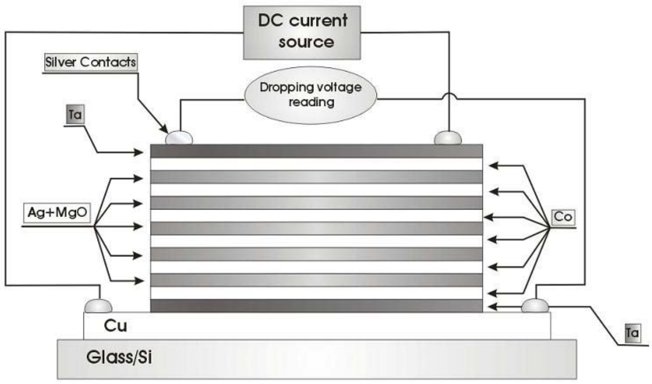

Fig. 9 – Electric four points measurement for the multilayer structure.

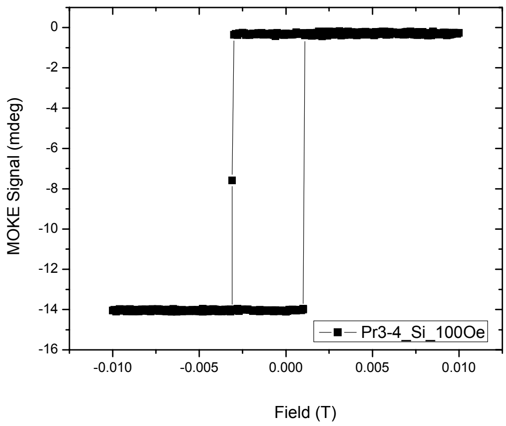

Fig. 10 – MOKE measurement for the multilayer structure.

It can be observed a variation of the resistance of the film when a magnetic field was applied on the probe. The electric current that passes through the structure has the electronic spins with a parallel or anti parallel orientation in respects with the electronic spins of the magnetic domains that are colliding with. Normally, the orientation of the electronic spins in the magnetic domains is a chaotic one, in the absence of a magnetic field. By applying a magnetic field, the electronic spins are orientated on the direction of this field. (As much as the thermal excitement permits it). The electron spins of the inductive current, meet in their way the spins of the magnetic material with the same direction, because of the magnetic field action, which assures a less resistance in going forward.

Depending on the densities' energy levels, by applying a magnetic field, it can be obtained a positive or a negative TMR effect. There are two possible cases: the structure has a big density of energy levels, and by applying the magnetic field, this density decreases, the result being a greater value of the resistance (TMR positive effect). The other case is for a lower density of energy levels, and by applying a magnetic field, this density increases, decreasing the value of the resistance (positive TMR effect). In Fig 11 it can be observed the influence of the magnetic field on the resistance when passing from a positive value of the field, to a negative one. When applying a magnetic field, the resistance of the probe is increasing, equivalent with a TMR negative effect. By diminishing the magnetic field the resistance is decreasing.

For the same probe, same contacts, the variation of the magnetic field were made from a negative value to a positive one. It was observed a variation of about 28% in the resistance of the structures, in both ways of the magnetic field. The measuring temperature was of 275K.

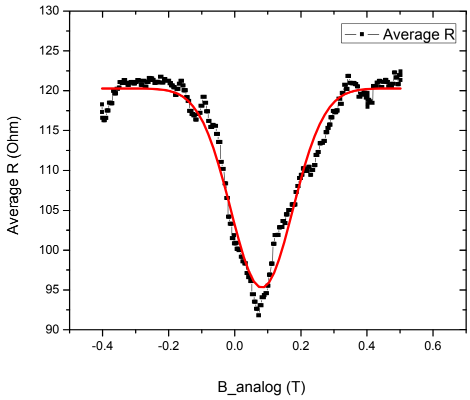

Fig.11 – The resistance variation in respect with the magnetic field applied.

4. CONCLUSIONS

Using the TVA method in obtaining multilayer structure proved its' efficiency. The optimization made to the various parameters like heating filament current, anode dropping voltage, inter electrodes distance made possible the control of the deposition rate in such way of obtaining the desired film thickness, a very important parameter for the GMR/TMR structures. Different concentrations obtained in respect with the distance between the ignition point and the substrates position, in a single deposition experiment, makes the place for further studies about magnetoresistive effects.

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