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# Characterization by nanoindentation and Scanning Electron Microscopy of the spin valves structures prepared by Thermionic Vacuum Arc (TVA) method

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The spin valves structures prepared were made by an anti-ferromagnetic layer composed by 50mass%Fe and 50mass%Mn and another layer composed by Fe and Ni in different mass proportions by Thermionic Vacuum Arc method. Mechanical tests were carried on deposited carbon film using a Fischerscope H100 DSI.depth sensing indentation tester, and scanning electron microscope (SEM) JEOL type with 1 nm resolution used after the nanoindentation print of different loads.

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## 1. Introduction

Giant magneto resistive (GMR) phenomenon appears in the magnetic and non-magnetic metallic composite thin films. The electrical conductibility of these structures changes under the influence of an external magnetic field. The change is due to the variation of the colissional cross section between two electrons as function of their spin orientation (parallel or anti-parallel) that generates corresponding magnetic moments. The phenomena encountered here are of the quantum nature; simply we can say that two electrons having parallel spin orientation are repelling each-other and if they have anti-parallel orientation they are attracting each-other, having the tendency to stay relatively long time together. As consequence, the mobility of the conduction electrons will be lower in the case when they are passing through the zones with localized electrons of the magnetic domains (characteristics of the ferromagnetic metals) having anti-parallel spin orientation than in the case the parallel spin orientation.

We have to mention that the spin of the localized electrons belonging to the magnetic domains can be reoriented in an external magnetic field. Is desirable that in the absence of the external magnetic field the orientation of the magnetic domains in two adjacent magnetic layers to the conducting non-magnetic layer to be as possible high anti-parallel. In this case the conduction electrons, doesn't matter of their spin orientation (then their magnetic moments) have low mobility in one of the layer and high in the next, creating in this way an "average" electrical resistance.

When an external magnetic field orients parallel all the magnetic domains from all magnetic layers, the conducting electrons with the spin orientation on this direction will encounter low resistance in their way and will produce a "short-circuit" on the total current, appearing in this mode a low resistance on all deposited layers.

In the case of the spin valves, on try to create a ferromagnetic layer highly coupled with an anti-ferromagnetic layer that can not be influenced by external magnetic fields of medium intensity (of the order of hundred of Gauss). Over this ferromagnetic layer can be deposited a non-magnetic conductor layer (as for example copper made) and this one can be coated by another ferromagnetic layer with the magnetic domains easily to be oriented by an external magnetic field of low intensity (as the order of few Gauss). Such kind of magnetic materials are nickel-iron alloys (permalloys) [1-4]

The electrical resistance variation in the above described structures can be explained as follow: when the magnetic domains of the upper permalloy layer are anti-parallel oriented relatively to the magnetic domains of the lower pinned magnetic layer, the whole electrical resistance is high and when the orientation is parallel, the electrical resistance is low. The low intensity magnetic field created by the electrical current circulating thru these structures influences these domains and the electrical resistance of the layers. The digital correlations between the two values of the electrical resistance correspond to the "0" or "1" bit of information. The whole structure is acting as a "valve" that is closing or opening at will.

In order to prepare and characterize spin valves structures we used the original technology of the thermionic vacuum arc, nanoindentation and scanning electron microscopy (SEM), respectively.

## 2. Experimental arrangement

Thin films were prepared in high vacuum conditions (less than $10^{-3}$Pa) in a reaction chamber with about 1 $m^3$ volume.

The spin valves structures prepared were made by an anti-ferromagnetic layer composed by 50mass%Fe and 50mass%Mn and another layer composed by Fe and Ni in different mass proportions in order to obtain the alloy with the minimum coercive force that can have easy to be oriented magnetic domains in external magnetic fields with as low as possible intensity.

The depositing material used in the thermionic vacuum arc technology is the anode of the discharge that is evaporating by an intense electron bombardment.[5-7] The electrons, highly accelerated to the anode, are emitted by the external heated cathode with a high current and low voltage power supply. In this way the anode is heated to a high temperature as the vapor pressure to be enough high (10-100 Pa) in order to be possible to ignite the electrical arc discharge in the evaporated atoms.

In order to prepare the spin valve structures were used two methods:

(i) depositions using an preformed anode alloy;
(ii) simultaneous depositions using two thermionic vacuum arcs running in the vapors of the two elemental components of the layer.

In the first case the evaporation temperature being the same, the evaporation rate of the elements composing the performed anode alloy was different due to the different vapor pressure of the two elements at the same temperature. When the 50mas%Fe/50mas%Mn performed anode alloy was used, the evaporation rate of Mn was 10-20 times larger than that of Fe, due to the higher vapor pressure of the Mn compared with those of the Fe at 1600 K.

In order to obtain the desired relative concentration of the Fe and Mn elements in the prepared layers were evaporated the two elements using two independent vacuum thermionic arcs. The anode temperature of the each element was adjusted in order to have comparable evaporation rates.

The substrates were settled above the evaporation sources, with different relative distances from each –other as can be seen in Fig. 1.

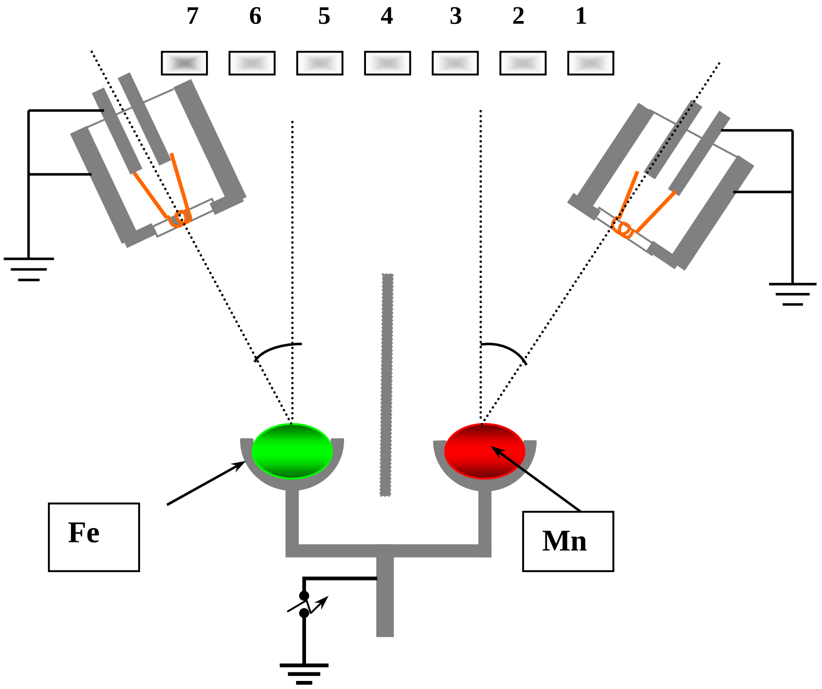

*Fig. 1. The set-up of the substrates for Fe/Mn spin valve structure deposition.*

In this case, due to the deposition rate that decreases with the square of the anode-substrate distance, we can expect that the samples situated close to the Fe anode to contain higher Fe concentration relative to the Mn concentration. The same experimental arrangement was used for the Fe-Ni layer preparation.

## 3. Results and discussion

There were performed three different samples P2, (“FeMn/Cu/Si”), P6 (“FeMn/Cu/Si”) and X3 (“FeMn”) with the mentioned methods. Fig. 2 shows the loads (in mN) used for indentations in each column and this scheme holds for all three samples P2, P6 and X3.

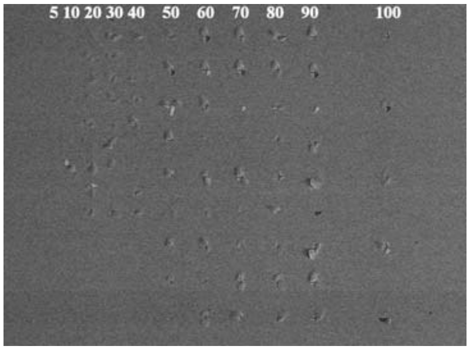

*Fig. 2 The scheme of the loads for all the samples.*

The investigations of the SEM images after the nanointendation print reveals the following conclusions.

### 3.1 Case of P2

The whole surface is covered by cracks. The preferential direction of cracks (about 45 degree with respect to sample edges) suggests the idea that there is relation between cracks direction and substrate crystallography. Indentations produce cracks at loads 10mN and higher (see P2_09 and P2_10). The cracks caused by indentations connect with cracks present already before indentation. Parts of the layer often peel off at indentation print region

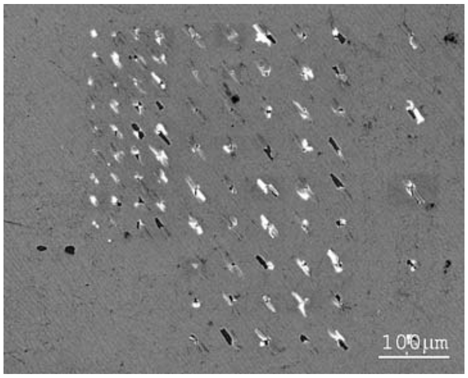

*Fig. 3. Sample no P2.*

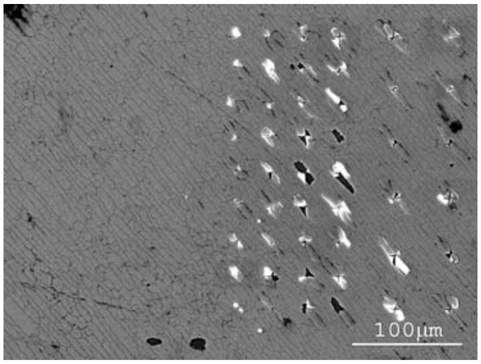

*Fig. 4. Sample no P2_10.*

### 3.2 Case of P6

Surface is clean of cracks Indentations produce cracks at loads 20mN and higher. The cracks around indentation prints decline from their usual direction: the either turn to "diagonal" direction (Fig. 5 and Fig. 6) or they are curved around the indentation print.

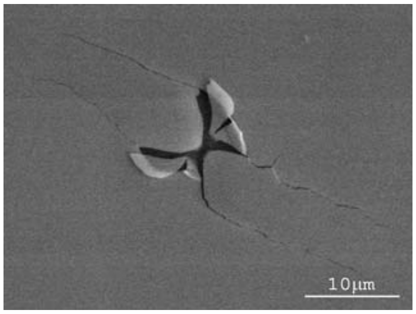

*Fig 5. Sample no P6_A11.*

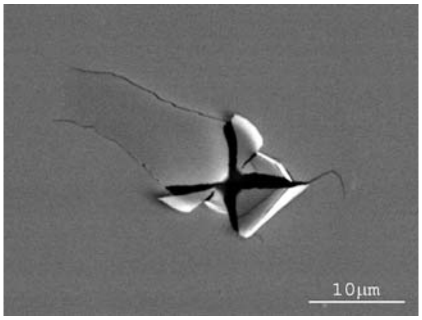

*Fig. 6. Sample no P6_B25.*

### 3.3 Case of X3

Most of the sample surface is clean of cracks (with some exceptions - Fig 7-in that case the cracks are curly (wavy), this feature was not observed in previous samples). Indentations produce cracks at loads 10mN and higher. The cracks around indentation prints often decline from their usual direction to the "diagonal" direction and after some length another turn of the crack is often observed. The shape of cracks is in many cases quite well reproducible (see Fig. 8).

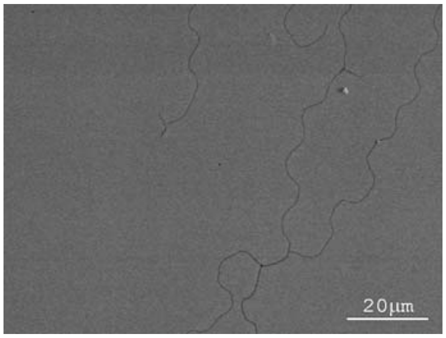

*Fig. 7. Sample no X3_03.*

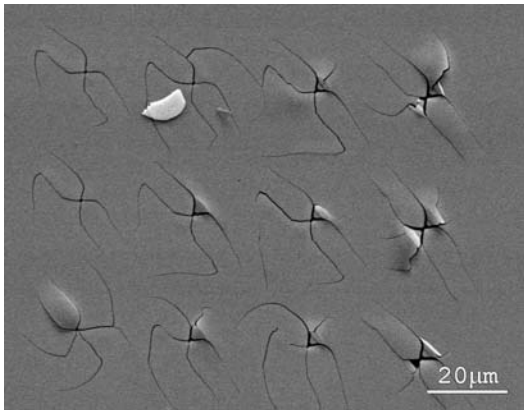

*Fig. 8. Sample no X3_C1143.*

## 4. Conclusions

The prepared FeMn structures were analyzed by nanoindentation using a Fisherscope naonindenter, a scanning electron microscope (SEM) JEOL JSM 6460 type, 20 kV with 1 nm resolution used after the nanoindentation print of different loads. The results give information regarding the delamination of the samples and also about the resistance against the intendation. We can conclude that the prepared samples in the case of X samples are very smooth, with a very good adherence, and higher hardness.

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