# Design and Fabrication of Giant Mangnetoresistance (GMR) Spin-Valve Structures

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***Abstract*—GMR Spin-Valve test structures have been fabricated in collaboration with Veeco/CVC. Various multi-layer spin-valve structures such as synthetic metal spin-valve, bottom nano oxide layer (BNOL) spin-valve, top nano oxide layer (TNOL) spin-value and surfactant spin-value structures were deposited utilizing Veeco's UHV Nexus PVD-10 Target Planetary system. The test structures were designed by using Mentor Graphics CAD tool. Photo masks were fabricated by using Perkin Elmer MEBES III electron beam writer. A photolithographic process consisting of etch and lift-off steps has been developed to define the dimensions of the spin valve test structure. The electrical and magnetic properties of sheet film stacks and patterned devices were tested and compared**

***Index Terms*— GMR, Spin-valves**

## I. Introduction

THE confluence of the semiconductor industry and the magnetic recording industry has recently been trigged by applying the Giant Magnetoresistive (GMR) stack into semiconductor for the application of spintronic device. The GMR multilayer has been widely used in the magnetic recording industry for the read head sensor. GMR sensors are the stacks of magnetic and non-magnetic thin film multilayer with a total thickness of approximately less than 50nm. The change in the total resistivity of the stack in the presence of magnetic field is called GMR effect. The main parameter is used to quantify GMR spin-valve is the MR ratio. A higher sensitivity of the GMR can be obtained from a higher MR ratio when the GMR is under an external field.

As the areal storage densities of hard disk drives increased dramatically to full fill the requirement of data storage, the dimensions of the hard disk, track width, bit size and various components associated with the medium have been scaled down as well as new technologies have been inserted. For example, inductive heads have been replaced by heads based on the anisotropic magnetoresistive (AMR) effect as well as most recently GMR based heads are replacing MR based read heads used to read bit of information from the medium. GMR based head are capable of sensing very smaller fields come off the medium, which allows the track width to be reduced and eventually result in higher areal storage density.

In 1990's, researchers of IBM introduced a new technology so called "Spin Valve Magnetoresistive" sensors to use in the hard disk and tape drives to read magnetically written signal from the medium very efficiently. The term "magnetorestance" was defined by large change in electrical resistivity of thin film multi-layer stack, composed of magnetic (ferromagnetic) and non-magnetic (conductive) layers due to an applied external field and it an appreciable change in resistivity.

Magnetoresistance effect was first identified in molecular beam epitaxy (MBE) grown Fe/Cr/Fe multi-layer by Binasch et al. in 1988, but the Giant Magnetoresistance effect was first reported by Baibich in Fe/Cr/Fe sandwich structure grown by MBE. However, the GMR effect was made possible for device applications by Perkin, when it was illustrated that higher GMR effects can be obtained from sputtered multi-layers. Currently, majority of the research is devoted to develop muti-layer structure to yield higher GMR effect via sputtering.

A typical GMR structure consists of an anti-ferromagnetic/ ferromagnetic (Pinned-layer)/non-magnetic (Spacer- layer)/ferromagnetic (Free-layer) layer structure. The purpose of anti-ferromagnetic is to pin the magnetization of the ferromagnetic layer in one orientation regardless of any external field. The interaction between these two layers is named "exchange bias". The thickness of the non-magnetic layer needs to be controlled in certain range to obtain an interlayer exchange-coupling field between adjacent ferromagnetic layers. Both of these exchange bias field and coupling field will affect the performances of a GMR sensor

## I. THEORY

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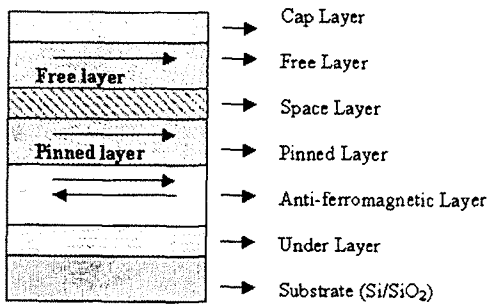
Two out of three fundamental properties of electrons have been utilized to operate most of the electronic component. However, in addition to charge and mass, electrons have a third property called spin, which has been overlooked in past decades. The electron spin is identified with two energy states according to "Pauli exclusion principle", so called spin up and spin down. Each electron that spin on it's axis generates a magnetic moment. The magnetic moment has another source from the orbital motion of the electron around the nuclei. In few materials such as iron, cobalt and nickel, the majority of magnetic moment is aligned in one direction making the material magnetic. Therefore, when an external field is applied, the net magnetic moment of a particular material would align with the external field. The GMR effect happens when the spin dependent scattering between the condition electrons and the magnetic materials results in the resistivity change under an external magnetic field.




Fig, 1. Basic Spin-valve structure

Generic GMR spin-valve (SV) structure is shown in figure1 consists of the four most important layers such as anti-ferromagnetic layer, pinned layer, spacer layer and free layer. This structure is known as bottom spin valve since the anti-ferromagnetic layer (AFM) is on the bottom of the stack. The magnetic orientation of the pin layer is pinned in one direction by adjacent AFM layer, known as exchange bias coupling, discovered by W.H. Meikeljohn and C.P. Bean in 1956 on CoO-Co multilayer structure. Spacer layer is a highly conductive layer used to separate both ferromagnetic layers; the thickness of this layer ought to be less than the mean free path of conduction electrons in order to mediate electrons in between two ferromagnetic layers. Free layer is the ferromagnetic layer, which is free to rotate in any direction due to an applied external field.

The GMR effect is presented between pinned layer/spacer/free layers. The magnetization of the free layer will be oriented into the external field direction, which will result both free and pinned layer to be in parallel. Under this circumstance, the mean free path of spin up conduction electrons is increased because of the less spin dependent scattering. However, the spin down conduction electrons occur spin dependent scattering when they enter a different magnetization direction of free layer or pinned layer. It results in a short mean free path of the spin down conduction electrons. In other words, the parallel state of both pinned and free layers will result in a lower resistances state. On the other, a higher resistance state will present when the pinned layer and the free layer are anti-parallel to each other due to the spin up and spin down conduction electrons are scattered.

Three main responses are characterized while optimizing spin-valve multi-layered structures.

1) MR Ratio (DR/R)
2) Pinning field (Hex)
3) Interlayer Coupling (Hint)

MR Ratio is one of the important response that is characterized and it's defined by,

$$MR\% = \frac{R_{AP} - R_P}{R_P}$$

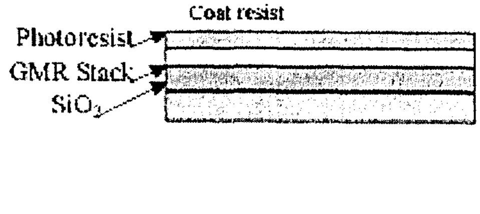
$R_{AP}$ and $R_p$ stands for resistance in anti-parallel orientation and parallel orientation respectively. The goal is to obtain a higher MR ratio to obtain a higher sensitive device. The pinning field is defined as the field between the anti-ferromagnetic and ferromagnetic layer. The goal is to obtain a higher pinning field, so the pinned layer is fixed by AFM layer. Finally, the interlayer-coupling field is the field between two ferromagnetic layers via spacer layer and can be optimized by controlling the spacer thickness.

## II. FABRICATION

All thin film layers were deposited by utilizing Veeco's UHV Nexus PVD-10 Target Planetary dc magnetron sputtering system on 4 inches $Si/SiO_2$ wafers. The chamber base pressure is -9e-10 Torr. Si/SiO2 substrates were pre-cleaned before depositing stack to remove absorbed contamination by using Ion Beam Oxidation tool. The synthetic metal spin-valve structure was Si/SiO2/Underlayer/PtMn/CoFe/Ru/

CoFe/Cu/CoFe/NiFe/Ta. Patterned devices were fabricated in Current-In-Plane (CIP) configuration and two lithography steps were used. Fabrication process flow is illustrated in Fig.2. Subsequently, fabricated samples were annealed in magnetic field for five hours at 280 $^0$C. The purpose of annealing is to perform a phase transformation from FCC to FCT for anti-ferromagnetic layer (PtMn)

1) Grow Oxide, dep GMR stack & Coat resist



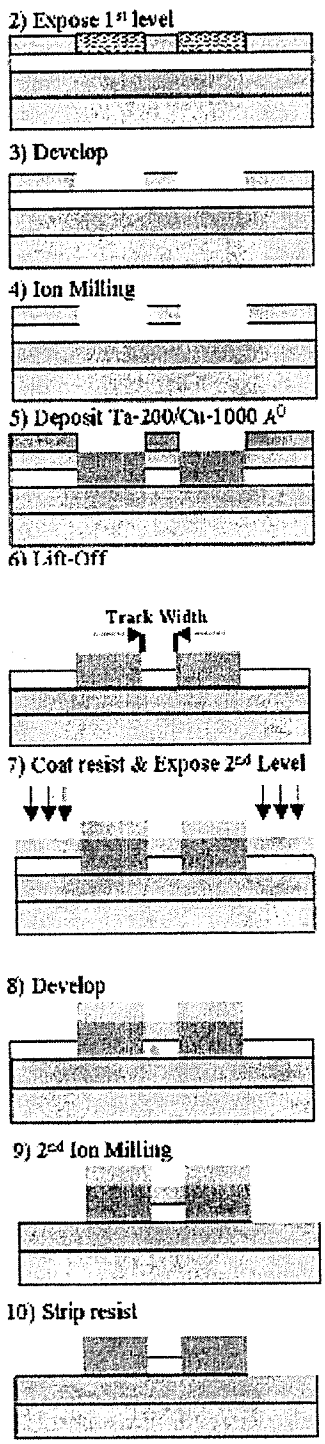



Fig.2. Process steps employed in the device fabrication.

## III. RESULTS AND DISCUSSION

Top-view of fabricated test structure is depicted Figure 3.

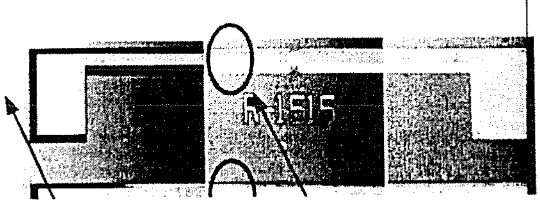


Fig. 3. Optical micrographs of the patterned spin valve devices

GMR Spin-Valve structures have been fabricated with various heights and widths to illustrate the size dependence on output responses. Table 1 summarizes the compared results between sheet film and patterned device.

TABLE I SHEET RESISTANCES

Comparison: Sheet Film Vs Patterned Device

| Respones | Sheet Film | Patterned Device |
|---|---|---|
| Sheet Resistance (Rs) | 16.3 Ω/□ | 5.5 Ω/□ |
| MR Ratio (ΔR/R%) | 14.10% | < 6% |
| Interlayer Coupling (Hint) | 21 Oe | 203 Oe |
| Pinning Field (Hex [H50]) | > 1800 Oe | > 1800 Oe |

As shown in the Table 1, the difference in the sheet resistance of patterned device and sheet film is due to contamination occurred during process. MR ratio vs. external field with different dimensions is shown in Figure.4. The measurement is performed on the Quasi-Static Wafer (QSW) test with ± 1000 Oe.The red curve is the MR% of the sheet with the follows the y-axis on the right hand side. The rest of the curves are MR% of the patterned devices, which follow the y-axis on the left hand side.

The decrease of the MR% after patterned into devices is possible due to the contamination during fabrication. It also can be found from the difference of the sheet resistance between the sheet film and the patterned device as shown in Table I.

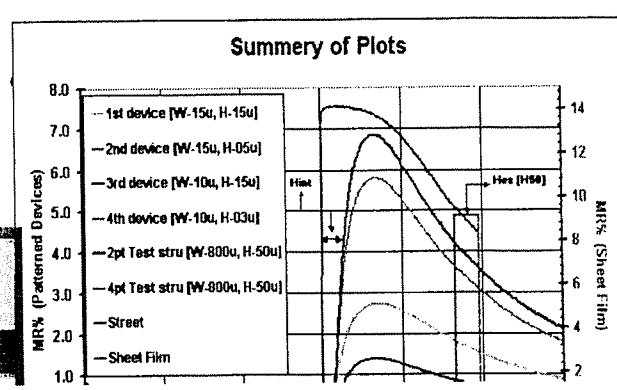


Fig. 4. MR ratio measured on spin valve structures with varying dimensions and for sheet film structures.

Before pattering, the sheet resistance is 16.3 Ω/square. It drops to 5.5 Ω/square after pattern into device. As the dimensions of the device shrunk, the self-demagnetization field becomes a main factor of the low MR%. The decrease of MR ratio is more significantly when sensor height is reduced same behavior is also obtained when the track width is reduced. The external field was applied in the sensor height direction, which enhances the demagnetization field along this direction. Therefore, the MR% is smaller by reducing the sensor height. . The interlayer-coupling field also increases significantly on patterned devices due to the same reason of the device's s dimensioning the contamination during the process. The higher interlayer coupling is associated lower MR ratio. When the interlayer coupling is increased, the free with the partially held by pinned layer. So, the completed rotation layer is not obtained. There is no The $H_{50}$, which is 50% of the MR% is above 1800 Oe for all of the devices. It indicates the synthetic structure has a stable performance at a relative high field operation with the advantage of synthetic spin-valve system.

## IV. CONCLUSION

The objectives of this project have been accomplished by successfully fabricating GMR Spin-Valve testing structures at Rochester Institute of Technology clean room in collaboration with Veeco/CVC, Rochester. As expected deviation between sheet film response and patterned device were seen. The major portion of the decay in results is due to contamination during process. Identified possible contaminations sources are as following: (1) device were left in acetone for approximately 75 minutes to perform lift-off process, during this time acetone could have feasibly penetrated in to the stack via edge regions. (2) While striping photoresist after each lithography step, 4000 Sccm of oxygen was flown in the chamber; this could have oxidized the surface and the edge regions of the stack.

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