Indigenous development of ultra high vacuum (UHV) magnetron sputtering system for the preparation of Permalloy magnetic thin films

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Abstract

We have designed and developed an indigenous ultra high vacuum (UHV) sputtering system which can deposit magnetic thin films with high purity and good uniformity. The equipment consists of state-of the-art technologies and sophistication. With this system it is possible to deposit coatings of various materials on a sample size of 3"×3" ×3". The $Ni_{81}Fe_{19}$ ferromagnetic thin films, with Tantalum (Ta) as a buffer and cap layers have been deposited on silicon substrates using this ultra high vacuum (UHV) sputtering system. The magneto transport measurement study indicated a significant variation in the AMR values of the films for varying thicknesses of tantalum and NiFe layers.

1. Introduction

For the magnetic thin films deposition one of the most important desired essence is the high purity of these thin films without any contamination. So, for the Permalloy thin film deposition, the ordinary sputtering system having max vacuum attainability up to 10^{-6} mbar can't be used because contamination level and oxides impurities formation is more in these sputtering systems. Hence for the deposition of these coatings, a special ultra high vacuum sputtering system has been used because in this system the maximum attainable vacuum is 10^{-10} to 10^{-11} mbar. Fig. 1 shows the photograph of the UHV sputtering chamber. Deposition of the Permalloy thin films on silicon substrates by using the UHV sputtering system provided us high purity samples. This UHV sputtering system is a balanced magnetron sputtering system, facilitated with two DC power supplies. The UHV sputtering system consists of several parts which are assembled together as follows:

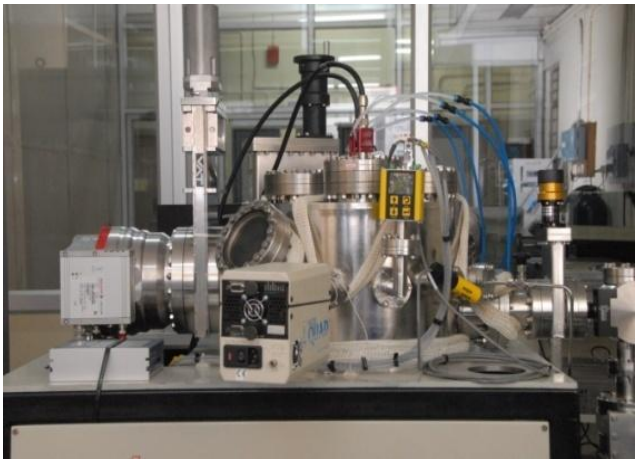

Fig.1 Photograph of the UHV sputtering system

2. Sputtering system details

2.1. Vacuum chamber

The vacuum chamber is cylindrical in shape and is equipped with two circular glass windows on either sides through which we can observe the experimental process. Inside the chamber there is a substrate holder which can be rotated both manually and using a DC stepper motor which is connected to a speed controlling electronic device by a software program accordingly. A feed through device facilitates the substrate to be heated up to 800^{o}c using a heater which is fixed below the base of the sample holder. The chamber has the provision for four sputtering guns at a time right now only two guns are being used. The sputter guns are installed with planar circular magnetrons that are water cooled.

2.2. Rotary Pump

The first and foremost step in pumping the chamber to Ultra High Vacuum is to create a rough vacuum. That is, the chamber must be pumped from the atmospheric pressure to a pressure of approximately 10^{-3} mbar. This process is known as Roughing and is done by using a two stage rotary pump.

2.3. Turbo Molecular Pump

Once the roughing vacuum is achieved, then the further pumping is carried out by Turbo Molecular pump (TP). The turbo pump can pump down the vacuum chamber up to a vacuum of 10^{-6} to 10^{-8} mbar. The UHV sputtering system is equipped by a PFEIFFER VACUUM LTD., made turbo molecular pump having a maximum attainable speed of 49200 rotations per minute. The Turbo molecular pump can be isolated from the vacuum chamber using a manually operated separation gate valve. The extent of evacuation of the carrier gases inside the vacuum chamber can be controlled by partially closing the turbo molecular pump gate valve while doing the deposition. In this way we can maintain the desired deposition pressure of the gasses, which are introduced inside the vacuum chamber.

2.4. Sputter Ion Pump

To achieve the ultra high vacuum inside the vacuum chamber, it is further facilitated with a sputtering ion pump. After achieving the vacuum of 10^{-8} mbar, sputter ion pump is used to pump down the vacuum chamber up to 10^{-10} to 10^{-11} mbar of pressure. The sputter ion pump also can be isolated from the vacuum chamber by means of a gate valve. The process of maintaining the ultimate ultra high vacuum (i.e., 10^{-10} to 10^{-11} mbar) inside the chamber is done by the help of Sputter ion pump. Inside the sputtering ion pump, a swirling cloud of electrons produced in hollow Penning cells ionizes incoming gas atoms and molecules and a strong electrical potential, typically 3 kV to 7 kV, is used to trap these gas ion and further to accelerate them into a solid electrode. The swirling ions strike the chemically active cathode inducing sputter and finally pumped down by chemisorptions which effectively remove them from the vacuum chamber and the result is a net pumping action.

2.5. Pressure Gauge

The measurement of vacuum pressure inside the chamber is done by a pressure gauge which is directly connected to the vacuum chamber. The UHV system is equipped with a four mode digital Pirani- Penning pressure gauge. Up to the roughing vacuum of 10^{-3} mbar, the pressure is read by the Pirani Gauge. A Pirani gauge is a Wheatstone-bridge circuit with the sensing resistor exposed to the gases pressure in the system. The measuring range is of the order of 10^{-1} to 10^{-3} mbar. However lower pressure readings below 10^{-3} mbar (i.e., from 10^{-4} to 10^{-11} mbar) are measured by the Penning gauge which can be pneumatically controlled by a switch provided on the control panel. The penning gauge, however, is an ionization gauge. It uses the idea of measuring the current of a glow discharge as an indicator of the gas pressure. A four mode digital Pirani- Penning gauge was used here.

2.6. Mass Flow Controller

Mass Flow controller is used to control flow rate of the gases inside the vacuum chamber. **T**hree mass flow controllers for controlling the flow rates of different gases e.g., Argon, Nitrogen and Oxygen gases are connected through a common gas pipe to the vacuum chamber and all the three mass flow controllers are controlled by three different digital electronic controllers.

2.7. Load Lock Chamber

A load lock chamber is used as a part of the UHV chamber for performing the sample loading at a pressure of 10^{-6} mbar. So without losing the vacuum inside the vacuum chamber, samples can easily be taken out or put inside the chamber easily by the load lock technique. The load lock chamber is a small spherical chamber with a loading and locking mechanism for the sample holder. The load lock chamber is separately pumped to a vacuum of 10^{-6} using a rotary and turbo molecular pump. For this, the turbo molecular pump is having a maximum speed of 75000 rotations per minute. After pumping the load lock chamber to high vacuum the sample holder mounted with the sample is transferred to the chamber. The load lock chamber also can be isolate from the vacuum chamber by means of a gate valve.

3. Experimental details

Highly pure ferromagnetic thin films of $Ni_{81}Fe_{19}$ (i.e., Permalloy) have been deposited on the silicon substrates (dimensions: 20 mm×20 mm), while the tantalum (Ta) was used as a buffer layer and cap layer for the Permalloy magnetic thin films on silicon substrate. Thin films were deposited for the varying thickness of the Ta and $Ni_{81}Fe_{19}$ thin films, respectively. To get the high purity Permalloy thin films, the deposition of these films was carried out in a controlled environment of Ar gas using a special ultra high vacuum (UHV) sputtering system at a base pressure of 10^{-9} to 10^{-10} mbar. Prior to the deposition of Permalloy thin films on the silicon substrates, the vacuum system was pumped down to a base pressure of 10^{-9} to 10^{-10} mbar. After this, the deposition pressure (Ar gas pressure) was kept constant at particular value of $1.35x10^{-3}$ mbar and all the experiments were performed at this constant pressure of Ar gas. First a 10 nm thick buffer layer of was deposited on silicon substrates. For this a highly pure (purity = 99.999%) Ta-sputtering target was used and the DC power supply used

for the buffer layer was 10 W. After this for the deposition of the $Ni_{81}Fe_{19}$ thin film, a highly pure (purity = 99.999%) compound sputtering target of $Ni_{81}Fe_{19}$ was used and the DC power supply used for this target was 14 W. After this, for the same deposition parameters as for buffer layer, a capping layer of Ta (10nm) was deposited over the top of the Permalloy thin film. Both the thin films were deposited at 8 SCCM of Ar-gas flow rate. During the in suit deposition of $Ni_{81}Fe_{19}$ thin films two hard magnets having a magnetic field of 250 gauss were placed parallel to thin film plane which helped us to aligned the spin of individual domains in the applied direction of external magnetic field as given in the Fig.2. The magnetic characterization of these coatings was carried out by the magneto transport system and vibrato sample measurement (VSM) system.

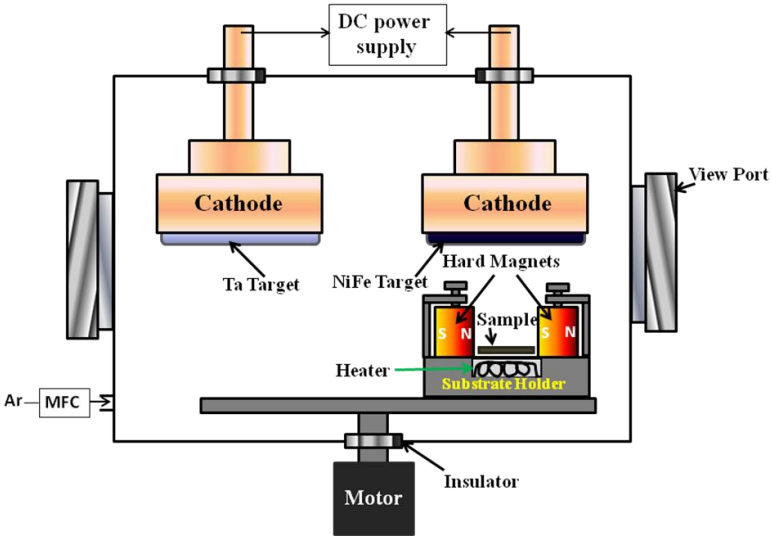

Fig.2 Block diagram of the UHV system chamber showing the arrangement of the various parts

4. Results and Discussion

4.1. Effect of varying thickness of NiFe thin films on its AMR value

$Ni_{81}Fe_{19}$ thin films of various thicknesses were deposited on silicon substrates and the variations in the AMR ratio with respect to the thickness were measured in the magneto transport system. Fig .7 shows the dependence of the AMR value of the NiFe thin film on its varying thickness. On increasing the thickness of the NiFe, increase in the AMR value were observed, indicating a size effect in the resistivity which is strongly influenced by the orientation of the magnetization with respect to the current direction [1].

4.2 Effect of varying thickness of Ta layer on NiFe thin film's AMR value

Ta/NiFe/Ta thin films were deposited on silicon substrates for varying Ta layer thickness and the effect of Ta layer thickness on the AMR values of the thin films was studied. Fig.8 shows the variation of the AMR values with respect to the Ta layer thickness. Up to 3 nm thickness of Ta layer increase in the AMR value was observed, however for the 4-5 nm thickness of the Ta layer, decrease in AMR value was observed. The reduction in AMR values is expected due the fact that the Ta interfaces, primarily, form magnetically dead layers with NiFe films and the result is the decrease in the total magnetic moment of NiFe

film, further, the alloy phases also cause the degradation of the magnetocrystalline anisotropy and consequently leads to lower value of AMR in Permalloy thin films [2,3].

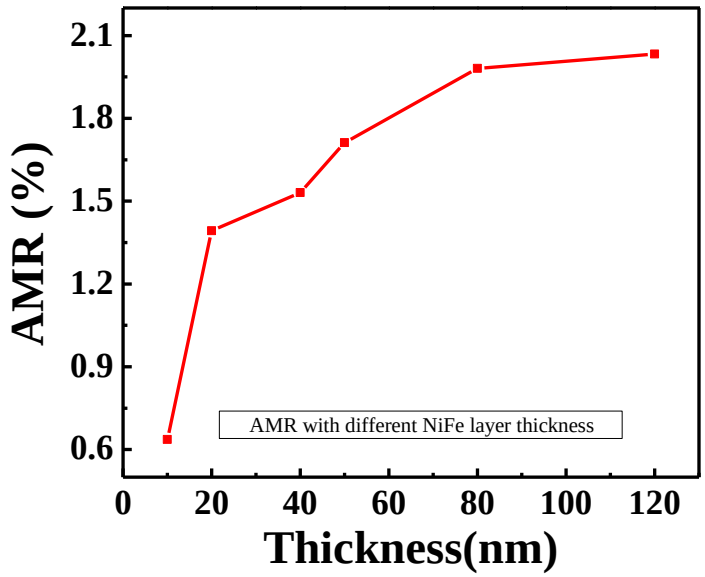

Fig.3 Variation of AMR ratio with respect to varying thickness of NiFe thin films

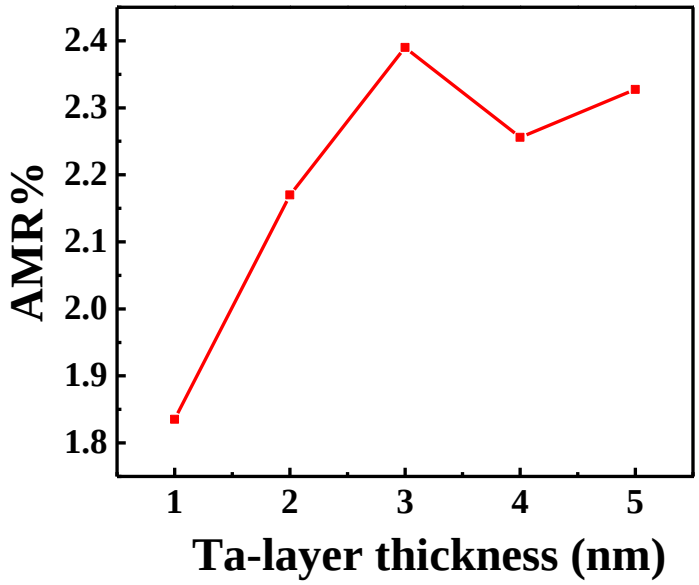

Fig.4 Variation of AMR ratio with respect to varying thickness of Ta thin films

5. Conclusions

An indigenous UHV sputtering system was designed and developed for deposition of magnetic thin films. Permalloy ($Ni_{81}Fe_{19}$) magnetic thin films having Ta as a buffer and cap layer were deposited on the silicon substrates using this UHV sputtering system. The magneto transport studies confirmed that the AMR ratio is strongly depends on the thickness of the Ta and NiFe layers.

Acknowledgements

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