Current Applied Physics 14 (2014) 259–263

Contents lists available at ScienceDirect

Current Applied Physics

journal homepage: www.elsevier.com/locate/cap

Magnetoresistance in silicon based ferrite magnetic tunnel junction

S. Ravi [a,*], A. Karthikeyan [a], N. Angel Nesakumari [b], K.S. Pugazhvadivu [c], K. Tamilarasan [c]

[a] Department of Physics, Mepco Schlenk Engineering College, Sivakasi, India
[b] Department of Nanoscience and Technology, Mepco Schlenk Engineering College, Sivakasi, India
[c] Department of Physics, Kongu Engineering College, Perundurai, India

ARTICLE INFO

Article history:
Received 31 May 2013
Received in revised form
20 November 2013
Accepted 21 November 2013
Available online 3 December 2013

Keywords:
Magnetic materials
Spintronics
Magnetoresistance
Ferrite based magnetic tunnel junction
Double spin-filter junction

ABSTRACT

We report magnetoresistance for silicon based magnetic tunnel junction. We used cobalt ferrite & cobalt nickel ferrite as free layer and pinned layer. The magnetoresistance measured at room temperature through silicon by fabricating FM/Si/FM magnetic tunnel junction. Magnetoresistance shows a loop type behavior with 3.7%. We have successfully demonstrated spin tunneling through silicon with ferrite junction that opens the door for potential candidate for spintronics devices. The spin-filtering effect for this double spin-filter junction is also discussed.

1. Introduction

Spintronics is now an essential field of research with major application in several technologies. The basic concept of spintronics is the manipulation of spin-polarized currents, in contrast to conventional electronics in which spin of an electron is ignored. Mott [1] experimentally demonstrated this influence followed by some important theoretical works [2–5] more than 10 years before the discovery of GMR. Nowadays spintronics is expanding in so many directions that aim at combining the potential semiconductors [6] and through DNA [7]. Excellent results have been obtained with GaAs doped with Mn [8] but with low Curie temperature of 170 K. Fabrication of hybrid structures associated with ferromagnetic metal and conventional semiconductors are done, but with only modest advances [9–18]. Recently the usage of silicon has attracted much attention due to its plenty of advantages. The main thing is that it can readily replace conventional electronics as we are living in the silicon world. The other things are due to its low atomic weight, lattice inversion symmetry, low isotopic abundance of species having nuclear spin, etc. [7,19,20]. It also possesses long spin life time and spin coherence lengths, which are very significant parameters in spintronics, enabling spin based silicon integrated circuits [21,22]. The main problem is the fundamental impedance mismatch between ferromagnetic metal and silicon [23]. Appelbaum [24] demonstrates spin transport across 10 μm undoped silicon in a device that operates by spin dependent ballistic hot electron injection. The usage ferromagnetic (FM) metal has an advantage of easy spin injection and detection (ignoring the impedance mismatch with indirect bandgap semiconductor), but the problem is its difficulty in device based applications as the most of FM metals are strong ferromagnetic in nature, which leads to complications in read/write process for future devices that run on spin. We used low-conductive ferromagnets (ferrites) and studied spin tunneling phenomenon through silicon. We designed a cobalt ferrite/Si/cobalt nickel ferrite based magnetic junction over copper coated silicon wafer and studied its magnetoresistive phenomenon. The other advantage of this type of junction is that it can act as a spin-filter junction leading to high MR. The schematic representation of the magnetic junction is shown in Fig. 1 with its *I*–*V* characteristic showing the expected non-linear behavior. The results are promising to use it in the future devices that run on spin.

2. Experimental section

Cobalt ferrite ($CoFe_2O_4$) and cobalt nickel ferrite ($CoNiFe_2O_4$) were prepared similar to the method reported by Maaz et al. [25]. Highly purified (99.99%) iron chloride, cobalt chloride and nickel chloride were used as precursors. Oleic acid (HPLC grade) is used as a surfactant. NaOH was used to maintain the pH level. Cobalt ferrite was prepared by dissolving iron chloride (0.4 M) and cobalt

* Corresponding author. Tel.: +91 4562235690; fax: +91 4562235111.
E-mail address: sravi@mepcoeng.ac.in (S. Ravi).

1567-1739/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.cap.2013.11.024

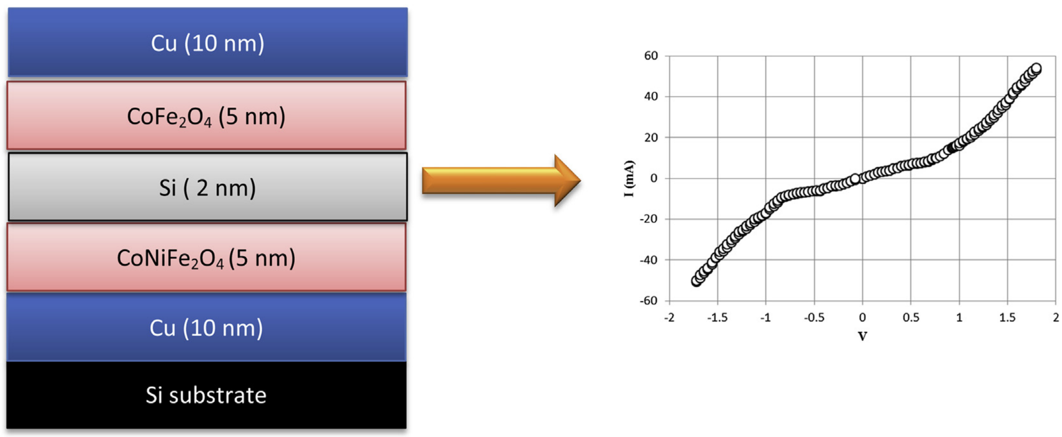

Fig. 1. Schematic representation of magnetic junction. *I*–*V* plot of this junction shows non-linear behavior.

chloride (0.2 M) in 50 ml double distilled water. The resultant mixture was stirred continuously. NaOH (3 M) solution was added slowly until the pH reaches the value of 12. Appropriate amount of oleic acid was added as surfactant. This was heated to 80 °C for 1 h and stirred at the rate of 1200 rpm. The resultant solution was filtered and washed several times in the double distilled water. The resultant product was maintained at 100 °C overnight and calcined to 800 °C for 10 h to obtain precise structure and size. For cobalt nickel ferrite, iron chloride (0.4 M), cobalt chloride (0.1 M) and nickel chloride (0.1 M) were dissolved in 50 ml of double distilled water. Same procedure was used to obtain fine cobalt nickel ferrite powder.

The synthesized cobalt ferrite and cobalt nickel ferrite was used to prepare sputtering targets. The sputtering targets were prepared by using Die casting mold to produce 2 inch diameter targets. 25 g of cobalt ferrite and cobalt nickel ferrite powder were taken separately and grinded finely in the mortar with 3% of poly vinyl alcohol (PVA) as a binder. A pressure of about 450 KN was applied to the mixture kept in the Die, using a Universal testing machine to make the sputtering targets. In this process, strong two inch diameter targets of cobalt ferrite and cobalt nickel ferrite were obtained. These targets were sintered for 900 °C for 10 h and allowed to cool at room temperature. In the similar way, silicon targets were also prepared by the same method using silicon nanopowder (99.99%, Sigma Aldrich) as starting material. These pellets were preserved under vacuum condition and taken at the time of sputtering.

Silicon wafer were scribed on the backside with a diamond pen in to 1 × 1 cm squares and cleaned using the ultrasonic cleaner with ethanol and acetone. To the polished side, copper was sputtered using commercially available copper target using RF magnetron sputtering at the pressure of 4×10^{-5} mbar. Copper film was deposited uniformly over the silicon wafer to the thickness of 10 nm, which was monitored by the thickness monitor of the sputtering unit. This 10 nm copper was used as conductive electrode to the magnetic junction. The prepared cobalt nickel ferrite targets were now placed in the target holder and sputtered to form 5 nm thickness cobalt nickel ferrite, which serves as pinned layer of the junction. Silicon layer was sputtered over this from the prepared silicon target and sputtered to form 2 nm thick silicon layer. Finally, the cobalt ferrite target was used to sputtered to form a 5 nm thick over this. Cobalt ferrite was used as free layer in the magnetic junction. Thus, we obtain Si/Cu(10 nm)/$CoNiFe_2O_4$(5 nm)/Si (2 nm)/$CoFe_2O_4$ (5 nm) based magnetic junction. All the layer thickness was controlled by the RF/DC sputtering unit.

3. Results and discussion

XRD measurements of cobalt ferrite and cobalt nickel ferrite pellets were presented in Fig. 2. In Fig 2a, calcined (800 °C) cobalt ferrite shows all the peaks for $CoFe_2O_4$ with indices quite agrees well with standard data (JCPDS: 22-1086). No other peaks and impurities were detected. Therefore, it confirmed the formation of phase pure $CoFe_2O_4$ particles. The particle size was found to be

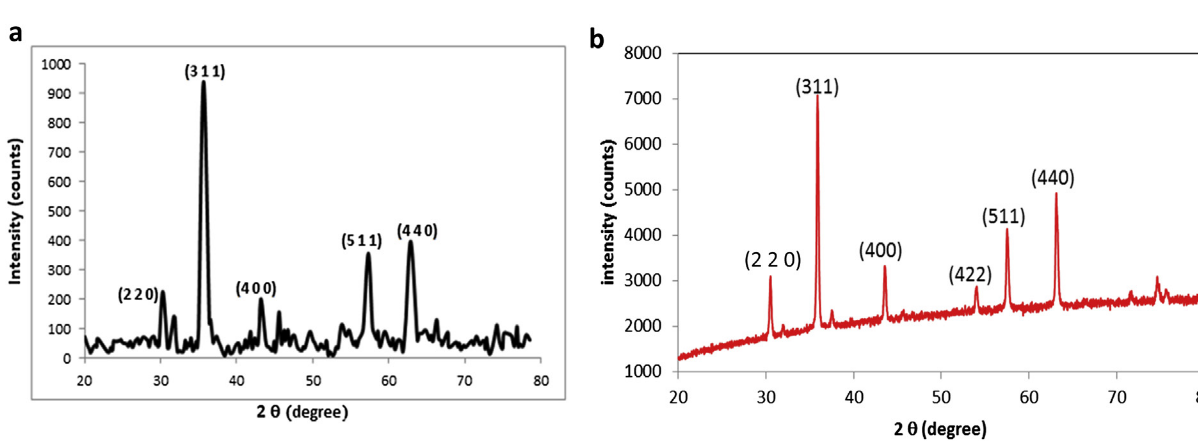

Fig. 2. XRD measurement for cobalt ferrite (a) and cobalt nickel ferrite (b) showing the formation phase pure product with particle size 20 nm (a) and 25 nm (b).