Journal of Magnetism and Magnetic Materials 322 (2010) 1834–1840

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

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

Effects of controlling Cu spacer inter-diffusion by diffusion barriers on the magnetic and electrical stability of GMR spin-valve devices

Jing Jiang [a], Ding Gui Zeng [a], Hojun Ryu [b], Kyung-Won Chung [c], Seongtae Bae [a,*]

[a] *Biomagnetics Laboratory (BML), & Information Storage Materials Laboratory (ISML), Department of Electrical and Computer Engineering, National University of Singapore, 117576, Singapore*
[b] *IT Convergence & Components Laboratory, ETRI, Yuseong-Gu, Daejon 305-700, Republic Korea*
[c] *Daion Co. Ltd., Incheon, 405-846, South Korea*

ARTICLE INFO

Article history:
Received 25 November 2009
Received in revised form
17 December 2009
Available online 7 January 2010

Keywords:
Controlling of Cu spacer inter-diffusion
Electrical and magnetic stability
GMR Spin-valve device
Co and CoFe diffusion barrier

ABSTRACT

An ultra-thin Co or CoFe diffusion barrier inserted at the NiFe/Cu interfaces was revealed to effectively control the electrical and magnetic stability of NiFe/Cu/NiFe-based giant magnetoresistance (GMR) spin-valve spintronics devices (SVSDs) operating at high current density. It was found that the activation energy, E_a, related to the electromigration (EM)-induced inter-diffusion process for the patterned NiFe(3)/Cu(2)/NiFe(3 nm) magnetic multi-layered devices (MMLD) was remarkably increased from 0.52 ± 0.2 eV to 1.17 ± 0.16 eV after the insertion of an ultra-thin Co diffusion barrier at the NiFe/Cu interfaces. The dramatically reduced "current shunting paths" from the Cu spacer to the NiFe thin films and the development of "self-healing process" resulted from the effectively restrained Cu inter-diffusion (intermixing with Ni atoms) due to the diffusion barriers were found to be primarily responsible for the improvement of electrical and magnetic stability. The further investigation on the effects of controlling Cu spacer inter-diffusion by diffusion barriers on the EM and thermomigration (TM)-induced magnetic degradation was carried out for the NiFe/(Co or $Co_{90}Fe_{10}$)/Cu/(Co or $Co_{90}Fe_{10}$)/NiFe/FeMn top exchange-biased GMR (EBGMR) SVSDs electrically stressed under the applied DC current density of $J=2.5\times10^7$ A/cm^2 ($I=16.5\sim17.25$ mA). It was clearly confirmed that the Co and the CoFe diffusion barriers effectively control the Cu spacer inter-diffusion resulting in a smaller reduction in both GMR ratio and exchange bias field of the EBGMR SVSDs. Furthermore, it was obviously observed that the effects of CoFe diffusion barrier on controlling the Cu spacer inter-diffusion are more significant than that of Co. The effectively reduced Mn atomic inter-diffusion at the NiFe/FeMn interface and the well-maintained interfacial spin-dependent scattering resulted from the control of EM and TM-induced Cu spacer inter-diffusion were the main physical reasons for the significant improvement of magnetic and electrical degradation of top EBGMR SVSDs.

1. Introduction

NiFe/Cu/NiFe($Ni_{81}Fe_{19}$)/(Mn-based anti-ferromagnetic layer, Mn-AFM) exchange-biased GMR (EBGMR) spin-valves (SV) have been paid a considerable attention in the various metallic spintronics devices such as a GMR magnetic read sensor and an in-vitro GMR biosensor [1–3] due to a high sensitivity at a low-switching magnetic field and an extremely small hysteresis [4]. However, as the device size has been dramatically scaled-down to achieve an extremely high-information storage density and to realize an ultra large-scale integrated sensor array, the operating current density allowing for a reasonably high SNR (Signal-to-Noise Ratio) is subsequently increased beyond $J=1\times10^8$ A/cm^2 [5]. This abruptly increased operating current density gives rise to a severe reliability problem relevant to the magnetic [6] and electrical [7] degradation of NiFe/Cu/NiFe/FeMn-based EBGMR SV spintroincs devices (SVSDs) primarily due to electromigration (EM) and thermally induced inter-diffusion, thermomigration (TM), across the GMR SV multi-layer interfaces driven by the temperature gradient resulted from the different film resistivity of each layer [8,9]. In particular, as the EM and TM-accelerated Cu inter-diffusion at the NiFe/Cu/NiFe interfaces and the Mn atomic inter-diffusion induced at the NiFe/Mn-AFM interface have been demonstrated to be the main physical reasons for the GMR and the magnetic degradation of NiFe/Cu/NiFe/Mn-AFM EBGMR SVSDs [6,10,11], the research activities to find a promising solution for effectively controlling the Cu spacer inter-diffusion as well as to explore its physical effects on the Mn atomic

* Corresponding author. Tel.: +65 6516 4037; fax: +65 6779 1103.
E-mail address: elebst@nus.edu.sg (S. Bae).

0304-8853/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmmm.2009.12.036