Journal of Magnetism and Magnetic Materials 394 (2015) 253–259

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

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

Thermal annealing and magnetic anisotropy of NiFe thin films on n^+-Si for spintronic device applications

Q.H. Lu [a,b,c], R. Huang [b], L.S. Wang [d], Z.G. Wu [a,*], C. Li [b,**], Q. Luo [d], S.Y. Zuo [a], J. Li [b], D.L. Peng [d], G.L. Han [c], P.X. Yan [a]

[a] School of Physical Science and Technology, Lanzhou University, Lanzhou 730000, People's Republic of China
[b] Department of Physics, Semiconductor Photonics Research Center, Xiamen University, Xiamen 361005, People's Republic of China
[c] Gansu Key Laboratory of Sensor and Sensor Technology, Institute of Sensor Technology, Gansu Academy of Science, Lanzhou 730000, People's Republic of China
[d] Department of Materials Science and Engineering, College of Materials, Xiamen University, Xiamen 361005, People's Republic of China

ARTICLE INFO

Article history:
Received 20 May 2015
Received in revised form 22 June 2015
Accepted 24 June 2015
Available online 30 June 2015

Keywords:
NiFe
Ni2p3
Spin injection electrode
Magnetic field annealing
Magnetic anisotropy

ABSTRACT

To ensure that the magnetic metal electrodes can meet the requirements of the spin injection, NiFe films prepared both on HfO_2 dielectric layer and n^+-Si directly by sputtering deposition, and treated by conventional furnace annealing and/or high vacuum magnetic field annealing were investigated. It was found that thermal annealing at 250 °C improved the crystalline quality and reduced surface roughness of the NiFe films, thus enhancing its saturation magnetization intensity. The 100 nm thick NiFe films had too large coercive force and saturation magnetization intensity in vertical direction to meet the requirements of Hanle curve detection. While, 30 nm thick NiFe films showed paramagnetic hysteresis loops in vertical direction, and the magnetization intensity of the sample after annealing at 250 °C for 30 min was less than 2% to the parallel when the external magnetic field was given between ± 10 Oe. This was preferred to Hanle curve detection. The thin HfO_2 dielectric layer between metal and Si partially suppressed the diffusion of Ni in NiFe into Si substrate and formation of NiSi, greatly enhancing the saturation magnetization intensity of the Al/NiFe/HfO_2/Si sample by thermal annealing. Those results suggest that Al/NiFe/HfO_2/Si structure, from the point view of magnetic electrodes, would be suitable for spin injection and detection applications.

1. Introduction

The development of silicon-based spintronic devices is one of the hottest research topics in semiconductor spintronics application fields [1,2]. The biggest challenge is to obtain efficient spin injection into non-magnetic semiconductors. Due to long-term suffer impedance mismatch problem [3], using magnetic tunnel junction (MTJ) to spin injection is one of the most effective ways at present [2,4,5].

When using MTJ to spin injection, spin polarization of the magnetic electrode material itself is fundamental, followed by tunnel spin polarization, both of them determine the final spin polarization in semiconductor and spin injection efficiency. However, in the previous studies, most of them are focused on the tunnel materials selection and interface properties between magnetic electrodes and semiconductors [6–14] with relatively high spin polarization magnetic metal electrodes, such as Fe [4], CoFe [15] and NiFe [16,17]. In fact, the properties of the magnetic metal thin films, applied as electrodes, should have a significant effect on the spin injection efficiency [18]. First of all, the magnetic metal materials should have high Curie temperature and good chemical stability; next, it is better to have larger saturation magnetization intensity and higher residual magnetic susceptibility in zero-field; finally, the magnetism should be easily reversed for application, such as smaller energy consumption in memory. In other words, the shape of magnetic hysteresis loop should be rectangular with small coercive force.

Furthermore, in order to carry out the electrical spin detection, such as Hanle curve detection [19], the magnetic anisotropy between parallel and vertical of thin-film plane should be considered. When an external magnetic field is applied to the thin film in a vertical direction to measure the Hanle curve, a large error would be introduced if the magnetic thin film electrode in the vertical direction can be easily magnetized with high

* Corresponding author. Fax: +86 0931 8913554.
** Corresponding author. Fax: +86 0592 2189426.
E-mail addresses: zgwu@lzu.edu.cn (Z.G. Wu), lich@xmu.edu.cn (C. Li).

http://dx.doi.org/10.1016/j.jmmm.2015.06.066
0304-8853/

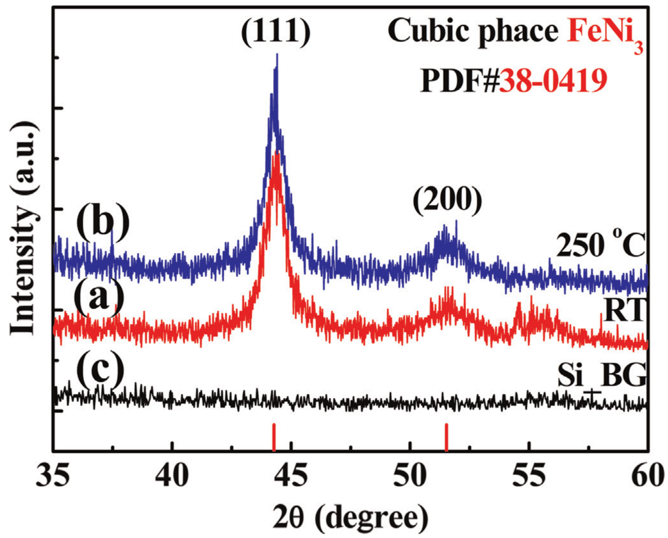

Fig. 1. XRD patterns of NiFe thin films (100 nm) deposited on n^+-Si: (a) fresh, (b) annealing at 250 °C in nitrogen atmosphere for 30 min, (c) substrate.

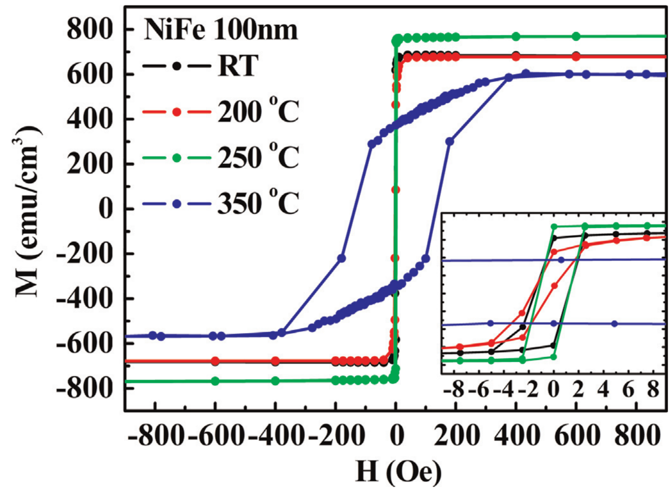

Fig. 3. VSM patterns of NiFe thin films deposited on n^+-Si and annealed in nitrogen atmosphere for 30 min at different temperatures: RT (fresh), 200 °C, 250 °C and 350 °C.

saturation magnetization intensity [20,21]. Although thin magnetic electrodes, e.g. 10 nm, are usually used to avoid this issue, it is necessary to address the effect of thickness of magnetic thin film on the spin injection.

In addition, it is well known that proper thermal annealing on magnetic thin film can improve its crystalline so as to enhance the magnetism. Earlier, thermal treatment had been carried out in order to improve the interfacial characteristics, when using Fe/AlGaAs/GaAs/AlGaAs to inject spin-polarized currents into GaAs [22,23]. Nevertheless, only a few literatures mentioned annealing in the latest research of silicon spin injection using MTJ [24]. Thermal annealing might cause inter-diffusion between metal and silicon and formation of silicide at the interface, deteriorating device performance, especially for the device with the ferromagnetic metals and semiconductors in contact directly [25]. However, for MTJ structure, an insulating layer, such as Al_2O_3 [16,26], MgO [10,15] and SiO_2 [17], was introduced into the interface, which might suppress the inter-diffusion and prevent the silicide

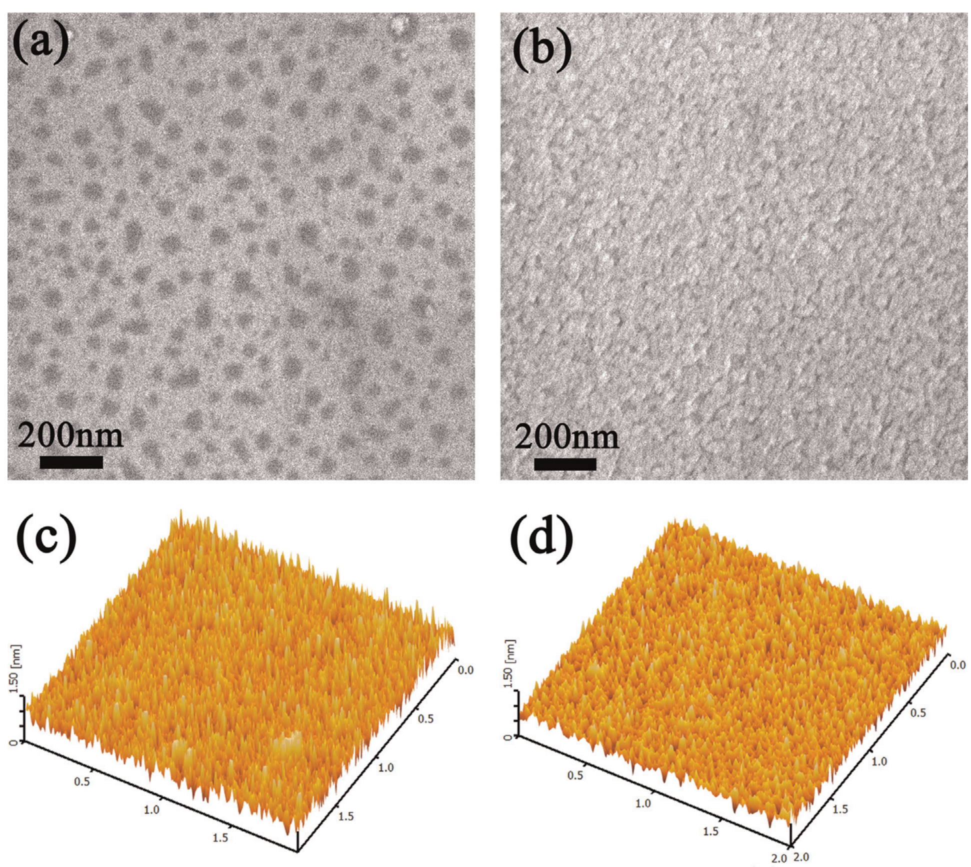

Fig. 2. (a) SEM image of NiFe thin films (100 nm) deposited on n^+-Si, (b) SEM image of annealed (a) at 250 °C in nitrogen atmosphere for 30 min, (c) a $2 \times 2\ \mu m^2$ AFM image in (a), (d) a $2 \times 2\ \mu m^2$ AFM image in (b).