Journal of Magnetism and Magnetic Materials 383 (2015) 50–55

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

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

Investigation of domain wall motion in RE-TM magnetic wire towards a current driven memory and logic

Hiroyuki Awano

Toyota Technological Institute, Tempaku, Nagoya 468-8511, Japan

ARTICLE INFO

Article history:
Received 20 June 2014
Received in revised form
29 December 2014
Accepted 31 December 2014
Available online 9 January 2015

Keywords:
Memory and logic
Magnetic wire
Spin logic
TbFeCo
Rare earth transition metal
Amorphous
ferrimagnetism
Critical current density
Low magnetization
Domain wall velocity
AND
OR
NOT
NAND
NOR
Polycarbonate substrate
Si substrate
Nano-imprint

ABSTRACT

Current driven magnetic domain wall (DW) motions of ferri-magnetic TbFeCo wires have been investigated. In the case of a Si substrate, the critical current density (Jc) of DW motion was successfully reduced to 3×10^6 A/cm^2. Moreover, by using a polycarbonate (PC) substrate with a molding groove of 600 nm width, the Jc was decreased to 6×10^5 A/cm^2. In order to fabricate a logic in memory, a current driven spin logics (AND, OR, NOT) have been proposed and successfully demonstrated under the condition of low Jc. These results indicate that TbFeCo nanowire is an excellent candidate for next generation power saving memory and logic.

© 2015 The Author. Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Introduction

Current driven domain wall (DW) motion has attracted much attention for new applications, such as low-power, high-speed, logic devices. Particularly, long-term preservation of data is possible because it does not have mechanical operation parts. DW displacement by spin polarized current was predicted by Berger [1]. Then, a lot of experimental results with in-plane magnetized FeNi magnetic wires have been reported [2–5]. The critical current density (Jc) of FeNi nanowire required large value of over 1×10^8 A/cm^2, and the Jc reduction was a big issue. Using FeNi nanowire, racetrack memory has been proposed [6] and demonstrated the accurate operation. Then several experiments have been conducted, Jc value was successfully reduced to 3×10^7 A/cm^2 by using a perpendicular magnetized Co/Ni nanowire [7–9]. As a reason of Jc reduction, it was considered that DW motion of Co/Ni nanowire is due to only intrinsic pinning effect [10,11]. It was very attractive to explain every experimental result by theoretical analysis. Therefore, the wall pinning force of Co/Ni nanowire has a very low value, it is considered that Co/Ni nanowire is not suitable for external data storage. Because external storage material such as HDD and computer tape requires large DW pinning force to save data with high reliability. However, it was considered that Jc is proportional to DW pinning force [12]; it seems that coexistence of low Jc and large DW pinning force is difficult.

On the other hand, Jc of perpendicular magnetized TbFeCo has been reported [13–18] as 3×10^6 A/cm^2 which is lower than that of Co/Ni. The DW pinning force was over 1 kOe and it can be easily controlled by Tb composition. It seems that coexistence of low Jc and large DW pinning force is possible in the TbFeCo nanowire. Moreover, in the TbFeCo nanowire, there are high density and relatively uniform pinning sites. Therefore, arbitrary shape domain can be recorded. In the case of Co/Ni nanowire, it requires a lot of artificially fabricated notches at the wire edge to keep position of recorded domains [7]. From these results, it seems that rear earth

http://dx.doi.org/10.1016/j.jmmm.2014.12.081
0304-8853/© 2015 The Author. Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

transition metal alloy such as TbFeCo is an attractive material for magnetic wire memory.

By the way, memory and logic are placed separately in the current computer, the memory and logic are connected by a data bus. Therefore, operation speed is rate-limiting in the communication speed between memory and logic. If memory and logic are prepared in the same area and directly connected each other, the operation speed would be improved. However, in the most spin logic reports [19–22], FeNi in-plane magnetized nanowires were used and most logics were operated by a rotational magnetic field from outside of the device. Therefore, current driven spin logic has been proposed. In this article, drastic Jc reduction of TbFeCo nanowire with PC substrate is reported, and low current driven AND, OR, and NOT operations with TbFeCo nanowire are presented.

2. Experimental procedure

The 0.3–1.5 μm-wide and 100-μm-length wire patterns were fabricated using electron beam lithography for a lift-off process as shown in Fig. 1(a). In this case, it is considered that the lift off process damages the magnetic film. Therefore, a new fabrication method with nanoimprint technique is proposed in Fig. 1(b). This method is similar to the optical disk fabrication and the substrate cost is very low compared with that of the Si substrate. When a magnetic film is deposited onto the grooved PC substrate, magnetic nanowire can be prepared without any damage. The 20-nm-thick $Tb_{26}Fe_{66.8}Co_{7.2}$ film was directly grown on SiO_2/Si substrate by RF magnetron sputtering. A Pt film with a thickness of 2 nm was subsequently capped on the film. The ultimate vacuum was less than 2×10^{-8} Torr and Ar sputtering gas pressure of 1 mTorr was kept during grown films. Ti/Al contacts were defined by optical lithography on top of each TbFeCo electrode. A scanning electron microscopy (SEM) image of the fabricated sample is shown in Fig. 2. The magnetic properties of the films and wires were measured using an alternating gradient force magnetometer (AGFM) and anomalous Hall voltage measurement. When a domain wall motion of the sample is observed, magnetically initialize process is performed to the sample using larger external magnetic field over the coercive force (Hc). Then, the magnetic DWs were cleated in the wires by using an Oersted field which is generated by current flow from the electrode A to B in Fig. 3. The motion of DWs was driven by current flow from the electrode C to B. Pulse voltage duration was 100 ns. The DWs dynamics in the wires were directly observed using polar Kerr microscopy as shown in Fig. 4. Hysteresis loop measurement on the films using AGFM (data not shown) confirmed that the films had a good perpendicular magnetic anisotropy with a saturation magnetization of M_s = 110 emu/cm^3.

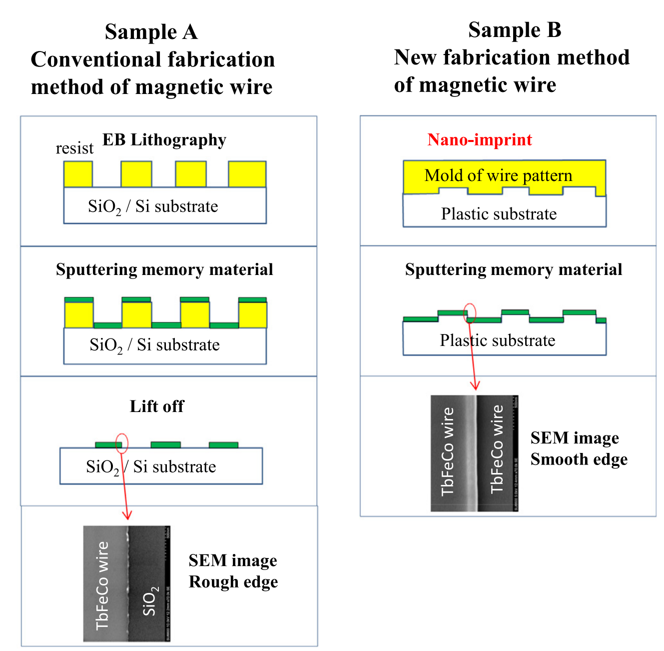

Fig. 1. Sample A: general fabrication process of magnetic nanowire. Sample B: proposed new fabrication process of magnetic nanowire. The feature is similar to the optical disk fabrication process. Therefore, the new fabrication process is attractive for low cost magnetic wire preparation and low Jc sample.

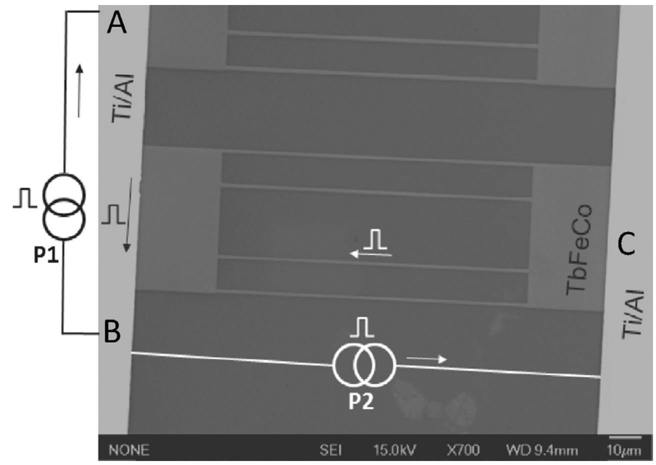

Fig. 2. SEM image of the Sample A set up for magnetic spin memory.

3. Results and discussion

3.1. Very low current driven DW motion in TbFeCo wire

Using the sample of Fig. 2, current driven DW motions in

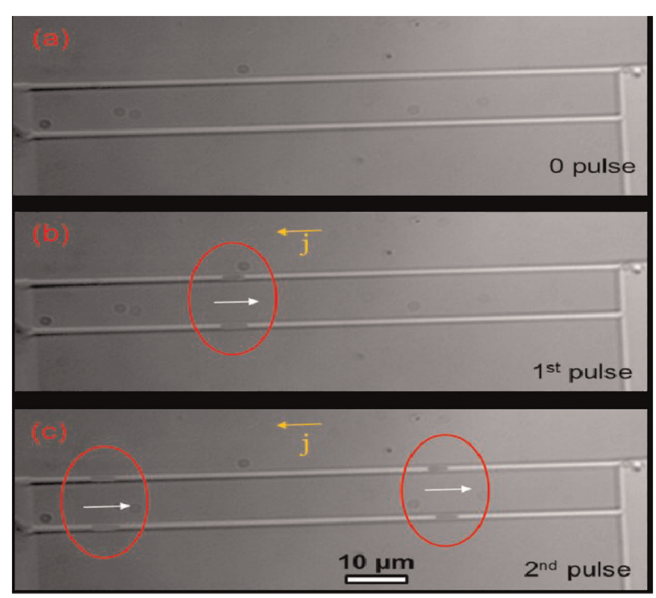

Fig. 3. Polar Kerr optical microscope image of TbFeCo magnetic nanowires on SiO_2/Si substrate. (a) After initialize process, (b) in each magnetic wire, one domain is recorded, then 1st pulse current is applied, each domain is displaced to the right hand side. (c) 2nd Domain is recorded at the left hand side, then injected 2nd pulse current drive both the 1st and 2nd recorded domains.

Download English Version:

https://daneshyari.com/en/article/8155902

Download Persian Version:

https://daneshyari.com/article/8155902

Daneshyari.com